University of Nevada, Reno

Low-level Modality Specific and Higher-order Amodal Processing in the Haptic and

Visual Domains

A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Psychology (Cognitive and Brain Sciences)

by

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Abstract

The aim of the current study is to further investigate cross- and multi-modal object processing with the intent of increasing our understanding of the differential contributions of modal and amodal object processing in the visual and haptic domains. The project is an identification and information extraction study. The main factors are modality (vision or haptics), stimulus type (tools or animals) and level (naming and output). Each participant went through four different trials: Visual naming and size, Haptic naming and size. Naming consisted of verbally naming the item; Size (size comparison) consisted of verbally indicating if the current item is larger or smaller than a reference object. Stimuli consisted of plastic animals and tools. All stimuli are readily recognizable, and easily be manipulated with one hand. The actual figurines and tools were used for haptic trials, and digital photographs were used for visual trials (appendix 1 and 2). The main aim was to investigate modal and amodal processing in visual and haptic domains. The results suggest a strong effect, of modality type with visual object recognition being faster in comparison to haptic object recognition leading to a modality (visual-haptic) specific effect. It was also observed that tools were processed faster than animals regardless of the modality type. There was interaction reported between the factors supporting the notion that once naming is accomplished, if subsequent size processing, whether it is in the visual or haptic domain, results in similar reaction times this would be an indication of, non-modality specific or amodal processing. Thus, through using animal and tool figurines, we investigated modal and amodal processing in visual and haptic domains.

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Introduction

We are constantly observing and interacting with a variety of different objects in our environment. Nevertheless all we know about these objects is what our sensory system tells us. Rececognizing objects are accomplished by using a combination of multisensory information. For example, a bumble bee can be recognized by seeing its characteristic yellow and black colors, by hearing its distinctive buzzing sound, by feeling the fuzzy surface of its body as it walks around our hand or by a combination of these and many other cues. No matter how we recognize that it is a bumble bee, we invariably access a wide range of additional information about that bee, not the least of which is that, bumble bees can sting and that their sting can hurt.

Recognizing and accessing additional information about various objects in our environment allows us to interact appropriately with our environment. We need to know whether to catch a baseball or dodge a rock, step onto a bus, or jump out of the way of a car, stop to pet a dog, or run from a tiger. But how do we know this?

One way is to identify the objects in the world around us before responding to them, though we may not always consciously identify such objects before we respond. Of course, such processing is not limited to the visual domain. Finding your lucky shirt in the dark, or knowing that you have a quarter in your hand, not a dime, or recognizing that your cat not your dog is rubbing up against your calf, all require using haptic information. Such identification often entails naming and subsequent conceptual processing of the items so that we can respond appropriately. This study will provide valuable information about how the objects are processed in both visual and haptic domains. Vision is the primary sensory modality that humans and other primates use to identify objects in their environment (James et al., 2002). Nevertheless, touch allows humans and primates to extract precise information about many dimensions of objects that are in their personal space, and can be reached and handled actively. Haptic perception (from the Greek word 'haptikos' means to 'to touch') incorporates both touch information from the skin and kinesthetic information from the position and movement of the joints and muscles (Newell et al., 2004). It provides the information about the properties of an object such as its shape, size and texture by means of exploratory manual movements (Henriques et al., 2005). Both the visual and haptic systems together can provide clues to the identity of the object. Both systems perceive a number of similar and a number of dissimilar object features, and through combination of this information the object can be successfully identified.

As this information is first experienced and transduced into sensory information, there are modality-specific (i.e. modal) processes and capabilities employed by the various sensory systems. Despite the fact that both visual and haptic systems can be used to identify objects, there are various differences between the nature of encoding information about an object and the type of information that can be encoded. The visual system can receive the information not only about objects that reside within personal space, but also those that are at some distance from the observer. When objects are at a distance, only the surfaces and parts of an object that face the observer can be processed visually. When objects are within reach, however, the object can be manipulated, thus, revealing the structure and features of the previously unseen surfaces and parts. Whereas, the haptic system can receive information only about objects that reside within personal space, i.e. those objects which are within arms reach.

Furthermore, the visual system involves the spatial analysis of a static image on the retina (Logothetis 1998; Riesenhuber and Poggio 2000), and an entire scene can be viewed at the same time, across a much larger scale. On the other hand, haptic system can only explore a set of objects one at a time through a series of successive impressions (Gibson, 1962).

Finally, some features of an object can only be perceived by one modality, usually referred to as a modality encoding bias (Lederman, Summers, & Klatzky, 1996). For example, color can only be directly perceived visually whilst object mass, surface friction, hardness and temperature can only be perceived directly through touch (Woods & Newell, 2004). These crossmodal differences in the timing of information pick-up and the modality encoding range may affect crossmodal performance.

Despite the above differences between the two systems, there is evidence that the higher-order processing of objects by vision and haptics may access the same store of semantic information once the initial sensory information has been transduced and translated into neuronal codes. For example, in many situations, particularly those in which differential information about surface features such as color and visual texture are not available, visual recognition of objects is view-point dependent. That is, if an object is explored visually from a particular viewing angle, recognition will be better for that view of the object than for other views (Harman & Humphrey, 1999; Humphery & Khan, 1992; Tarr, 1995).

Current evidence suggests that when we look at an object as we move or the object moves, our visual system is presented with a sequence of different views of the object and contains information that can aid in the process of representing and recognizing objects (Harman & Humphrey 1999). They investigated whether seeing a series of perspective views of objects in sequence led to more efficient recognition than seeing the same views of objects but presented in a random order. Further, images of 20 novel three-dimensional objects rotating in depth under one of two study conditions were studied by the participants. In the first condition, participants studied a set of seven views, either in a regular sequence of views, in a random order of views, or in an order where views and objects are randomized. In the other study condition, participants were presented the same object views, but in a random order. It was found that recognition accuracy was equal for the two groups whereas, differences in reaction times between the two study groups were not equal. That is, the random study group responded reliably faster than the sequence study group suggesting that studying a regular sequence of object views can lead to more efficient recognition than studying a random presentation of object views.

Although the concept of 'viewing angle' in haptic exploration of fixed objects is not as well-defined as it is in vision but it is still used to compare visual and haptic studies. Further, it is reported that view point specific haptic representation of objects is based on the observation that common motor tasks such as grasping and manipulating objects require information about the position and orientation of an object relative to the observer. However, such motor tasks are usually guided by vision, and therefore all the necessary information is available visually suggesting that it is generally unnecessary to invoke any haptic representation for even simple visual identification of the objects. That is, we do not need to necessarily need to grasp an object in order to identify that object (Goodale et al., 1994; Goodale, Milner, Jakobson, & Carey, 1991). Even for tasks in which visual information is not available, such as reading Braille or playing musical instruments, orientation and position information can, in theory, be attached to an omni directional, viewpoint independent haptic representation (Kennedy, 1993; Millar, 1997). On the whole, people recognize objects best when they see the objects from a familiar view and worse when they see the objects from views that were previously occluded from sight. Similarly, haptic object recognition also appears to be view-point dependent as well.

Newell et al. (2001) measured the effects of viewpoint for visual, haptic, and crossmodal object recognition. Their findings support the notion that haptic object representation is viewpoint specific given that the haptic testing with hand-sized objects demonstrated a preference for the back side of objects, and visual testing demonstrated a preference for the front view of objects. They postulated that the effect might be due to the fact that the back side of a hand-sized object is more accessible to the haptic system than the front of a hand-sized object, whereas the front is more accessible than the back to the visual system. Furthermore, it was found that the transfer of object information between the visual and haptic system is view-point specific as the recognition performance was best when the objects were rotated back-to-front between learning and recognition. Thus, the above findings suggest that the information about the structure of an object is encoded and stored in a similar way by the visual and the haptic systems. However, they each encode slightly different information.

In support of the above study, various researchers suggested that vision and touch are independent modalities but they still obey similar operating principals. Behrmann & Ewell (2003) conducted two experiments using raised line patterns. These patterns were recognized in inverted version and the part-whole version to examine expertise in tactile pattern recognition. The inversion effect involved better recognition of upright pattern than inverted pattern whereas the part-whole effect involved better recognition of whole than a part pattern. Experiment 1, asked participants to recognize these patterns by training them to different degrees of accuracy (expert, novices) tactically. Experiment 2 investigated cross-modal transfer by training participants as visual or tactile experts and comparing their recognition performance in both the trained and nontrained modalities. It was found that like visual object recognition, tactile object recognition can be modified by experience and learning. Also, crossmodal transfer between visual and haptic was asymmetric, with visual identification being faster and can be used for the haptic identification. Whereas, information acquired haptically, is not transferred to visual identification. Thus, despite the apparent independence, the two modalities undergo same computational processes.

Additionally, it is suggested that the accuracy of haptically matching a 2-D drawing to its 3-D counterpart of an object is better when the drawing was depicted with perspective, despite the fact that the distortions of perspective, such as foreshortening, are associated with visual processing, and not haptic processing (Heller et al., 2002). Experiments were conducted to study the perception of raised-line pictures in blindfolded-sighted, congenitally blind, late-blind, and low-vision participants. In the first experiment, participants were asked to feel two wooden boards joined at 45°, 90°, or

135°, and were asked to pick the correct perspective raised line drawing from among four choices. In the second experiment, blindfolded-sighted participants were asked to feel geometric solids and select the appropriate raised-line drawing from a matching array consisting of four picture choices. Surprisingly, performance was not impaired for the 3-D drawings in comparison to the frontal viewpoints. Participants were also especially fast and more accurate when matching top views. Also, data indicate that top views were easiest for all of the visually impaired participants, including those who were congenitally blind. Thus, the study demonstrates that participants are more accurate to match a tangible drawing to its 3-D counterpart haptically when the drawing was depicted with perspective, despite the fact that distortions of perspective, such as foreshortening, are associated with visual processing, not haptic processing. This supports the notion that haptic and visual processing interacts, perhaps at later stages in the processing stream.

Various studies in the field of visual recognition support the view of a dichotomy between a fast, parallel perceptual system that performs a featural analysis of the visual scene, and a slower, more limited memory system that is dedicated to keeping track of the objects in view (Kahneman, Treisman, & Gibbs 1992; Kanwisher & Driver 1992; Printzmetal 1995; Treisman, & Gibbs, 1991). These studies built on previously conducted research (Potter 1975, 1976) in which viewers of a picture sequence were asked to detect a picture described by a brief title that was not explicit about pictorial details (e.g., "a boat," "a picnic on the beach," "two people drinking"). In these studies the detection results were very different from recognition memory results with the same set of pictures: detection was above 60% at 125 msec per picture and above 80% at 250 msec per picture, when recognition memory was about 12% and 30% respectively. Thus, there is a strong indication that a viewer can comprehend a scene in 100-200 msec but cannot retain it without additional time for processing or consolidation, during which time the scene is vulnerable to conceptual masking from the next picture. However, if given additional processing time, conceptual information about the object can be accessed.

Recent research has suggested that the characteristics of the visual and haptic object recognition system are very similar, thus leading to speculation that the two modalities actually share the same underlying representation (James et al., 2001). The question now arises as to whether the same processes involved in visual object recognition are also involved in haptic object recognition, and whether or not these representations can be shared across vision and haptic senses. For the purpose of object recognition, both vision and haptics can be considered as image-based, in that both the modalities can acquire shape information for recognition, but by using different means.

Various behavioral investigations have shown crossmodal priming between touch and vision, and vision and touch. Easton et al., (1997) used crossmodal priming between vision and haptics to show that exposure to real objects in one modality affected later naming of the objects when they were presented using the other modality. According to them, the term priming here refers to the facilitative effect that prior exposure to a stimulus has on responses to that stimulus during a subsequent encounter, a facilitative effect of which people are usually quite unaware. Further, in a crossmodal priming experiment, participants were first exposed to objects in one modality and then were required to identify or discriminate between the same objects presented in the other modality. Various crossmodal priming and within-modality priming experiments resulted in similar effect sizes, suggesting that a visual representation of an object can be activated as much by a haptic presentation of the object as by a visual presentation of the object (and vice-versa).

Reales & Ballesteros (1999) investigated real-world objects and data-driven visual and haptic implicit memory tests performed in within-modal as well as in crossmodal conditions. The study showed significant priming between and withinmodalities. The first experiment explored crossmodal and within-modal priming by combining the study modality and the test modality factorially i.e. if object priming were mediated by abstract, structural, modality independent representations, then crossmodal priming should be similar to within-modal priming. Experiment 2 used two different implicit memory tests: picture-fragment completion and object decision to investigate whether crossmodal priming is mediated by name codes. Further, experiment 3 was designed to see whether crossmodal priming between touch and vision is long lasting. Participants used the procedure in experiment 1 and performed a speeded object naming task under immediate and 0.5-hr delayed conditions followed by the explicit memory test. Results showed that crossmodal priming was significant in all the experiments. Though, studying pictures produced higher priming than studying haptic or visual real objects. Thus, the findings suggest that although each modality contributes specialized information about these objects but at the same time, similar structural descriptions mediate object priming in vision and touch. There is within-modality advantage and visual advantage when cross modality priming occurs.

In another study, Norman et al., (2004) conducted experiments comparing naturally shaped three-dimensional objects, using the senses of vision and touch in order

to evaluate participants ability towards shape recognition. The first experiment required participant to actively feel or haptically explore one of the 12 objects in a limited time period and then match the object with the same shaped object presented visually. In the second experiment, two objects were presented sequentially and the participants were required to indicate whether their 3-D shape was the same or different. The two objects were presented either unimodally (vision-vision or haptic-haptic) or crossmodally (vision-haptic or haptic-vision). Thus, the results suggest that vision and touch have functionally overlapping, but not necessarily equivalent, representations of 3-D shapes.

In continuation to the above study Norman, et al. (2006) investigated the effect of aging on natural object shape recognition with respect to visual and haptic modalities. Experiment 1 involved visual, haptic and cross-modal shape discrimination task involving three experimental conditions: vision-vision, haptic-haptic, cross-modal (either haptic-vision or vision-haptic). Stimuli consisted of 12 plastic copies of ordinary bell peppers. Subjects were instructed to judge whether two sequentially presented objects were the same or different in 3-D shape in all the three conditions. Further, experiment 2 was the cross-modal shape-matching task wherein subjects were asked to report that which of the 12 visible objects possessed the same 3-D shape. There were three groups of older adults in shape-matching task. The first group of 10 older adults required matching 12 objects in 7sec. A second group required matching 6 objects in 7 sec and the third group used the entire set of 12 objects, but was given an unlimited time to haptically match the objects. Results of experiment 1 indicate that both younger and older adults perform equally in perceiving natural object shape in both visual and haptic modalities. Experiments 2 reported that older adults performed better when the number?

of objects were decreased from 12 to 6 and when they were given unlimited time to explore the objects haptically.

Research suggests that aging has no effect on unimodal visual or unimodal haptic perception of 3-D natural object shape whereas, age-related deficits are reported for cross-modal shape matching task. One explanation of the deficit could be that crossmodal matching task requires divided attention wherein the older adults are required to haptically explore the objects as well as visually examine the shape of objects. Another explanation for the age-related deficit can be due to cerebral-slowing suggesting that the speed of Central Nervous System (CNS) is slowed with growing age.

Additionally, Cooke, et al., (2004) focused on modality-specific as well as crossmodal similarity and categorization of three-dimensional objects. Stimuli consisted of novel, 3D objects with different shapes and textures. There were three pair-wise similarity rating tasks wherein subjects were asked to rate the similarities between objects on a scale of 1-7 with 1 as low similarity and 7 as high similarity using: vision alone, haptic alone and both haptic and vision together. Further, a free sorting categorization task was performed and subjects were asked to categorize each object. Similarity data was analyzed using multidimensional scaling analysis (MDS). It was reported that in the visual condition, shape dominated texture, whereas in both haptic and bimodal conditions, both shape and texture weighed evenly. This suggests that modality-specific biases affect both the tasks in a uniform manner. Also, a connection was established between similarity and categorization: low similarity was observed for pairs which subjects placed in different categories and high similarity was observed for pairs placed in the same category. It can be because subjects were instructed to use free categorization task which biased them to use the unidimensional rules instead of classifying objects on the basis of shape and texture.

Various researchers have shed light on the crossmodal consequences of viewing the Muller-Lyer illusion, and have shown that being purely visual illusion, it can also be demonstrated in touch (Coren and Girgus, 1978; Fry, 1975). The Muller-Lyer illusion consists of two identical lines that are actually perceived as being of different lengths, due to presence of "fins" with a particular orientation placed at each end of each line. The line flanked by fins pointing outward (hereafter labeled "wings-in") is perceived to be shorter than it really is, while the line flanked by fins pointing inward (labeled as "wingsout") is perceived as being longer (Coren, 1970; Coren and Girgus, 1978). Gallace and Spence (2005) examined whether the visual perception of illusion would have any crossmodal consequences for haptic perception. In this experiment, the wings-in part of the illusion was placed on the participant's left, and the wings-out part on their right. This version of the illusion was presented visually in front of the participants on the screen and was asked to compare the "felt" length of two sticks placed on the back of the screen, one behind either part of the illusion. The results show that the haptically perceived sticks presented directly behind the wings-in part of the illusion were reported to be longer than those presented behind the wings-out parts of the illusion. Thus, we can say that the visual perception of the Muller-Lyer illusion can influence the haptic perception of line length.

Further, various researchers have investigated haptic competencies of infants with regards to size and shape recognition (Streri & Feron, 2005). Various studies were carried out on infants from birth to five months old. A habituation/dishabituation method

was used wherein an object was placed in baby's right hand and the holding time was recorded. Habituation was observed if the holding times decreased with repeated presentation of the object suggesting that newborns are capable of detecting differences in the contour of two small objects. Further, studies revealed asymmetry between the left and the right hand within first five months in young infants. It was reported that in infants up to two months of age, both the right and the left hands are used for shape processing. However, four-month old infants show asymmetries between two hands suggesting they detect different details better with their right hand and differentiate contours better with their left hand. Next, the question of intermodal transfer was addressed revealing that at two months of age, touch-to-vision transfer occurs but not the reverse whereas, at five months of age, vision-to-touch transfer occurs but touch-tovision transfer disappears. Furthermore, cross-modal transfer was observed in tasks such as perceiving the unity of an object partially occluded or detecting numerosity suggesting that at high level cognitive processing is involved in cross-modal transfer of information. In summation, it is suggested that young infants are capable of haptic shape processing.

Apart from the behavioral data, several recent neuroimaging studies have shown that both visual and haptic object identification produces activation in the occipital cerebral cortex. Amedi et al., (2002) used fMRI to demonstrate that a region within the human lateral occipital complex (LOC) is activated when the objects are either seen or touched. They termed this cortical region as the lateral occipital tactile-visual region (LOtv). It was reported that voxels in the lateral occipital tactile-visual region (LOtv) which is a sub region of the LOC show preference for graspable visual objects over faces or houses. Further, the nature of object representation in LOtv (lateral occipital tactile-

visual region) was examined by studying its responses to stimuli in three modalities: auditory, somatosensory, and visual. It was found that the object activation was quite strong in both visual and somatosensory modalities, while no activation was produced by the auditory signals. Thus, it is suggested that LOtv (lateral occipital tactile-visual region) plays an important role in determining the geometrical shape of objects, whereas auditory information plays a little role in shape recognition of an object.

Various studies have shown that haptic exploration of novel three-dimensional objects produces activation, not only in the somatosensory cortex, but also in areas of the occipital cortex associated with visual processing. In 2002, James et al., reported possible interactions between the visual and haptic systems. They used fMRI to measure the effects of crossmodal haptic-to-visual priming on brain activation. Participants were asked to study novel three-dimensional clay objects either visually or haptically before entering the scanner. Further, in the test phase, participants were asked to view visually primed, haptically primed, and non-primed objects followed by haptically exploring non-primed objects. It was found that the visual and haptic exploration of non-primed objects produced significant activation in several brain regions, and produced overlapping activation in the middle occipital area (MO). Thus, viewing visually and haptically primed objects in both middle occipital areas (LO).

Reed, Shoham & Halgren (2004) investigated naturalistic tactile object recognition (aka TOR) of real objects using fMRI. Group activation maps were compared between tasks involving tactile object recognition (TOR) of common real objects, palpation of nonsense objects, and rest. It was reported that tactile object recognition

(TOR) evoked a prominent activation in secondary somatosensory areas in the parietal operculum and insula, suggesting, modal processing for tactile object recognition (TOR). Prominent activation was also reported in medial and lateral secondary motor cortices. Also, activation in lateral occipitotemporal area associated previously with visual object recognition suggests amodal collateral activation. Finally, activation was reported in medial temporal and prefrontal areas suggesting a common final pathway of modality-independent object recognition. Thus, the study suggests that tactile object recognition (TOR) is a complex network of parietal and insular somatosensory association cortices, as well as occipitotemporal visual areas, prefrontal, and medial temporal areas and medial and lateral secondary motor cortices.

Furthermore, it has been found that different sensory modalities provide both complementary and redundant information about objects, which may improve recognition speed and accuracy in various circumstances. Amedi et al., (2005) reviewed various function magnetic resonance imaging (fMRI) studies on crossmodal object recognition in humans. The studies showed that visual, tactile, and auditory information about objects can activate cortical association areas that were once believed to be modality-specific. Thus, the above studies support a general mechanism for crossmodal object recognition involving modal and amodal mechanisms suggesting that the recruitment and location of multisensory convergence zones varies depending on the information content and the dominant modality.

The aim of the current study is to further investigate cross- and multi-modal object processing with the intent of increasing our understanding of the differential contributions of modal and amodal object processing in the visual and haptic domains. By investigating cross modal recognition performance we will be able to provide a clearer understanding of what similar processes are involved in visual object recognition and haptic object recognition, how these representations can be shared across vision and haptics, and how there are hierarchical stages of processing that initially require modal processing and subsequently require amodal processing.

Methods

Study Design

The study was designed to contrast visual and haptic processing. The specific format was a 2*2*2 design. The main factors were modality type (vision or haptics), stimulus type (tools or animals) and response type (naming and size comparison).

Naming consisted of verbally naming the item. Size comparison involved verbally indicating if the current item is larger or smaller than a reference object (see appendix 1 and 2). Participants became familiar with the figurines and tools during a 5-10 minute pretesting session during which each participant named and touched few tools and animals objects in order to get acquainted with the experiment Pictures of stimulus items are shown in appendix 1 and 2. Additionally, the reference items for animals and tools were identified by the participant at this time. Subsequently, each participant completed two experimental trials: Visual Naming/Size and Haptic Naming/Size. Trials were divided into four different pre-testing and testing conditions: Visual Naming/Size, Haptic Naming/Size, Visual Naming/Size, Haptic Naming/Size. The orders of the trials were randomized for each participant. Conditions were counterbalanced across participants, starting with Visual Naming/Size or Haptic Naming/Size.

Participants

The study was conducted with 40 participants and utilized a within subject design. All participants were students at the University of Nevada, Reno, with normal or corrected to normal vision.

Stimuli

Stimuli consisted of plastic animals and tools. All stimuli were readily recognizable, and could be easily manipulated with one hand. The actual figurines and tools were used for haptic trials, and digital photographs were used for visual trials (appendix 1 and 2).

Procedure

Each participant was asked to complete a demographic questionnaire; age, year in school, handedness, primary language, and second language (see appendix 3). Then all participants were given several minutes of practice time to become well acquainted with the stimuli. Others have shown that this practice time was necessary so the participants were able to easily identify the stimuli (Reales & Ballesteros, 1999).

Experiment 1: Visual Naming/Size

The experiment required participants to verbally name the animal or tool after viewing them visually. All participants began the experiment by viewing each of the digitized photographs for 2500 msec with a 500 msec interstimulus interval (ISI) using SuperLab running on a laptop. Each participant was required to name the objects in the photographs presented to them as quickly as possible. A microphone was used to record voice onset time in order to collect reaction time as the dependent variable within the data files. Since we expected participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect percent correct. This ensured that the participant was accessing the correct semantic information.

Further, each participant was required to examine additional semantic information related to the object (animal or tool). Participants retrieved the size of each tool or the

animal item by comparing it with the size of the neutral tool or animal item. That is, after participants verbally name the object, they were supposed to say "smaller" or "larger" indicating they have retrieved the size of object. Again, reaction times were collected as the dependent variable using a microphone to obtain voice onset time. Since, we expected participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect percent correct. This ensured that the participant was accessing the correct semantic information.

Experiment 2: Haptic Naming/Size

For the haptic naming, the figures of the same digitized pictures were displayed for 5500 msec with a 500 msec ISI. This increase in trial length is necessary to accommodate the transfer of haptic stimuli to and from the participant's hand. During these runs, an experimenter was supposed to hand over the animal and tool figurines to the participant and each participant was required to name the objects in the models presented to them with the use of a microphone in order to record reaction time and verbal responses within the stimulus presentation program data files. A second experimenter was required to hand the stimuli to the experimenter and record incorrect and correct answers. In order to ensure consistent timing, the experimenter viewed the stimulus display while handing the stimuli to the participants. During the experiment, participants were seated in front of a table in such a way that their view of the object was blocked with the help of a cardboard in front of them so that they cannot see the stimuli across the table. Again, a microphone was used to detect the voice onset in order to collect reaction time as the dependent variable. Since, we expect participants to be at ceiling for naming and usage following the practice session, a second experimenter was

present to collect percent correct. This ensured that the participant was accessing the correct semantic information.

In addition to using the same procedures used in the Haptic Naming experiments, in which participants palpate and name objects that have been handed to them by the experimenter; participants were also required to retrieve the size of each tool or the animal figurine by comparing it with the size of the neutral tool or animal figurine. Therefore, after participants verbally named the object, they were also asked to say "smaller" or "larger" indicating they have retrieved the size of an object. Again, a microphone was used to detect the voice onset time in order to collect reaction time as the dependent variable. Since, we expected participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect the percent correct. This ensured that the participant was accessing the correct semantic information.

Data Analysis

Reaction time data were analyzed using analysis of variance (ANOVA). Data were subjected to a 2*2*2* ANOVA with modality type (visual-haptic), stimulus type (tool-animal) and response type (name-size) as factors. It was reported that there was a main effect of sensory modality, with visual processing being faster than tactile processing. A main effect of stimulus type, with tools being faster than animals was also observed. Further, certain interactions between various stimulus conditions were also observed. Specifically, interactions between modality and stimulus type

Results and Discussion

Modality (Haptic vs. Visual overall)

The main aim was to investigate modal and amodal processing in visual and haptic domains. An analysis of variance (ANOVA) was conducted. Analysis revealed a statistically significant main effect of modality type [F (1, 40) = 206.97, p<.0001], with visual object recognition (MS = 1478.64) being faster in comparison to haptic object recognition (MS = 4707.57) leading to a modality (visual-haptic) specific effect (Fig.1.0.). This can be due to our greater familiarity with naming and identifying objects visually compared to haptic naming.

Stimulus (Animal vs. Tool)

Additionally, a stimulus (tool-animal) type main effect was observed with tools being processed faster than animals. Analysis revealed that tools (MS = 2174.93) were being processed faster than animals (MS = 4011.28), leading to a statistically significant main effect of stimulus type [F (1, 40) = 70.63, p<.0001] (Fig. 1.1.). This is likely due to the proximity and familiarity of holding tools and not holding animals.

Response (Name vs. Size)

Finally, a main effect of response type (name-size) was also evident [F (1, 40) = 189.32, p<.0001]. Although we expected naming to take less time than size comparison, but this was not the case. It was revealed that naming (MS = 4691.34) takes longer than judging the size (MS = 1494.87) of an object (both animals and tools) (Fig. 1.2.).

Interactions

It was observed that there was interaction between the factors. Analysis reported that haptic animal processing (MS = 6418.03) takes quite a bit longer than haptic tool processing (MS = 2997.12). On the other hand, visual animal processing (MS = 1604.53) also takes a bit longer than visual tool processing (MS = 1352.74) leading to non significant interaction between modality and stimulus type (Fig. 1.3.). Thus, tools can be processed faster haptically as well as visually. It was also revealed that there was significant interaction between modality and response type as the time to make the size comparison is expected to be the same regardless of the modality type as haptic size (MS = 1707.66) processing takes almost similar time as visual size (MS = 1282.08) processing. Whereas, haptic naming (MS = 7707.49) takes longer than visual naming (MS = 1675.19) (Fig. 1.4). Finally, it is predicted that there was significant interaction between the stimulus type (animal vs. tool) and the response type (naming vs. size) given that moving from naming to accessing additional conceptual information will be the same for animals and tools as animal size (MS= 1591.57) processing takes almost similar time as tool size (MS = 1398.17) processing. On the other hand, tool naming (MS=2951.68) takes less time than animal naming (MS = 6430.99) (Fig.1.5.).

General Discussion

The purpose of this study was to investigate modal and amodal processing in visual and haptic domains. The results suggest a strong effect, of modality type with visual object recognition being faster in comparison to haptic object recognition leading to a modality (visual-haptic) specific effect. This can be due to our greater familiarity with naming and identifying objects visually compared to haptic naming. Currently, published research regarding higher-order amodal object recognition is still limited. However, Newell et al. (2005) investigated visual, haptic and cross modal recognition of scenes. It was stated that it takes less than a second to capture the gist of a visual scene (Biederman et al. 1974; Potter 1976; Thorpe et al. 1996) suggesting that visual scenes are encoded in a holistic manner. Conversely, haptic encoding requires sampling the objects in a scene one at a time, almost serially, and a representation of the scene is subsequently built by integrating the interobject relations over time (Newell, et al, 2005). Another difference between visual and haptic encoding is that visual scene encoding involves peripheral vision. Henderson and Hollingworth (2003) conducted an experiment on eye movements and visual memory and reported that changes made to a peripheral target object in a scene could be detected more often than chance, suggesting that a relatively rich scene representation is retained across saccades and stored in visual memory even prior to fixation. Thus, it is clear that the representations of objects in a visual scene can accumulate in visual memory due to orienting of eyes and attention whereas, haptic encoding is limited to a localized, one object at a time encoding in a scene in order to build up a representation.

Additionally, various studies have reported that haptic space is generally non-Euclidean (Blumenfeld, 1973) resulting in distortions of distance estimation (Lederman, et al., 1985) and judgments of parallelity across the workspace (Kappers, 1999; Kappers & Koenderink, 1999; and Zuidhoek, et al., 2003). Kappers and Koenderink (1999) investigated haptic perception of spatial relations. Subjects were blindfolded and asked to perform three tasks: subjects were asked to rotate the test bar such that it felt parallel to the reference bar. Secondly, they were supposed to rotate the test and reference bar that they were collinear to each other and finally subjects had to point a test bar in the direction of a marker. In all experiments, large systematic deviations were made. Subjects showed identical trends and also a significant haptic oblique effect was found with deviations strongly correlating with horizontal (right-left) but not with vertical (forward-backward) distance resulting in non-euclidean haptic space. Studies also suggest that haptic spatial representations can be more allocentric with delays between learning and test. Consistent with the above notion, Zuidhoek, et al. (2003) conducted two experiments to investigate the effect of delay between the perception of a reference bar and the parallel setting of a test bar. It was reported that a 10-sec delay improved the performance in both the experiments. Thus, the improvement can be interpreted as haptic object recognition and can be allocentric leading to modality specific effect.

Another possibility of the modality specific effect can be due to differences in the nature of the object attributes that were encoded across the modalities. Lederman et al. (1996) suggested that certain features of stimuli can result in a modality encoding bias leading to a rich representation in one modality relative to the other modality. This can lead to poor crossmodal performance. For example, color can only be encoded by vision

and if stimuli differed only along the color dimension then crossmodal performance would be impaired because there would be no difference in the haptic domain.

Further, a stimulus (tool-animal) type main effect was observed with tools being processed faster than animals. This is likely due to the proximity and familiarity of holding tools and not holding animals. Martin, et al. (1996) used positron emission tomography (PET) to map brain regions associated with naming animals and tools. It was suggested that the region of the left middle temporal gyrus was active when identifying tools, but not animals. This area is nearly identical to the area activated in studies in which participants generated action words associated with objects (Wise, R. et al, 1991; Martin, A. et al, 1995). Also, the region of the left premotor cortex was activated when subjects named tools, but not animals. This area is nearly identical to the area activated when subjects imagined grasping objects with their right hand (Decety, J. et al., 1994). Both the left middle temporal gyrus and the left premotor cortex were also selectively activated by naming tool silhouettes relative to naming animal silhouettes. Thus, identifying tools may be mediated, in part, by areas that mediate knowledge of object motion and use

Consistent with the above notion, various studies have shown that object knowledge is organized around sensory/functional features may result in distinctions between object categories. Another possibility of stimulus type main effect can be that feature norms in adults demonstrate that natural kinds such as animals are mainly defined by perceptual/visual attributes, while artifacts such as tools are mostly characterized by functional/motor features. Kalenine, et al. (2009) did a behavioral and fMRI study on the sensory-motor specificity of taxonomic (e.g., hammer-saw) and thematic (hammer-nail)

conceptual relations. Subjects were given a picture matching task and were suppose to identify taxonomic and thematic relations for non-manipulable and manipulable natural and artifact targets (e.g., animals, fruit, tools and vehicles, respectively) inside and outside a 3 T MR scanner. Behavioral results suggest that taxonomic relations are identified faster in natural objects while thematic relations are processed faster in artifacts, particularly manipulable ones (e.g., tools). Also, Neuroimaging data showed that taxonomic processing specifically activates the bilateral visual areas particularly for non-manipulable natural objects (e.g., animals). On the contrary, thematic processing specifically recruited a bilateral temporo-parietal network including the inferior parietal lobes and middle temporal gyri. Thus, it can be suggested that knowledge about objects would depend on the brain areas involved in the processing of their main features, visual/perceptual or functional/motor features. Also, various neuroimaging studies support the sensory-motor feature-based hypothesis. They reveal that conceptual processing of objects recruits similar brain areas as those involved in perception and action, and thus depends on object categories (Martin, 2007). Retrieving both knowledge about tools and actions activates areas of the visuomotor action system, i.e. premotor, parietal and posterior temporal cortices, predominantly in the left hemisphere (Noppeney, 2008; Weisberg et al., 2007). Whereas, knowledge about living things such as animals appears closely linked to perceptual knowledge (e.g., form, color). Both perceptual knowledge and natural object concepts rely on brain areas involved in visual processing, i.e. ventro-temporal and occipital cortices (Goldberg et al., 2006a; Marques, 2006; and Simmons et al., 2007).

Additionally, in support of the stimulus type main effect, Marques (2002) investigated dissociations between names, concepts, features and the living/nonliving things in terms of organization of conceptual semantic representations and in the activation of name representations. Subjects were tested on name centrality and conceptual centrality tasks and were made to judge functional and perceptual/visual features of living (e.g., tiger, horse, etc.) and nonliving objects (like, helicopter, saw, etc.). Data analysis suggest that with regards to conceptual centrality, visual features are more important than functional features for the representation of living things and no feature type advantage is found for nonliving things. Name centrality results show that functional features are more important than sensory/visual features.

Finally, it was also found that there was a main effect of level type (name-size). Analysis shows that judging the size took less time in comparison to naming the object (both animal and tool). This could be due to the practice effects, as the experiment was repeated twice for each participant which can lead to faster size processing in comparison to naming. Studies show that when the participants are viewing or holding, scaled down, tangible, representations of the objects they will be unable to make a perceptually-based size judgment. Instead, they might be necessarily accessing higher order, conceptual information about the objects.

Further, it was also observed that there was interaction between factors. While looking at the modality and stimulus type it was found that haptic animal (HA) processing took quite a bit longer than haptic tool (HT) processing. Additionally, visual animal (VA) processing also takes a bit longer than visual tool (VT) processing leading to non significant interaction between the modality and stimulus type. Thus, tools can be

processed haptically as well as visually faster. It was also found that there was significant interaction between modality and response type as the time to make the size comparison is expected to be the same regardless of the modality type. Analysis show that haptic size processing takes almost similar time as visual size processing and haptic naming takes longer than visual naming leading to amodal or non-modality specific processing. It was predicted that there was significant interaction between the stimulus type and the response type given that moving from naming to accessing additional conceptual information will be the same for animals and tools. Thus, animal size processing takes almost similar time as tool size processing. On the other hand, tool naming is faster in comparison to animal naming.

Certainly, the initial processing is modality specific (modal) (Fig. 1.6). But it is unclear what happens beyond this early modality specific processing. Once naming is accomplished, if subsequent size processing, whether it is in the visual or haptic domain, results in similar reaction times this would be an indication of, non-modality specific or amodal processing. Thus in our study, visual size recognition and haptic size recognition result in equivalent processing requirements regardless of stimulus type or modality type leading to an example of amodal processing (Fig. 1.7).

Vision and haptic processes are very different information capture systems that measure a range of object attributes. Through integration of information across the senses we are able to create a much richer representation of our world. As these processes take place processing begins in a modality specific manner. Touching a horse is different from seeing a horse; each one uses modality specific processing regions. However, once the modality specific information is processed, amodal, or non-modality specific processing takes over as higher order information regarding the horse is accessed. That is, a horse is a horse of course.

This initial study suggests that rudimentary object identification involves modality-specific primary processing. Moving from rudimentary to higher order levels is consistent across modalities, suggesting a single, modality-independent, process may be involved. Research shows robust activation in primary tactile/motor and visual cortical regions for tactile and visual processing (Wessinger & Vanmeter, 2005). Consistent with the above notion, future research includes collecting a neuroimaging data where participants will name and conceptually do size comparison in the visual and haptic domains. Further, we would like to address the question that whether haptic adaptation affects visual adaptation as research shows that adaptation is an important factor with regards to vision, specifically visual face adaptation. We would like to explore haptic adaptation with regards to object recognition initially with geometrical shapes. Various studies have shown visual, haptic and auditory object recognition (Amedi et al., 2005). We would like to investigate modal and amodal object recognition in haptic and auditory domains as both these modalities are an example of proximal processing in comparison to vision which involves both distal and proximal processing. Clearly further research is required to increase our understanding of the differential contributions of modal and amodal object processing in the visual and haptic domains. Yet one fact still remains the same, "A horse is a horse of course."
Figure Captions

Figure 1.0. - Main effect of modality type (visual – haptic)

Figure 1.1 – Main effect of stimulus type (animal – tool)

Figure 1.2 – Main effect of response type (name - size)

Figure 1.3 – Interaction between modality and stimulus type (visual – haptic and animal – tool)

Figure 1.4 – Interaction between modality and response type (visual – haptic and namesize)

Figure 1.5 – Interaction between stimulus and response type (animals – tool and name - size)

Figure 1.6 – Modal processing (visual naming and haptic naming)

Figure 1.7 – Amodal processing (visual size and haptic size)













Figure 1.3 – Interaction between modality and stimulus type (visual – haptic and animal – tool)





Figure 1.4 – Interaction between modality and response type (visual – haptic and namesize)



Figure 1.5 – Interaction between stimulus and response type (animals – tool and name - size)



Figure 1.6 – Amodal processing (visual naming and haptic naming)

Figure 1.7 – Amodal processing (visual size and haptic size)



- Appendix 1 Animal stimuli list
- Appendix 2 Tool stimuli list
- Appendix 3 Demographic information questionnaire

Appendix 1

Animal list

Reference object - Cow



Turtle

Horse

Bull

Appendix 2

Tool List

Reference Object – Eraser



Appendix 3

Demograp	hic	Ques	tionn	aire
2 June Brap		X		

Please Complete:

Date:_____

Time:_____

Group:_____

Age:_____

Yr in School:_____

Handedness:_____

Primary Language:_____

Second Language (if applicable):_____

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Modal and Amodal processing in the Visual and Haptic domains

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Abstract

Our ability to recognize objects is not limited to the vision alone and we can also recognize objects using more than one sensory modality. Thus, the aim of the current study is to investigate cross- and multi-modal object processing with the intent of increasing our understanding of the differential contributions of modal and amodal object processing in the visual and haptic domains. Each participant went through four different trials: Visual naming and size, Haptic naming and size. Naming consisted of verbally naming the item; Size (size comparison) consisted of verbally indicating if the current item is larger or smaller than a reference object. Stimuli consisted of plastic animals and tools. All stimuli are readily recognizable, and easily be manipulated with one hand. The actual figurines and tools were used for haptic trials, and digital photographs were used for visual trials (appendix 1 and 2). The results suggest a strong effect, of modality type with visual object recognition being faster in comparison to haptic object recognition leading to a modality (visual-haptic) specific effect. It was also observed that tools were processed faster than animals regardless of the modality type. There was interaction reported between the factors supporting the notion that once naming is accomplished, if subsequent size processing, whether it is in the visual or haptic domain, results in similar reaction times this would be an indication of, non-modality specific or amodal processing. Thus, by using animal and tool figurines, we investigated modal and amodal processing in visual and haptic domains.

Introduction

We are constantly observing and interacting with a variety of different objects in our environment. Nevertheless all we know about these objects is what our sensory system tells us. Recognizing objects are accomplished by using a combination of multisensory information. For example, a bumble bee can be recognized by seeing its characteristic yellow and black colors, by hearing its distinctive buzzing sound, by feeling the fuzzy surface of its body as it walks around our hand or by a combination of these and many other cues. No matter how we recognize that it is a bumble bee, we invariably access a wide range of additional information about that bee, not the least of which is that, bumble bees can sting and that their sting can hurt.

Recognizing and accessing additional information about various objects in our environment allows us to interact appropriately with our environment. We need to know whether to catch a baseball or dodge a rock, step onto a bus, or jump out of the way of a car, stop to pet a dog, or run from a tiger. But how do we know this?

One way is to identify the objects in the world around us before responding to them, though we may not always consciously identify such objects before we respond. Of course, such processing is not limited to the visual domain. Finding your lucky shirt in the dark, or knowing that you have a quarter in your hand, not a dime, or recognizing that your cat not your dog is rubbing up against your calf, all require using haptic information. Such identification often entails naming and subsequent conceptual processing of the items so that we can respond appropriately. This study will provide valuable information about how the objects are processed in both visual and haptic domains. Vision is the primary sensory modality that humans and other primates use to identify objects in their environment (James et al., 2002). Nevertheless, touch allows humans and primates to extract precise information about many dimensions of objects that are in their personal space, and can be reached and handled actively. Haptic perception (from the Greek word 'haptikos' means to 'to touch') incorporates both touch information from the skin and kinesthetic information from the position and movement of the joints and muscles (Newell et al., 2004). It provides the information about the properties of an object such as its shape, size and texture by means of exploratory manual movements (Henriques et al., 2005). Both the visual and haptic systems together can provide clues to the identity of the object. Both systems perceive a number of similar and a number of dissimilar object features, and through combination of this information the object can be successfully identified.

As this information is first experienced and transduced into sensory information, there are modality-specific (i.e. modal) processes and capabilities employed by the various sensory systems. Despite the fact that both visual and haptic systems can be used to identify objects, there are various differences between the nature of encoding information about an object and the type of information that can be encoded. The visual system can receive the information not only about objects that reside within personal space, but also those that are at some distance from the observer. When objects are at a distance, only the surfaces and parts of an object that face the observer can be processed visually. When objects are within reach, however, the object can be manipulated, thus, revealing the structure and features of the previously unseen surfaces and parts. Whereas, the haptic system can receive information only about objects that reside within personal space, i.e. those objects which are within arms reach.

Furthermore, the visual system involves the spatial analysis of a static image on the retina (Logothetis 1998; Riesenhuber and Poggio 2000), and an entire scene can be viewed at the same time, across a much larger scale. On the other hand, haptic system can only explore a set of objects one at a time through a series of successive impressions (Gibson, 1962).

Finally, some features of an object can only be perceived by one modality, usually referred to as a modality encoding bias (Lederman, Summers, & Klatzky, 1996). For example, color can only be directly perceived visually whilst object mass, surface friction, hardness and temperature can only be perceived directly through touch (Woods & Newell, 2004). These crossmodal differences in the timing of information pick-up and the modality encoding range may affect crossmodal performance.

Despite the above differences between the two systems, there is evidence that the higher-order processing of objects by vision and haptics may access the same store of semantic information once the initial sensory information has been transduced and translated into neuronal codes. For example, in many situations, particularly those in which differential information about surface features such as color and visual texture are not available, visual recognition of objects is view-point dependent. That is, if an object is explored visually from a particular viewing angle, recognition will be better for that view of the object than for other views (Harman & Humphrey, 1999; Humphery & Khan, 1992; Tarr, 1995).

Current evidence suggests that when we look at an object as we move or the object moves, our visual system is presented with a sequence of different views of the object and contains information that can aid in the process of representing and recognizing objects (Harman & Humphrey 1999).

Although the concept of 'viewing angle' in haptic exploration of fixed objects is not as well-defined as it is in vision but it is still used to compare visual and haptic studies. Further, it is reported that view point specific haptic representation of objects is based on the observation that common motor tasks such as grasping and manipulating objects require information about the position and orientation of an object relative to the observer. However, such motor tasks are usually guided by vision, and therefore all the necessary information is available visually suggesting that it is generally unnecessary to invoke any haptic representation for even simple visual identification of the objects. That is, we do not need to necessarily need to grasp an object in order to identify that object. (Goodale et al., 1994; Goodale, Milner, Jakobson, & Carey, 1991). Even for tasks in which visual information is not available, such as reading Braille or playing musical instruments, orientation and position information can, in theory, be attached to an omni directional, viewpoint independent haptic representation (Kennedy, 1993; Millar, 1997). On the whole, people recognize objects best when they see the objects from a familiar view and worse when they see the objects from views that were previously occluded from sight. Similarly, haptic object recognition also appears to be view-point dependent as well.

In support of the above study, various researchers suggested that vision and touch are independent modalities but they still obey similar operating principals. Behrmann &

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Ewell (2003) conducted two experiments using raised line patterns. These patterns were recognized in inverted version and the part-whole version to examine expertise in tactile pattern recognition. The inversion effect involved better recognition of upright pattern than inverted pattern whereas the part-whole effect involved better recognition of whole than a part pattern. It was found that like visual object recognition, tactile object recognition can be modified by experience and learning. Also, crossmodal transfer between visual and haptic was asymmetric, with visual identification being faster and can be used for the haptic identification. Whereas, information acquired haptically, is not transferred to visual identification. Thus, despite the apparent independence, the two modalities undergo same computational processes. Additionally, it is suggested that the accuracy of haptically matching a 2-D drawing to its 3-D counterpart of an object is better when the drawing was depicted with perspective, despite the fact that the distortions of perspective, such as foreshortening, are associated with visual processing, and not haptic processing (Heller et al., 2002).

Various studies in the field of visual recognition support the view of a dichotomy between a fast, parallel perceptual system that performs a featural analysis of the visual scene, and a slower, more limited memory system that is dedicated to keeping track of the objects in view (Kahneman, Treisman, & Gibbs 1992; Kanwisher & Driver 1992; Printzmetal 1995; Treisman, & Gibbs, 1991). However, if given additional processing time, conceptual information about the object can be accessed.

Recent research has found that the characteristics of the visual and haptic object recognition are so similar, that there is a speculation that the two modalities actually share the same underlying representation (James et al., 2001). The question now arises as

to whether the same processes involved in visual object recognition are also involved in haptic object recognition, and whether or not these representations can be shared across vision and haptic senses. For the purpose of object recognition, both vision and haptics can be considered as image-based, in that both the modalities can acquire shape information for recognition, but by using different means.

Various behavioral investigations have shown crossmodal priming between touch and vision, and vision and touch. Easton et al., (1997) used crossmodal priming between vision and haptics to show that exposure to real objects in one modality affected later naming of the objects when they were presented using the other modality. Various crossmodal priming and within-modality priming experiments resulted in similar effect sizes, suggesting that a visual representation of an object can be activated as much by a haptic presentation of the object as by a visual presentation of the object (and vice-versa). Reales & Ballesteros (1999) investigated real-world objects and data-driven visual and haptic implicit memory tests performed in within-modal as well as in crossmodal conditions. The study showed significant priming between and within- modalities.

In another study, Norman et al., (2004) conducted experiments comparing naturally shaped three-dimensional objects, using the senses of vision and touch in order to evaluate participants ability towards shape recognition and the results suggest that vision and touch have functionally overlapping, but not necessarily equivalent, representations of 3-D shapes.

Furthermore, various researchers have thrown light on the crossmodal consequences of viewing the Muller-Lyer illusion, and have shown that being purely visual illusion, it can also be demonstrated in touch (Coren and Girgus, 1978; Fry, 1975).

The Muller-Lyer illusion consists of two identical lines that are actually perceived as being of different lengths, due to presence of "fins" with a particular orientation placed at each end of each line. The line flanked by fins pointing outward (hereafter labeled "wings-in") is perceived to be shorter than it really is, while the line flanked by fins pointing inward (labeled as "wings-out") is perceived as being longer (Coren, 1970; Coren and Girgus, 1978).

Apart from the behavioral data, several recent neuroimaging studies have shown that both visual and haptic object identification produces activation in the occipital cerebral cortex. Amedi et al., (2002) used fMRI to demonstrate that a region within the human lateral occipital complex (LOC) is activated when the objects are either seen or touched. They termed this cortical region as the lateral occipital tactile-visual region (LOtv). It was reported that voxels in the lateral occipital tactile-visual region (LOtv) which is a sub region of the LOC show preference for graspable visual objects over faces or houses. Further, the nature of object representation in LOtv (lateral occipital tactilevisual region) was examined by studying its responses to stimuli in three modalities: auditory, somatosensory, and visual. It was found that the object activation was quite strong in both visual and somatosensory modalities, while no activation was produced by the auditory signals. Thus, it is suggested that LOtv (lateral occipital tactile-visual region) plays an important role in determining the geometrical shape of objects, whereas auditory information plays a little role in shape recognition of an object.

Various studies have shown that haptic exploration of novel three-dimensional objects produces activation, not only in somatosensory cortex, but also in areas of the occipital cortex associated with visual processing. In 2002, James et al., reported possible

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interactions between the visual and haptic systems. They used fMRI to measure the effects of crossmodal haptic-to-visual priming on brain activation and it was found that the visual and haptic exploration of non-primed objects produced significant activation in several brain regions, and produced overlapping activation in the middle occipital area (MO). Thus, viewing visually and haptically primed objects produced more activation than viewing non-primed objects in both middle occipital (MO) and lateral occipital areas (LO).

Reed, Shoham & Halgren (2004) investigated naturalistic tactile object recognition (aka TOR) of real objects using fMRI. Thus, the study suggests that tactile object recognition (TOR) is a complex network of parietal and insular somatosensory association cortices, as well as occipitotemporal visual areas, prefrontal, and medial temporal areas and medial and lateral secondary motor cortices.

Furthermore, it has been found that different sensory modalities provide both complementary and redundant information about objects, which may improve recognition speed and accuracy in various circumstances. Amedi et al., (2005) reviewed various function magnetic resonance imaging (fMRI) studies on crossmodal object recognition in humans. The studies showed that visual, tactile, and auditory information about objects can activate cortical association areas that were once believed to be modality-specific. Thus, the above studies support a general mechanism for crossmodal object recognition involving modal and amodal mechanisms suggesting that the recruitment and location of multisensory convergence zones varies depending on the information content and the dominant modality. The aim of the current study is therefore to further investigate cross- and multimodal object processing with the intent of increasing our understanding of the differential contributions of modal and amodal object processing in the visual and haptic domains. By investigating cross modal recognition performance we will be able to provide a clearer understanding of what similar processes are involved in visual object recognition and haptic object recognition, how these representations can be shared across vision and haptics, and how there are hierarchical stages of processing that initially require modal processing and subsequently require amodal processing.

General Methods

Study Design

The study was designed to contrast visual and haptic processing. The specific format was a 2*2*2 design. The main factors were modality type (vision or haptics), stimulus type (tools or animals) and response type (naming and size comparison).

Naming consisted of verbally naming the item. Size comparison involved verbally indicating if the current item is larger or smaller than a reference object (see appendix 1 and 2). Participants became familiar with the figurines and tools during a 5-10 minute pretesting session during which each participant named and touched few tools and animals objects in order to get acquainted with the experiment Pictures of stimulus items are shown in appendix 1 and 2. The reference items for animals and tools were identified by the participant at this time too. Subsequently, each participant went through two experimental trials: Visual Naming/Size and Haptic Naming/Size. Trials were divided into four different pre-testing and testing conditions: Visual Naming/Size, Haptic Naming/Size, Kisual Naming/Size, Haptic Naming/Size. The order of the trials was

random for each participant. Conditions were counterbalanced across participants, starting with Visual Naming/Size or Haptic Naming/Size.

Participants

The study was conducted with 40 participants and utilized a within subject design. All participants were students at the University of Nevada, Reno, with normal or corrected to normal vision.

Stimuli

Stimuli consisted of plastic animals and tools. All stimuli are readily recognizable, and easily be manipulated with one hand. The actual figurines and tools were used for haptic trials, and digital photographs were used for visual trials (appendix 1 and 2).

Procedure

Each participant was asked to complete a demographic questionnaire (age, year in school, handedness, primary language, and second language). Then all participants were given several minutes of practice time to become well acquainted with the stimuli. Others have shown that this practice time is necessary in order that participants are able to easily identify the stimuli (Reales & Ballesteros, 1999).

Experiment 1: Visual Naming/Size

The experiment required participants to verbally name the animal or tool after viewing them visually. All participants began the experiment by viewing, each of the digitized photographs for 2500 msec with a 500 msec interstimulus interval (ISI) using SuperLab running on a laptop. Each participant was required to name the objects in the photographs presented to them as quickly as possible. A microphone was used to record voice onset time in order to collect reaction time as the dependent variable within the data files. Since, we expected participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect percent correct. This ensured that the participant was accessing the correct semantic information.

Further, each participant was required to examine additional semantic information related to the object (animal or tool). Participants retrieved the size of each tool or the animal item by comparing it with the size of the neutral tool or animal item. That is, after participants verbally name the object; they were supposed to say "smaller" or "larger" indicating they have retrieved the size of object. Again, reaction times were collected as the dependent variable using a microphone to obtain voice onset time. Since, we expected participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect percent correct. This ensured that the participant was accessing the correct semantic information.

Experiment 2: Haptic Naming/Size

For the haptic naming, the figures of the same digitized pictures were displayed for 5500 msec with a 500 msec ISI. This increase in trial length is necessary to accommodate the transfer of haptic stimuli to and from the participant's hand. During these runs, an experimenter was supposed to hand over the animal and tool figurines to the participant and each participant was required to name the objects in the models presented to them with the use of a microphone in order to record reaction time and verbal responses within the stimulus presentation program data files. A second experimenter was required to hand the stimuli to the experimenter and record incorrect and correct answers. In order to ensure consistent timing, the experimenter viewed the stimulus display while handing the stimuli to the participants. During the experiment, participants were seated in front of a table in such a way that their view of the object was blocked with the help of a cardboard in front of them so that they cannot see the stimuli across the table. Again, a microphone was used to detect the voice onset in order to collect reaction time as the dependent variable. Since, we expect participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect percent correct. This ensured that the participant is accessing the correct semantic information.

In addition to using the same procedures as in the Haptic Naming experiments, in which participants palpate and name objects that have been handed to them by the experimenter, participants were also required to retrieve the size of each tool or the animal figurine by comparing it with the size of the neutral tool or animal figurine. So, after participants verbally named the object; they were also asked to say "smaller" or "larger" indicating they have retrieved the size of an object. Again, a microphone was used to detect the voice onset time in order to collect reaction time as the dependent variable. Since, we expected participants to be at ceiling for naming and usage following the practice session, a second experimenter was present to collect the percent correct. This ensured that the participant was accessing the correct semantic information.

Results and Discussion

Reaction time data was analyzed using analysis of variance (ANOVA) statistical techniques. Data was subjected to a 2*2*2* ANOVA with modality type (visual-haptic), stimulus type (tool-animal) and response type (name-size) as factors. It was reported that

there was a main effect of sensory modality, with visual processing being faster than tactile processing. A main effect of stimulus type, with tools being faster than animals was also observed. Further, certain interactions between various stimulus conditions were also observed.

Analysis revealed a statistically significant main effect of modality type [F (1, 40) = 206.97, p<.0001], with visual object recognition (MS = 1478.64) being faster in comparison to haptic object recognition (MS = 4707.57) leading to a modality (visual-haptic) specific effect. This can be due to our greater familiarity with naming and identifying objects visually compared to haptic naming.

Further, a stimulus (tool-animal) type main effect was observed with tools being processed faster than animals. Analysis revealed that tools (MS = 2174.93) were being processed faster than animals (MS = 4011.28), leading to a statistically significant main effect of stimulus type [F (1, 40) = 70.63, p<.0001]. This is likely due to the proximity and familiarity of holding tools and not holding animals.

Finally, a main effect of response type (name-size) was also evident [F (1, 40) = 189.32, p<.0001]. Although we expected naming to take less time than size comparison, but this was not the case. It was revealed that naming (MS = 4691.34) takes longer than judging the size (MS = 1494.87) of an object (both animals and tools).

It was observed that there was interaction between the factors. Analysis reported that haptic animal processing (MS = 6418.03) takes quite a bit longer than haptic tool processing (MS = 2997.12). On the other hand, visual animal processing (MS = 1604.53) also takes a bit longer than visual tool processing (MS = 1352.74) leading to non significant interaction between modality and stimulus type (Fig. 1.0.). Thus, tools can be
processed faster haptically as well as visually. It was also revealed that there was a significant interaction between modality and response type as the time to make the size comparison is expected to be the same regardless of the modality type as haptic size (MS = 1707.66) processing takes almost similar time as visual size (MS = 1282.08) processing. Whereas, haptic naming (MS = 7707.49) takes longer than visual naming (MS = 1675.19) (Fig. 1.1). Finally, it is predicted that there was a significant interaction between the stimulus type (animal vs. tool) and the response type (naming vs. size) given that moving from naming to accessing additional conceptual information will be the same for animals and tools as animal size (MS = 1591.57) processing takes almost similar time as tool size (MS = 1398.17) processing. On the other hand, tool naming (MS = 2951.68) takes less time than animal naming (MS = 6430.99) (Fig. 1.2.).

General Discussion

The main aim was to investigate modal and amodal processing in visual and haptic domains. The results suggest a strong effect, of modality type with visual object recognition being faster in comparison to haptic object recognition leading to a modality (visual-haptic) specific effect. This can be due to our greater familiarity with naming and identifying objects visually compared to haptic naming. Currently, published research regarding higher-order amodal object recognition is still limited. However, Newell et al. (2005) investigated visual, haptic and cross modal recognition of scenes. It was suggested that it takes less than a second to capture the gist of a visual scene (Biederman et al. 1974; Potter 1976; Thorpe et al. 1996) suggesting that visual scenes are encoded in a holistic manner. Conversely, haptic encoding requires sampling the objects in a scene one at a time, almost serially, and a representation of the scene is subsequently built by integrating the interobject relations over time (Newell, et al, 2005). Another difference between the visual and haptic encoding is that, visual scene encoding involves peripheral vision. Henderson and Hollingworth (2003) conducted an experiment on eye movements and visual memory and reported that changes made to a peripheral target object in a scene could be detected more often than chance, suggesting that a relatively rich scene representation is retained across saccades and stored in visual memory even prior to fixation. Thus, it is clear that the representations of objects in a visual scene can accumulate in visual memory due to orienting of eyes and attention whereas, haptic encoding is limited to a localized, one object at a time encoding in a scene in order to build up a representation.

Additionally, various studies have reported that haptic space is generally non-Euclidean (Blumenfeld, 1973) resulting in distortions of distance estimation (Lederman, et al., 1985) and judgements of parallelity across the workspace (Kappers, 1999; Kappers & Koenderink, 1999; and Zuidhoek, et al., 2003). Kappers and Koenderink (1999) investigated haptic perception of spatial relations. Subjects were blindfolded and asked to perform three tasks: subjects were asked to rotate the test bar such that it felt parallel to the reference bar. Secondly, they were supposed to rotate the test and reference bar that they were collinear to each other and finally subjects had to point a test bar in the direction of a marker. In all experiments, large systematic deviations were made. Subjects showed identical trends and also a significant haptic oblique effect was found with deviations strongly correlating with horizontal (right-left) but not with vertical (forward-backward) distance resulting in non-euclidean haptic space. Studies also suggest that haptic spatial representations can be more allocentric with delays between learning and test. Consistent with the above notion, Zuidhoek, et al. (2003) conducted two experiments to investigate the effect of delay between the perception of a reference bar and the parallel setting of a test bar. It was reported that a 10-sec delay improved the performance in both the experiments. Thus, the improvement can be interpreted as haptic object recognition can be allocentric leading to modality specific effect.

Another possibility of the modality specific effect can be because of differences in the nature of the object attributes that were encoded across the modalities. Lederman et al. (1996) suggested that certain features of stimuli can result in a modality encoding bias leading to a rich representation in one modality relative to the other modality. This can lead to poor crossmodal performance. For example, color can only be encoded by vision and if stimuli differed only along the color dimension then crossmodal performance would be impaired because there would be no difference in the haptic domain.

Further, a stimulus (tool-animal) type main effect was observed with tools being processed faster than animals. This is likely due to the proximity and familiarity of holding tools and not holding animals. Martin, et al. (1996) used positron emission tomography (PET) to map brain regions associated with naming animals and tools. It was suggested that the region of the left middle temporal gyrus was active when identifying tools, but not animals. This area is nearly identical to the area activated in studies in which participants generated action words associated with objects (Wise, R. et al, 1991; Martin, A. et al, 1995). Also, the region of the left premotor cortex was activated when subjects named tools, but not animals. This area is nearly identical to the area activated when subjects imagined grasping objects with their right hand (Decety, J. et al., 1994). Both the left middle temporal gyrus and the left premotor cortex were also selectively activated by naming tool silhouettes relative to naming animal silhouettes. Thus, identifying tools may be mediated, in part, by areas that mediate knowledge of object motion and use. Various studies have shown that tools are unique objects because they have a visual structure that affords action and also a specific functional identity. Creem-Regehr & Lee (2005) used functional magnetic resonance imaging (fMRI) to investigate the extent of a tool's graspability or its functional use. Participants were asked to view and imagine grasping images of 3D tools with handles or neutral graspable shapes. Analysis shows that in the viewing task, motor-related regions of cortex were associated with tools compared to shapes. Whereas, for the imagined grasping task, a frontalparietal-temporal network of activation was seen with both types of objects. However, differences were found in the extent and location of premotor and parietal activation, and additional activation in the middle temporal gyrus and fusiform gyrus for tools compared to shapes. Thus, we can say that the functional identity of graspable objects influences the extent of motor representations associated with them and we are more familiar in holding tools in day to day life.

Consistent with the above notion, various studies have shown that object knowledge is organized around sensory/functional features may result in distinctions between object categories. Another possibility of stimulus type main effect can be that feature norms in adults demonstrate that natural kinds such as animals are mainly defined by perceptual/visual attributes, while artifacts such as tools are mostly characterized by functional/motor features. Kalenine, et al. (2009) did a behavioral and fMRI study on the sensory-motor specificity of taxonomic (e.g., hammer-saw) and thematic (hammer-nail) conceptual relations. Subjects were given a picture matching task and were suppose to

identify taxonomic and thematic relations for non-manipulable and manipulable natural and artifact targets (e.g., animals, fruit, tools and vehicles, respectively) inside and outside a 3 T MR scanner. Behavioral results suggest that taxonomic relations are identified faster in natural objects while thematic relations are processed faster in artifacts, particularly manipulable ones (e.g., tools). Also, Neuroimaging data showed that taxonomic processing specifically activates the bilateral visual areas particularly for non-manipulable natural objects (e.g., animals). On the contrary, thematic processing specifically recruited a bilateral temporo-parietal network including the inferior parietal lobes and middle temporal gyri. Thus, it can be suggested that knowledge about objects would depend on the brain areas involved in the processing of their main features, visual/perceptual or functional/motor features. Also, various neuroimaging studies support the sensory-motor feature-based hypothesis. They reveal that conceptual processing of objects recruits similar brain areas as those involved in perception and action, and thus depends on object categories (Martin, 2007). Retrieving both knowledge about tools and actions activates areas of the visuomotor action system, i.e. premotor, parietal and posterior temporal cortices, predominantly in the left hemisphere (Noppeney, 2008; Weisberg et al., 2007). However, knowledge about living things such as animals appears closely linked to perceptual knowledge (e.g., form, color). Both perceptual knowledge and natural object concepts rely on brain areas involved in visual processing, i.e. ventro-temporal and occipital cortices (Goldberg et al., 2006a; Marques, 2006; and Simmons et al., 2007).

Additionally, in support of the stimulus type main effect, Marques (2002) investigated dissociations between names, concepts, features and the living/nonliving

things in terms of organization of conceptual semantic representations and in the activation of name representations. Subjects were tested on name centrality and conceptual centrality tasks and were made to judge functional and perceptual/visual features of living (e.g., tiger, horse, etc.) and nonliving objects (like, helicopter, saw, etc.). Data analysis suggest that with regards to conceptual centrality, visual features are more important than functional features for the representation of living things and no feature type advantage is found for nonliving things. Name centrality results show that functional features are more important than sensory/visual features.

Finally, it was also found that there was no main effect of level type (name-size). Analysis shows that judging the size took less time in comparison to naming the object (both animal and tool). It can be due to the practice effects, as the experiment was repeated twice for each participant which can lead to faster size processing in comparison to naming.

Further, it was also observed that there was interaction between factors. While looking at the modality and stimulus type it was found that haptic animal (HA) processing took quite a bit longer than haptic tool (HT) processing. Additionally, visual animal (VA) processing also takes a bit longer than visual tool (VT) processing leading to non significant interaction between the modality and stimulus type. Thus, tools can be processed haptically as well as visually faster. It was also found that there was significant interaction between modality and response type as the time to make the size comparison is expected to be the same regardless of the modality type. Analysis show that haptic size processing takes almost similar time as visual size processing and haptic naming takes longer than visual naming leading to amodal or non-modality specific processing. It was predicted that there was significant interaction between the stimulus type and the response type given that moving from naming to accessing additional conceptual information will be the same for animals and tools. Thus, animal size processing takes almost similar time as tool size processing. On the other hand, tool naming is faster in comparison to animal naming.

Certainly, the initial processing is modality specific (modal). But it is unclear what happens beyond this early modality specific processing. Once naming is accomplished, if subsequent size processing, whether it is in the visual or haptic domain, results in similar reaction times this would be an indication of, non-modality specific or amodal processing. Thus, in our study, visual size recognition and haptic size recognition result in equivalent processing requirements regardless of stimulus type or modality type leading to an example of amodal processing.

Thus, vision and haptic are very different information capture systems that measure a range of object attributes. Through integration of information across the senses we are able to create a much richer representation of our world. As these processes take place processing begins in a modality specific manner. Touching a horse is different from seeing a horse; each one uses modality specific processing regions. However, once the modality specific information is processed, amodal, or non-modality specific, processing takes over as higher order information regarding the horse is accessed. That is, a horse is a horse of course.

This initial study suggests that rudimentary object identification involves modality-specific primary processing. Moving from rudimentary to higher order levels is consistent across modalities, suggesting a single, modality-independent, process may be

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involved. Research shows robust activation in primary tactile/motor and visual cortical regions for tactile and visual processing (Wessinger & Vanmeter, 2005). Consistent with the above notion, future research includes collecting a neuroimaging data where participants will name and conceptually do size comparison in the visual and haptic domains. Further, we would like to address the question that whether haptic adaptation affects visual adaptation as research shows that adaptation is an important factor with regards to vision, specifically visual face adaptation. We would like to explore haptic adaptation with regards to object recognition initially with geometrical shapes. Various studies have shown visual, haptic and auditory object recognition (Amedi et al., 2005). We would like to investigate modal and amodal object recognition in haptic and auditory domains as both these modalities are an example of proximal processing in comparison to vision which involves both distal and proximal processing. Clearly further research is required to increase our understanding of the differential contributions of modal and amodal object processing in the visual and haptic domains. Yet one fact still remains the same, "A horse is a horse of course."

Appendix 1

Animal list

Reference object - Cow



Cow



Ape



Buffalo





Elephant







Hippo



Moose



Turtle

Horse



Appendix 2

Tool List

Reference Object - Eraser



Figure 1.0 – Interaction between modality and stimulus type (visual – haptic and animal – tool)







Figure 1.2 – Interaction between stimulus and response type (animals – tool and name - size)



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