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Crossmodal Perception of Object Shape: A Study on the Effect of Modal Order on Successful Shape Recognition

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CROSSMODAL PERCEPTION OF OBJECT SHAPE:
A STUDY ON THE EFFECT OF MODAL ORDER ON SUCCESSFUL SHAPE RECOGNITION

A Capstone Experience/Thesis Project Presented in Partial Fulfillment

of the Requirements for the Degree Bachelor of Science with

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By

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ABSTRACT

Visual and haptic (tactile) modes of perception, while occasionally exercised independently, most often occur concurrently. The degree to which the ordering of the two modes of perception affects successful recognition of three-dimensional shapes varies. Some have found that the cross-modal orders (vision followed by haptics or vice versa) produce equal performance (Caviness, 1964; Lacey, Peters, & Sathian, 2007; Norman et al., 2006), while other researchers found visual-haptic (VH) performance to be superior to haptic-visual (HV) performance (Davidson, Abbott, & Gershenfeld, 1974; Norman, Clayton, Norman, & Crabtree, 2008). The current experiment used an old-new recognition task (with cookie cutter stimuli). In one condition, half of the participants visually studied four randomly chosen cookie cutters and their recognition ability was then tested haptically. In a second condition, the remaining half of the participants studied four cookie cutters haptically through active touch and their recognition ability was then tested visually. The participants' recognition performance was equally high for both conditions (i.e., 80.0 and 76.3 percent correct for the vision-haptic and haptic-vision conditions, respectively). The current results demonstrate that human participants can effectively compare object shapes across the sensory modalities of vision and touch.

ACKNOWLEDGEMENTS

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VITA

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INTRODUCTION

The human brain is constantly working in conjunction with sensory mechanisms within the body (e.g., eyes & hands) to assist in the perception of an individual's environment. There are five perceptual modalities: audition (hearing), vision (sight), haptics (active touch), olfactory (sense of smell), and gustatory (taste). While all five modalities are used routinely, this study focuses specifically on the haptic and visual modalities, because these are the only perceptual modalities through which we perceive object shape.

According to Forrester (2021), visual perception can be traced back to a complex processing pathway involving the cerebral cortex and the retina of the eye. The patterns of light that enter the eyes are detected by rod and cone photoreceptors in the retina (Hubel, 1988). This visual information is relayed by the retinal ganglion cells to neurons in the lateral geniculate nucleus of the thalamus (Hubel, 1988). From there, visual information is sent to the primary visual cortex in the occipital lobe of the brain (the primary visual cortex is responsible for conscious visual perception). After the primary visual cortex, various aspects of visual analysis are performed by a wide variety of cortical areas located in both the temporal and parietal lobes of the brain (Albright, 2013). In the context of the current study, it is important to know that neuronal mechanisms within the inferior parts of the temporal lobe are responsible for successful visual object recognition (Albright, 2013).

At this point, it is also important to remember people recognize objects not only through vision, but also from the sense of touch. When someone explores an object using their hands and fingers (active touch or haptics, e.g., see Gibson, 1966), the resulting tactile stimulation activates sensory mechanoreceptors embedded within the skin; the mechanoreceptors that detect touch are Meissner's corpuscles, Merkel's Discs, Pacinian corpuscles, and Ruffini's endings (Gardner & Johnson, 2013). This mechanical tactile information enters the spinal cord through the dorsal nerve root and ascends to the ventral posterior (VP) nucleus of the thalamus within the brain. From the VP, the ascending tactile information is sent onwards to the primary somatosensory cortex (cortical areas 3b, 1, and 2). Interestingly, it has been demonstrated that both visual and tactile input eventually converge in cortical areas, such as the lateral occipital complex (LOC, e.g., see Amedi, Jacobson, Hendler, Malach, & Zohary, 2002; Jao, James, & James, 2015; Lacey & Sathian, 2015). This convergence of tactile and visual information in the cerebral cortex could account for the human ability to compare the shapes of objects across the senses of vision and touch.

Visual and haptic perception of shapes and objects, while occasionally exercised independently, most often occur concurrently. Furthermore, in most instances people can reliably compare objects that they see with those they only experience by touch. Nevertheless, crossmodal perception fails to be completely understood. Several aspects, including the effect of the order of modalities on the ability to recognize objects, continue to be heavily debated. The experimental findings have been contradictory to date. One set of previous studies (e.g., Lacey, Peters, & Sathian, 2007; Woods, O'Modhrain, & Newell, 2004) found no significant difference between conditions where stimulus objects are explored haptically (active touch) first followed by visual presentation (haptic-vision condition) and conditions where stimulus objects are presented in the opposite order (vision first, haptics second). In the study by Lacey et al. (2007), participants became familiar with a set of objects using one modality (e.g., vision) and then their recognition of the objects was tested in the other modality (e.g, haptics). Their results indicated that there was no significant difference between visual-haptic and haptic-visual recognition performance. On any given trial in the study by Woods et al. (2004), the participants were presented with two L-shaped objects (that varied in aspect ratio) and they were required to judge whether the two stimulus objects were the same or were different. The study incorporated both haptic-visual and visual-haptic orders of the two stimulus objects. Once again, no significant difference was obtained between the visual-haptic and haptic-visual comparison of object shape.

In contrast to the previously discussed crossmodal studies, other previous research has found visual-haptic performance to be superior to haptic-visual performance. For example, Norman, Clayton, Norman, and Crabtree (2008) conducted a study on perceptual learning that incorporated both unimodal and crossmodal conditions. Their results indicated that the participants' perceptual sensitivity to object shape was 33.2 percent higher in the visual-haptic condition than in the otherwise equivalent haptic-visual condition. Next, consider an experiment conducted by Davidson, Abbott, & Gershenfeld (1974). These authors used a set of solid objects (sculptures often called "feelies") developed by Gibson (1966; also see Caviness, 1964). On any given trial, Davidson et al. presented a "standard" object to their participants in one of the two modalities (e.g., vision). Three successive "comparison" objects were then presented in the other modality (e.g., haptics). The participants' task was to indicate which comparison object had the same shape as the standard object. As in the experiment by Norman et al. (2008), the participants' performance was higher in the visual-haptic condition (i.e., the error rates were 20.7 percent lower in the visual-haptic condition than in the haptic-visual condition).

Since the results of previous crossmodal research are contradictory, the goal of the current study was to obtain additional information about crossmodal object recognition using a new set of stimulus objects that are quite different than those that have been used previously (animal, fruit, and vegetable cookie cutters).

METHOD

Stimulus Displays

The experiment involved the use of two sets of eight cookie cutters, either animals or fruits and vegetables; these 16 individual cookie cutters were chosen because of their high recognizability (see Figures 1 & 2). The cookie cutters were presented in their physical form during the haptic portion of the trials. In the visual portion of the experiment, the cookie cutters were depicted as digital renderings (Figures 3 & 4) on a computer screen. These renderings were created by stamping the cookie cutters on paper and digitally scanning their outlines.

Figure 1: The animal cookie cutters.

Figure 2: The fruit and vegetable cookie cutters.

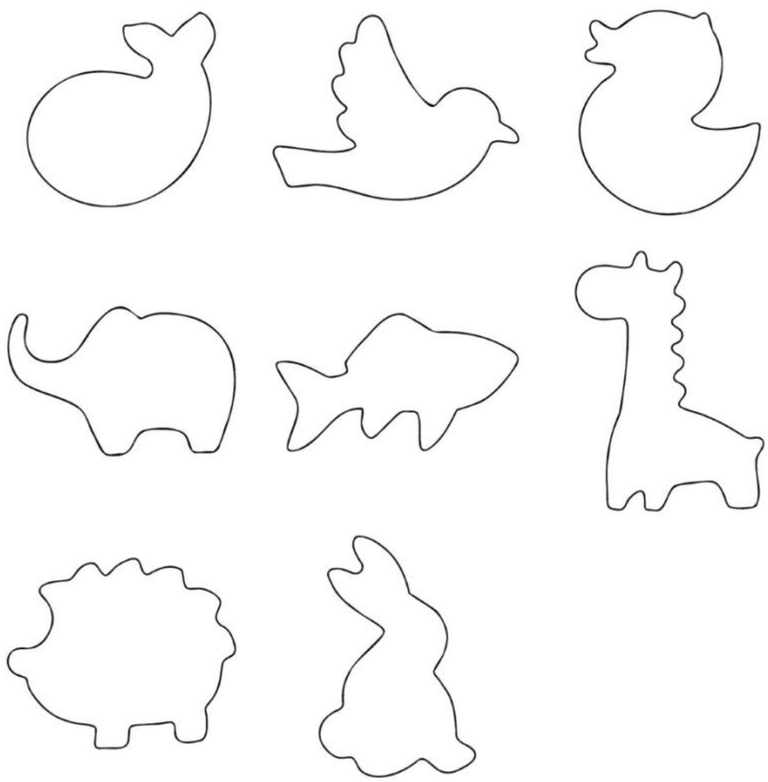

Figure 3: The digital renderings of the animal cookie cutters.

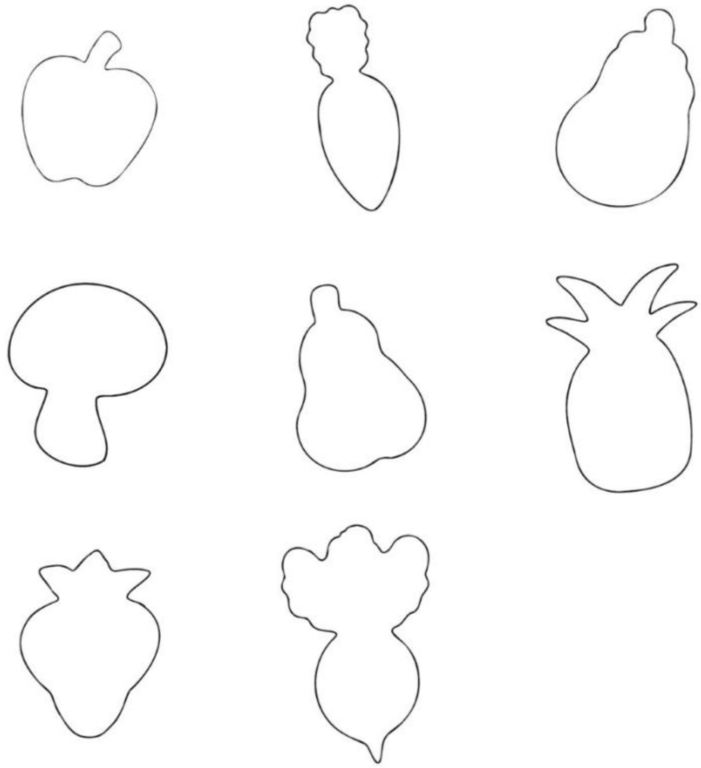

Figure 4: The digital renderings of the fruit and vegetable cookie cutters.

Apparatus

The cookie cutters were visually presented (when appropriate) on an Apple iMac computer. The order of the stimulus presentation, as well as the collection of behavioral responses, was also controlled by the same computer. The participants were not allowed to see the stimulus objects during haptic (i.e., tactile) exploration; their view of the cookie cutter stimuli was blocked by an occluding black curtain (Figure 5).

Figure 5: The experimental apparatus.

<u>Procedure</u>

Participants were split into two groups. Half of the participants were familiarized with the cookie cutter objects visually, and their memory of those objects was later tested haptically (vision-haptic, or VH, condition). The remaining half of the participants studied the stimulus objects haptically, and their memory was tested visually (haptic-vision, or HV, condition). Within those groups, participants were split evenly so half were presented with the animal cookie cutters and half were presented with the fruit and vegetable cookie cutters. Before the experiment was run, participants were asked to complete a visual acuity test and sign a consent form. Each method had a study session and a test session.

Vision-Haptic Condition

In the study session, the computer randomly chose four of the eight cookie cutters to be shown on the monitor for 15 seconds each. Each of these four study objects were visually presented four separate times. The total exposure to each visual study object was therefore one minute. Once the study objects had been presented four times, the complete set of eight physical cookie cutters were placed behind the curtain for the haptic test session.

In the test session, all eight cookie cutters were presented sequentially in a random order. Each cookie cutter was placed on a layer of playdoh to ensure that the object remained stable and did not move during haptic exploration. Once each cookie cutter was stabilized, the participant was given 15 seconds to trace the outline of the given object using their index finger. After completion of the 15 second haptic exploration, participants were asked to indicate whether each object was old (i.e., had been presented during the study session) or new (i.e., was not presented during the study session). The participants' responses were entered into the computer for later analysis.

Haptic-Vision Condition

In the study session, the computer randomly chose four of the eight cookie cutters to be explored haptically. Each of those objects was pressed into the playdoh one-by-one and participants were given 15 seconds to trace their outline. This occurred four times so that each cookie cutter was haptically explored for a total duration of one minute.

In the test session, all eight cookie cutters were presented one-by-one visually. Each cookie cutter was displayed on the computer monitor for 15 seconds. Afterwards, the participants were asked to indicate whether each object was new (i.e., had been haptically explored during the study session) or old (i.e., was not explored during the study session). The participants' responses were entered into the computer for later analysis.

Participants

The 20 participants were all between the ages of 18 to 24 years. All participants gave written consent prior to participating in the experiment. The participants' visual acuity was also assessed to ensure normal or corrected-to-normal vision.

RESULTS

The results for the four groups of participants are shown in Figure 6. As can be seen from an inspection of the graph, the participants' recognition performance was similar for the VH and HV conditions when presented with both the animal and fruit/vegetable cookie cutters. In the VH condition, participants judging both the animal and fruit/vegetable cookie cutters had an 80 percent success rate (in correctly judging old objects as old and new objects as new) on average, with standard errors of 10.9 and 6.4, respectively. In the HV condition, participants judging the animal cookie cutters had a 77.5 percent success rate and a standard error of 7.3, while those judging the fruit/vegetable cookie cutters had a 75.0 percent success rate and a standard error of 5.6. Overall, the VH condition had an average success rate of 80 percent correct while the HV condition had an average success rate of 76.25 percent correct. Overall, the animal cookie cutters produced an average success rate of 78.75 percent correct, while the fruit/vegetable cookie cutters produced an average success rate of 77.5 percent correct.

A 2 (crossmodal condition: VH versus HV) x 2 (cookie cutter type: animals versus fruits & vegetables) factorial analysis of variance (ANOVA) was conducted upon the results shown in Figure 6. The results of the ANOVA revealed that there was no significant effect of cookie cutter type ($F(1, 16) = 0.03$, $p = 0.88$, $\eta^2_p = .002$); the participants exhibited equal recognition performance for both cookie cutter types. The ANOVA also revealed that there was no significant effect of crossmodal condition ($F(1, 16) = 0.23$, $p = 0.64$, $\eta^2_p = .014$). In addition, there was no significant interaction between cookie cutter type and crossmodal condition ($F(1, 16) = 0.03$, $p = 0.88$, $\eta^2_p = .002$). It is clear the participants were just as able to complete the information transfer from haptics to vision as from vision to haptics for both cookie cutter types.

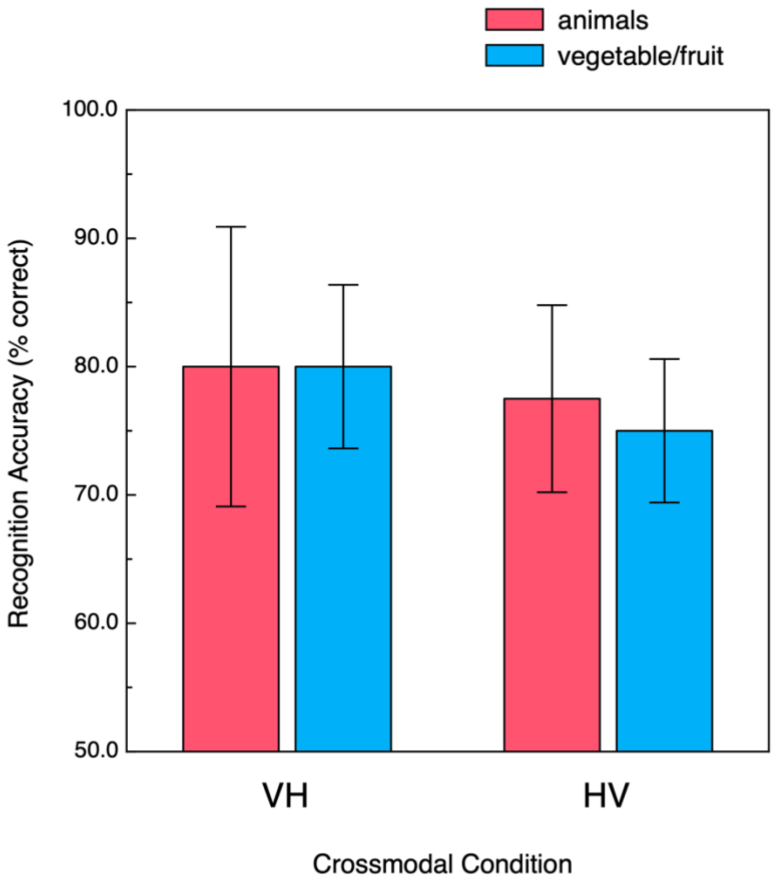

Figure 6: The participants' recognition accuracies are plotted for each of the crossmodal conditions (HV and VH). The results for the animal cookie cutters are plotted in red, while those for the fruit/vegetable cookie cutters are plotted in blue. The error bars indicate ± 1 standard error.

DISCUSSION

Even though crossmodal interactions between the visual and haptic systems have been studied for decades (e.g., see Caviness, 1964; Gibson, 1966), several questions remain. What remains most unclear is whether information transfer is equivalent (or at least similar) from vision to haptics and from haptics to vision. Does the direction of information transfer matter? A large body of previous research indicates that it does not (Caviness, 1964; Lacey, Peters, & Sathian, 2007; Newell, Ernst, Tjan, & Bülthoff, 2001; Norman et al., 2006; Woods, O'Modhrain, & Newell, 2004). However, other research studies have demonstrated that visual-haptic performance is superior to haptic-visual performance (Abravanel, 1973; Davidson, Abbott, & Gershenfeld, 1974; DiMattia, Posley, & Fuster, 1990; Goodnow, 1971; Lacey & Campbell, 2006; Norman, Clayton, Norman, & Crabtree, 2008). The purpose of the current experiment was to address this issue with a completely different set of stimulus objects. The current results (see Figure 6) demonstrate that visual-haptic object recognition is clearly similar to haptic-visual object recognition. Nevertheless, it is true that the participants' performance in the current study was numerically lower in the haptic-visual condition relative to that obtained in the visual-haptic condition (compare the two red bars in Figure 6 and then compare the two blue bars). It is possible that the failure to detect an effect of crossmodal order (i.e., HV versus VH) was due to a lack of power; if the current experiment had included a larger number of participants, then the small numerical differences shown in Figure 6 could potentially have become statistically significant.

Future research could investigate this possibility. In addition, it would be worthwhile to also ask participants to perform the same task using unimodal vision and unimodal haptics -- would the resulting unimodal object recognition performance be similar to crossmodal object recognition? It will be up to future research to investigate this possibility.

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APPENDIX: FORMS

INFORMED CONSENT DOCUMENT

Project Title: The perception of 3-D shape/structure
Investigator: J. Farley Norman, Psychological Sciences Department, WKU, (270) 745-6930

You are being asked to participate in a project conducted through Western Kentucky University. The University requires that you give your signed agreement to participate in this project.

You must be 18 years old or older to participate in this research study.

The investigator will explain to you in detail the purpose of the project, the procedures to be used, and the potential benefits and possible risks of participation. You may ask any questions you have to help you understand the project. A basic explanation of the project is written below. Please read this explanation and discuss with the researcher any questions you may have.

If you then decide to participate in the project, please sign this form in the presence of the person who explained the project to you. You should be given a copy of this form to keep.

1. **Nature and Purpose of the Project**: The research in this project is being undertaken in order to understand how human observers perceive the 3-dimensional shape/structure of environmental objects. The purpose of this research is to evaluate the accuracy, reliability, and precision of human observers' visual and haptic (i.e., touch) perceptions of 3-D shape/structure.

2. **Explanation of Procedures:** On any given trial, you will be asked to either: 1) make judgments about a single object's 3-D shape, or 2) to make comparisons between two (or more) object's 3-D shapes. In addition, we will evaluate your basic sensory abilities (e.g., visual acuity, tactile acuity, and/or manual dexterity). The experiment will take less than 1.5 hours.

3. **Discomfort and Risks:** There are no known risks associated with participation in these experiments. However, you are free to take a break or quit at any time.

4. **Benefits**: Your participation will further our efforts to understand how human observers perceive 3-D shape/structure, a fundamental psychological process. From the moment we wake up to the time we go to sleep, we are constantly perceiving and

interacting with 3-dimensional objects. The goal of our research is to understand human perception. If you wish, we would be happy to share your individual experimental results with you after your data collection is complete.

5. **Confidentiality**: Our experiments are solely concerned with evaluating your ability to perceive 3-dimensional shape/structure. Your experimental results are completely confidential. The results of these experiments may be published in scientific journals or book chapters, so that others may benefit from the knowledge that is gained -- however, your experimental results will never be identified by name. Your anonymity is guaranteed. Records will be viewed, stored, and maintained in private, secure files only accessible by the P.I. for three years following the study, after which time they will be destroyed.

6. **Refusal/Withdrawal:** Refusal to participate in this study will have no effect on any future services you may be entitled to from the University. Anyone who agrees to participate in this study is free to withdraw from the study at any time with no penalty.

Please check one of the following options :

I prefer the use of __________ my actual initials
or __________ randomly generated initials

if my individual experimental results are presented in scientific publications, such as book chapters or professional journal articles.

You understand also that it is not possible to identify all potential risks in an experimental procedure, and you believe that reasonable safeguards have been taken to minimize both the known and potential but unknown risks.

____ ________________
Signature of Participant Date

____ ________________
Witness Date

THE DATED APPROVAL ON THIS CONSENT FORM INDICATES THAT
THIS PROJECT HAS BEEN REVIEWED AND APPROVED BY
THE WESTERN KENTUCKY UNIVERSITY INSTITUTIONAL REVIEW BOARD
Robin Pyles, Human Protections Administrator
TELEPHONE: (270) 745-3360