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The Effect of Size Upon Haptic Shape Discrimination

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THE EFFECT OF SIZE UPON

HAPTIC SHAPE DISCRIMINATION

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By

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ABSTRACT

Object shape perception is fundamentally important for daily life. It has been suggested (e.g., Gibson, 1962) that the visual and haptic modalities are equivalent with regards to the ability to perceive shape. Norman et al. (2012) showed that visual and haptic shape discrimination accuracies are indeed comparable. Craddock and Lawson (2009) found that haptic shape discrimination performance was adversely affected by a size change. However, this result was obtained for man-made objects (i.e., bathtubs and benches). The purpose of the current investigation was to determine whether size changes also reduce haptic shape discrimination accuracy for naturally-shaped objects. On any given trial, adult participants haptically explored two bell pepper replicas and judged whether they possessed the same or different shapes. In one condition, the two explored objects were of the same overall size, while in two other conditions, the objects differed in size (either by smaller or larger amounts). The results indicated that while size changes do have negative effects upon haptic shape discrimination, larger magnitude size changes do not hurt performance any more than smaller size changes. Although visual shape discrimination is not appreciably affected by size change (e.g., Landau & Leyton, 1999; Norman, Swindle, Jennings, Mullins, & Beers, 2009) and haptic shape discrimination of man-made objects is adversely affected by size change (Craddock & Lawson, 2009), the current results demonstrate that the haptic system can indeed tolerate some object size change without impairment in human discrimination performance.

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INTRODUCTION

Since the 1860's, perceptual abilities have been investigated through systematic methodology (i.e., through psychophysical methods, see Fechner, 1860). Senses such as vision and touch are critical for completion of everyday life activities. A distinction has been made (e.g., Gibson, 1962) between situations where someone has *been touched* and when someone deliberately *touches an object*. These two forms of touch are referred to as passive touch and active touch, respectively. James Gibson (1962) speculated that vision and active touch were equally accurate with regards to the ability to perceive object shape, but he never provided any empirical evidence to justify that conclusion. In his informal studies of haptic (i.e., active touch) perception, Gibson (1966) used sculptured objects (p.124, also referred to as "feelies") that possessed complicated shapes. While each of the feelies was randomly shaped, they were nevertheless very similar (and thus perceptually confusable), because they all were smoothly curved and possessed six "protuberances".

About 50 years later, Norman and colleagues (2012) investigated visual and haptic 3D shape discrimination using Gibson's feelies. In their Experiment 1, each trial required a participant to judge whether the shape of two objects (presented either visually or haptically) was the same or different. Half of the participants made judgments with bell pepper replicas, while the remaining half of participants made judgments with Gibson's feelies. Each participant made both visual and haptic judgments (the order of modality was counterbalanced across participants). Norman et al. found that the resulting shape discrimination performance was identical for both vision and haptics. Therefore, Norman et al. (2012) supports Gibson's original assertion that haptics is perceptually equivalent to vision.

Past research has demonstrated that there are significant differences in discrimination ability depending upon the type of object (e.g., naturally shaped or artificially shaped) that is presented to a participant (Norman et al., 2012; Norman et al., 2016). Norman et al. (2016) investigated haptic shape discrimination accuracy for both bell pepper replicas and "glavens" (Glavens are artificially-shaped, globally convex objects that vary in complexity; see Phillips & Egan, 2009). In their study, Norman et al. (2016) found that their participants' haptic performance was higher for the bell pepper replicas and lower for the glavens. Norman et al. (2012) similarly found shape discrimination accuracy to be higher for bell pepper replicas than for Gibson's feelies. The outcome of both studies (Norman et al., 2012; Norman et al., 2016) indicates that shape discrimination performance is superior for naturally shaped objects.

As past research has shown, shape discrimination performance varies depending upon the type of object used to make judgments (i.e., naturally shaped vs. artificially shaped). The current thesis project investigates how the size change of objects affects the haptic discrimination accuracy of naturally shaped objects. Literature concerning the effect of size changes upon the haptic discrimination of manmade objects (e.g., bathtubs, sinks, chairs, & benches) currently exists (Craddock & Lawson, 2009), but it is unclear as to whether and to what extent changes in size affect the haptic perception of naturally-shaped objects. Craddock and Lawson (2009) found that object discrimination ability diminishes as the size of objects change; the current thesis project determined whether this is also true for bell pepper replicas.

MATERIALS AND METHODS

Objects

The current stimuli were plastic replicas of bell peppers (*Capsicum annuum*) that were either “large”, “medium”, or “small”. The large bell pepper replicas are life-sized (average volume is 350 cm^3: Dowell et al., 2018; Norman, Norman, Clayton, Lianekhammy, & Zielke, 2004) and were made with liquid plastic (Smoothcast 322, Smooth-On, Inc.). The large replicas were laser scanned (NextEngine Laser Scanner) and proportionately decreased in size to create the medium and small bell pepper replicas. The medium replicas were scaled by a factor of 0.5 in all dimensions (width, height, and depth; Cartesian coordinates x, y, and z), creating replicas one-eighth (0.5 x 0.5 x 0.5 = 0.125 times) the volume of the original objects. The small replicas were scaled by a factor of 0.33 from the original object dimensions along all coordinate axes (width, height, and depth); therefore, the size of the small replicas was 1/27th (1/3 x 1/3 x 1/3) the volume of the original objects. The medium and small bell pepper replicas were 3D-printed by a Bits From Bytes 3D Touch printer; the stimulus material was polylactic acid (PLA) plastic.

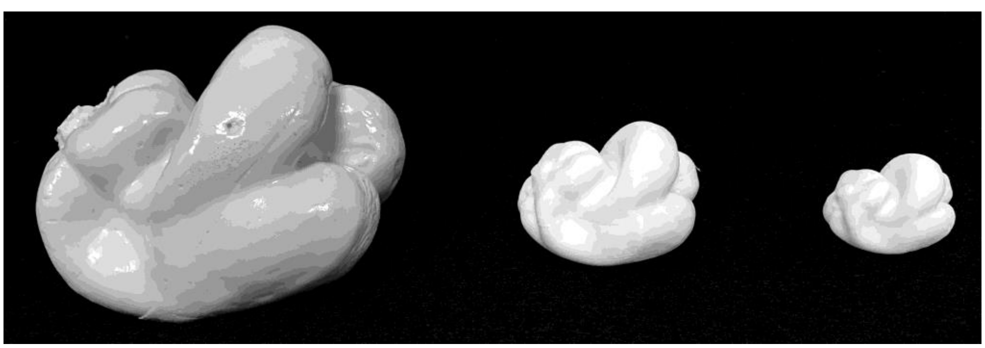

Figure 1: Bell pepper 1 in large, medium, and small sizes, arranged from left to right.

The large bell pepper replicas have been used in numerous previous studies (Crabtree & Norman, 2014; Norman & Bartholomew, 2011; Norman et al., 2012; Norman et al, 2004), while the medium-size replicas have been used in a more recent investigation (Dowell et al., 2018).

Task

Thirty-six younger adults volunteered to participate in the experiment. Each participant was required to sit at a table and place their hands through a black, opaque curtain to prevent their seeing the experimental stimuli. Each participant was assigned to one of three conditions: no size change (medium-size stimuli only), “one-step” size change (either small and medium object pairings or medium and large object pairings), or “two-step” size change (small and large object pairings only). On each trial, a participant was presented with a bell pepper replica in a random orientation. During the three second presentation time, participants were required to haptically explore the shape of each object thoroughly with both hands. After three seconds, the experimenter took the first replica away, which was followed by a three second interstimulus interval (ISI). The experimenter then presented the second bell pepper replica (either of the same or varying size, depending upon condition) to the participant in another random orientation for three additional seconds. After feeling both objects, the participant was asked to judge whether the objects possessed the same shape or had different shapes.

Ninety-six pairs of objects (i.e., trials) were presented to each participant, where 48 trials had same-shape pairings (where the object was randomly chosen on each trial) and 48 trials had different-shape pairings. On different shape trials, there were eight presentations of each “easily confusable” (Norman et al., 2004) pair: objects 1 & 3, 1 & 7, 2 & 11, 3 & 7, 3 & 8, and 5 & 12 (Figure 2).

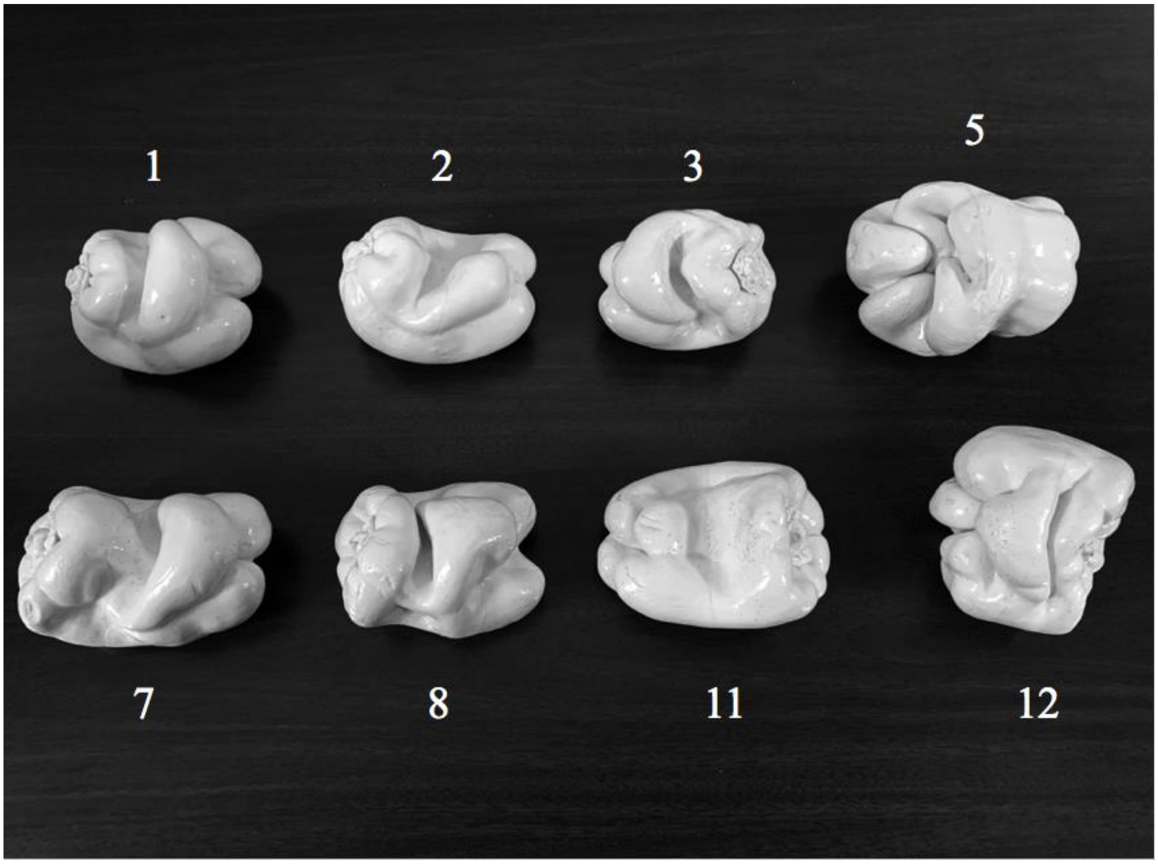

Figure 2: Large bell pepper replicas with varying shapes. Replicas are arranged on the top from left to right: objects 1, 2, 3, and 5. Replicas are arranged on the bottom from left to right: objects 7, 8, 11, and 12.

The order of presented pairs of objects was randomly determined by an Apple MacBook computer. In the variable size conditions (one-step and two steps), sometimes the larger object would be presented first on any particular trial (50 percent probability); on other trials the smaller object would be presented first (50 percent probability).

Participants

The younger adult participants ranged between 18 and 32 years of age (mean = 21.5; SD = 2.5). There were 36 participants total, 12 participants for each size condition. Informed consent was obtained from all participants. The study was approved by the Western Kentucky University Institutional Review Board.

RESULTS

The same/different judgments provided by the participants during the shape discrimination task were used to calculate each participant's perceptual sensitivity (i.e., d' value; see MacMillan & Creelman, 1991). The highest sensitivities were obtained in the same-size condition (indicated by size change 0 in Figure 3); the participants' d' values were considerably lower in both the one-step and two-step size change (indicated by size changes 1 and 2 in Figure 3) conditions. The shape discrimination performance within the one step condition (i.e., either the small and medium pairings or medium and large pairings) was not significantly different [$t(10) = -1.38$, $p = .2$]. Regardless of the *amount* of size change, any size change at all lowers shape discrimination ability significantly.

A one-way between-subjects analysis of variance (ANOVA) was conducted to evaluate the potential significance of size change upon haptic shape discrimination. There was indeed a main effect of size [$F(2, 33) = 8.9$, $p < 0.001$, partial $\eta^2 = 0.35$]. A Tukey HSD (honestly significant difference) post-hoc test further revealed that one-step and two-step size changes do not statistically differ in terms of shape discrimination accuracy (as indicated by d'; the means for the one-step and two-step conditions were 1.29 and 1.28, respectively). The Tukey HSD test additionally showed that performance in the zero-step (i.e., same size) condition was significantly different (i.e., the mean d' value was higher, 1.97) from that obtained in both the one-step and two-step size change conditions.

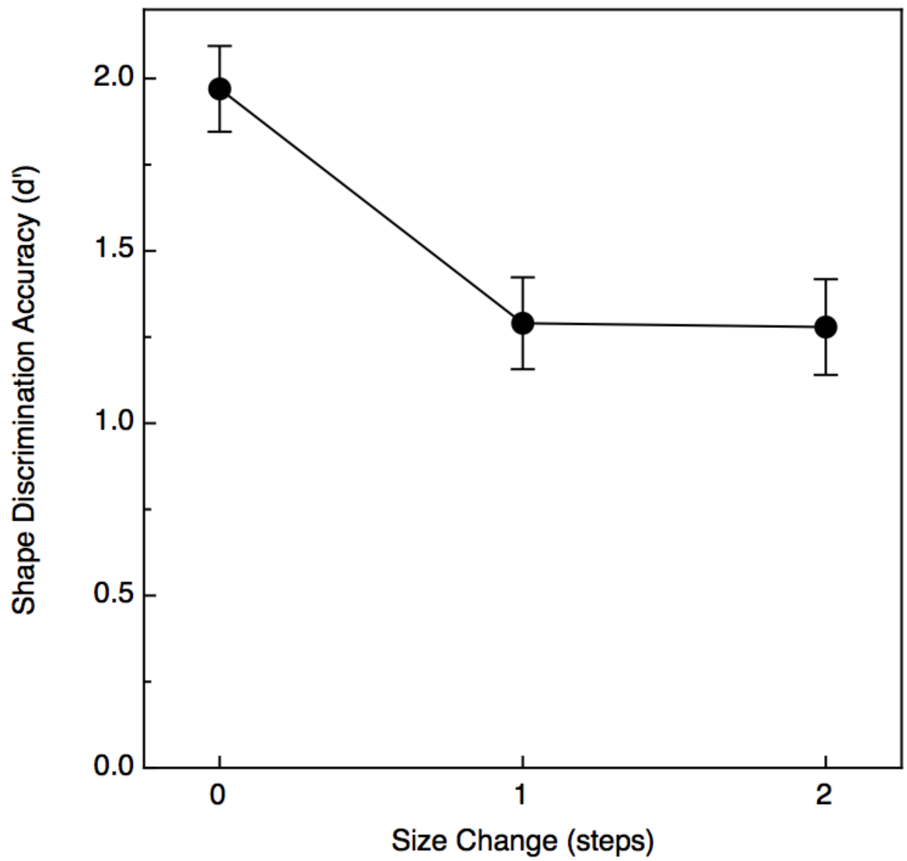

Figure 3: Participants' discrimination accuracies by condition. Size change 0 = No size change (medium stimuli only); Size change 1 = Small-Medium or Medium-Large pairings; Size change 2 = Small-Large pairings. The error bars indicate +/- one standard error.

DISCUSSION

The current investigation sought to clarify if size change would affect haptic solid shape discrimination. In many instances, the shape of a solid object has been described in terms of the positions of each of its constituent points (where the location of each surface point is specified by Cartesian coordinates, such as x, y, & z; e.g., see Frost, 1886). According to this definition, an object's shape would vary with changes in size. If object shape is defined in a different manner, then it can be independent of changes in size (e.g., see Koenderink, 1990, p. 319). In this view, a curved object can be completely characterized by its constituent surface regions, which can generically only be "bump-like" (*elliptic* is the term used by mathematicians), "dimple-like" (*elliptic* again), or shaped like a horse saddle (referred to as *hyperbolic*). The shape of solid objects defined in this manner is independent of changes in size. Consider for example, a golf ball, a soccer ball, and the planet Earth: they all possess the same shape (i.e., are spherical, all surface points are elliptic) despite the fact that their absolute sizes vary over orders of magnitude.

The results of the current study indicate that the human judgment of solid shape is dependent upon size, but is nevertheless partially size invariant. Consider Figure 3. The participants' shape discrimination performance obtained for the one-step size change condition was significantly lower than that obtained for the same-size condition. This finding demonstrates that human haptic shape perception does depend upon size (i.e., there is a cost in discrimination performance when size changes occur). However, the current results also indicate that human haptic shape perception is partially size invariant. When the stimulus objects differed by two steps in size, the obtained shape discrimination performance was no lower than that obtained for the one-step size change condition. If the human ability to perceive shape was completely dependent on size, then more extreme size changes should have produced lower performance than that obtained in the one-step size change condition (and this was not the case, as can be seen from an inspection of Figure 3).

The implications of size change for visual shape perception have been investigated previously (Landau & Leyton, 1999; Norman, Swindle, Jennings, Mullins, & Beers, 2009). In the study by Landau and Leyton, three-year-old children viewed two-dimensional (2-D) objects with specific features (these objects were called “daxes” and “riffs”) and were required to respond appropriately to a presented object (e.g., the participant was asked “is this a dax?”; the participant was then required to respond “yes” or “no”). Landau and Leyton found that three-year-olds were able to reliably identify the shape of a stimulus object (as either a “dax” or a “riff”) even when the size of the object was changed. In addition to 2-D drawings, the shapes of solid objects can also be visually discriminated in a manner that is independent of size changes (Norman et al., 2009). The stimuli were deformed spheres that were “sinusoidally modulated in depth” (p. 130) to create distinctive objects that varied in shape. On every trial, two deformed spheres were sequentially presented to a participant. The two objects either possessed the same shape or had different shapes, and participants were required to indicate whether the two objects had the same shape or possessed different shapes. Each member of a pair of stimulus objects was individually scaled up or down in size by amounts up to 40 percent (across trials, the larger member of a pair of objects could be up to 2.1 times as large as the smaller member). The task thus required participants to discriminate object shape, even when the two objects to be discriminated on any given trial had different sizes. Norman et al. found that size changes (up to approximately a doubling in size) do not appreciably affect the accuracy of visual shape discrimination.

The haptic shape discrimination results obtained in the current study are only in partial accord with the previously obtained results concerning visual shape discrimination (because changes in size in the current study produced a significant deterioration in discrimination performance). In a previous haptic study that utilized man-made (i.e., artificially-shaped) objects (Craddock & Lawson, 2009), it was found that changes in size hampered object shape discrimination; our current results (see Figure 3) are similar in that a change in stimulus size produced a deterioration in haptic discrimination performance. In the past, it has been asserted that haptic shape and visual shape have a common cortical representation in the ventral extrastriate visual cortex (e.g., Amedi, Jacobson, Hendler, Malach, & Zohary, 2002; James et al., 2002). If this were true, size changes would produce similar effects for both modalities. The current results (and those of Craddock & Lawson) are inconsistent with results from similar studies that have investigated visual shape discrimination (e.g., Norman et al., 2009). It therefore appears that visual and haptic solid shape discrimination may be mediated by differing (as well as similar) neurophysiological mechanisms. The ability of human participants to match and discriminate solid shape across vision and haptics (e.g., Norman et al., 2004) indicates that some neurophysiological mechanisms share information about visual and haptic shape, but the current results (when compared to the analogous visual research of

Norman et al., 2009) indicates that while visual and haptic cortical mechanisms may overlap, separate representations must exist for haptic and visual object shape in addition to any common ones.

It is important to note that the texture of the objects was not held constant across all objects. The large objects (made with Smoothcast 322 liquid plastic, Smooth-On Inc.) were smoother than the medium and small objects (printed with PLA plastic using a Bits from Bytes 3D printer). The layers of the PLA plastic produced an object surface that possessed fine ridges; the large objects were absent of this texture. There is evidence for common cortical representation for both shape and texture in the postcentral gyrus (Servos, Lederman, Wilson, & Gati, 2001). To rule out any possibility that texture could have affected shape perception, all objects should be made of the same material (and therefore, have the same texture) in subsequent investigations.

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