How Attention Is Allocated When Using Haptic Touch: Shape Feature Distinction and Discrimination Strategy

Torø Graven(✉)

Department of Experimental Psychology, University of Oxford,
9 South Parks Road, Oxford OX1 3UD, England
`toro.graven@psy.ox.ac.uk`

Abstract. This study investigated how attention is allocated by the physical distinction between tactile 2D shape features: Part 1 tested whether certain shape feature distinctions are perceived efficiently (pre-attentively), as opposed to inefficiently (attention dependent). Part 2 explored what discrimination strategies are at use, and with what level of attention (from pre to focused).

It was found (Part 1) that the straight line ↔ angle distinction and the curve ↔ straight line distinction are perceived pre-attentively; the angle ↔ curve distinction attention dependent. Furthermore (Part 2), three discrimination strategies were identified: The figure identity strategy has three levels of attention; it ranks a feature conjunction as the most important target-discriminating feature. The global characteristics strategy and the touch vision strategy have two levels of attention; both rank one separate feature as the most important target-discriminating feature. Despite this, they are equally fast, accurate, and after-decision certain.

Keywords: Attention · Blind · Discrimination strategy · Haptic touch · Shape feature distinction

1 Introduction

Pictures, at least symbols and illustrations, embrace the conventional shape of certain phenomena [1], i.e., the configuration of angles, curves and straight lines. Previous research has found that individuals who are blind recognize tactile pictures of common objects [2, 3] but their recognition fails when the pictured object has to be named [4, 5]. Heller and Gentaz's [2] explanation is that naming requires several cognitive skills, such as perception, categorization, and language. Failure may arise during any of these processes, not only at the recognition stage. Pathak and Pring [5] offer another explanation: all attention is focused on the perceptible features of the pictured object to the exclusion of retrieving the object name. According to Lavie and Cox [6] (cf. also Lavie [7]), sighted individuals cannot reduce the amount of attention paid to visual features – perception is an automatic process: clear physical distinction between the features helps allocate their attention. Currently little is known about the physical distinction and allocation of attention when perceiving tactile 2D shape features, e.g. angles amid curves.

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Haptic touch perceives information serially [8, 9]. Numerous finger pad-sized pieces of information are perceived and linked together in order to recognize, e.g. the picture of some scissors [10] – and with a high quantity of perceived information, perceptual load soon occurs [11]: Selective attention is needed for the perceptual process to proceed [12. Cf. also 13]. Then again, Treisman and Gelade [14] found that certain (visual) features pop out; are perceived automatically – bearing little, or no perceptual load: Popped out features are processed pre-attentively, before selective attention kicks in.

In fact, Treisman [15] suggested a continuum of attention, from pre-attention at one end to focused attention at the other: Pre-attention processes information perceived in parallel about one separate feature [e.g. color (red vs. green)], independent of attention and fast – it calls upon attention. Focused attention, in contrast, processes information perceived serially about feature conjunctions [e.g. color (red vs. green) and orientation (horizontal vs. vertical) [14–17]]. Constant focusing of attention results in attentional load – the information processing system shuts down: Reset only by a feature pop-out [15, 16].

Considering that, haptic touch perceives information serially and that only information perceived in parallel pops out, is pop out not possible by nature when using haptic touch? If this were the case – that pop out is restricted or even impossible –, then individuals who are blind would suffer from constant attentional load. Surely, previous research has found pop out of (tactile) coldness, edges, movement, roughness, surface contour, and vertices, using tasks in which the participants had to search for, e.g. a vertex-target amid sphere-distractors [18–22]. However, none of this research was conducted with 2D shape feature distinctions: The shape features were presented either in 3D objects or in isolation, nor did it include participants with an actual blindness – the most experienced in using haptic touch [23] –, and haptic touch itself was restrained. Experienced participants with no restrains on haptic touch would have used their skills automatically, automaticity possibly reducing any load put on attention [17].

Moreover, Treisman and Paterson [24] suggested that (sighted) individuals may adopt different, even personal, strategies for ranking (visual) target-discriminating features in order of importance – separate features are processed in pre-attention, feature conjunctions in focused attention [14–17]. Graven [25], therefore, investigated how individuals who are blind describe discriminating braille characters, including ranking target-discriminating features in importance – their discrimination strategy[1]. In short, the global characteristics strategy ranks one separate feature (dot location or shape property) as the most important target-discriminating feature, the figure identity strategy a feature conjunction (dot location and dot quantity); the global characteristics strategy lies on the pre-attention end and the figure identity strategy on the focused attention-end of Treisman's [15] continuum of attention [25]. A touch vision strategy was also identified; yet not how it ranks target-discriminating features in order of importance, thus not where it lies on Treisman's [15] continuum of attention [25].

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[1] "(…) organized, domain-specific, nonobligatory pattern of decisions activated when confronted with (…) problems, and goal directed to attain the solution of the problem" [26, p. 12].

The aim of this study was to go beyond the braille characters and investigate how attention is allocated by the physical distinction between tactile 2D shape features: Part 1 tested whether certain shape feature distinctions are perceived efficiently (pre-attentively), as opposed to inefficiently (attention dependent). Part 2 explored what discrimination strategies (see footnote 1) are at use, and with what level of attention (from pre to focused).

2 Method

2.1 Design

Part 1 was designed as a one-sample experiment, with three conditions of shape feature distinctions: (1) straight line ↔ angle, (2) angle ↔ curve, and (3) curve ↔ straight line[2]. Each experimental condition included two types of trials, with either shape feature serving as the target and the other as the distractors (cf. Table 1).

Part 2 was a mixed design (see footnote 2): Qualitative (think-aloud [28]) data were collected to explore how people describe discriminating, including ranking shape features in order of importance – their discrimination strategy (see footnote 1); quantitative data to examine further on which end of Treisman's [15] continuum of attention each discrimination strategy lies.

2.2 Participants

Nine males and nine females, mean age 48.4 years participated[3]. All were blinded before four months of age: ICD-10 categories 5 and 4; including (cat. 5) total blindness and (cat. 4) light perception, light projection and minimal color perception [27], thus were not influenced; positively or negatively, by previous or current visual shape feature experiences [30, 31]. These individuals participated in Part 1 and Part 2: N = 18.

Because Graven [25] identified a separate discrimination strategy among those who have had, or were still having visual shape feature experiences, seven more individuals participated in Part 2: Two males and five females, mean age 40.4 years (see footnote 3). Three were blinded (ICD-10, cat. 5 and 4) between four and 12 months of age, one was totally blinded less than 25 months before this study, and three were congenitally blinded, ICD-10, category 3; two of whom had light perception in one eye until 10 and 28 years old, now totally blinded in this eye and in both eyes, respectively [27]. N (including Part 1) = 25.

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[2] A pilot study, with one congenitally and two early blinded females (see footnote 3) [27], assessed the number of trials; the shape feature distinctions (e.g. size); the a priori themes [29] used for scoring Part 2.

[3] They had no cognitive delay or impairment, and no physical disability. They had never before explored the Moon characters (see footnote 4). They were offered a remuneration to compensate for their time.

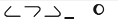
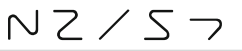
2.3 Test Materials

Thirty shape feature distinctions were used, ten in each experimental condition, i.e., one per trial. Each shape feature distinction comprised five Moon characters[4], one per shape feature. The five shape features were situated next to each other in a horizontal line; (1) making it possible to explore them simultaneously with the fingers of one hand [8, 9, 14–17], and (2) minimizing the time spent on locating them (cf. Fig. 1).

The shape feature distinctions followed either one or both of two criteria: (a) Two or more shape features had to resemble a global shape [33–35]. Example: (Table 1) Trial 1; shape features 2 + 3 = square, or Trial 29; shape features 1 + 2 = circle. (b) The target/target lines had to be oriented in the same direction as two or more distractors/distractor lines. Example: (Table 1) Trial 4; both target-angle and distractor-curves on the left (shape features 1, 2, 3, and 5), or Trial 3; diagonal left-to-right and right-to-left lines in angle-target and straight line-distractors (shape features 1, 2, and 3).

Printing size was 24 pt; printed on off-white swell paper. All shape feature distinctions were glued, separately, on foam board: 5 mm thick; 130 mm long; 50 mm wide, and presented in the middle of a blue silicone mat [385 × 275 mm (cf. Fig. 1)].

Table 1. Shape feature distinctions: some examples

Trial	Experimental condition	Shape feature distinction (TARGET and distractors)
1	(1) straight line ↔ angle	 angle, angle, angle, STRAIGHT LINE, angle
3	(1) straight line ↔ angle	 straight line, ANGLE, straight line, straight line, straight line
4	(2) angle ↔ curve	 curve, curve, curve, curve, ANGLE
6	(3) curve ↔ straight line	 STRAIGHT LINE, curve, curve, curve, curve
11	(2) angle ↔ curve	 angle, CURVE, angle, angle, angle
12	(3) curve ↔ straight line	 straight line, straight line, straight line, CURVE, straight line
13	(3) curve ↔ straight line	 curve, curve, curve, STRAIGHT LINE, curve
15	(1) straight line ↔ angle	 angle, angle, angle, angle, STRAIGHT LINE
16	(2) angle ↔ curve	 curve, ANGLE, curve, curve, curve
17	(2) angle ↔ curve	 angle, angle, CURVE, angle, angle
18	(3) curve ↔ straight line	 curve, curve, STRAIGHT LINE, curve, curve
19	(1) straight line ↔ angle	 straight line, straight line, straight line, ANGLE, straight line
24	(2) angle ↔ curve	 curve, curve, curve, ANGLE, curve
29	(2) angle ↔ curve	 curve, curve, ANGLE, curve, curve

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[4] Moon were invented in 1845, to allow reading by haptic touch: Straight lines and curves form nine basic shapes, rotated to create the 26 letters of the English alphabet ([32]. Cf. Table 1, e.g. Trial 1: shape features 1, 2, 3 and 5 = Moon "m", "l", "y" and "e", respectively). The Moon "h", "n", "o", "z", "8", and the contraction for "and" all comprise more than one shape feature; however always a curve, thus were included in the test material (cf. Table 1, e.g. Trial 18).

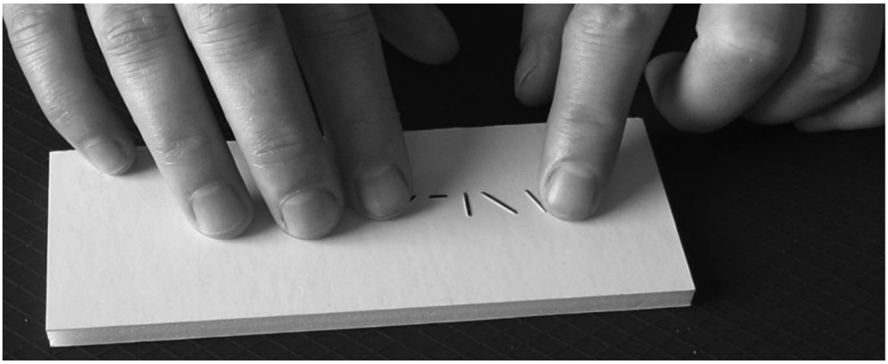

Fig. 1. Test material

2.4 Procedure

The three experimental conditions (and their two types of trials) were presented in random order and the (30) trials were counterbalanced across participants[5].

First, the participant had to make a fist with both hands, to prevent them from taking a peek at the shape features. Guided by the experimenter, the participant had to place both fists in the middle of the test material: the experimenter's hand was on top of the participant's fists. At this point, the participant was asked to explore the shape features: to start when the experimenter's hand was removed and to stop by tapping on the detected target. The participant was not told how many shape features there were in each shape feature distinction, or whether their detected target was correct.

- Task 1: To detect the target, fast and accurately.
- Task 2: To rate own after-decision certainty [36],
- Task 3: To describe what had unified the distractors [28, 37] – how the target was discriminated from the distractors.

In Task 3, the experimenter mirrored back to the participant the essence of what they had thought-aloud; allowing them to correct what was being scored; clarify, add comments and give examples. Part 1 included Tasks 1 and 2; Part 2 included Task 3.

2.5 Scoring

- (Part 1) Task 1: (a) Exploration time and (b) accuracy, i.e., number of (a) seconds from when the experimenter's hand was removed from the participant's fists to when the participant tapped on detected target, and (b) correct target detections.

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[5] The experiment took place in a quiet room, neutral in color. Distinct light sources, e.g. a specific lamp, were removed to minimize possible visual distractions; the general lighting of the room was lowered to minimize the color contrast between the (off-white) shape feature distinctions and the (blue) silicone mat. Before testing, the experimenter explained both the silicone mat – that it prevented the shape feature distinctions from moving around on the table – and the test itself. The test material was presented directly in front of the participant.

- (Part 1) Task 2: After-decision certainty, i.e. 1 ‘Not at all sure’; 2 ‘Unsure’; 3 ‘Not very sure’; 4 ‘Fairly sure’; 5 ‘Sure’; 6 ‘Very sure’ and 7 ‘100 % sure’.
- (Part 2) Task 3 was scored in two steps. In step one, the participant’s thinking-aloud [28] was coded as one of 17 a priori themes [29]; all anchored in Treisman’s work [13] and the characteristics of braille [38], and added to by the data from the pilot study (see footnote 2). These a priori themes included the shape features themselves, i.e. angle, curve and straight line, plus the orientation and quantity of these, “angled-curve”, “curved-angle”, “gap”, “orientation of gaps”, “quantity of gaps”, “global shape”, “no unifying feature”, and “other things – which?” (cf. Table 2, Code/Themes 01–17). In step two, the participant’s clarifications, added comments and/or examples were written down (in exact wording) in a think-aloud protocol [28].

Table 2. Structure of qualitative data analysis: code → theme → combined themes + rich data = templates.

Code	Themes	Combined themes			R	
01	Angle	Named shape feature: codes 01, 04 and 07	“Deductive” name	“Inductive” name	I	
02	Orientation of angles	Orientation of named shape feature: codes 02, 05 and 08			C	
03	Quantity of angles	Quantity of named shape feature: codes 03, 06 and 09			H	
04	Curve	Named shape feature: codes 01, 04 and 07	“Deductive” name	“Inductive” name		
05	Orientation of curves	Orientation of named shape feature: codes 02, 05 and 08				
06	Quantity of curves	Quantity of named shape feature: codes 03, 06 and 09				
07	Straight line	Named shape feature: codes 01, 04 and 07	“Deductive” name	“Inductive” name		
08	Orientation of straight lines	Orientation of named shape feature: codes 02, 05 and 08				
09	Quantity of straight lines	Quantity of named shape feature: codes 03, 06 and 09				
10	“Angled-curve”	Deleted				**T**
11	“Curved-angle”					**E**
12	Gap					**M**
13	Orientation of gaps					**P**
14	Quantity of gaps					**L**
15	Global shape	Global shape – unnamed (global shape) feature				**A**
16	No unifying feature	No unifying feature				**T**
17	Other things – which	Deleted				**E**
18	Different angle openings	Different angle opening	Spatial relations of named shape features			**S**
19	More open angles					
20	More pointed/sharp angles					
21	More open curves	Different curve opening				
22	More pointed/sharp curves					
23	Bent lines	Bent lines				
24	Continuous lines	Continuous lines				
25	Length of lines	Size: codes 25 and 28			D	
26	Orientation of features	Orientation of unnamed shape features			A	
27	Quantity of features	Quantity of unnamed shape features			T	
28	Size	Size: codes 25 and 28			A	

2.6 Analysis

Part 1 was analyzed in three separate (repeated measures) ANOVA tests: (Task 1a) exploration time, (Task 1b) accuracy, and (Task 2) after-decision certainty; to test whether certain shape feature distinctions are perceived efficiently (pre-attentively), as opposed to inefficiently (attention dependent).

Part 2 (Task 3) was approached by Template Analysis [29, 39]: Step one was (a) to read, and (b) to reread the think-aloud protocols. In step two, eleven new themes were discovered: different angle openings, more open angles, more pointed/sharp angles, more open curves, more pointed/sharp curves, bent lines, continuous lines, length of lines, orientation of features, quantity of features, and size (cf. Table 2, Codes/Themes 18–28). Step three was to merge related themes, e.g. different angle openings, more open angles and more pointed/sharp angles into "different angle opening", and delete redundant ones; e.g. those concerning gaps (cf. Table 2, Combined themes). In step four, the think-aloud protocols were read through again, pursuing clarifications, added comments and examples, i.e. rich data. At last, the coded themes and the rich data were unified to identify templates of how people describe discriminating tactile shape features, including ranking them in order of importance – their discrimination strategy.

All (25) participants were assigned to one of the identified discrimination strategies (see footnote 1), based on the quantity of coded themes under each template (i.e. min. 50 %). Finally, the quantitative data were analyzed, using parametric statistics, to examine further on what end of Treisman's [15] continuum of attention each discrimination strategy lies.

3 Results

3.1 Part 1: Efficiency/Inefficiency in Perceiving Shape Feature Distinctions

There was a significant difference in mean exploration time between experimental condition 1 (M = 14.7, SD = 8.60), experimental condition 2 (M = 31.7, SD = 20.43), and experimental condition 3 (M = 16.5, SD = 10.61): F(1.125, 19.131)[6] = 27.5, $p = 0.000$, N = 18. Post hoc tests using the Bonferroni correction revealed that experimental conditions 1 and 3 elicited less exploration time than experimental condition 2: $p_{\text{ec1/ec2}} = 0.000$; $p_{\text{ec3/ec2}} = 0.000$; $p_{\text{ec1/ec3}} = 0.183$. The straight line ↔ angle distinction and the curve ↔ straight line distinction are both perceived efficiently (pre-attentively) compared to the angle ↔ curve distinction, which is perceived inefficiently (attention dependent): Did in fact the focused attention required to detect the target in the angle ↔ curve distinction result in attentional load?

Indeed it did: experimental condition 1 (M = 8.9, SD = 1.31), experimental condition 2 (M = 3.4, SD = 1.54) and experimental condition 3 (M = 8.9, SD = 1.11): F(2, 34) = 115.96, $p = 0.000$, N = 18. Post hoc tests using the Bonferroni

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[6] Mauchly's test indicated that the assumption of sphericity had been violated: $\chi^2_{\text{explorationtime}}(2) = 24.0, p = 0.000\,(\varepsilon = 0.56)$ and $\chi^2_{\text{after-decisioncertainty}}(2) = 12.6, p = 0.002\,(\varepsilon = 0.65)$, thus the degrees of freedom were corrected using Greenhouse-Geisser estimate of sphericity.

correction revealed that experimental condition 2 elicited lower accuracy than experimental conditions 1 and 3: $p_{ec2/ec1}$ = 0.000; $p_{ec2/ec3}$ = 0.000; $p_{ec1/ec3}$ = 1.000. The mean accuracy for the straight line ↔ angle distinction and the curve ↔ straight line distinction was well above 85%; for the angle ↔ curve distinction, it was less than 35% – barely above chance.

So, did the participants know that their information processing system was shutting down in the angle ↔ curve distinction? There was a significant difference also in mean after-decision certainty, i.e. experimental condition 1 (M = 6.9, SD = 0.21), experimental condition 2 (M = 6.3, SD = 0.55) and experimental condition 3 (M = 6.9, SD = 0.21): F(1.295, 22.021) (see footnote 6) = 20.412, p = 0.000, N = 18. Post hoc tests, using the Bonferroni correction, revealed that experimental condition 2 elicited lower after-decision certainty than experimental conditions 1 and 3: $p_{ec2/ec1}$ = 0.000; $p_{ec2/ec3}$ = 0.002; $p_{ec1/ec3}$ = 1.000. The after-decision certainty was the lowest when the exploration time was the longest and the accuracy the lowest – they certainly did know that their information processing system was shutting down in the angle ↔ curve distinction.

3.2 Part 2: Discrimination Strategies

Line Analysis → "Inducting" Shape Feature Name. Six males and seven females (mean age 47.4 years) described treating the shape features as lines; in fact counting up the quantity of lines. They clarified that: "An angle has two lines"; "When the shape has more than two lines, then it is a curve; not an angle". Having analyzed line quantity, the shape feature-distractors were then named in (186 of 282) 66.0% of all correct target detections [cf. Table 1, e.g. Trial 11 (angle ↔ CURVE distinction); Table 2].

Merely the quantity of lines was reported in 28.4% of all correct target detections, e.g.: [Trials 6 (curve ↔ STRAIGHT LINE distinction) and 15 (STRAIGHT LINE ↔ angle distinction)] "They have more than one line", and [Trial 12 (CURVE ↔ straight line distinction)] "They have less than three lines". Four participants then counted up the quantity of named angles and/or curves; in target and distractors [see e.g. Trials 13 (curve ↔ STRAIGHT LINE distinction) and 17 (angle ↔ CURVE distinction)][7]. See Tables 1 and 2.

In 5.6% of all correct target detections, orientation of features were reported – named [e.g. Trial 15 (STRAIGHT LINE ↔ angle distinction): "Direction of straight lines"] and unnamed [e.g. Trial 1 (STRAIGHT LINE ↔ angle distinction)], and further; size, e.g.: "Length of line", spatial relations of named features, e.g.: "Different angle opening", and "global shape" [e.g. Trials 4, 29 and 24, respectively (ANGLE ↔ curve distinction)]. In three cases the correct target was detected, but with "no unifying shape feature" for the distractors [e.g. in Trial 1 (STRAIGHT LINE ↔ angle distinction). Cf. Tables 1 and 2].

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[7] For an example of incorrect targeting, see Table 1, Trial 11 (angle ↔ CURVE distinction): "Three figures with two angles and two figures with one angle".

These 13 participants described an identical discrimination strategy, including three levels of attention: *Figure identity*. Level 1: Specific analysis of the line quantity in each shape feature. Level 2: Recognizing and naming the shape features, according to a set of rules. In levels one and two, the ranking of features in order of importance depends on different, even personal, strategy (not on target and distractors): a feature conjunction [i.e. line quantity and ("inducted") shape feature name] is ranked as the most important. Level 3 (if necessary): Analyzing the quantity of named angles and curves in each shape feature. (See Table 3).

Noticing Global Shape → "Deducting" Shape Feature Name. Five males and five females (mean age 46.4 years described treating the shape features as global shapes; one participant clarifying that: "I search for the differences in the global shape: I don't think of them as angles or curves". These participants added comments such as: [Trial 13 (curve ↔ STRAIGHT LINE distinction)] "The others are 'zigzags'", [Trial 16 (ANGLE ↔ curve distinction)] "The others have one short and one long", and [Trial 19 (straight line ↔ ANGLE distinction)] "The others have nothing in another direction" (cf. Table 1). They reported "global shape" in (15 of 216) 6.9% of all correct target detections.

These participants found it necessary to analyse – "break down", in their own words – the global shape in 93.1% of all correct target detections; as one participant clarified it: "When they have too many lines". One participant, for example, broke down "global shape" in Trial 11 [angle ↔ CURVE distinction. Cf. Table 1)]: "One and two are mirror 'thingies'; three and five are curves. (…) A 'thingy' is something messy or indefinable".

Having assessed the global shapes, the distractors were named in 60.7% of all correct target detections. Shape features were named and counted up in 31.8% [e.g. in Trial 18 (curve ↔ STRAIGHT LINE distinction): "The others have more than one straight line"]; named and oriented in 6.0% [e.g. in Trial 17 (angle ↔ CURVE distinction): "Different direction of the angles"]; named and related spatially in 1.5% [e.g. in Trial 4 (ANGLE ↔ curve distinction): "The others have a more open angle". Cf. Tables 1 and 2].

Also these ten participants described an identical discrimination strategy, including two levels of attention: *Global characteristics*. Level 1: Noticing differences in the global shape. Level 2 (if necessary): Specific analyses of the global shape difference(s). In level two, the ranking of features in order of importance depends on different, even personal, strategy (not on target and distractors): one separate feature [i.e. ("deducted") shape feature name] is ranked as the most important. (See Table 3).

Global Shape Association to Regular Print Letters → Analyzing Shape Features. Two females (mean age 37.5 years[8]) clarified that: "I treat them as global shapes". They then associated the global shapes to regular print letters, e.g.: "The regular print 'z' is a symbol for all global shapes that resemble the z" (cf. Table 1, e.g. Trials 4 [ANGLE ↔ curve distinction] and 18 [curve ↔ STRAIGHT LINE distinction]).

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[8] One was totally blinded about two years before this study and the other was congenitally blinded, with minimal visual shape perception in one eye and light perception in the other [27] until the age of 28; now totally blinded (for more than 20 years).

When an instant association between the global shape and a regular print letter did not occur, then these participants analyzed the global shape; in fact did so in all correct target detections – reporting ("deducted") shape feature name in (23 of 41) 56.1%; combining line quantity and ("inducted") shape feature name in 43.9%: "I recognize them because I count lines."

Indeed, these participants described a third discrimination strategy, including two levels of attention: *Touch vision.* Level 1: Noticing differences in the global shape and associating the global shapes to regular print letters. Level 2 (if necessary): Specific analyses of the global shape difference(s). In level two, the ranking of features in order of importance depends on different, even personal, strategy (not on target and distractors): one separate feature [i.e. ("deducted") shape feature name] is ranked as the most important. (See Table 3).

Table 3. Top three ranking of target-discriminating features

		One separate feature	Feature conjunction	
Global characteristics strategy	**1**	"Deducted" shape feature name		**1**
	2	Shape feature name		**2**
	3		(...) name + quantity	**3**
Touch vision strategy	**1**	"Deducted" shape feature name		**1**
	2		Line quantity + "inducted" (…) name	**2**
	3	Yet not clear what target-discriminating feature is ranked as no. 3		**3**
Figure identity strategy	**1**		Line quantity + "inducted" (…) name	**1**
	2	Line quantity		**2**
	3	Orientation of shape feature		**3**

Exploration Time, Accuracy, and After-Decision Certainty. Before the statistical analyses, one statistical outlier was identified in the figure identity strategy, with mean exploration time almost seven times above that of the others (174.0 vs. 26.0). Following Treisman's work [13], this participant's targeting accuracy should, therefore, be below that of the others; but this was not the case – it was in fact above (M = 24.0 vs. 21.5). This participant clarified, in the think-aloud protocol [28] that: "I'm comparing the trials. There must be a pattern of where it is situated", thus was omitted from all statistical analyses. Furthermore, because only two participants described the touch vision strategy, it would have no statistical power. Then again, the touch vision strategy shows clear similarities with the global characteristics strategy – two levels of attention, treating the shape features as global shapes, and ranking one separate feature [("deducted") shape feature name] as the most important target-discriminating feature (see Table 3). The touch vision strategy therefore joins forces with the global characteristics strategy.

There was no statistically significant difference between the figure identity strategy and the global characteristics/touch vision strategy: Mean exploration time was 26.0 (SD = 17.65. N = 12) and 20.9 (SD = 7.76. N = 12), respectively: t(15.101)[9] = 0.915, $p > 0.05$. Mean accuracy was 21.5 (SD = 1.93. N = 12) and 21.4, SD = 2.84. N = 12),

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[9] Leverne's Test for Equality of Variances = 0.013.

respectively: t(24) = 0.084, $p > 0.05$. Mean after-decision certainty was 6.8 (SD = 0.27. N = 12) and 6.6 (SD = 0.33. N = 12), respectively: t(24) = 1.127, $p > 0.05$.

4 Discussion

Part 1 found that the straight line ↔ angle distinction and the curve ↔ straight line distinction are both perceived efficiently (pre-attentively); the angle ↔ curve distinction inefficiently (attention dependent): There is a clear tactile physical distinction be-tween straight lines and angles, and between straight lines and curves; but not between angles and curves [cf. 6, 7]. Both the straight line ↔ angle distinction and the curve ↔ straight line distinction allocate attention to the pre-attention end of Treisman's [15] continuum of attention. When it comes to the angle ↔ curve distinction, however, selective attention is needed for the perceptual process to proceed [12, 13]: attention being allocated to the focused attention end of Treisman's [15] continuum of attention – in fact resulting in attentional load [16]. To this end, individuals are aware of any attentional load (at least when processing tactile 2D shape feature distinctions).

Part 2 identified three discrimination strategies, including with what level of attention they are used, i.e. the figure identity strategy, the global characteristics strategy, and the touch vision strategy. The first has three levels, the latter two have two levels of attention; the first ranks a feature conjunction [line quantity and ("inducted") shape feature name], the latter two rank one separate feature [("deducted") shape feature name] as the most important target-discriminating feature. Thus, the figure identity strategy should lie on the focused attention end of Treisman's [15] continuum of attention; both the global characteristics strategy and the touch vision strategy on the pre-attention end. However, there is no statistically significant difference between the discrimination strategies, i.e. on exploration time, accuracy, and after-decision certainty.

As both the straight line ↔ angle distinction and the curve ↔ straight line distinction allocate attention to the pre-attention end of Treisman's [15] continuum of attention, the straight line appears to stand out. Was haptic touch in fact scanning loosely over the angle ↔ curve distinction, in anticipation of a straight line to stand out, or even pop out – to call upon attention [17]? After all, "An angle has two lines" and "When the shape has more than two lines, then it is a curve; not an angle". Furthermore, did too many straight lines call upon attention, causing chaos in attention? If this were the case, then the angle ↔ curve distinction would be problematic because of chaos in attention (and not because of attentional load per se) [cf. 16].

Then again, the load must also have been heavier in the angle ↔ curve distinction than in the two straight line distinctions. Perceiving, e.g. 6 + 3 + 6 + 3 + 2 (=20[10]) lines put more load on perception, thus inevitably on attention than perceiving, e.g. 1 + 2 + 1 + 1 + 1 (=6 (see footnote 10)) lines [cf. Table 1, Trials 4 (ANGLE ↔ curve distinction) and 3 (straight line ↔ ANGLE distinction), respectively [11, 16]]. Moreover, the angle ↔ curve distinction could also have been problematic because of conjunction illusions and/or conjunction errors, in which the individuals fail to combine, e.g.

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[10] "An angle has two lines." "When the shape has more than two lines, then it is a curve (…)."

the quantity and orientation of straight lines into angles and curves [14, 16]. Alternatively, did the individuals rather prefer to keep the quantity of straight lines and the orientation of straight lines as two separate features; in order to reduce any load put on perception, and thus on attention [cf. 14, 40]?

The three discrimination strategies identified in this study are quite similar to those identified in Graven's [25] study, suggesting that they are specific to the individuals (and not the task). Indeed, both studies found that the ranking of features in order of importance depends on different, even personal strategy (not on target and distractors [cf. also 24]): The individuals' voluntary control over what is relevant and irrelevant information does not depend on braille character/shape feature distinction [cf. 6]. Angles and curves are treated as straight lines because the individuals do not alter, or are not capable of altering their ranking, e.g. of line quantity as the most important target-discriminating feature. More in this vein, did they not; or were they not capable of altering their discrimination strategy according to shape feature distinction? Although they are amongst the most experienced in using haptic touch [23], they were naive to the Moon characters; and, as such, may not yet have developed a repertoire of appropriate discrimination strategies [cf. 26, 41, 42]. In fact, Graven [41] found that braille readers often continue the discrimination task at hand with a failing discrimination strategy.

On the subject of developing appropriate discrimination strategies. Although the test materials were larger and the number of distractors was higher in Graven's [25] study than in this study[11], both the figure identity strategy and the global characteristics/touch vision strategy[12] were noticeably faster in Graven's [25] study[13]. On the one hand, this could be because the tactile physical distinction between braille characters is clearer than that between 2D shape features [cf. 6, 7]. On the other hand, it could be because individuals who are blind are more experienced in discriminating braille characters than 2D shape features – they have not yet developed an appropriate discrimination strategy for 2D shape features. Surely, with more experience comes more automatic use of achieved skills, automaticity possibly reducing any load put on attention [cf. 17].

Further research is indeed needed to investigate how and why discrimination strategies fail, and also to improve the proficiency in discriminating tactile 2D shape features. Surely mixing up angles and curves makes interpreting pictures, e.g. symbols and illustrations, problematic: the Euro symbol (€) may be mistaken for the capital E and the Pythagorean triangle may have no right angle.

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[11] 21 × 21 cm [25] vs. 13 × 5 cm; 11 distractors [25] vs. 4 distractors.

[12] The touch vision strategy was not included in Graven's [25] statistical analyses.

[13] The figure identity strategy used (M) 17.7s [25] vs. 26.0s, and the global characteristics/touch vision strategy (M) 14.3s [25] vs. 20.9s (see footnote 12).

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