Haptic estimates of discordant visual-haptic size vary developmentally

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In two size-conflict experiments, children viewed various squares through a reducing (1/2) lens while manually grasping them through a hand-concealing cloth. Then, using either vision or touch, they selected a match from a set of comparison squares. Forty 6-, 9-, and 12-year-olds participated in Experiment 1. Vision dominated the visual estimates of all three age groups; however, for the haptic estimates, the dominant modality varied developmentally: Vision dominated the 6-year-olds' haptic estimates, whereas neither modality dominated the 9-year-olds' haptic estimates, and touch dominated the 12-year-olds' haptic estimates. In Experiment 2, 24 six-year-olds were tested, as in Experiment 1; however, half of them were shown the size-distorting effects of the lens just prior to testing. Although this reduced the visual dominance of their haptic estimates, the effect was weak and short-lived. The haptic dominance seen in the data of the 12-year-olds was conspicuously absent.

With one exception (Rock & Victor, 1964, discussed below), researchers have found that touch dominates vision when adult observers make haptic estimates of the size of discordant stimuli whose visual and haptic sizes differ (Hershberger & Misceo, 1996; Klein, 1966; McDonnell & Duffett, 1972; Ogawa, 1976). However, Klein's developmental study indicates that this does not hold true for younger participants. Klein tested five groups, of 24 participants each, whose mean chronological ages were 9.5, 11.5, 13.8, 15.9, and 18.0 years. Each participant examined a discordant standard stimulus comprising a pair of wooden dowels attached to the front and rear surfaces of a panel so as to simulate a single dowel protruding through a hole; the participants felt the one in back while viewing the one in front. The diameters of the visual and haptic dowels were 2.54 and 1.75 cm, respectively. While examining this discordant dowel, the participants simultaneously judged its diameter by selecting with the other hand one of eight haptic comparison stimuli. In addition to the discordant (D) condition, visual and haptic controls were

used. In the visual control (V) condition the dowel was only viewed, and in the haptic control (H) condition it was only felt. In both control conditions, the comparison stimuli remained haptic.

Every participant made four consecutive estimates in each of the three conditions. Averaging these four estimates, a single "visual capture score," $(D - H)/(V - H)$, was calculated for each participant. The value of this ratio ranges from 1 to 0, with 1 representing complete visual dominance, 0 representing complete haptic dominance, and 0.5 representing equal dominance (or no dominance of either type). The group means, from youngest to oldest, were 0.36, 0.51, 0.37, 0.30, and 0.14. Only the last two means differed significantly from 0.5 ($p < .05$). Thus, only the two oldest groups evinced haptic dominance. Because the younger participants cannot be said to have exhibited intermodal dominance of either type, haptic or visual, the developmental trend in Klein's (1966) data appears to originate from an asymptotic baseline of zero dominance, or modal equipotency. Would touch and sight exhibit a reversal of fortunes were even younger participants to be tested? Addressing this question, the present experiments examined whether 6-year-old observers (i.e., children younger than those tested by Klein) might exhibit visual dominance when rendering haptic estimates of discordant visual-haptic size.

Developmental investigations of discordant shape consistently have found that young children's estimates of discordant shape exhibit visual dominance (e.g., Hatwell, 1987; McGurk & Power, 1980), but those findings do not

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provide an answer to the present question concerning estimates of size because one cannot safely generalize from shape to size on questions of modal dominance (see Hershberger & Misceo, 1996). The shape of a distal 2-dimensional object may correspond exactly with the shape of its retinal image, but the lineal size of the retinal image specifies the visual angle subtended by the distal object, not its lineal size. The lineal size of the distal object also depends on the distance of regard. In other words, the retinal image normally provides a more definitive estimate of shape than size. Therefore it is not surprising that vision sometimes (but not always: Heller, 1983, 1992) dominates perceptual judgments of discordant visual-haptic shapes (e.g., McGurk & Power, 1980; Power, 1980, 1981; Power & Graham, 1976; Rock & Victor, 1964).

Rock and Victor's (1964) optical method of inducing intersensory discordance was used in the present experiments because the efficacy of Klein's (1966) method has been questioned by some (Welch & Warren, 1980). In Rock and Victor's method, participants grasp a square piece of plastic while simultaneously viewing it through a reducing lens. This optical technique allows observers to see the entire discordant stimulus, not just part of it protruding through a hole, so it is immediately apparent to the observer that the stimulus is a monolithic unit that can be examined, at once, both visually and haptically. Further, by using a stimulus that is thin enough to be regarded as 2-dimensional (i.e., a square), the four edges viewed from above are unequivocally perceived to be the same four edges that are grasped from below (i.e., rectangles have only four edges). Furthermore, by using a square (i.e., a rectangle whose four edges are of equal length), physical size is determined by a single metric—edge length. Thus the visual-haptic conflict engendered by a reducing lens used in the manner of Rock and Victor is tightly joined—touch registers one value and sight registers another value of the very same physical variable, edge length.

Rock and Victor's (1964) method of inducing intersensory size conflict presupposes that the discordant information is actually processed; that is, size must be registered by each modality for intersensory conflict to be possible. Unfortunately, few (20%) of Rock and Victor's participants actually noticed the intersensory discordance. This is ironic but not surprising. Although when called on adults can make very accurate haptic estimates of size (Chan, Carello, & Turvey, 1990), college students judging the relative size of two visible objects rarely use touch except "to bring the objects into better view" (Klatzky, Lederman, & Matula, 1993, p. 738). This, in effect, is what Rock and Victor's participants appear to have done—they held the discordant square but did not haptically process its size. This is unsurprising given the brevity of their experiment; Rock and Victor used a single discordant square that they presented to their participants only once for 5 sec, without the participants knowing that they would later be asked to estimate the square's size. When subsequently asked to select a matching square from a set of haptic comparison squares, they had to cross-modal

match (see Milewski & Iaccino, 1982) the remembered (i.e., visual) standard; accordingly, their matches approximated the discordant square's visual size.

To ensure that intersensory size conflict was fully joined in the present experiments, participants were expressly asked to note the size of the examined standard square. Further, they examined several different standard squares several times, estimating the size of each, in turn, by selecting, either haptically or visually, a matching square from a set of comparison squares. Hence, the present results, in contrast to Rock and Victor's (1964), should reflect the relative potency of vision and touch and not be attributable simply to the participants' ignorance of the experimenter's impending queries about size.

In Experiment 1, 6-, 9-, and 12-year-old children judged five discordant standards three times. Half of the children at each age level used haptic comparisons and the other half used visual comparisons to render their estimates. The anticipated age $\times$ comparison interaction was found, with the 6-year-olds evincing visual dominance irrespective of the type of comparison stimuli used. Experiment 2 examined whether the 6-year-olds' judgments might simply reflect their naiveté regarding the illusory effects of lenses. Experiment 2 was a partial repetition of Experiment 1 using another group of 6-year-olds, half of whom had been shown how a lens can reduce the apparent size of objects.

EXPERIMENT 1

Method

Participants. One-hundred-twenty children from public and private schools in Atchison, Kansas, participated in the study. They were recruited by means of a general invitation to participate in a study of how well they could judge size. Every child participated voluntarily, with the consent of his/her guardian. The participants comprised three age groups: 40 (19 males, 21 females) 6-year-olds ($M = 6.56$, $SD = .28$), 40 (21 males, 19 females) 9-year-olds ($M = 9.46$, $SD = .26$), and 40 (21 males, 19 females) 12-year-olds ($M = 12.28$, $SD = .38$).

Discordant standard stimuli. Each child estimated the size of five different squares that had been cut from a sheet of black plastic 5 mm thick. The five squares measured 40, 45, 50, 55, and 60 mm, on a side. Each square was presented for inspection in a large box (approximately 46 cm wide $\times$ 46 cm deep $\times$ 44 cm tall) with a conical viewing tube mounted in its top. The viewing tube was 75 mm long, with an inside diameter of 76 mm at one end (the mouth into which the children peered) and 51 mm at the other end (the base). A negative meniscus lens 52 mm in diameter was wedged into the base of the tube.¹ This lens had a focal length of minus 238 mm. A focal length of about a foot was used because that distance is a convenient reading and reaching distance. The lens' diameter avoided imaging squares in the extreme periphery of the lens. A viewing field restricted to the center of the lens, and its long focal length, and hence its low power (4.20 diopters), controlled for achromatic aberrations. The shape of the virtual images exhibited neither pin-cushion (positive) nor barrel (negative) distortions. A light source placed on the same side as the square (i.e., inside the inspection box) minimized the formation of reflections by the lens.

Every square examined was positioned face up 238 mm directly beneath the lens and held there by means of a long, 3-mm-thick rod attached to its edge. The square was held stationary in the lens'

focal plane by securely clamping the square's horizontal shaft to a sturdy, vertical ring stand located just behind the viewing box. Because the square was situated in the lens' secondary focal plane, the virtual square visible to the child was located 119 mm beneath the lens and was half size (or one-quarter area). Thus, the visual and haptic sizes were discordant. To view a square, the child rested his/her forehead on a headrest and positioned the bridge of his/her nose about 30 mm from the mouth of the viewing tube; the reducing lens mounted in the base of the tube (about 100 mm from the child's eyes) afforded a binocular view of the square's virtual image. A loosely fitting opaque white cloth suspended directly beneath the square acted as a false floor below which the child could insert his/her writing hand. The viewing tube afforded a view of the square and the cloth, but nothing else.

The children could neither see nor touch the squares while they were removed from and replaced in the inspection box. Thus, when cued, each child viewed each square through the reducing lens while simultaneously grasping the square from below through the white cloth preventing sight of his/her hand. The children were instructed to grasp the square's edges with their thumbs and fingertips and to look at the square at the same time. Their performance was carefully monitored to ensure compliance with these instructions. They were explicitly instructed to "study the size of the square—get a good feel and a good look." No time constraint was imposed on how long they examined the discordant standard, and they typically examined the standard for 5–10 sec.

Comparison stimuli. On each trial, the children estimated the size of the discordant standard stimulus by selecting a match from among a set of 12 comparison squares ranging in size from 15 to 70 mm in 5-mm increments. There were two such sets, one for visual comparison and one for haptic comparison. The two sets of comparison stimuli were arrayed differently to minimize cross-modal response generalization.

The visual comparison squares were randomly labeled with alphabetic letters and mounted in a circular array on the wall directly behind the children's position for examining a standard stimulus. Thus, by simply turning around, the children could use saccadic eye movements to quickly select a match and call out its letter. The haptic comparison squares, suspended on posts, were mounted in a horizontal row, in order of their size, inside a box with a curtained opening, allowing the children to reach in and touch the squares without seeing them. This box was located immediately to the right of the children's position for examining a standard stimulus. The ordinal arrangement of the squares allowed the children to anticipate where in the array a match would be found, and thus to find it quickly. The children selected the haptic comparison with the same hand they had used to examine the discordant standard—their writing hand. They were instructed to take their time in finding the best matching square.

Training. Before testing began, several training devices were used to familiarize the children with the type of comparisons they would be asked to make. To demonstrate the use of haptic comparison stimuli to estimate the haptic size of the standard square (H/H comparison task), the children were shown a small box containing a hidden square that they could grasp by reaching through a curtained opening. They were asked to reach through the curtain with their writing hand and to grasp the square's edges with their fingertips. While grasping without seeing the standard square, they were told to study the size of the square until they had a good feel for its size. Then they were asked to put their writing hand into another curtained box and to choose a match from among a set of three different comparison squares (varied in 10-mm increments), one of which was equal to the standard. To demonstrate the use of visual comparison stimuli to estimate the visual size of the standard square (V/V comparison task), the children were asked to view only a standard square. While viewing without grasping the square, they were told to study the size of the square until they had a good look

for its size. Then they were asked to turn around and look at a panel displaying three comparison squares (varied in 10-mm increments, one of which was the same size as the standard) and to choose the matching square by reading its identifying label—a letter of the alphabet. Each child received one trial of each type of demonstration, with the size of the standard square varying across trials. The children were given feedback on their performance on these demonstration trials. Only 2 children failed to match exactly both standard squares, and all demonstrated their ability to make size estimates using either type of comparison stimuli.

Control trials. Prior to estimating the size of the discordant standard stimuli, the children judged 10 control trials. Half of the children at each age level used the visual comparison stimuli to estimate the visual size of the standard squares; that is, they looked at the standard squares but did not touch them and then selected a match from the set of visual comparison stimuli (V/V controls, 30 males and 30 females). The other half of each age level used the haptic comparison stimuli to estimate the haptic size of the standard squares; that is, they touched the standard squares but did not look at them and then selected a match from the set of haptic comparison stimuli (H/H controls, 31 males and 29 females). During these control trials, as during the subsequent test trials described below, the five standard stimuli were presented in a randomized sequence with the restriction that each square was presented once in each successive five-trial block.

Test trials. Every child judged 15 test trials, wherein he/she simultaneously viewed and grasped each standard square. Half (i.e., 10) of the children at each age level who judged 10 H/H control trials estimated the size of the discordant square by selecting a match from among either the haptic comparison set (comparison D/H) or the visual comparison set (comparison D/V). The other half at each age level who judged 10 V/V control trials estimated the size of the discordant square by selecting a match from among either the visual comparison set (comparison D/V) or the haptic comparison set (comparison D/H).

All children judged the size of each of the five discordant standard squares three times in a randomized sequence, with the restriction that each standard was judged once in each successive five-trial block. Because each of these five standard squares was judged once in each five-trial block, the objective size of the average haptic standard stimulus was 50 mm for each block of trials, and the size of the average visual standard stimulus (being reduced to half size) was 25 mm for each block of trials. The children turned to the comparison stimuli only after having finished their examination of the discordant standard stimulus.

Results

Control trials. The control-trial data, summarized in Table 1, were subjected to a 3 (age) $\times$ 2 (modality: V/V and H/H) $\times$ 2 (trial block) mixed analysis of variance (ANOVA).² The analysis yielded two significant (alpha set at .05) effects, a main effect of modality [$F(1,114) = 871, p < .0001$; standard $\omega^2 = .87$; see Dodd & Schultz, 1973; Keppel, 1991] and an age $\times$ modality interaction [$F(2,114) = 5.65, p < .005$; $\omega^2 = .01$]. The average haptic estimate was 47.27 ($SE = .42$), and the average visual estimate was 24.66 ($SE = .45$). These values are slightly less than the average objective haptic size of 50 mm and the average objective visual size of 25 mm, respectively. Two follow-up analyses of the age $\times$ modality interaction revealed that the haptic estimates did not increase with increasing age [$F(2,114) = 2.21, p > .10$; $\omega^2 = .04$], whereas the visual estimates decreased with increasing age [$F(2,114) = 3.88, p < .03$; $\omega^2 = .08$]. Post hoc tests

Table 1
Mean Estimated Size (in Millimeters) of the Haptic Standards
Estimated Haptically (H/H Control) and the Visual Standards
Estimated Visually (V/V Control) by Age Level and Trial Block

Age	Type of Control			
	H/H		V/V	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Block 1				
6	45.90	1.36	25.65	1.31
9	46.65	0.76	24.60	0.79
12	48.85	0.77	23.45	0.49
Block 2				
6	46.50	1.47	27.65	1.86
9	46.90	0.71	24.05	0.59
12	48.85	0.66	22.55	0.56

Note—For each five-trial block, the objective size of the average standard was 50 mm haptically and 25 mm visually.

(Newman-Keuls) showed that only the visual estimates of the 12-year-olds ($M = 23.00$, $SE = .37$) were significantly ($p < .05$) smaller than those of the 6-year-olds ($M = 26.65$, $SE = 1.13$).

Test trials. Each participant estimated the size of each of the five discordant standard squares once during each block of test trials. These five estimates were averaged to yield a single estimate (i.e., of the average square's discordant size) for each block of trials. Then, although the interaction accounted for only 1% ($\omega^2 = .01$) of the total response variance, each of these estimates of discordant size (EDS) was normalized to control for the age $\times$ modality interaction observed in the control-trial data. This was done by calculating a relative dominance ratio (RDR) for each participant for each block of test trials using the formula $RDR = (EDS - V/V)/(H/H - V/V)$, where V/V and H/H represent the participant's age level control-trial means (i.e., the mean apparent visual size of the average standard square estimated visually, and the mean apparent haptic size of the average standard square estimated haptically, respectively). RDRs could range from 0 to 1, with 0 signifying complete visual dominance, 1 signifying complete haptic dominance, and 0.5 signifying equal dominance.

The RDRs were subjected to a 3 (age levels) $\times$ 2 (type of prior practice: H/H or V/V control trials) $\times$ 2 (comparison modality) $\times$ 3 (trial block) mixed, four-way ANOVA. The analysis yielded four significant effects—three main effects and one interaction. The main effects were age [$F(2,108) = 26.67$, $p < .0001$; $\omega^2 = .23$], type of practice [$F(1,108) = 5.66$, $p < .02$; $\omega^2 = .02$], and comparison modality [$F(1,108) = 37.38$, $p < .0001$; $\omega^2 = .16$]; the significant interaction was between age and modality [$F(2,108) = 4.26$, $p < .02$; $\omega^2 = .03$]. Two follow-up analyses confirmed that the haptic estimates [$F(2,108) = 26.05$, $p < .0001$; $\omega^2 = .44$] and the visual estimates [$F(2,108) = 4.80$, $p < .01$; $\omega^2 = .12$] increased with increasing age. The age and modality main effects, together with their interaction, are illustrated in Figure 1.

As for the main effect of prior practice, the mean RDR for participants who had previously made haptic estimates of the haptic size of the five standard squares during the control trials was higher (.39) than the mean RDR for participants who had made visual estimates of the visual size of the five standard squares during the control trials (.30). Although a practice (memory) effect is not, perhaps, surprising, it should be noted that both values are below .5 (z test scores were, respectively, -2.45 and -5.37 [both $ps < .01$]), implying that this memory effect is attributable solely to a memory for the visual size of the squares used during the control trials.

To summarize these results, we have found that children using visual comparison stimuli to estimate discordant visual-haptic size exhibit visual dominance (as do adults, Hershberger & Misceo, 1996), irrespective of their age; that is, although the mean RDR increased with age level, the mean RDR for each age level was less than .5 ($p < .005$). However, when haptic comparison stimuli are used, modal dominance varies with age: 12-year-olds exhibit haptic dominance (as do adults, Hershberger & Misceo, 1996), 6-year-olds exhibit visual dominance, and 9-year-olds exhibit equal dominance, or no dominance of either type. Thus whereas the haptic estimates of the 12-year-olds were above .5 [$t(19) = 4.46$, $p < .0001$], those of the 6-year-olds were below .5 [$t(19) = -5.73$, $p < .0001$], and those of the 9-year-olds were neither above nor below .5 [$t(19) = -0.82$, $p > .20$].

The present findings replicate those reported earlier by Klein (1966), who found that 9-year-olds do not exhibit the haptic dominance that their elders do when rendering haptic estimates of discordant visual-haptic size. The new finding is that even younger children exhibit a reversal of fortunes. In other words, 6-year-olds exhibit visual dominance when estimating discordant visual-

Figure 1. Mean relative dominance ratio (RDR) as a function of chronological age (in years) by type of comparison stimuli for discordant-haptic (D/H) and discordant-visual (D/V) comparisons. The horizontal line (RDR = 0.5) signifies equal dominance (values above indicate haptic dominance and those below indicate visual dominance).

Table 2
Mean Estimated Size (in Millimeters) of the
Average Discordant Square by Type of Instruction,
Trial Block, and Modality of the Match

Trial Block	Type of Instruction			
	Informed		Uninformed	
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>
Haptic Match				
1	30.83	1.08	27.67	1.86
2	32.00	1.89	26.83	2.02
3	29.67	0.99	27.00	1.06
Visual Match				
1	37.33	3.12	28.50	1.36
2	34.50	2.39	28.17	0.70
3	30.17	0.70	28.50	1.56

Note—For each five-trial block, the objective size of the average standard was 50 mm haptically and 25 mm visually.

haptic size, irrespective of whether they use visual or haptic comparisons to render their estimate. To test the strength of this visual bias, we conducted a similar experiment in which children were first shown the size-distorting effects of a reducing lens.

EXPERIMENT 2

Method

Participants. Twenty-four 6-year-old students ($M = 6.80$, $SD = .39$) from public and private schools in Atchison, Kansas, participated in Experiment 2; 12 were males, 12 were females. Six males and 6 females were assigned randomly to each of two groups, one of which made haptic estimates of size-discordant stimuli (D/H group) and one of which made visual estimates of size-discordant stimuli (D/V group).

Procedure. Experiment 2 was very similar to Experiment 1. The same standard and comparison stimuli were used for both experiments, and the D/H and D/V test trials were identical as well. Further, the same training devices were used to familiarize the children with the type of comparisons they would be asked to make during testing. Experiment 2, however, had no H/H or V/V control trials. Instead, prior to the test trials, half of the participants (3 males and 3 females) in each group (Groups D/H and D/V) were shown the optical effects of a reducing lens. These instructed children were asked to look at a square placed under a negative lens ($FL = -238$ mm), to grasp the lens, and to move it away from the square. When they were asked to describe what happened to the square, they all said that the square's size became smaller. Immediately prior to the test trials, these instructed children were told that their task involved studying the size of squares through the same glass. The optical effects of the lens were not shown to the uninstructed children, and nothing was said to them about the glass in the viewing tube.

Results

Each participant estimated the size of each of the five discordant standard squares once during each block of test trials. These five estimates were averaged to yield a single estimate (i.e., of the average square's discordant size), one for each block of trials. Table 2 shows the mean estimated size for each block of trials. Note that children who were informed about the effects of the lens gave

bigger estimates than those who were uninformed and that the mean estimates are below the 37.5-mm value of equal potency.³ These data were subjected to a 2 (level of instruction) $\times$ 2 (comparison modality) $\times$ 3 (trial block) mixed, three-way ANOVA. The analysis yielded a main effect of instruction [$F(1,20) = 10.18$, $p < .005$; $\omega^2 = .20$], a main effect of block [$F(2,40) = 4.33$, $p < .02$; $\omega^2 = .03$], and an instruction $\times$ block interaction [$F(2,40) = 3.76$, $p < .03$; $\omega^2 = .02$].

All three significant effects are illustrated in Figure 2. On average, the estimates of the instructed children were larger than the estimates of the uninstructed children, particularly for the first two blocks of trials. This was true irrespective of the comparison stimuli the children used to render their estimates; although the observed difference is not statistically reliable, the mean estimate of the children who used haptic comparisons (29.0 mm) was, paradoxically, smaller than that of those who used visual comparisons (31.2 mm). Because the estimates of the uninstructed children remained stable across blocks [$F(2,22) < 1$; $\omega^2 = .01$], the instruction $\times$ block interaction is attributable to the trend in the instructed children's data [$F(2,22) = 4.96$, $p < .02$; $\omega^2 = .10$], reflecting the waning effects of the instructions. Further, although our instructions temporarily increased our 6-year-olds' estimates of the average square's discordant size, their estimates never exhibited haptic dominance; on all three blocks of trials, our instructed 6-year-olds' mean size estimates were closer to the average square's apparent visual size (26.7 mm, according to the control data from Experiment 1) than to its apparent haptic size (46.2 mm, according to the control data from Experiment 1). Thus, by showing 6-year-old children the size-distorting effects of a reducing lens, we effectively decreased the relative dominance of vision, but the effect was relatively weak and short-lived. The haptic dominance found in the data of the 12-year-olds and adults remained conspicuously absent.

GENERAL DISCUSSION

The principal finding of Experiment 1 is that vision dominates 6-year-old children's size estimates of size-discordant (visual-haptic) stimuli, irrespective of the type of comparison stimuli (visual or haptic) they use to render their size estimates. Further, the results of Experiment 2 reveal that this bias is not attributable simply to naiveté about the optical effects of lenses. The visual bias persists even when 6-year-olds are shown the size-distorting effects of the reducing lens through which the size-discordant stimuli are viewed. This finding is antithetical to Berkeley's (1709/1950) hoary thesis that veridical visual size is taught by the dominant sense of touch.

Vision also dominates older children's visual estimates of discordant visual-haptic size, but not their haptic estimates. We found that when estimates of discordant size are rendered haptically, 12-year-olds exhibit haptic dominance and 9-year-olds exhibit no dominance of either type. These findings with 9- and 12-year-old children

Figure 2. Mean estimated size (in millimeters) as a function of trial block for instructed and uninstructed children. The horizontal line at 37.5 mm signifies equal dominance (values above indicate haptic dominance and those below indicate visual dominance).

replicate those reported earlier by Klein (1966). Moreover, the estimates of the 12-year-olds are consistent with those of young adults. With 18-year-olds, Hershberger and Misceo (1996) found an average D/H estimate of 40.0 mm ($SE = .76$) and an average D/V estimate of 33.6 mm ($SE = 1.22$),⁴ which are comparable to the 12-year-olds' D/H ($M = 41.8$, $SE = .76$) and D/V ($M = 31.6$, $SE = .86$) estimates.

The basis of the developmental shift in our D/H data is obscure. It does not appear to reflect the development of an ability to detect visual-tactual discrepancies of size; Bushnell (1982) has reported that infants have developed this ability by 15 months of age. Neither does it reflect the development of a cognitive ability to grasp reality-appearance distinctions; Flavell, Flavell, and Green (1983) have found that children have already developed that ability by 6 years of age. Nor does it reflect an inability of 6-year-olds to register the haptic size of the squares used in the present experiments; the H/H control-trial mean for the 6-year-olds in Experiment 1 was 46.2 mm—only slightly less than actual size, 50 mm. Why then did the 6-year-olds in the D/H condition not use the haptic comparison stimuli to render haptic estimates of the discordant square's veridical haptic size rather than making cross-modal estimates of the illusory visual size?

Apparently, the veridical haptic size of the discordant squares was not registered by the 6-year-olds. In postexperiment interviews, 82.5% of the 12-year-olds and 47.5% of the 9-year-olds, but only 10% of the 6-year-olds responded affirmatively to the direct question of whether they had noticed a difference between the felt and the seen size of the examined discordant squares. Thus, the 6-year-olds either ignored the haptic input (perhaps regarding it as an intolerable complication), or their haptic input was

fully captured (i.e., distorted) by their visual input, so that the squares felt as small as they looked.

Rock (1966) favored the latter alternative. Doubting that touch possesses an indigenous spatiality, Rock proposed an image-mediation model of haptic perception (see Lederman, Klatzky, Chataway, & Summers, 1990) in which the apprehension of haptic size requires "prior education of touch by vision" (p. 237). More specifically, Rock proposed that haptic stimulation calls forth visual imagery and that visual dominance occurs because directly seeing takes precedence over mediated visualization. We, instead, are inclined to favor the former alternative, because we have found that adults can exhibit either visual or haptic dominance on any given trial when the type of estimate to be made (haptic or visual comparison) is not announced until after the discordant stimulus has been examined (see Experiment 2, Hershberger & Misceo, 1996); that is, adults register intersensory discordance to the degree that they cannot fully resolve it. We thus propose that the size of a discordant standard is registered as a bivariate (tactual and visual) observation, with each variate biasing the other. This being the case, it appears likely that what 6-year-olds developmentally lack is this ability to register intersensory discordance. That is, 6-year-olds may deal with intersensory discordance by filtering out (i.e., ignoring) the less salient sensations (the role of sensory salience in intersensory discordance has been discussed at length by Welch & Warren, 1980).

Perhaps it should be noted that the developmental trend in our haptic data does not appear to be an artifact of our participants' physical size. Because 6-year-olds have shorter arms than their elders, our 6-year-olds had to extend their arms more fully than our 9-year-olds in order to grasp the discordant standard (located 238 mm beneath the reducing lens), which was twice as far as the standard's virtual image (located 119 mm beneath the reducing lens). This discordance between the visual and haptic distance (or depth) of the standard might, arguably, have been more apparent to the 6-year-olds because of their shorter arms. However, if this served to increase the apparent depth of the visible virtual image for the 6-year-olds, it should have increased the apparent size of the standard; that is, it would have reduced visual dominance especially for the 6-year-olds—which is opposite to the present developmental finding.

As noted, it is not safe to generalize the findings of studies of discordant shape to questions of discordant size. Nevertheless, the present developmental finding does suggest the possibility that the experimental procedures used by Heller (1983, 1992) to find haptic dominance of discordant shape might not have yielded haptic dominance had his experimental participants been 6-year-olds. When McGurk and Power (1980) tested young children, they found visual dominance, but their methods differed from Heller's. It remains to be seen whether touch's dominance of discordant visual-haptic shape evinces a developmen-

tal progression such as we have found for touch's dominance of discordant visual-haptic size.

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NOTES

1. A negative meniscus lens has an outward (convex) and an inward (concave) curved surface. Because the concave face is sharper than the convex one (i.e., the lens is thinner in the center than at the edges), incident parallel light rays emerge as divergent rays. Back tracing the divergent rays locates the image on the same side as the object but closer to the lens surface. Thus, negative meniscus lenses act as reducing lenses; the image is minified, upright, and virtual (Hecht, 1987). In placing every square 238 mm (one focal length) from the lens, it formed virtual images located 119 mm from the lens. This optical arrangement produced virtual images whose lateral magnification was one half the size of the squares. Although the virtual distance of the square's image was closer to the lens than the square's objective distance, both distances remained constant for all standard squares. Thus virtual distance did not vary with virtual size.

2. In all three ANOVAs reported herein, sex was not included as a factor because the male and female estimates did not differ.

3. Only the average estimate of the informed children who used visual comparisons ($M = 37.33$, $SE = 3.12$) approached the 37.5-mm value of equal dominance. An inspection of the individual data indicated that the estimates of 2 children were primarily responsible for the inflated mean. Both exhibited haptic dominance of the first block, then one on the second block, and finally neither on the third block. Thus these individuals may have overcompensated for the visual distortion immediately after the effects of the lens were demonstrated.

4. The estimates of the young adults are based on testing conditions comparable to those of the 12-year-olds, namely the same number of discordant five-trial blocks. A procedural difference between the two groups that could not be equated was the number of control trials. Young adults judged discordant standards after judging four control blocks, whereas 12-year-olds did so after judging two control blocks.

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