Perception, 2003, volume 32, pages 499 – 511

DOI:10.1068/p3423

Superior haptic perceptual selectivity in late-blind and very-low-vision subjects

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Received 23 July 2002, in revised form 5 December 2002; published online 7 March 2003

Abstract. Blindfolded sighted, congenitally blind, late-blind, and very-low-vision subjects were tested on a tangible version of the embedded-figures test. The results of ANOVAs on accuracy measures yielded superior performance by the very-low-vision and late-blind subjects compared with the blindfolded sighted and congenitally blind participants. Accuracy of the congenitally blind subjects was similar to that of the blindfolded sighted participants. However, all groups of blind subjects were significantly faster than the blindfolded sighted subjects. It is suggested that experience with pictures combined with haptic skill aid perceptual selectivity in touch.

1 Introduction

The ability to locate figures against a background is a basic perceptual skill, and is as important in haptics as in vision. One way to study this ability has been to use variations of the embedded-figures test, in which forms are camouflaged in complex backgrounds. The purpose of this study was to clarify the possible impact of visual experience on perceptual selectivity in haptics.

The visual embedded-figures test was originally designed as a measure of cognitive skills, and tests field dependence (Axelrod and Cohen 1961; Teuber and Weinstein 1956). Field dependence refers to the distracting influence of a visual background on perceptual judgments, eg of the phenomenal vertical (Bitterman and Worchel 1958). Performance on the embedded-figures task depends upon an individual's ability to locate a target against a distracting background, and is affected by age and level of general cognitive functioning (Axelrod and Cohen 1961; Teuber and Weinstein 1956). Practice improved performance on the visual version of the Gottschaldt hidden-figure test, but gender did not alter performance (Schaefer and Thomas 1998).

Witkin et al (1968) argued that cognitive functioning can be described as global or articulated, with global functioning representing a relative failure to engage in effective perceptual selectivity. According to Witkin (1967, page 234), "perception may be conceived as articulated, in contrast to global, if the person is able to perceive item as discrete from organized ground when the field is structured (analysis) ...". He argued that the global cognitive style is characteristic of an early developmental stage of intellectual development, and is related to field dependence, and performance on the rod-and-frame task. Witkin et al (1968) suggested that a lack of visual experience would hamper the development of articulation and thus yielded lower performance on the tactile embedded-figures test (also see Revesz 1950). However, their task required the subjects to remember the target stimuli. Thus, it is not known if performance differences between the sighted and blind children derived from differences in spatial memory or differential skills in figure – ground segregation.

Figure – ground segregation is a basic component of the perception of haptic pictures, but has not been studied in blind adults. Witkin et al (1968) studied the haptic embedded-figures test in blind children, and Huckabee and Ferrell tested blind adolescents on the

Gottschaldt figures, but compared them with older college students (Huckabee and Ferrell 1971). Huckabee and Ferrell provided no information about the prior visual history of their six blind subjects, and it is not known if any of them were congenitally blind. Field-dependence has been assumed by some researchers to reflect reliance on visual information, but this could not be the case for congenitally blind persons and a haptic version of the task. Understanding of the phenomenal vertical has been assumed to be dependent upon vision, but blind subjects were less affected by postural tilt than blindfolded sighted subjects when judging the vertical (Bitterman and Worchel 1958). Furthermore, Heller et al (1996a) reported that congenitally blind subjects were more accurate than the blindfolded sighted participants at matching raised-line pictures to a vertical panel.

It is important to note that early studies in this area (eg Axelrod and Cohen 1961) used balsa wood glued to plywood or plastic for the creation of stimuli. None of the early studies used raised-line drawings, and so these earlier studies were restricted to relatively simple forms and backgrounds. For example, Huckabee and Ferrell (1971) constructed stimuli from 3 mm × 1.5 mm balsa, and this constrained the detail that could be represented. In the present experiments we used a raised-line material that permitted finer details, since narrower lines could be produced. However, it should be noted that line drawings do not make use of a variety of cues possible with mixed media, and this may increase the difficulty of locating a figure against a background. For example, texture has been shown to enhance the perception of haptic patterns (Thompson and Chronicle 2002). In addition, the earlier studies used versions of the Gottschaldt figures, and these are also different from the embedded-figures stimuli that were used in the present study.

Revesz (1950) argued that congenitally blind people were extremely limited in their understanding of form and space. Haptics, according to Revesz, is unable to understand interposition or covering, perspective and depth, or the cardinal orientations of the vertical or horizontal (but see Heller et al 2001; Holmes et al 1998). In addition, Revesz claimed that congenitally blind individuals would have difficulty relating parts to wholes, because of a few factors. He thought that the successive nature of touch would make it more difficult to get an overview of a complex display, and relate parts to wholes. In addition, Revesz believed that haptic perception of a whole is a cognitive achievement, and is not direct. He also claimed that blind people are only able to understand relatively simple forms, and are not interested in form. These stereotypical characterizations would lead one to a negative prognosis on the ability of congenitally blind persons to engage in perceptual selectivity. On the Revesz theoretical viewpoint, one might expect extremely low performance by congenitally blind persons on the haptic embedded-figures test.

Lederman and Klatzky (eg Lederman et al 1990) suggested that haptics is limited in its ability to interpret two-dimensional patterns, such as raised-line drawings. Thus, blindfolded sighted subjects report using visual imagery when feeling patterns. They further proposed that this visual mediation is needed for the interpretation of pictures, since haptics excels in the perception of solids. Solid forms possess the substance-related attributes that haptics does very well with, namely texture (see Heller 1989b), hardness, thermal properties, and so forth. An important line of data that supports this position derives from the finding that blindfolded sighted subjects may have difficulty naming unfamiliar tangible pictures (Lederman et al 1990), yet are able to name the identical solid objects (Klatzky et al 1993). However, naming failures may derive from lack of access to semantic memory and diminished familiarity, and may not reflect deficiencies in haptic pattern perception per se (Heller et al 1996b). For example, a young child may look at a cat and call it a "doggy". We would not then assume that this naming failure represented an inability to perceive the cat (Dretske 1990). Moreover, haptic picture matching accuracy was over 90% correct for blind subjects, and nearly perfect for very-low-vision subjects (Heller et al 2002a). High performance levels were also found when subjects searched for a haptic target picture among three choices (Heller et al 1996b).

Sighted and visually impaired subjects were exposed to raised-line drawings of embedded-figures stimuli adapted from the embedded-figures test (Ottman et al 1971). In experiment 1, we examined the tactile embedded-figures task in blindfolded sighted subjects. In experiment 2, we studied groups of congenitally blind, late-blind, very-low-vision, and blindfolded sighted adults. If visual experience were necessary for the development of figure – ground segregation and haptic perceptual selectivity, then one might expect lower performance by congenitally blind subjects in this task.

2 Experiment 1

The aim of this experiment was to test blindfolded sighted subjects on haptic embedded-figures performance. Independent groups of subjects had simple or complex backgrounds. Subjects felt a target stimulus and four choices. They were asked to select the picture choice that included the target and then trace its outline. Performance was expected to suffer for locating targets in the complex backgrounds.

2.1 *Method*

2.1.1 *Participants.* There were twenty-eight undergraduate subjects (sixteen females, twelve males), with fourteen subjects per group. Twenty-five of the participants were right handed, two were ambidextrous, and one was left handed.

2.1.2 *Stimuli.* The stimuli were raised-line drawings of modified versions of embedded-figures stimuli (see figure 1) taken from Ottman et al (1971). The drawings were produced with a Swedish raised-line drawing kit that yields durable, tangible lines. This kit is available from the Swedish Institute of Special Education (SIH Laromedel Solna, Gardsvagen 7, S-169 70 Solna). Visibility of the lines was reduced by drawing them without using ink. This yielded a colorless tangible line that was designed to be invisible for the very-low-vision subjects in experiment 2. The line is slightly brighter than the background, but was not visible to the very-low-vision participants. They all said that they could not see the 'colorless' lines, and had to be verbally guided to the pictures as they reached for them. The mean width of the targets was 6.5 cm, and the average height was 5.8 cm. The mean width of the simple backgrounds was 6.38 cm, and the mean height was 6.67 cm. The complex backgrounds were somewhat larger, with a mean width and height of 10.42 cm and 8.17 cm, respectively.

The target stimuli were identical for both groups of subjects, but one group had six simple backgrounds and another had six complex backgrounds. Note that some of the complex backgrounds were modifications of the ones that were visually normed by Ottman et al (1971), but others were merely enlargements. Some lines were deleted from the complex backgrounds B and F, since it was not possible to reproduce them exactly on the raised-line drawing paper.

Practice stimuli were used to explain the task. Four choice stimuli were placed closer to the subjects, flat on the table top at the body midline. The target stimulus was placed above the choices, at their middle (see figure 2). The targets were presented in a random sequence. On each trial, the choice stimuli consisted of the background that contained the correct target, and three other backgrounds that were randomly selected from the set of simple or complex backgrounds, as appropriate.

2.1.3 *Design and procedure.* Independent groups of subjects felt simple or complex backgrounds. Subjects were first given the practice stimulus (the triangle) and the practice background, and told that their task was to feel the target and find it in the background. They were told that the pattern corresponding to the target would

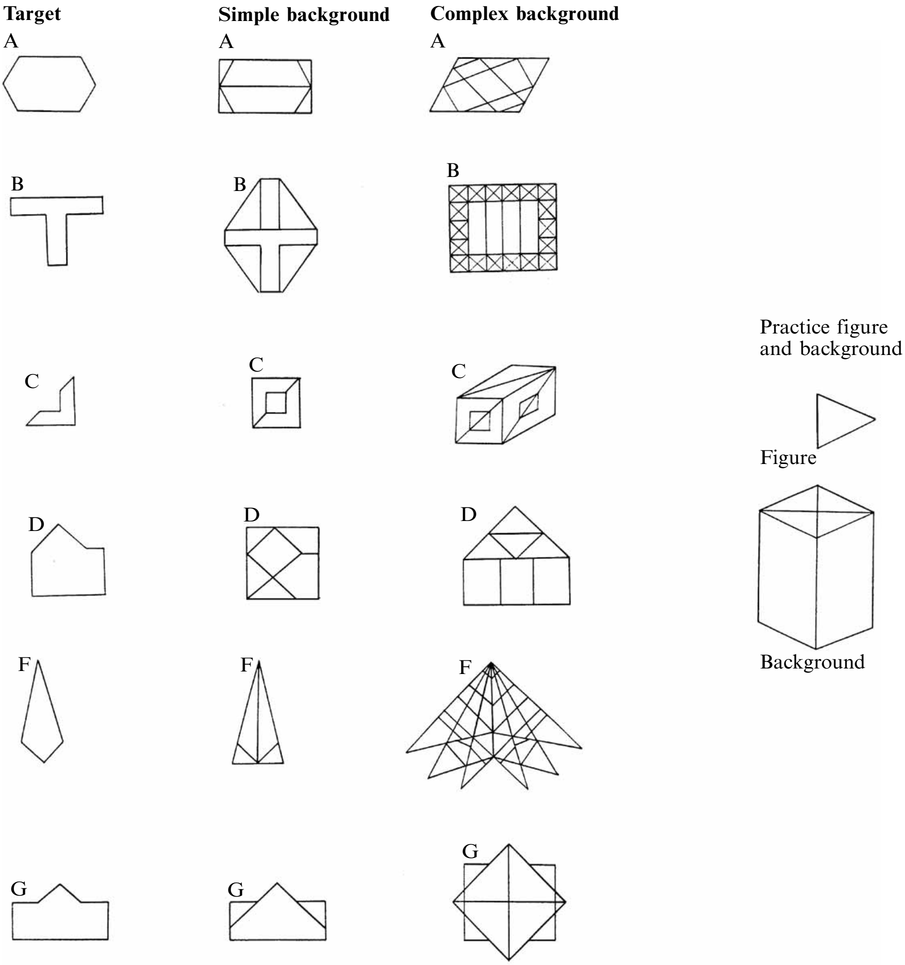


Figure 1. Target stimuli and simple and complex backgrounds. In addition, the practice figure is present on the right. The letters correspond to the labels of the target stimuli taken from the embedded-figures test (Ottman et al 1971).

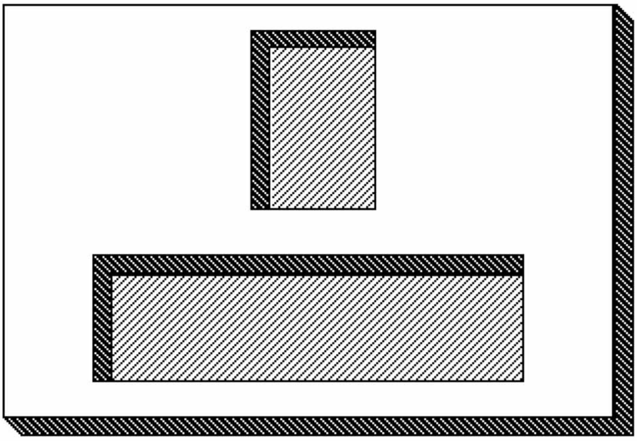


Figure 2. Framework used to hold the target and four background choices. The four choices were placed closer to the subjects in the horizontal rectangular recess. The target was inserted in the vertical hollow.

be the same size and position in the background. In addition, they were instructed that there were extra lines in the background that were designed to camouflage the target, and that they may need to ignore some lines to find the target stimulus. If a subject failed to find the target in the practice background, the experimenter took his/her preferred index finger and traced the target with it. This was done to show the subjects where the target was, and ensure that they understood the task.

The subjects were exposed to the six targets in random order. They were to feel the target and then feel the four picture choices. They were instructed to indicate which choice contained the target, but were to feel all four choices before making a decision. They were then told to attempt to trace the target within their selection. Thus, the subjects had to first select the correct background choice, if they were to succeed in correctly tracing the target. If they made an incorrect choice in the multiple-choice task, they could not be correct when attempting to trace the target in the chosen background. This procedure was adopted to avoid providing any negative or positive feedback, since pilot work indicated that the task was very difficult. Subjects were not given feedback of any sort by the experimenter.

The subjects were timed on the multiple-choice task. The time score reflected the time to feel the target, feel the four picture choices, and then indicate which background included the target. A stopwatch was used to time the subjects, from the instant that they touched the target until they made their choice. The subjects were told that they would be timed, but were to try for accuracy.

No constraints were provided on method of exploration, and subjects were permitted to use one or both hands, as they wished. In addition, they were allowed to go back and feel the target again, while examining the picture choices.

The multiple-choice task is a relatively crude measure of form perception and perceptual selectivity, since subjects could often base their judgments on an overall, generalized global estimate of shape or proportion (see Witkin et al 1968). Thus, target F is a "tall, narrow, and pointy" configuration. Subjects could select the correct background that contained this target by simply attending to these features of the stimulus. Tracing a target in a background requires a more precise understanding of the shape, and the tracing task demands the ability to ignore distracting lines that camouflage the configuration.

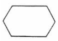
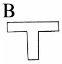
2.2 *Results and discussion*

Tables 1 and 2 summarize the results of the experiment, and show that subjects were more accurate with the simpler backgrounds, but only for the tracing response measure. Accuracy scores were low, the subjects were slow, and the task was very difficult. There was considerable variability across subjects in performance for the tracing response measure with complex backgrounds. While performance as measured by mean number correct, M, in the multiple-choice task was slightly better for the complex backgrounds ($M = 4.43$) than the simple ones ($M = 4.0$), a t-test showed that any difference between the means failed to reach significance ($t_{26} = 1.19$, $p > 0.20$). However, tracing yielded significantly lower performance for the complex backgrounds ($M = 1.14$ correct; $t_{26} = 2.17$, $p < 0.05$).

Table 1. Mean number correct (maximum possible score = 6) with standard deviations in parentheses in embedded-figures multiple-choice and trace tasks for blindfolded sighted subjects with simple and complex backgrounds (experiment 1).

Task	Background	
	simple	complex
X-choice	4.0 (1.04)	4.43 (0.85)
Trace form	2.29 (1.64)	1.14 (1.10)

Table 2. Mean response time in seconds (with standard deviation in parentheses) for tactile embedded figures for blindfolded sighted subjects (simple versus complex backgrounds).

Target figures	Background		Overall mean time per item
	simple	complex	
A 	142.12 (63.14)	207.94 (66.47)	175.03
B 	171.46 (78.25)	149.92 (79.29)	160.69
C 	159.02 (57.23)	197.96 (79.84)	178.49
D 	140.95 (68.01)	166.23 (107.98)	153.59
F 	109.94 (57.78)	154.74 (66.28)	132.34
G 	140.66 (55.59)	187.20 (94.40)	163.93

The time scores (in seconds) were analyzed with a 2 (background) × 6 (figure) analysis of variance (ANOVA). The main effect of background complexity was non-significant, as were all interactions (all ps > 0.10).

Further analysis revealed a significant effect of figure ($F_{5,103} = 2.38$, $p < 0.05$). A Newman–Keuls test indicated significantly faster performance for target F (see table 2).

The embedded-figures task was attempted visually by an additional twelve naïve subjects (eight females, four males). The visual task was run, since the stimuli were modified from the originals used by Ottman et al (1971). The aim was to gain an understanding of task difficulty in vision. The subjects viewed black ink drawings that were identical in size and layout to the stimuli of experiment 1. A repeated-measures design was used, and complexity of the stimuli was balanced. The only difference in methodology consisted of providing a separate drawing for target 'tracing', after selection of the background form. Thus, after each subject indicated which background contained the target, he/she was given a duplicate of this choice and asked to trace the target with a red pencil in the selected background.

Performance was extremely high, with a mean number correct in the multiple-choice task of 6.0 on the simple backgrounds, but the score for complex backgrounds was slightly lower at 5.92 correct. The effect of background complexity was highly significant ($F_{1,11} = 17.37$, $p < 0.01$). Tracing yielded a mean number correct of 5.92 for the simple backgrounds, and 4.0 for the complex backgrounds. This difference was also significant ($F_{1,11} = 37.54$, $p < 0.01$). A separate ANOVA on time scores showed that subjects were much faster with the simple backgrounds ($M = 3.31$ s) than the complex backgrounds ($M = 10.51$ s). Note that target A was extremely difficult when embedded in the complex background (see figure 1). Subjects were slower on this target than any of the others in the multiple-choice task ($M = 20.3$ s), but not for the simple backgrounds ($M = 1.6$ s). Performance was high for simple backgrounds, for both tasks. Vision was much faster than was found for sighted subjects using touch in experiment 1, and vision was also far more accurate.

3 Experiment 2

Experiment 2 was designed to study the possible effect of visual experience on performance in the haptic embedded-figures task. If visual experience were necessary for the development of skills in haptic perceptual selectivity, one would expect that the congenitally blind subjects would perform at a lower level than all of the other groups of participants. However, visually impaired individuals are more familiar than sighted persons with the use of touch for pattern perception. Their potentially increased levels of haptic skill could yield superior performance. This is especially likely for the groups of subjects with prior visual experience with pictures, namely the very-low-vision and late-blind subjects (see Heller 1989a).

3.1 *Method*

3.1.1 *Participants.* There were four groups of subjects, including congenitally blind (CB, $n = 8$), late-blind (LB, $n = 10$), very-low-vision (VLV, $n = 9$), and blindfolded sighted (BS, $n = 10$) participants. Table 3 summarizes the characteristics of the subjects.

Table 3. Characteristics of the blind subjects including gender, age, education, age of onset, cause of blindness, and presence of light perception.

Gender	Age/years	Education	Age of onset/years	Cause	Light perception
Congenitally blind					
M	47	MA	–	ROP	yes
F	38	JD	–	ROP	no
F	29	SC	–	ROP	no
F	55	HS	–	RP, nystagmus, other unknown causes	yes
F	31	JD	–	RP other unknown causes	yes
M	41	JD	–	ROP	no
M	47	SC	–	ROP	no
F	47	HS	–	ROP	yes
Late blind					
F	35	SC	7	detached retina	no
M	55	PhD	43	virus, trauma, glaucoma	no
M	32	SG	9	hydrocephalus	no
F	60	SC	2	optic nerve damage	no
F	44	SC	22	RP	yes
F	58	BA	8	retinal degeneration	yes
M	56	BA	2	retinal blastoma	no
M	57	MA	2–4	retinal blastoma	no
M	30	SC	15	glaucoma	no
F	52	HS	14	glaucoma	no
Very low vision					
F	39	MA	34	RP	yes
M	19	SC	birth	microophthalamus	yes (one eye)
F	42	SG	birth	ROP	yes (one eye)
F	23	SC	6	ROP	yes
F	27	MSW	4	ROP	yes
F	71	SC	20	retinal degeneration	yes
M	31	SC	8	hydrocephalus	yes
F	27	SC	birth	glaucoma	yes
F	54	HS	birth	ROP	yes

Note: F, female; M, male; ROP, retinopathy of prematurity; RP, retinitis pigmentosa; SC, some college; SG, some graduate school; BA, college degree; MA, Master of Arts degree; GED, high school equivalency diploma; HS, high school diploma; PhD, Doctor of Philosophy degree; JD, law degree; MSW, Master of Social Work degree.

The mean ages of the CB, LB, VLV, and BS subjects were 41.9, 47.9, 37, and 35.1 years, respectively. The BS subjects were similar in age to the VLV subjects, but slightly younger than the other visually impaired participants. Subjects were considered CB if they were blinded at birth, or during the first year of life. The LB subjects lost vision after the first year of life. The VLV participants considered themselves as 'blind', but all had light perception and could see the direction of strong light sources. A few were able to see close hand motion, given bright, high-contrast lighting. In addition, some of the VLV subjects could see very large forms, given high-intensity lighting. Thus, one VLV person could see the shape and location of a large 'picture window' when the sun was bright, but not on an overcast day. Low vision is a term that is often used to describe people who generally read with magnification. The VLV subjects in the present experiment, however, were braille readers.

3.1.2 *Stimuli and apparatus.* The materials were identical to those of the first experiment.

3.1.3 *Design and procedure.* The experiment was a between/within design, with the between-subjects factor being visual status (CB, LB, VLV, BS); the within-subjects factor was complexity of the background (simple versus complex). All subjects were exposed to the simple backgrounds first, since experiment 1 showed that the task was extremely difficult. While this design includes the possibility of learning effects modifying any interpretation of comparisons between the simple and complex backgrounds, it was identical for all groups of subjects. It was thought that starting half of the blind subjects with complex backgrounds, as in a balanced design, might prove too frustrating for the subjects. The major purpose of the study was to study the influence of visual experience, and this was still possible in the design that was adopted. In all other respects, the procedure was identical to that of experiment 1.

3.2 *Results and discussion*

Tables 4 and 5 summarize the results of this experiment, and show superior performance by the LB and VLV subjects. An ANOVA on number correct in the multiple-choice task showed a significant effect of visual status ($F_{3,33} = 5.58$, $p < 0.01$). However, the effect of background complexity failed to reach significance ($p = 0.09$), and the interaction effect was also non-significant ($F < 1$). A Newman–Keuls test indicated that the LB and VLV subjects performed significantly better than the BS and CB subjects ($p < 0.05$).

Table 4. Mean number correct (maximum possible score = 6 per type of background, and 12 overall) with standard deviation in parentheses in embedded-figures test for congenitally blind, late-blind, very-low-vision, and blindfolded sighted subjects with simple and complex backgrounds.

Task	Background		Overall
	simple	complex	
	Congenitally blind		
X-choice	3.8 (1.8)	3.5 (2.0)	7.3 (3.7)
Trace form	2.5 (1.7)	1.4 (1.6)	3.9 (3.1)
	Late blind		
X-choice	5.0 (0.9)	5.1 (0.9)	10.1 (1.6)
Trace form	4.5 (1.3)	2.7 (1.3)	7.2 (2.1)
	Very low vision		
X-choice	5.7 (0.7)	5.2 (1.3)	10.9 (1.5)
Trace form	4.9 (1.3)	3.6 (2.1)	8.4 (3.1)
	Blindfolded sighted		
X-choice	4.7 (0.9)	3.8 (0.9)	8.5 (1.0)
Trace form	2.9 (1.4)	1.0 (0.8)	3.9 (1.8)

Table 5. Mean response time in seconds as a function of visual status, target, and background complexity (with standard deviations in parentheses).

Target (see figure 1)	Background		Overall
	simple	complex	
	Congenitally blind		
A	70.33 (50.33)	94.36 (50.11)	82.34 (48.95)
B	62.89 (53.98)	85.40 (72.61)	74.14 (61.52)
C	71.65 (53.06)	100.15 (60.43)	85.90 (38.82)
D	77.77 (51.78)	91.53 (58.10)	84.65 (48.85)
F	87.63 (106.42)	87.16 (52.47)	87.39 (72.13)
G	82.17 (46.82)	100.05 (75.07)	91.11 (58.35)
	Late blind		
A	55.55 (26.84)	154.23 (79.46)	104.89 (39.40)
B	57.47 (45.57)	91.07 (53.84)	74.27 (33.82)
C	104.53 (65.54)	111.44 (91.81)	107.98 (65.94)
D	69.11 (33.04)	122.22 (65.72)	95.66 (41.29)
F	48.53 (23.43)	108.68 (65.05)	78.60 (43.22)
G	51.99 (20.76)	73.56 (40.08)	62.77 (27.70)
	Very low vision		
A	43.41 (24.04)	111.30 (91.40)	77.36 (55.65)
B	38.01 (16.49)	77.40 (57.45)	57.71 (30.95)
C	67.42 (60.76)	103.53 (105.35)	85.48 (80.92)
D	48.78 (31.52)	113.33 (93.33)	81.06 (61.58)
F	42.45 (26.90)	81.35 (43.25)	61.90 (29.47)
G	84.19 (63.32)	95.18 (81.89)	89.68 (57.16)
	Blindfolded sighted		
A	149.35 (57.45)	219.53 (76.49)	184.44 (55.40)
B	185.97 (87.65)	156.36 (58.45)	171.16 (62.30)
C	171.74 (46.93)	195.57 (66.36)	183.66 (42.98)
D	150.10 (69.47)	150.42 (62.32)	150.26 (52.44)
F	113.37 (36.72)	145.54 (84.76)	129.46 (48.17)
G	148.92 (87.73)	155.02 (66.74)	151.97 (68.80)

The difference between the LB and VLV groups was non-significant, as was the comparison between the CB and BS subjects (both ps > 0.05). A second analysis on number of patterns traced correctly yielded similar results to that for the multiple-choice task. Again, the VLV and LB subjects had similar performance, and both were superior to the CB and BS subjects. However, the main effect of background complexity had a highly significant effect on tracing performance ($F_{1,33} = 45.28$, $p < 0.01$). Much lower performance occurred when subjects attempted to trace the targets in complex backgrounds.

A second ANOVA on time scores showed that the sighted subjects were significantly slower than the visually impaired subjects ($F_{3,33} = 8.7$, $p < 0.001$). A Newman–Keuls test confirmed that all groups of visually impaired subjects were significantly different from the BS subjects, and much faster than the sighted participants ($p < 0.05$), but did not differ from each other ($p > 0.05$). The main effect of background complexity was significant ($F_{1,33} = 28.1$, $p < 0.0001$), as was the main effect of figure ($F_{5,165} = 3.0$, $p < 0.05$). The interaction between visual status and figure failed to reach significance ($p > 0.05$), as did the interaction between visual status, background complexity, and figure ($F < 1$). However, the interaction between figure and background complexity was significant ($F_{5,165} = 2.9$, $p < 0.05$). Tests of the simple effect of the interaction between figure and background complexity showed that subjects were generally slower for the more complex backgrounds, but the difference was especially large for target pattern A. The simple effect of background complexity was non-significant for targets B and G (both ps > 0.14).

The similar accuracy scores of the CB and BS subjects indicate that visual experience is not necessary for haptic perceptual selectivity. In fact, the CB subjects were much faster than the BS subjects, and their tracing accuracy was comparable.

The high levels of performance by the VLV and LB subjects are noteworthy, and suggest that research on haptics with sighted subjects may often underestimate the capability of touch. These subjects achieved performance levels that approached vision, at least in terms of accuracy. Of course, haptic performance is much slower than visual form perception. However, the high levels of performance in this task by the VLV subjects was surprising, given the much lower levels in tracing accuracy shown by the blindfolded controls. The results are consistent with earlier research that showed superior performance by blind subjects over the sighted when experimental stimuli are equally familiar to both blind and sighted subjects (eg Heller 1989a; Heller and Kennedy 1990; Heller et al 1996a).

4 General discussion

The haptic embedded-figures test is difficult for blindfolded sighted subjects, and they performed at low accuracy levels, and very slowly in experiment 1. Experiment 2 showed that visual experience is not necessary for the development of perceptual selectivity, since the CB subjects performed as well as the blindfolded subjects. The CB subjects were as accurate as the BS subjects, but they were also much faster. The VLV and LB subjects showed very high levels of performance, that approached the accuracy levels found in vision. Of course, vision is much faster than touch.

The superiority of the LB and VLV subjects is probably due to the effects of experience with pictures combined with increased haptic skill levels (see Grant et al 2000; Sathian 2000). Familiarity and practice can improve performance with a task, and lack of familiarity can lower accuracy (Heller et al 1996b, 1999). It is not likely that the experience with pictures need have been specifically visual sensory experience, since the CB subjects were as accurate as the BS participants. Note that visual guidance of exploration can aid haptics in the sighted, and performance of naïve blindfolded sighted subjects may not be asymptotic (Heller et al 2002b). It is important that the blind subjects were twice as fast as the sighted subjects in experiment 2, and the LB and VLV subjects were much more accurate.

The present results are relevant to theories of haptics that assume deficiencies in that sense and in perception by blind people (eg Revesz 1950). Thus, Revesz argued that imagery and perception in blind people were very different from those of the sighted, and that haptics was deficient in the perception of form (but see Hollins 1985; Kennedy 1993, 1997; Millar 1994). The present results are clearly inconsistent with this theoretical viewpoint, and also with views that haptics is somehow not suited for the perception of two-dimensional configurations (Klatzky et al 1993; Lederman et al 1990).

One reviewer cogently pointed out that mental imagery could be considered visuospatial, and thus can include haptics. This sort of amodal imagery could be used by congenitally blind persons. CB individuals have been noted to use mental rotation, but it is not clear whether or not there are important differences between the imagery of sighted and blind people (see Cornoldi and Vecchi 2000).

The high levels of performance by the VLV subjects in tracing performance (60% correct for the complex stimuli) are not consistent with the idea that touch is deficient in the perception of raised-line pictures. Note that visual performance was very similar at 66.7% correct for tracing targets in complex backgrounds. Half of the subjects in the visual experiment had the complex backgrounds before the simpler ones. Logically, this compromises any comparison between the modalities, because of the possibility of learning and practice effects in haptics in experiment 2. However, there was no evidence of learning effects in the performance of the sighted subjects in experiment 2, since their scores were lower on the complex stimuli. In addition, the performance of the sighted subjects in experiment 2 was similar to that of the BS subjects in experiment 1, despite the difference in design. If anything, multiple-choice performance was lower in the sighted subjects in experiment 2, perhaps owing to fatigue effects. Theories that assume deficiencies in haptic perception of two-dimensional configurations would not predict the relatively high levels of performance shown by the LB and VLV subjects, since they had scores of 84.2%–90.1% correct in the haptic multiple-choice task. Nor would these theories expect similar accuracy for the modalities in the tracing task with complex backgrounds.

Of course, vision does hold some important advantages over touch. First, vision has better spatial acuity than touch. Also, touch is affected by scale (Millar 1994), and vision is certainly better able to obtain simultaneous pattern information from much larger arrays. Consequently visual information is less likely to place a burden on memory. The largest background in the present study was only about 15.5 cm × 11 cm (see complex background F in figure 1). Results might be very different for much larger configurations that exceed the span of one or two hands.

However, the superiority of vision for simultaneous perception of an array can sometimes represent a liability. Thus, target A is difficult to see in the complex background, mainly because of the interfering effect of the surround. Similarly, using touch, BS subjects tended to trace the outside contours of the complex background, and were distracted by the outside corners. Conceivably they applied the principle of good continuation in vision to their haptic exploration, and sought a global appreciation of the overall configuration. A few blind subjects did not have this sort of difficulty with location target A in the background, perhaps because of the sequential nature of haptic exploration. Thus, difficulty in obtaining an overview of a larger configuration may not be a handicap, when components of the larger configuration are likely to camouflage the target. This may be the case for the corners of the complex background (bottom left, and top right). The failure to simultaneously perceive these corners may have helped some blind subjects when they searched for target stimulus A. Therefore, simultaneous perception of the entire background may sometimes lead to increased task difficulty for vision, as opposed to touch. This may occur when the background includes distracting lines that may obscure a target. Note that the distracting effects of interior lines can camouflage targets in other cases, such as in target F (see figure 1).

Research with BS individuals underestimates the capability of the sense of touch. These individuals are less familiar with the use of touch for pattern perception, and may not perform as well as the blind when familiarity is controlled for. Tracing scores were twice as high in the VLV subjects compared with the BS participants. In addition, blind subjects may not adopt the same methods for feeling stimuli as the sighted. Some of the sighted subjects in the research reported here opted to feel both the targets and the choices with one hand. This is a normal strategy for sighted individuals (Symmons and Green 2000), but will slow haptic exploration. Sighted subjects often spontaneously explore tangible pictures with the index finger of one hand. None of the visually impaired subjects in this study used one hand to feel the targets and choices. They all used the two index fingers, or multiple fingers of two hands. Thus, information that is gathered from sighted subjects may differ from that of the blind. The possibility of such differences should be considered in the planning of studies on haptics, and in the interpretation of the results of these studies. They certainly question any attempt to engage in simple generalizations from studies of perception in the sighted directly to blind persons.

The performance of the LB subjects was similar to that of the VLV subjects. One possible explanation for this similar outcome could derive from the late-onset loss of sight for many of the subjects in the VLV group. Nonetheless, it is likely that their performance advantages derived from prior experience with the use of touch for pattern perception, and consequent increased levels of haptic skill.

Past research in this area has used very vague terminology, and equally unclear theories. Notions like global and articulated, field dependence versus independence, and whole versus part perception are often used too loosely. Thus, field dependence was described as an excessive reliance upon a visual background. This particular reliance upon vision would not be relevant to the present study, and it could be a difficult construct to operationalize. Certainly, these vague terms and ideas should be questioned and examined critically.

There is a need for further study of factors that influence perceptual selectivity. For example, it is possible that the method of exploration could influence perceptual selectivity, as could a number of important stimulus characteristics. Perhaps BS subjects would show enhanced performance with instructions and training in the use of bimanual exploration methods. These variables will be the subject of forthcoming research in this area.

Acknowledgments. Preparation of this report and the research were supported by NIH Grant RO1-EY 12040. Faith Heller provided helpful comments on an earlier version of this manuscript.

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ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

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VOLUME 32 2003

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