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Aging and the visual, haptic, and cross-modal perception of natural object shape

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Abstract. One hundred observers participated in two experiments designed to investigate aging and the perception of natural object shape. In the experiments, younger and older observers performed either a same/different shape discrimination task (experiment 1) or a cross-modal matching task (experiment 2). Quantitative effects of age were found in both experiments. The effect of age in experiment 1 was limited to cross-modal shape discrimination: there was no effect of age upon unimodal (ie within a single perceptual modality) shape discrimination. The effect of age in experiment 2 was eliminated when the older observers were either given an unlimited amount of time to perform the task or when the number of response alternatives was decreased. Overall, the results of the experiments reveal that older observers can effectively perceive 3-D shape from both vision and haptics.

1 Introduction

Vision and haptics (active touch) represent the two sensory modalities by which human observers perceive 3-D object shape—we see environmental objects and we feel, grasp, and utilize them with our hands. Without vision, we cannot perceive the 3-D shape of objects at a distance. Without the effective use of haptics (for example, after damage to the median nerve in the hand), we cannot interact well with objects—we drop objects and tools (Bunnell 1927; Moberg 1960, 1962) and thus develop a higher risk of accidents. Indeed, Bunnell, when discussing how people use their hands, refers to the fingers as having “eyes”. He did so to point out the essential functional similarity in how the eyes and the fingers initiate and enable the perception of 3-D object shape. In performing ordinary everyday behaviors, vision and haptics work together to perceive the shapes of the objects with which we interact (also see Gibson 1966). Moberg (1962) referred to this ability of the hand and fingers to perceive object shape as “tactile gnosis”. Modern neurophysiological research has indicated that vision and haptics may be more than just ‘functionally similar’. Zangaladze et al (1999) showed that disrupting the functioning of visual extrastriate cortex by transcranial magnetic stimulation causes a deterioration in the tactile perception of orientation. In addition, recent studies using functional magnetic resonance imaging (James et al 2002; also see Amedi et al 2001; Pascual-Leone and Hamilton 2001; Reed et al 2004) have shown that both visual and haptic exploration of an object’s shape produces overlapping patterns of activity in a cortical brain area (middle occipital, MO, area) that was previously believed to be purely visual in function. James et al argued from their results that there must be a *common* cortical representation of object shape to which both haptics and vision contribute; they further speculated that area MO is a likely candidate for this common representation. Thus, Gibson’s belief (1966, page 47) that the external senses, such as haptics and vision, are “interrelated rather than mutually exclusive” may be valid.

Aging is known to affect human observers' ability to visually perceive 3-D object shape from binocular disparity (Norman et al 2000, 2006) and motion (Andersen and Atchley 1995; Norman et al 2000, 2004a). Aging is also known to affect simple sensory functions in the hand: for example, two-point thresholds are higher for older observers (Stevens 1992). The ability to tactually perceive 2-D shape also deteriorates with age (Kleinman and Brodzinsky 1978). At this point, however, little is known about whether or how aging affects either the haptic or cross-modal perception of 3-D object shape. Given that reductions in tactile gnosis (Bunnell 1927; Moberg 1960, 1962) lead to an increased risk of accidents in the home or workplace (eg dropping objects, sharp tools, etc, owing to the fact that the fingers and hand cannot perceive and thus grasp the 3-D shape of an object), we believe that it is very important to investigate how aging affects the haptic perception of 3-D object shape. The purpose of the current experiments was to evaluate the ability of older observers to perceive 3-D object shape using their senses of vision and active touch. In this study, experiment 1 was designed to assess visual, haptic, and cross-modal shape discrimination, while experiment 2 required observers to perform a cross-modal shape-matching task.

2 Experiment 1

2.1 *Method*

2.1.1 *Stimulus displays.* The visual and haptic stimuli were plastic copies of 12 ordinary bell peppers (Capsicum annuum)—these objects are shown in figure 1 and were previously used by Norman et al (2004b). Negative molds were created from the original objects by using liquid rubber (Evergreen 30, Smooth-on). The positive copies of the objects were then created by pouring liquid plastic (Smooth-on) into these rubber molds until it cured. Two sets of these 12 naturally shaped objects were created: one set for the visual stimuli and one set for the haptic stimuli. The average volume of the replicas of the bell peppers was 350 cm^3 ($\sigma = 61.0$); the objects thus had a mean diameter of 8.7 cm. The use of these natural objects has some distinct advantages. For example, they all have unique individual shapes, but yet are confusable to human observers. If typical manufactured objects were used (eg spheres, cones, cubes, cylinders, etc), observers would rarely, if ever, make a mistake in either a discrimination or matching task. It would be possible to create a set of man-made objects that are quite similar and thus confusable, but the results could be influenced by some distinct peculiarity of the manufactured objects. We believe that the use of naturally shaped objects is best, because the results that are obtained are more likely to be representative of a wide variety of other objects.

During the experiment, the observers judged whether two sequentially presented objects were the same or different in 3-D shape. The objects were presented either to the same modality (both presented visually or haptically) or to different modalities (either in the order haptic-vision or vision-haptic). For the conditions involving vision, the viewing conditions were full-cue. The objects were binocularly viewed by the observers under ample lighting (provided by several overhead fluorescent light fixtures). The objects also rotated in depth about a Cartesian vertical axis, which was located at a viewing distance of 50 cm. The plastic object surfaces were shiny (like those of the original bell peppers). Because of the lighting, the object movement, and the smooth, shiny object surfaces, the visual objects were defined by many simultaneously available optical sources of information: image shading, specular highlights, binocularly disparate shading and highlight fields, and deforming shading and highlight fields. These optical sources provide human observers with a wealth of information to specify 3-D object shape (eg see Bülthoff and Mallot 1988; Doorschot et al 2001; Fleming et al 2004; Koenderink and van Doorn 1980; Koenderink et al 1996a, 1996b; Liu and Todd 2004; Norman et al 1995, 2004c; Todd 1985; Todd and Reichel 1989).

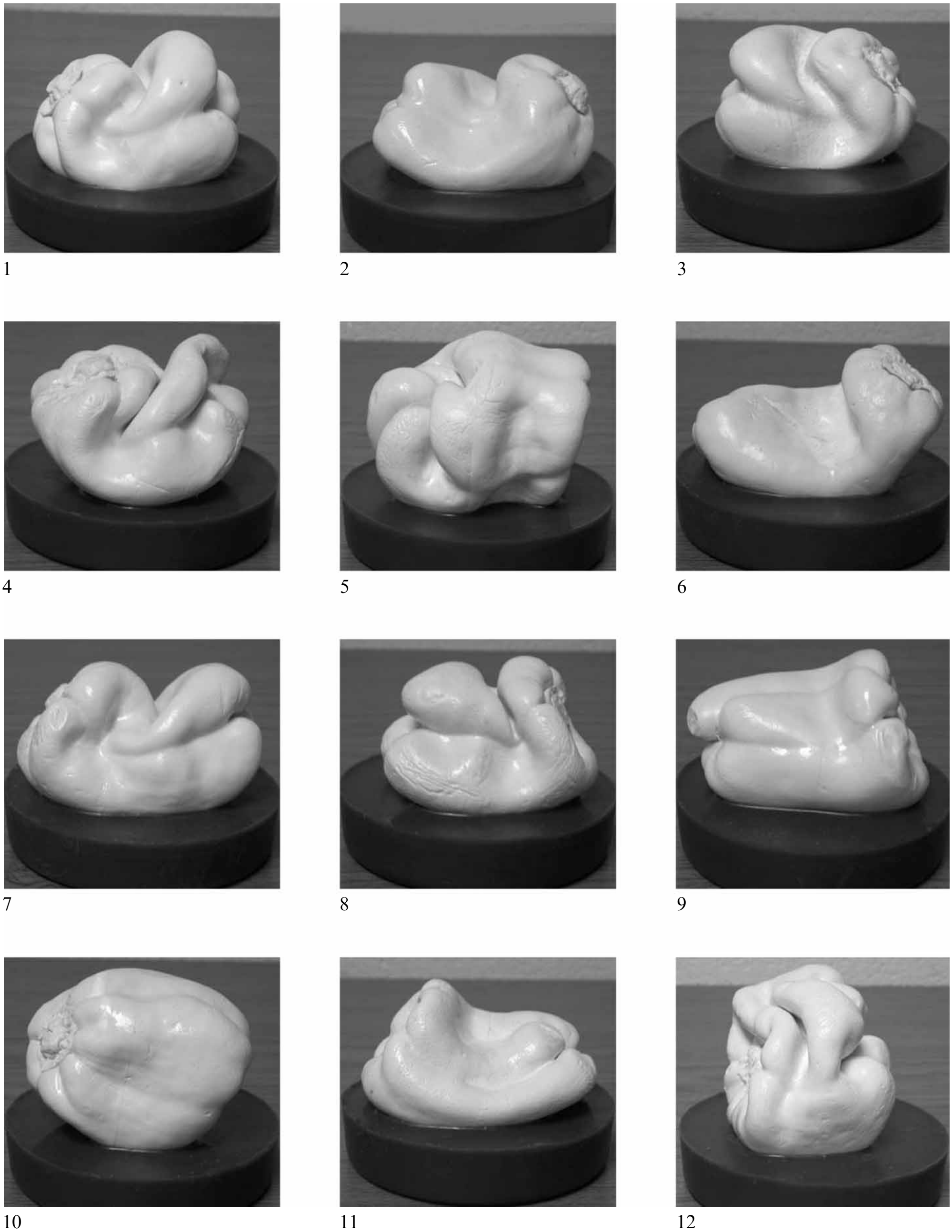

Figure 1. Photographs of the 12 naturally shaped three-dimensional objects (bell peppers, Capsicum annuum) that were used as the experimental stimuli [originally published in the paper by Norman et al, 2004b (*Perception & Psychophysics* **66** 342 – 351)].

2.1.2 *Procedure.* Each observer participated in one of three experimental conditions: (i) vision-vision; (ii) haptic-haptic, and (iii) cross-modal (either haptic-vision or vision-haptic). In all conditions the observers were sequentially presented with two of the objects on every trial, and they were then required to judge whether the two objects possessed the same shape or had different shapes. Each object was presented for 3 s; the interstimulus interval (ISI) was also 3 s. In the conditions involving vision, the objects rotated in depth around a Cartesian vertical axis at a constant angular speed of 30 rev. min^{-1} (given that the objects were presented for 3 s, this speed of rotation would allow the objects to make 1.5 complete revolutions). These parameters (stimulus duration, ISI, speed of rotation) were identical to those used by Norman et al (2004b). All observers participated in five experimental sessions consisting of 24 trials each. Thus, at the end of the fifth session, each observer had judged 120 pairs of objects (10 trials for each of the 12 stimulus objects). On each trial, the object was either paired with itself, creating 'same' trials, or was paired with another randomly chosen object, creating 'different' trials. There was an equal number of same and different trials (60 same trials and 60 different trials); the order of same and different trials was randomly determined for each individual observer.

For the observers in the haptic-haptic condition, we assessed their tactual acuities by obtaining two-point thresholds. It is widely known that there is a significant deterioration in tactile spatial acuity that accompanies increasing age (eg see figure 1 of Stevens 1992); we wanted to evaluate whether this age-related decrease in tactile acuity affects the ability of older observers to haptically judge object shape. The two-point thresholds were measured near the fingertip (on the inside surface) of the index finger of each observer's dominant hand. An adaptive staircase procedure (2 down, 1 up rule, see Levitt 1970) was used to obtain the two-point thresholds. The use of this rule estimates the 70.7 percentage point on the observers' psychometric functions. On every trial, an observer's fingertip was randomly touched by either two points or one point with a pair of digital calipers (Mitutoyo 500-196; these calipers have a resolution of 0.01 mm); the observer was then required to judge whether his/her finger had been touched by one point or two. The observers' vision was occluded during the procedure to ensure that their judgments were completely based upon their sensations of touch. At the beginning of the staircase, the initial separation (for a two-point trial) was 6.0 mm for the older observers and 3.0 mm for the younger observers. After every two correct responses, the separation was decreased by 0.15 mm; after each incorrect response, the separation was increased by 0.15 mm. The staircase was terminated after ten reversals. The final estimates of the observers' two-point thresholds were obtained by averaging the separations for the final six reversals. On average, it took about 55 trials and approximately 20 min to estimate each observer's tactile acuity.

We performed one more test for the observers in the haptic-haptic condition. The observers' manual dexterity was assessed with the Moberg pick-up test (Moberg 1958), as modified by Dellon (1981) and Desrosiers et al (1996). We administered this test, because many adults over 65 years of age have arthritis, and it is conceivable that the presence of arthritis could adversely affect the older observers' ability to haptically perceive 3-D object shape (it has been estimated by the United States Centers for Disease Control and Prevention that 47.8% of those 65 years or older have doctor-diagnosed arthritis, see Bolen et al 2005). In the Moberg pick-up test, a participant picks up 12 small metal objects one at a time and places them into a small box. The cumulative time it takes to pick up all of the 12 objects and place them into the box is recorded. The participants do this both with and without vision. Someone with normal tactile sensitivity and manual dexterity can perform this task even while blindfolded. The score of the pick-up test is the difference in the two obtained times (ie with and without vision; the test typically takes longer without vision). In our experiment, each participant performed the pick-up test twice. The final measure recorded was the faster of these two performances. The following 12 objects were used in the test (the same objects as used by Dellon 1981): flat-head screw (18 mm long, 5 mm diameter shaft), nickel (21 mm diameter), dime (17 mm diameter), key (53 mm long, approximately 12 mm in width), paper clip (6 mm $\times$ 30 mm), safety pin (5 mm $\times$ 28 mm), small hex nut (8 mm diameter), large hex nut (16 mm diameter), square nut (8 mm diameter), nail (36 mm long, 2 mm diameter shaft), wing-nut (10 mm × 21 mm), and washer (15 mm outside diameter, 6 mm inside diameter).

2.1.3 *Observers.* There were a total of sixty observers. One group of observers consisted of thirty older adults (mean age 73.5 years, SD = 4.7 years; ages ranging from 63 to 82 years). The other group consisted of thirty younger observers (mean age 21.7 years, SD = 3.4 years; ages ranging from 18 to 31 years). Half of each age group was male, and half was female. All of the observers were naive with regards to the purposes of the experiment. Twenty of the observers (ten younger and ten older) performed purely visual judgments. A different set of twenty observers performed purely haptic judgments, while a third set of twenty observers performed cross-modal judgments. With regards to the observers in the cross-modal condition, half of them viewed the objects first and then haptically explored the comparison stimuli, while the opposite order of the haptic and visual stimuli was used for the remaining half of the observers.

The observers were asked (self report) whether they possessed eye or retinal problems, such as macular degeneration glaucoma, or cataracts. One older female (aged 74 years), who was randomly assigned to the unimodal vision condition, had macular degeneration in the left eye, but not in the right eye. Because she had good visual acuity in the right eye, she was allowed to participate in the experiment. Her subsequent performance was good and was approximately the same as the mean of the other older observers assigned to that condition. None of the other observers had significant eye disorders.

The observers' visual acuities were measured at a distance of 100 cm with a Landolt C chart (Riggs 1965). The younger observers' average acuity was 1.0 min of arc^{-1} while that for the older observers was slightly less, 0.86 min of arc^{-1} (1.0 min of arc^{-1} is equivalent to 20/20 vision measured at 20 feet; 0.8 min of arc is equivalent to 20/25 vision). If the observers typically wore corrective lenses (eg bifocals), they used the correction that gave the best visual acuity to view the experimental stimuli.

2.2 *Results and discussion*

The results are shown in figures 2–4. The observers' results for the four unimodal and cross-modal conditions are plotted in figure 2. There was a significant main effect of age ($F_{1,52} = 4.7$, $p < 0.05$, MSE = 127.2, $\eta^2 = 0.08$), but it is clear from an inspection of figure 2 that the effect of age is limited to the cross-modal haptic-vision condition.

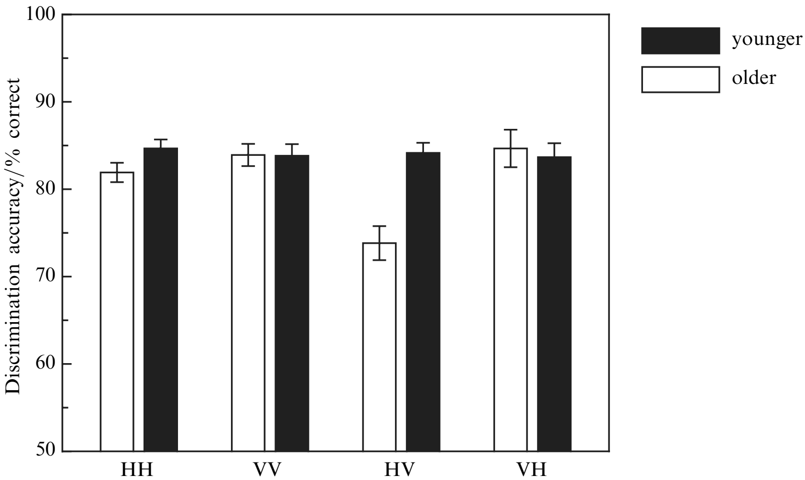

Figure 2. Results of experiment 1 for the four modality conditions (HH refers to the haptic-haptic condition, VV refers to the vision-vision condition, while HV and VH refer to the haptic-vision and vision-haptic conditions, respectively). The error bars indicate ±1 SE.

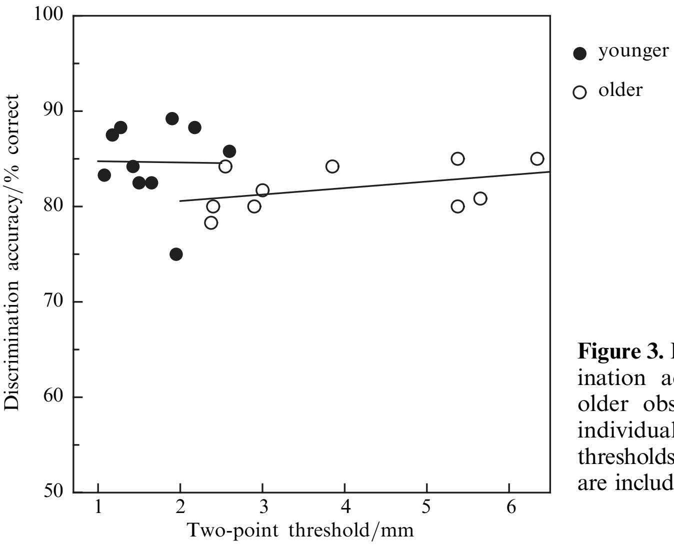

Figure 3. Results of experiment 1. Discrimination accuracies of the younger and older observers as a function of their individual tactile acuities (ie two-point thresholds). The best-fitting regression lines are included.

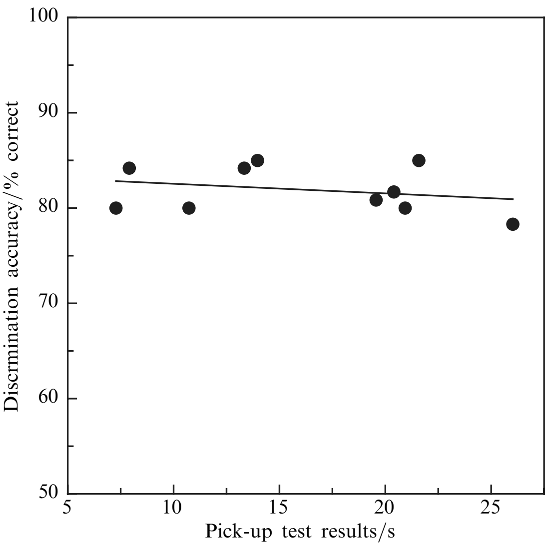

Figure 4. Results of experiment 1. Discrimination accuracies of the older observers as a function of their performance on the modified Moberg pick-up test. The best-fitting regression line is included.

The discrimination performances for the older and younger observers were essentially identical for the three remaining modality conditions (haptic-haptic, vision-vision, and vision-haptic). This pattern of results produced a significant age × modality interaction ($F_{3,52} = 2.85$, $p < 0.05$, MSE $= 127.2$, $\eta^2 = 0.14$). There were no other significant effects. For example, the observers' performance remained constant and did not either improve or deteriorate across the five experimental sessions ($F_{4,208} = 0.7$, $p > 0.05$).

In our experiment, the older observers (who were on average 51.8 years older than the younger observers) performed just about as well as the younger observers in the unimodal haptic condition (see figure 2). This result is consistent with the findings of Ballesteros and Reales (2004). They found that, while older observers were slower in responding than younger observers in a haptic object-identification task, the magnitude of haptic priming exhibited by older observers was comparable to that of younger observers (see their figure 2). Taken together, the current results and those of Ballesteros and Reales suggest that older observers have a highly preserved sense of active touch.

In a previous study involving the learning of Braille letters by both vision and touch, Hall and Newman (1987) also found a superiority of performance for vision-haptic over haptic-vision (just like the pattern exhibited by our older observers). In their experiment, the participants were required to haptically recognize Braille symbols that they had learned visually or were required to visually recognize Braille symbols that they had learned through haptics. It is interesting that this asymmetry (the order vision-haptic leads to higher performance than the opposite order, haptic-vision) occurred both in the experiment by Hall and Newman and in our current experiment, given that the two sets of stimuli were quite different (Braille symbols versus solid object shape).

The observers' performance in the haptic-haptic condition is plotted in figure 3 as a function of their individual tactile acuities (ie two-point thresholds). One can clearly see that the younger observers possessed better tactile acuity (ie smaller two-point thresholds) than the older observers. Notice, however, that among the older observers, poorer tactile acuity did not result in impaired shape discrimination performance—indeed, the older observers with the worst tactile acuities performed better than those with better tactile acuities.

The manual dexterity of the older observers in the unimodal haptic condition was good: the older observers had slightly longer times in the modified Moberg pick-up test than the younger observers (16.2 s and 15.2 s, respectively), but this small difference was not statistically significant ($t_{18} = 0.3$, $p > 0.05$). The individual results for the older observers are plotted in figure 4 as a function of their performance on the pick-up test. It is readily apparent that there is a significant amount of variability within the older group of observers, but these individual differences in dexterity did not significantly influence the observers' performance on the 3-D shape discrimination task. The observers all exhibited about the same level of shape discrimination performance regardless of their individual dexterities (the Pearson r correlation coefficient was -0.262; thus only 6.9% of the variance in the observers' shape discrimination performance could be accounted for by differences in their individual dexterities).

3 Experiment 2

The results of the first experiment revealed that in most conditions there is little or no difference between the capabilities of older and younger observers in perceiving and discriminating natural object shape. The similarity in performance for unimodal shape comparisons (see figure 2) demonstrates that the basic functionality of the older observers' visual and haptic systems is still good, at least up to the age of 82 (the age of the oldest observers that participated in our experiment). In the second experiment, we modified the task to one involving cross-modal shape matching—the observers no longer had to simply discriminate *whether* two objects possessed the same or different 3-D shape, but were required to select *which* of 12 visible objects possessed the same shape as a randomly selected object known only by active touch.

3.1 *Method*

3.1.1 *Stimulus displays.* The experimental stimuli were the same 12 naturally shaped objects that were used in experiment 1. During the experiment, the 12 visual objects were spaced evenly across a tabletop in front of an observer in a semicircular arrangement (all objects were located at a 60 cm viewing distance). In this experiment, the visual objects were stationary (ie they did not rotate in depth). The viewing conditions were otherwise full-cue.

3.1.2 *Procedure.* On every trial, the observers' task was to haptically explore a randomly selected object (1 – 12) and then indicate which of the visual objects possessed the same 3-D shape. The observers actively manipulated each haptic object for 7 s (behind an occluding curtain) before making their matching judgment. In a previous study with identical procedures, Norman et al (2004b) found that their observers' haptic-to-visual matching performance improved from 3 to 5 to 7 s and did not improve with longer haptic exploration times. The observers could see the entire set of visual objects while they were simultaneously feeling each of the haptic objects.

All of the observers participated in four experimental sessions. The observers could take a short break between the sessions if they wished. Each object was haptically presented twice within each session; thus, there were 24 (12 objects $\times$ 2 repetitions) trials per session. At the end of the four sessions, the observers had performed 96 cross-modal matching judgments (12 objects $\times$ 8 total repetitions per object). Within each session, the haptic objects were presented in a randomly determined order.

3.1.3 *Observers.* Forty observers (four groups of ten) participated in the experiment: thirty older observers (mean age 70.0 years, SD = 5.8 years; ages ranging from 60 to 81 years), and ten younger observers (mean age 20.8 years, SD = 1.0 years; ages ranging from 19 to 22 years). The younger observers and one group of older observers performed the cross-modal matching task exactly as earlier described. A second group of ten older observers performed the cross-modal shape-matching task with a smaller set of objects. These observers, on any given trial, haptically explored one of only 6 objects for 7 s (randomly selected from objects 7 – 12) and later indicated which of 6 visual objects (7 – 12) matched it in terms of 3-D shape. A third group of ten older observers used the entire set of 12 objects, but were given an unlimited time to haptically explore the objects (instead of the 7 s given to the first two groups of observers).

The observers were once again screened for macular degeneration, glaucoma, cataracts, or other retinal or eye problems (none were reported). The results of one older observer (male, aged 65 years) were not included in the analysis because of a history of a stroke occurring in the occipital lobe. The thirty older observers' mean visual acuity was 0.85 min of arc^{-1}, while that for the ten younger observers was 1.0 min of arc^{-1} (1.0 min of arc^{-1} is equivalent to 20/20 vision measured at 20 feet; 0.8 min of arc^{-1} is equivalent to 20/25 vision). If the observers typically wore corrective lenses (eg bifocals), they used the correction that gave the best visual acuity while performing the cross-modal shape-matching task. In each age group, half of the observers were male and half were female. None of the observers had participated in experiment 1, and all of the observers were thus unfamiliar with the experimental objects. All of the observers were naive with regards to the purposes of the experiment.

3.2 *Results and discussion*

The observers' results for the cross-modal shape-matching task are shown in figure 5. It is readily apparent that when the full set of 12 objects was used and the observers' haptic exploration time was constrained to only 7 s there was a large effect of age upon the observers' performance (67.6% matching accuracy for the younger observers versus 42.4% accuracy for the older observers). Under these circumstances, the younger observers' performance was approximately 60% higher than that of the older observers. One can also see, however, that this effect of age disappeared when either the stimulus set was reduced to 6 objects or when the older observers were given an unlimited time to haptically explore the object shapes. The results of a split-plot factorial ANOVA confirm these intuitions. Significant differences exist between the performances of the four groups of observers that are depicted in figure 5 ($F_{3,36} = 11.1$, $p < 0.0001$, MSE = 618.1, $\eta^2 = 0.48$). A posteriori tests (Tukey HSD) revealed that there were significant pairwise differences between (i) the younger and older age groups who judged 12 objects and were allowed only 7 s of haptic exploration time; (ii) the older group who judged the entire set of 12 objects with a limited haptic exploration time and the older group who judged only 6 objects; (iii) the older group who judged 12 objects with a 7 s haptic exploration time and the older group who also judged 12 objects but were given an

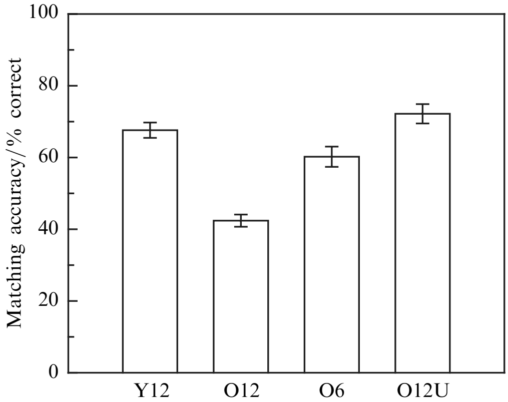

Figure 5. Results of experiment 2 for the four groups of observers. Y12 and O12 refer to the younger and older groups of observers who judged the entire set of 12 objects and who were allowed 7 s of haptic exploration time. O6 refers to a second group of older observers who judged a smaller set of 6 objects (also using a 7 s haptic exploration time). O12U refers to a third group of older observers who judged the entire set of 12 objects, but who were given an unlimited haptic exploration time. The error bars indicate ±1 SE.

unlimited haptic exploration time. The a posteriori tests revealed that there were no significant differences between the performance of the younger observers and the older observers who judged only 6 objects or who were allowed an unlimited amount of time to haptically perceive each object's shape.

The effect of increasing experience (ie sessions) was also significant ($F_{3,108} = 10.8$, $p < 0.0001$, $\mathrm{MSE} = 80.3$, $\eta^2 = 0.23$), but that effect itself depended upon the different groups of observers. As can be seen in figure 6, the performances of the younger observers and the older observers with unlimited haptic exploration time both showed a significant increase across sessions. There was little or no increase across the four experimental sessions, in contrast, for the two groups of older observers who were allowed only 7 s to haptically explore the object shapes. This pattern of results generated a significant group × sessions interaction ($F_{9,108} = 2.6$, $p < 0.01$, $\mathrm{MSE} = 80.3$, $\eta^2 = 0.18$).

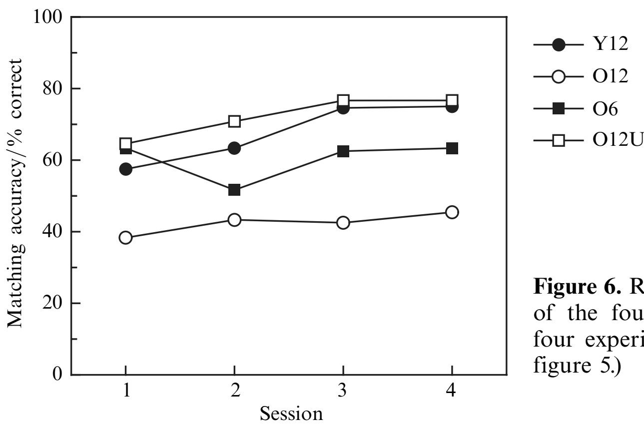

Figure 6. Results of experiment 2. Performance of the four groups of observers across the four experimental sessions. (For legends, see figure 5.)

4 Discussion

The results of experiment 1 indicate that human observers (both younger and older) can perceive natural object shape through their sense of active touch about as accurately as when using vision (see figure 2). This result is consistent with the findings of Klatzky et al (1985); they showed that younger observers (20 – 23 years of age) could identify tactually presented familiar objects with a 94% accuracy after 5 s or less of haptic exploration. Our current results are also similar to those of Norman et al (2004b, see their figure 7), who conducted an analogous experiment with fifty-six younger observers and found no significant difference between discrimination performances obtained with unimodal vision and unimodal haptics. This functional similarity between haptics and vision is quite interesting given the obvious differences in the sensory physiology of the hand and eye. It is obvious from an inspection of figure 2 that haptic exploration of a solid object with one's hands and fingers leads to an effective perception of the object's shape, even with haptic exploration times as short as 3 s (cf Klatzky et al 1985).

Prior to the current experiments, little was known about how older observers perceive 3-D shape from active touch. One important purpose of our current experiments was, therefore, to remedy this lack of information and investigate whether and to what extent aging affects the haptic perception of 3-D shape. Previous research dealt with both local and global aspects of haptic shape perception in younger observers (eg Lakatos and Marks 1999; Louw et al 2002; Norman et al 2004b; Pont et al 1997, 1998, 1999). The present experiments were among the first to examine older observers' haptic capabilities to perceive 3-D object shape (also see Ballesteros and Reales 2004). It is important to investigate this issue, since it is known that failure to adequately perceive object shape from haptics results in accidents and potential injury (imagine dropping or mishandling a knife in a kitchen or an electric saw in a home workshop, for example, owing to a failure to perceive the shape of an object that one is grasping; see Bunnell 1927; Moberg 1960, 1962). If aging did lead to a significant deterioration in haptic shape perception (as it does to tactile acuity, see figure 3; also Stevens 1992), this deterioration would be an important contributing factor to accidents and resulting injury among older adults. It is thus gratifying to find in the current experiments that older observers can effectively perceive 3-D object shape from active touch, at least up to the age of 81 – 82 years (the ages of the oldest observers in our study).

The results of both experiments also revealed that human observers can effectively compare the 3-D shapes of objects across the modalities of vision and active touch (see figures 2 and 5). Reliable cross-modal priming (both visual-haptic and haptic-visual) has previously been demonstrated in studies of explicit and implicit memory (Easton 1997a, 1997b; Reales and Ballesteros 1999); these results, combined with those obtained in the current experiments suggest that there is a significant amount of interaction between the two perceptual modalities and they could potentially share common representations. One could thus conclude that haptics and vision constitute a single functional 'system' (von Fieandt 1958; Gibson 1966). This could be implemented neurophysiologically by having both vision and haptics contribute to a single common cortical representation of shape (Amedi et al 2001; James et al 2002). At the least, the results of our experiments would appear to indicate that there is considerable functional overlap between vision and haptics (cf Marks 1978), and that it is possible for the two senses to work together to effectively perceive 3-D object shape.

The results of both of the current experiments demonstrated the existence of an age-related deficit in the ability to perform cross-modal shape comparisons (eg see figures 2 and 5). The reduction in performance with increasing age was most severe in experiment 2. What are the possible causes of this age-related deficit? One possible explanation involves attention. It has long been known that aging has large effects upon performance for tasks that require divided attention (eg Ball et al 1990; Broadbent and Gregory 1965; Broadbent and Heron 1962; Inglis and Caird 1963; Kirchner 1958; McDowd and Craik 1988; Sekuler et al 2000; Wright 1981). The cross-modal matching task requires divided attention—the observers must manually explore the solid shape of an object using their sense of haptics, while at the same time they must also look at and examine the shape of the 12 (or 6) visible objects. It is therefore possible that the increased attentional demand placed upon the older observers in the cross-modal matching task is responsible for the relatively large age effect that is depicted in figure 5. The results of recent research on aging and visual search (Hommel et al 2004) have revealed that older observers, while searching for a visual 'target', are more affected than younger observers by increases in the number of distractors. Our cross-modal shape-matching task is similar in many ways to a typical visual-search task: the observers must search for a visual 'target' object embedded amongst a set of 'distractors'. Our finding that the performance of the older observers (figure 5) is influenced by the number of 'distractor' objects is consistent with research on aging and attention by means of the visual-search paradigm.

A quite different explanation for the observed age-related deficit in cross-modal shape comparison involves 'cerebral slowing'. In their review, Birren and Fisher (1995; also see Salthouse 1991, 1996, 2000) suggest that "there is a general factor of speed of the central nervous system (CNS) that is slowed with age". According to Salthouse (1996), this "reduction in speed leads to impairments in cognitive functioning". The results of experiment 2 (see figure 5) are consistent with this idea, because the effect of age disappeared when the older observers were given an unlimited amount of time to haptically explore the object shapes. If this idea is correct, then apparently this cerebral slowing is limited to the neural mechanisms that implement the ability to perform cross-modal shape comparisons. It is probably important to note in this context that there is no evidence of adverse effects of cerebral slowing (in either the visual or haptic systems) in the unimodal conditions of experiment 1 (see figure 2). In that experiment, the older observers performed just as well as the younger observers in making unimodal shape comparisons, and the stimulus presentation times for both age groups was a short 3 s.

5 Conclusion

Aging has little to no effect upon either the unimodal visual or unimodal haptic perception of 3-D natural object shape. Significant age-related deficits do occur, however, for cross-modal shape comparisons (see figures 2 and 5). Such deficits can be completely eliminated by reducing the demand upon the older observers' attentional capabilities or by increasing the amount of time available for haptic shape exploration.

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