Title
HAPTIC PERCEPTION IN CATEGORIZATION LEARNING TASKS

Author
Aulakh, Jasleen

Publication Date
2026-06-15

HAPTIC PERCEPTION IN CATEGORIZATION LEARNING TASKS

By

Jasleen Kaur Aulakh

A capstone project submitted for Graduation with University Honors

May 7, 2026

University Honors

University of California, Riverside

APPROVED

Dr. David Rosenbaum

Department of Psychology

Dr. Begoña Echeverria, Howard H Hays, Jr. Chair

University Honors

ABSTRACT

Haptic perception is the ability to understand the world through touch. It is a fundamental sensory process that allows individuals to gather information about objects through physical interaction. Humans rely on tactile input such as texture, weight, temperature, and shape to interpret their surroundings, often in situations where visual information is limited or unavailable. Research in haptic perception has significant implications in learning how effectively we can perform tactile based tasks and further significance in clinical applications. Findings suggest that incorporating haptic technology, robotic or non-robotic, supports improvements in motor control and sensorimotor function in therapeutic settings. Medical and dental education settings have begun to use haptics to improve essential hands-on skills such as stitching simulators. (Pacheco-Barrios et al., 2024). In my personal experience, I have applied haptic perception to decision-making while shadowing an oncologist, particularly through the use of palpation to feel and identify lumps in breast cancer patients. As an aspiring future dental student, I am excited to further explore how I can apply the knowledge I have learned throughout this study of haptics to my continuing education.

In the presented study, we explored a specific area of haptic perception known as haptic category learning. Category learning refers to the cognitive process by which individuals group stimuli based on shared features or underlying rules. In standard category learning tasks, individuals actively construct and adjust hypotheses to determine how categories are defined. (Schwarzer et al., 1999). People interpret the world by recognizing similarities and differences among objects, which allows them to group those objects into categories (Medin and Schaffer 1978).

The current study aims to investigate whether individuals can use haptic search to accurately categorize two pipes based on differences in length. Pipes were grouped into the same category if they were both either less than one inch long or greater than one inch long. In contrast, the two pipes were considered to belong to different categories when one measured less than one inch and the other measured more than one inch. Participants were instructed to state “same” or “different” depending on whether they believed the pipes were in the same or different category respectively. Are individuals able to accurately guess “same” or “different” depending on their ability to accurately categorize the pipes using haptics? The following paper presents significant results regarding the way individuals process and assess similarities and differences in length.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

I would like to give a special thanks to my faculty mentor, Dr. David Rosenbaum for his mentorship and guidance throughout this project. It was a privilege to get to work with such a distinguished individual within the field of Psychology. I also thank Ph.D. student Hunter Sturgill for all of his help and support throughout the development of this project. This work would not be possible without their unwavering support. Lastly, I give great thanks to the University Honors program for giving me the opportunity to be supported by a network of inspiring faculty and students who played a critical role in helping me navigate my undergraduate career.

INTRODUCTION

Haptic is a word that stems from the Greek root "haptikos" which translates to the sense of touch related to the perception of objects in different environments (Pacheco-Barrios et al., 2024). This process relies on the perception of tactile properties such as texture, shape, weight, and size, allowing individuals to form meaningful distinctions often without the benefit of visual input. Although vision is often the dominant sensory modality for categorization, haptic processing plays a critical role in situations where visual information is unavailable or limited.

Individuals are capable of perceiving multiple dimensions of a stimulus across all stages of development; however, they differ in which dimensions they prioritize. While this framework has been well supported in visual and auditory domains, its application to haptic processing remains largely underexplored (Schwarzer et al., 1999). Specifically, it is unclear whether individuals can isolate a single stimulus dimension when relying exclusively on haptics. Unlike vision, which often allows for simultaneous processing of multiple features, haptic perception unfolds sequentially through touch, potentially making it more challenging to selectively attend to only one dimension while ignoring others. (Schwarzer et al., 1999). As a result, it remains uncertain whether individuals naturally engage in selective attention or rely on more holistic processing when interpreting haptic information.

A further dimension of haptic learning is category, referring to the process in which individuals organize and classify objects using tactile information alone. Through active exploration, individuals extract and evaluate relevant stimulus dimensions, enabling them to form meaningful categories based on touch. This raises the question of whether a single tactile dimension is sufficient for accurate categorization, as successful categorization depends on the ability to detect and use relevant differences between stimuli. The present study addresses this gap by investigating whether individuals can rely on a single haptic dimension—length—to accurately categorize objects as “same” or “different” in the absence of visual input. Although haptic category learning may initially appear to involve holistic processing, it in fact promotes more analytical forms of thinking (Schwarzer et al., 1999).

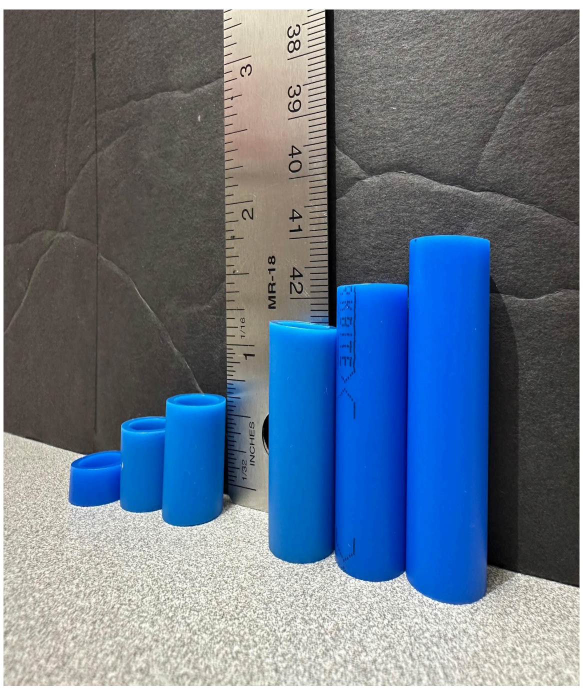
Category learning is challenging. This is especially true when category members closely resemble members of other categories (Jacoby 2024). In this experiment, an underlying rule defined the categories: pipes shorter than one inch were classified as the same, as were pipes longer than one inch. However, if one pipe was shorter than one inch and the other longer, they were categorized as different. Through repeated trials and increased exposure to the task, participants were expected to gradually learn this rule, or at minimum recognize that a distinction exists between the two groups, with the magnitude of the difference serving as the basis for categorization. Importantly, individuals are not typically explicitly taught such categories. Rather, they acquire them through repeated exposure to examples in everyday life, allowing patterns and similarities to emerge over time (Medin & Schaffer, 1978). Thus, concept formation through experience represents a fundamental mechanism of human learning.

PARTICIPANTS

All participants in this study were students under UC Riverside’s Department of Psychology who participated for course credit. The current UCR undergraduate student population is 39.3% Hispanic or Latino, 32% Asian, and 10.9% white. 5% identify with two or more ethnicities, 3.8% Black or African American, and 0.1% Native Hawaiian or Pacific Islander. A data pool of 25 participants was used. This sample size was generated using an A priori power analysis.

APPARATUS

The lab room was set up with a desk and a computer on top. There are two cameras on the desk to record the participant's hands. Subjects sat at a table where they could find the experiment apparatus. The participant found two containers on the table. During each trial, the participant was presented with two PVC pipes. Each container holds a respective pipe. The desk has a black pipe framework that holds up a posterboard. This posterboard falls right around the participants neck/chest area. The purpose of this posterboard is to seclude the participant's vision of the apparatus. The participant must depend on his/her sense of touch for this search task. As instructed, the participant was required to determine whether or not the two pipes in each container belong to the same category or different categories, and to respond as quickly and accurately as possible. There were a total of six pipes randomly used in different combinations of two throughout the experiment. Three of the pipes were shorter than an inch while three pipes were longer than an inch. The object length serves as the stimulus that differentiates items across trials. Although participants based their decisions on perceived length, they were not told that the six pipes were actually grouped into two different categories, "short" or "long" that define the rule of the task. The short category consisted of three pipes that fall under the length of 1 inch; 0.25 inches, 0.5 inches, and 0.75 inches while the long category consisted of three pipes greater than 1 inches long; 1.25 inches, 1.5 inches, and 1.75 inches. For the purpose of our experiment, we refer to 1 inch as being the boundary length.


38
39
40
41
42
MR-18
INCHES

PROCEDURE

At the start of the experiment, participants were first asked to sign an informed consent form outlining the purpose of the study, potential risks and benefits, confidentiality, and other important considerations related to participation. They then completed a background questionnaire collecting information on demographics, handedness, and previous experience with music, sports, video games, and other relevant activities.

The instructions explaining the task were then read aloud. Participants were informed that during each trial they would randomly be assigned two different pipes - one placed in the left-hand container and one in the right-hand container. After they observed the location of the empty containers on the table, a posterboard shield was placed over the containers to prevent visual inspection. It was then made clear that their task was to respond “same” or “different” depending on whether they believed the two pipes belonged to the same or different categories. Emphasis was placed on completing the categorization task as quickly and accurately as possible.

Accuracy feedback was provided after each trial and recorded on a data sheet as either “correct” or “incorrect.” This was done to assess whether participants could learn the underlying rule of the experiment, which was defined by there being a short and long category, divided by the 1 inch barrier. Haptic feedback provides critical information about the success or failure of movements, stimulating the nervous system to adjust performance to improve accuracy (Pacheco-Barrios et al., 2024). A total of 36 trials were generated using ChatGPT, which randomized pairs from the six different pipe lengths. Thirty-six trials were used because both the left and right containers could each take on any of the six possible lengths. The order of presentation was treated as significant. For example, a pair with a 0.25-inch pipe in the left container and a 1.75-inch pipe in the left container was considered a distinct condition from a pair with a 1.75-inch pipe in the left container and a 0.25-inch pipe in the right container.

PREDICTIONS

All pipe combinations were tested using both hands as part of a counterbalancing procedure. Although no specific effects of hand use were hypothesized, this approach ensured that all conditions were presented across both container positions. In addition to counterbalancing hand use, the order of condition presentation was also controlled. Trials were randomized so that participants did not encounter the same sequence of pipe combinations, preventing order effects. This design ensured that the dependent variable was not influenced by repeated trial order and participants were not able to anticipate any of the upcoming trials.

We can predict that accuracy will be greater among participants when the two pipes that the participant is distinguishing between possess a greater length difference. For example, when comparing a pipe that is 0.25 inches long in one container and a pipe that is 1.75 inches long in the other container, it may be easier to guess that they are in different categories. On the other hand, this category difference may not be as easy to spot when comparing a 0.75 inch pipe and a 1.25 inch pipe due to them having a smaller length difference. In either scenario, they would be considered to be in different categories.

Ratios can be used as a statistical tool to predict performance. We predict that as the ratio between the lengths of the two pipes within the same category increases, participants are less likely to answer the categorization question correctly by mistakenly categorizing them as different. For example, increasing a pipe from 0.25 inches to 0.5 inches (both within the short category) represents a doubling in length, whereas increasing from 1.25 inches to 1.5 inches (both within the long category) does not reflect the same proportional change, despite both increases being 0.25 inches. We can understand why using the following relative change formula:

Relative change = (L2-L1) / (L1)

where: L1 is the length of the shorter pipe and L2 is the length of the longer pipe

Short Category : (1.5-1.25)/(1.25) = 0.2

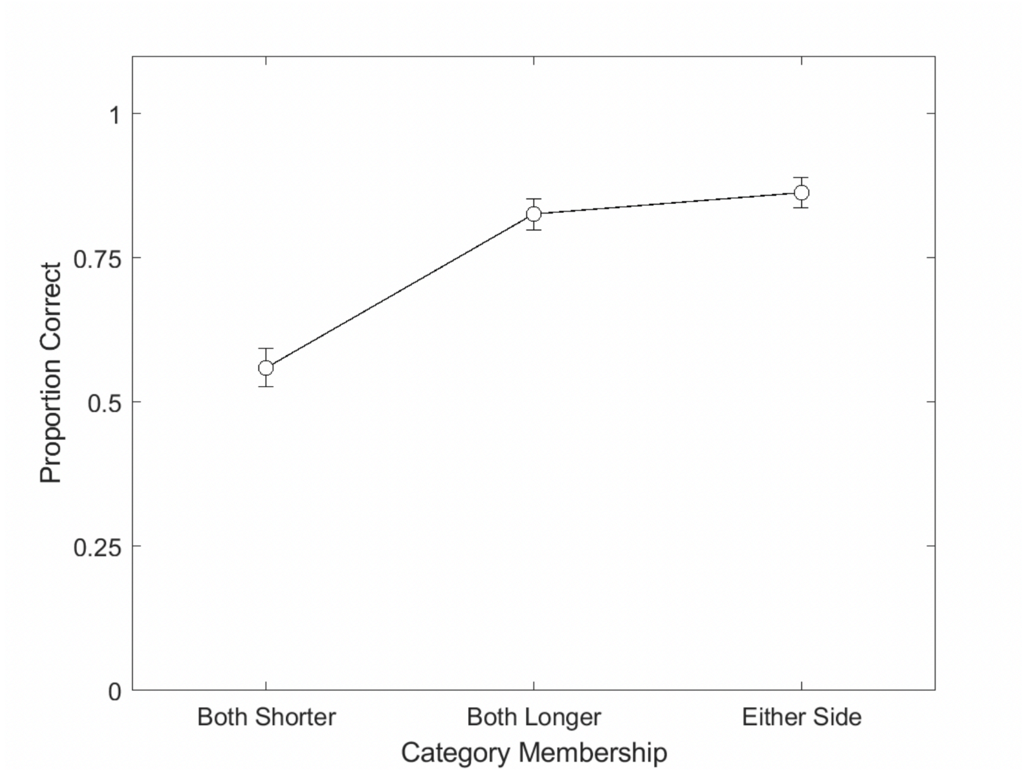
Long Category: (0.5-0.25)/(0.25) = 1

Based on the calculations performed, increasing from a 0.25 inch pipe to a 0.5 inch pipe represents a doubling in length (100% increase), whereas increasing from a 1.25 inch pipe to a 1.5 inch pipe corresponds to a 20% increase. Therefore, we predict that even when two pipes have the same absolute difference, the pair with the smaller relative increase is more likely to be correctly grouped into the same category while the pair with the larger relative increase is more likely to be inaccurately grouped into different categories.

RESULTS AND DISCUSSION

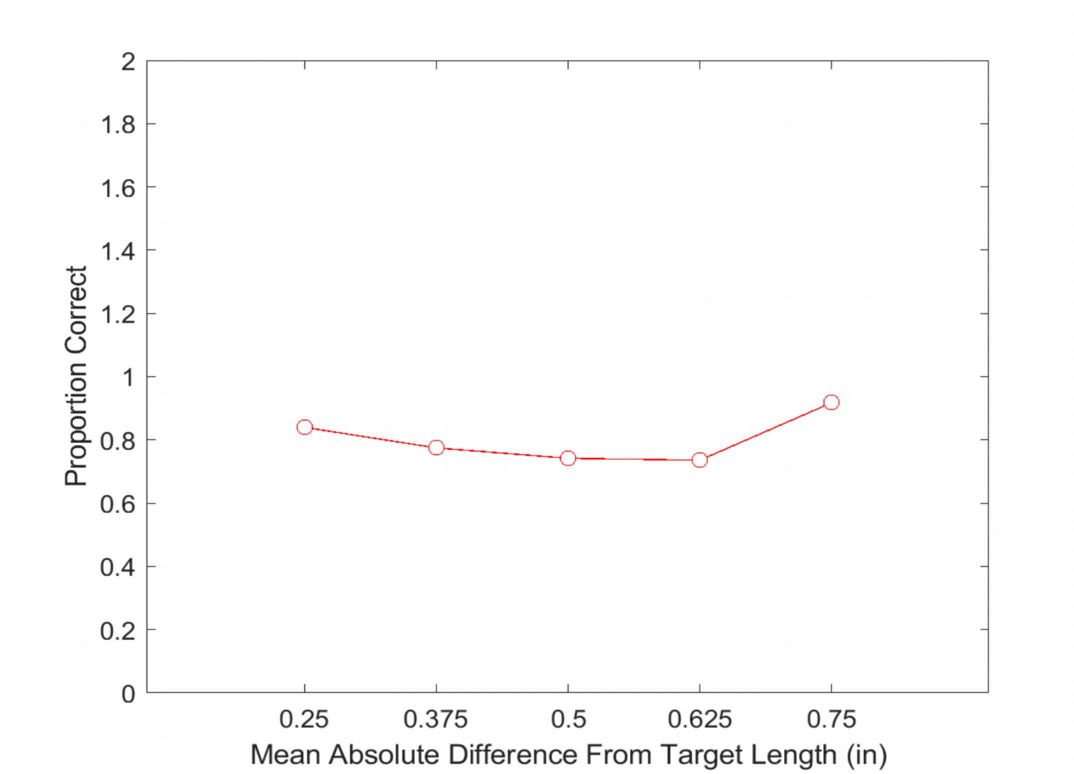
In this study, data was collected from 25 UC Riverside undergraduate participants.

Figure 1



Pipes were more accurately identified as belonging to the same category when both pipes were long, compared to when both were short. Overall, accuracy was highest for identifying that short and long pipes belong to different categories and for identifying that two long pipes belong to the same category. Proportion correct for identifying pipes to be within the same category was lower than the proportion correct for identifying pipes to be within different categories. This pattern of higher accuracy and greater error suggests that categorizing two pipes as belonging to the short category may have been the most difficult task.

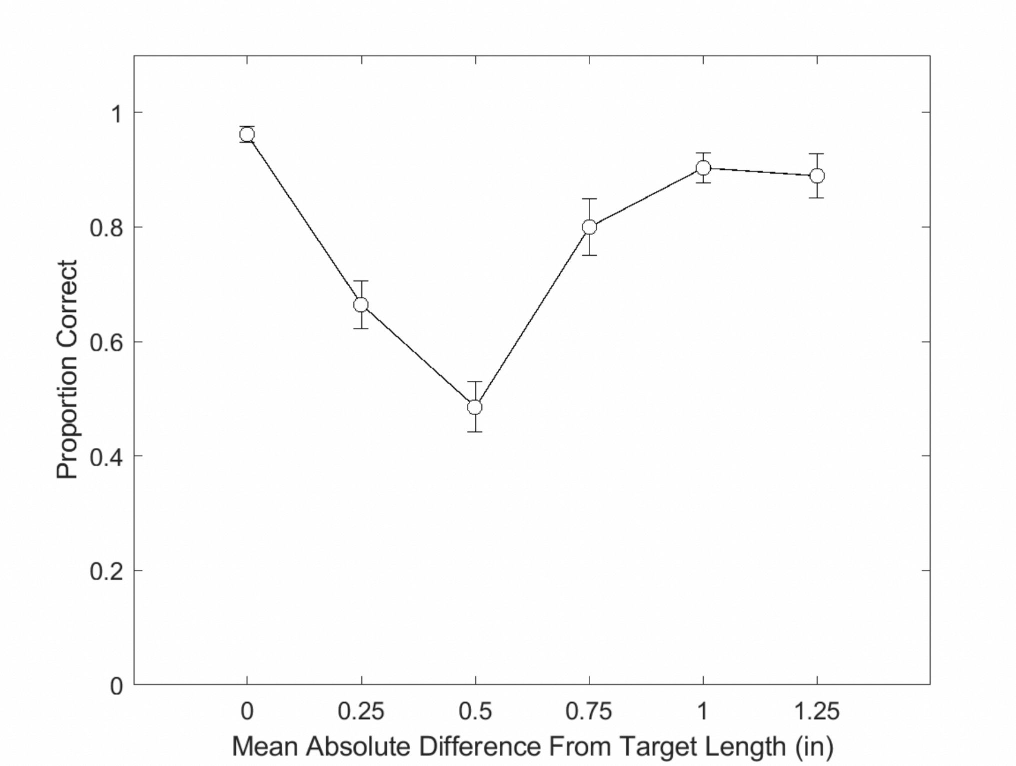
Figure 2



The target length is 1 inch. The x-axis, labeled "Mean Absolute Difference From Target Length (in)," is calculated by subtracting this boundary value (1 inch) from each of the two respective pipe lengths in a trial, taking the absolute value of each respective difference, and then averaging those values.

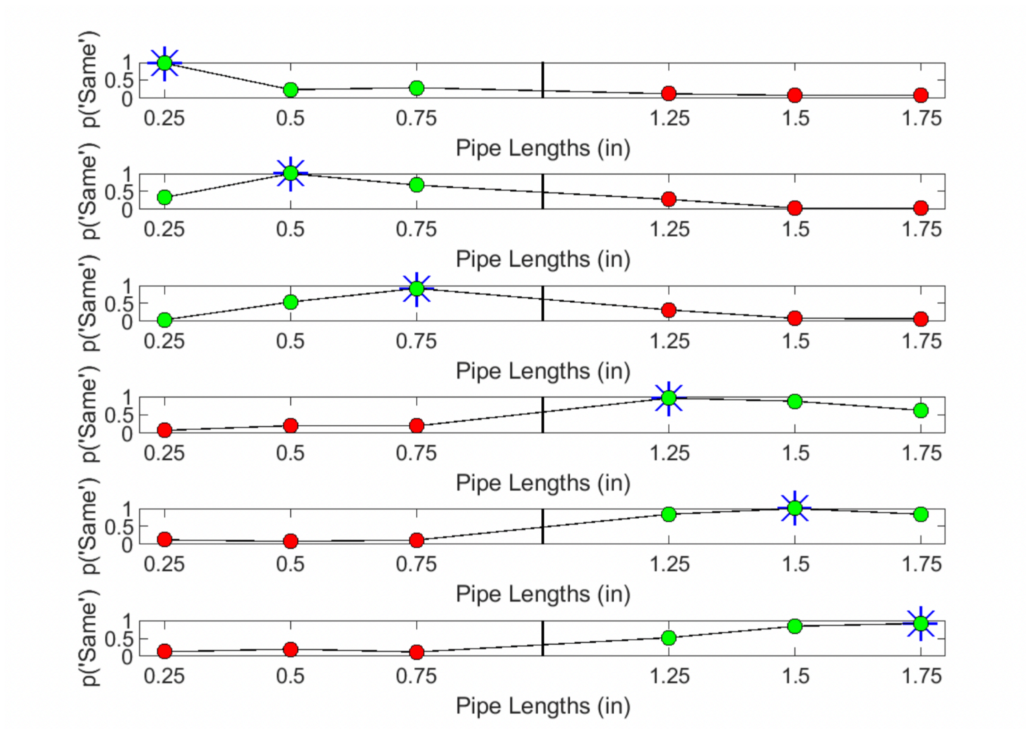
As shown in the graph, the proportion of correct responses remains relatively constant up to about 0.625 inches, after which it begins to increase. This trend is consistent with expectations. As the absolute difference from the boundary grows, the pipe lengths become more distinguishable relative to that boundary. This makes categorizing them as different easier for participants. Accuracy is higher when the difference between the pipe lengths is greatest, as it becomes more straightforward to determine that the pipes belong to different categories.

Figure 3



In the graph shown above, the x axis represents the mean difference from the target length and the y axis represents the proportion correct, similar to Figure 2. The data shows that the proportion correct when the "Mean Absolute Difference From Target Length (in)" is equal to 0, the proportion correct is almost 1. The absolute difference being 0 represents the condition where the same exact pipe length is placed in each container. The proportion correct is the lowest right at the middle point where the "Mean Absolute Difference From Target Length (in)" is equal to 0.5. When the absolute difference is not obviously small or large, it can be more difficult to distinguish whether or not the pipes belong to the same category as the perception of them does not seem to fit into one defined boundary. As the mean absolute difference increases further (e.g., to 1.25), the proportion correct rises again to near 1. At this stage, the difference between the pipe lengths is large enough that they are more easily distinguishable, allowing participants to confidently categorize them as belonging to different categories. Overall, this pattern is reflective of a categorical perception effect where accuracy is highest for stimuli that are clearly within or across boundaries, and lowest for stimuli that fall near the boundary.

Figure 4



This set of six graphs represents each pipe length used in the experiment as a separate condition. The conditions progress from 0.25 inches (the smallest pipe length) to 1.75 inches (the largest). Each graph shows how a given pipe length was tested, beginning with the 0.25 inch condition and increasing incrementally. The stars represent the reference length being tested against itself (i.e. same reference length in both containers) . The green dots represent the pipe lengths that are within the same category as the reference length and the red dots represent the pipe lengths that are in a different category. The x-axis displays the range of pipe lengths, and the vertical line in each graph marks the 1 inch target boundary which separates the “short” and “long” categories. The y-axis depicts the proportion of saying “same” category. For the purpose of our analysis we will label the top graph as Graph #1 and the bottom graph as Graph #6, with the remaining graphs numbered sequentially in between.

In Graph #1, we observe that when both the left and right containers held 0.25-inch pipes, the probability of participants correctly judging them as belonging to the same category (proportion of saying “same”) was 1. However, when the 0.25-inch pipe was paired with a 0.5-inch pipe, the probability of responding “same” dropped to nearly zero. This low probability remained consistent when the 0.25-inch pipe was compared with the 0.75-inch pipe, as well as with any of the longer pipe lengths greater than 1 inch. Overall, comparisons involving the smallest pipe (0.25 inches) and progressively larger pipes seem to lead participants to classify nearly all of them as different, likely due to the pronounced size contrast with the 0.25-inch reference. While the proportion of “same” responses for long-category pipes compared to the 0.25-inch pipe was zero, and thus accurate, this pattern did not hold for comparisons with the 0.5- and 0.75-inch pipes. In those cases, the proportion of “same” responses was also zero, but this reflects miscategorization, as those pipe lengths belong to the same category as the 0.25-inch pipe.

When examining the 0.5-inch condition, a similar pattern emerges. The probability of responding “same category” was very low when the 0.5-inch pipe was compared with the 0.25-inch pipe. In contrast, when the 0.5-inch pipe was paired with the 0.75-inch pipe, the probability of judging them as the same category was much higher, approaching 1. However, when the 0.5-inch pipe was compared with any of the longer pipe lengths, the probability again dropped close to zero.

This general trend continues with the 0.75-inch condition. In Graph #3, where the 0.75-inch pipe serves as the reference, the probability of responding “same category” when paired with the 0.5-inch pipe was approximately 0.5. When paired with the 0.25-inch pipe, however, this probability dropped to zero—even though both pipes belong to the same (short) category. This suggests that this comparison may have been particularly challenging. The difference between 0.25 and 0.75 inches (0.5 inches) is the same as the difference between 0.75 inches (short category) and 1.25 inches (long category). Because these differences are equal, participants may have relied on perceived magnitude differences rather than the category boundary, leading them to incorrectly classify the 0.25- and 0.75-inch pipes as belonging to different categories.

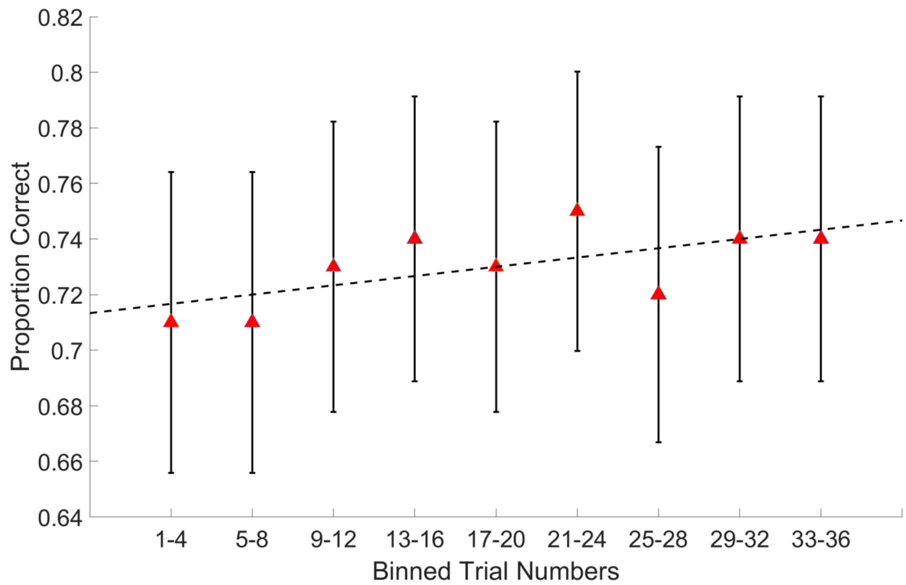
Turning to Graph #4-6, we see that when the long pipes were tested against each other the proportion of grouping them within the same category was almost always 1 and therefore correct almost 100% of the time. This pattern suggests that participants were more accurate when identifying long pipes as belonging to the same category compared to short pipes. One explanation relates to relative (percent) differences: the proportional difference between smaller pipe lengths is greater than that between larger pipe lengths, even when the absolute difference is the same. As a result, differences among shorter pipes may feel more pronounced, making it harder for participants to group them into the same category, whereas longer pipes may feel more similar and thus easier to classify together.

This pattern is consistent with Weber's Law, which states that perception is driven by relative differences rather than absolute ones. For this analysis, the smaller pipe in each pair (0.25 inches and 1.25 inches, respectively) can be treated as a reference stimulus. Changes are perceived relative to this baseline, meaning that larger baseline stimuli require greater absolute differences to be noticed. Thus, the 1.25-1.5 inch comparison involves a larger initial stimulus and makes the 0.25-inch difference feel less significant than in the 0.25-0.5-inch comparison.

More broadly, participants may not be judging pipe lengths based on absolute size, but instead relying on a relative comparison strategy. For example, when comparing a 0.25-inch pipe with a 0.75-inch pipe, the difference is proportionally large - the 0.75-inch pipe is three times longer. This can make the pair feel as though it is spanning two different size regions rather than belonging to the same category. In contrast, when pipe lengths are closer in size, their relative difference is smaller, potentially increasing the likelihood that they will be grouped together.

Additionally, certain pipe lengths may be perceived as more clearly belonging to a category than others. The 0.25-inch pipe is likely an obvious member of the "short" category, while the 0.75-inch pipe may feel closer to the category boundary When these two are paired, the contrast may exaggerate their perceived difference, making the 0.75-inch pipe seem even larger by comparison. Finally, it is possible that participants were not applying an explicit rule at all, but instead relying on perceived similarity. Pairs like 0.5 and 0.75 inches may feel moderately similar and are therefore more often grouped into the same category, whereas pairs like 0.25 and 0.75 inches feel much less similar and are more likely to be classified as belonging to different categories.

Figure 5



The figure above was generated to explore the learning component of this study. The x axis represents all 36 trials. The y axis represents the proportion correct among all participants. Although we anticipated that repeated exposure to different pipe length combinations, along with accuracy feedback, might allow participants to infer the underlying rule, the figure indicates that this was not the case. The proportion correct for each trial remains within the 70-75% range all throughout the experiment. While this is a relatively good percentage in terms of accuracy, this does not attest to any potential significant learning happening. The proportion correct did increase about 2-3% from trial 1 to trial 36, but we cannot confidently state that this is because participants were able to identify the boundary rule. Overall participants did not appear to learn or identify the boundary rule, as the proportion of correct responses did not significantly increase over the course of the experiment. If learning had occurred at any point, we would expect to see a greater upward trend in accuracy across trials with a steeper positive slope.

KEY FINDINGS

The aim of this project was to address gaps in research on haptic category learning, especially the limited focus on length as a stimulus dimension. We investigated whether participants could implicitly learn an underlying categorization rule based on repeated exposure to combinations of different pipe lengths.

Our results showed that accuracy was higher when both pipes were longer compared to when both pipes were shorter. This suggests that participants found it easier to categorize pairs of long pipes as belonging to the same category than pairs of short pipes. This pattern aligns with our predictions regarding proportional change. There is a larger proportional difference between smaller pipe lengths (e.g., 0.25 inch vs. 0.5 inch) than between larger pipe lengths (e.g., 1.25 inch vs. 1.75 inch). This greater proportional difference among smaller stimuli may have led participants to incorrectly judge short-pipe pairs as belonging to different categories, even when they were actually in the same category. Additionally, longer pipes provide more surface area and spatial information for the fingers to explore, which may have made it easier to detect similarities and differences.

There could also have been a motor component to these results. With longer pipes, participants can spread their fingers farther apart, which increases spatial separation between contact points. The wider spacing gives the nervous system a clearer signal about length because it’s easier to detect differences in finger position when they’re farther apart. In contrast, short pipes force the fingers into a cramped position, where small changes in length produce only very small changes in finger spacing. This makes differences harder to detect. This is known as the "finger-span method". The finger span method involves the use of the thumb and index finger to explore the length of an object (Durlach et al., 1989). From the recordings of this experiment, we saw that participants often employed this strategy of the finger span method to gather information regarding the stimulus. This method is easier to practice with longer pipe lengths where they can be more easily held. This could explain why we see higher accuracy for grouping the long pipes in the same category.

Overall accuracy was highest when one pipe belonged to the short category and the other to the long category, compared to trials in which both pipes were either short or both long. This indicates that participants were more accurate when judging "different category" pairs than "same category" pairs. One possible explanation is that participants relied more on perceived differences in length rather than similarities when making categorization judgments. This raises an important question for future research: To what extent do participants base haptic categorization decisions on perceived similarity versus perceived difference between stimuli?

While our study yielded significant results, we are currently continuing this research with a larger data pool to allow for further analysis. By the end of spring quarter we expect to have collected data from approximately 40 participants in total. One interesting extension of length discrimination as a stimulus dimension would be to examine the use of different materials beyond PVC pipes. Within the lab, it was discussed that manipulating length using softer, more flexible materials such as pipe cleaners could yield different results. Because this type of material has a smaller and less rigid surface area than PVC pipes, the finger-span method may become more difficult to apply. As a result, participants may adopt alternative strategies to complete the categorization task.

In addition, we hope to conduct future research on this topic with different stimuli apart from length. Categorizing objects based on size, texture, or weight could result in completely different patterns. We predict that it may be easier to haptically categorize objects of varying weight and an experiment with these stimuli would result in a trend of greater accuracy. Weight discrimination tends to be less precise and differences in weight are often more perceptually noticeable than differences in length as described by Weber's Law. We could also examine combinations of different stimuli presented simultaneously, such as length and texture, to examine whether participants prioritize one stimulus over the other when making categorical judgements. Ultimately, we hope to explore which type of stimuli yields the highest proportion of categorization accuracy.

REFERENCES

Durlach, N. I., Delhorne, L. A., Wong, A., Ko, W. Y., Rabinowitz, W. M., & Hollerbach, J. (1989). Manual discrimination and identification of length by the finger-span method. *Perception & psychophysics*, *46*(1), 29–38. https://doi.org/10.3758/bf03208071

Jacoby, V. L., Massey, C. M., Mettler, E., & Kellman, P. J. (2022). Comparisons in Adaptive Perceptual Category Learning. *CogSci ... Annual Conference of the Cognitive Science Society. Cognitive Science Society (U.S.). Conference*, *44*, 2372–2378.

Medin, D. L., & Schaffer, M. M. (1978). Context theory of classification learning. *Psychological Review, 85*(3), 207–238. https://doi.org/10.1037/0033-295X.85.3.207

Pacheco-Barrios, K., Ortega-Márquez, J., & Fregni, F. (2024). Haptic technology: Exploring its underexplored clinical applications—A systematic review. *Biomedicines, 12(12), 2802. https://doi.org/10.3390/biomedicines12122802*

Schwarzer G, Küfer I, Wilkening F. Learning categories by touch: on the development of holistic and analytic processing. *Memory Cognition* 1999 Sep;27(5):868-77. doi: 10.3758/bf03198539. PMID: 10540815.

Wang, Y., Zhang, J., Li, X., & Chen, Z. (2023). Human spatial navigation in large-scale environments relies on a combination of egocentric and allocentric reference frames. *Frontiers in Behavioral Neuroscience, 17*, 10316997. https://doi.org/10.3389/fnbeh.2023.10316997