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Shape-from-shading is independent of visual attention and may be a 'texton'

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Abstract—Shading was used to generate the appearance of an obliquely illuminated surface with spherical indentations and protrusions. The "pop-out" of an apparent indentation among numerous apparent protrusions served as a psychophysical assay for shape-from-shading. Detectability of the pop-out varied with the direction of apparent illumination, a finding which is characteristic for shape-from-shading and which demonstrated the appropriateness of this assay. Observers were able to concurrently detect two shape-from-shading pop-outs in different parts of the display, demonstrating that shape-from-shading is a parallel process. In another experiment, visual attention was engaged by a letter discrimination task. Nevertheless, observers were able to detect a shape-from-shading pop-out concurrently in the unattended part of the display, suggesting that shape-from-shading is independent of visual attention. Thus, shape-from-shading shares some of the characteristics of Julesz' textural stimulus dimensions ('textons').

INTRODUCTION

It has been known at least since the days of Pompeii that appropriate variations of light and dark can produce a compelling illusion of depth (e.g., De Franciscis, 1978). Scientific interest in this phenomenon, which has been called *shape-from-shading*, has a somewhat shorter history (Boring, 1948; Gibson, 1950). Although shape-from-shading can be affected by seemingly cognitive factors (Ramachandran, 1988), experiments using the paradigm of visual search have shown that shape-from-shading is processed in parallel across the visual field (Enns and Rensink, 1990, 1991; Kleffner and Ramachandran, 1992; Sun and Perona, 1993). These results place shape-from-shading at the side of textural features such as luminance, orientation, spatial frequency, and others (Julesz, 1981), which are also processed in parallel across the visual field (e.g., Bergen and Julesz, 1983; Sagi and Julesz, 1985; Malik and Perona, 1991; Nothdurft, 1991).

To further investigate the possibility that shape-from-shading is a textural feature, or 'texton' (Julesz, 1981), I conducted experiments with an alternative paradigm, namely, the method of concurrent tasks (Kahneman, 1973; Sperling and Melchner, 1978). In a concurrent task experiment, one task can be used to draw limited resources away from the other, making this the method of choice for demonstrating that a particular task does not draw on a particular resource. Over the past years, I have used such experiments to investigate the perception of textural borders (Braun and Sagi, 1990, 1991; Ben-Av *et al.*, 1992; Braun, 1993; Braun and Julesz, in preparation), and was able to show that tasks involving textural borders place no measurable demand on visual attention. Apparently, textural borders are an exceptional stimulus, since voluntary reports about other types of stimuli require a shift of visual attention

(Duncan, 1980, 1984; Treisman *et al.*, 1983; Treisman, 1993). A similar conclusion has been reached by Rock and collaborators (Rock *et al.*, 1992).

The experiments reported here were conceived as an extension of experiments reported previously (Braun and Sagi, 1991). Experimental design was identical, except that shading replaced orientation as the critical stimulus feature.

The analysis of concurrent task experiments involves complex theoretical issues which are beyond the scope of this report (e.g., Sperling and Dosher, 1986). In general, concurrent task experiments reveal conflicting claims on a limited resource, which can be visual attention, memory, encoding of responses, or some other resource. In any given experiment, the source of conflict can be identified by varying different aspects of the situation. For example, variations in the timing of stimulation, presence of distractors, or stimulus geometry should affect a conflict over visual attention, but not a conflict over memory or the encoding of responses. These issues are discussed more fully elsewhere (Braun and Julesz, in preparation).

METHODS

Observers

Three practised psychophysical observers participated, all with normal, or corrected-to-normal, visual acuity. One observer was the author (JB), but two others (SW, NA) were unaware of the purpose of the study.

Apparatus

Displays were generated on a Hitachi video monitor by an Adage 3106 raster display system and a Sun 3/140 workstation. The system generates a raster of 512 by 512 pixels by 8 bits, which is displayed at 55.5 Hz, or 18 ms per frame (non-interlaced). Viewing distance was 80 cm, viewing was binocular, and a headrest was not used. Mean luminance was 50 cd/m^2, with higher and lower luminance levels corrected to near linearity with a γ parameter of about 2.0. Display size was 20 by 20 deg.

Pattern elements

The stimulus was composed of discrete pattern elements of two types: Letter elements were T- or L-shaped and were rotated randomly. For letter elements, 40% luminance contrast was used. This contrast rendered letter elements more salient than shading elements (see below). If the relative salience of letter and shading elements had been reversed, substantially longer SOAs would have been required for letter discrimination. Shading elements produced a vivid illusion of depth, appearing to be obliquely illuminated, spherical surface elements. Their luminance distribution $I_{(\theta_n,\alpha_n,\theta_i,\alpha_i)}$ duplicated the reflectance pattern of an obliquely illuminated Lambertian sphere:

$$I_{(\theta_n,\alpha_n,\theta_i,\alpha_i)} = I_{\max} \cos\theta_n(\cos\theta_i \cos\theta_n + \sin\theta_i \sin\theta_n \cos(\alpha_n - \alpha_i)).$$

On the flat surface surrounding the sphere,

$$I_{(\theta_i)} = I_{\max} \cos\theta_i.$$

Here, $\theta_n, \alpha_n, \theta_i, \alpha_i$ are angles describing two unit vectors: the normal vector of a spherical surface element (θ_n, α_n), and the irradiance vector pointing from the surface

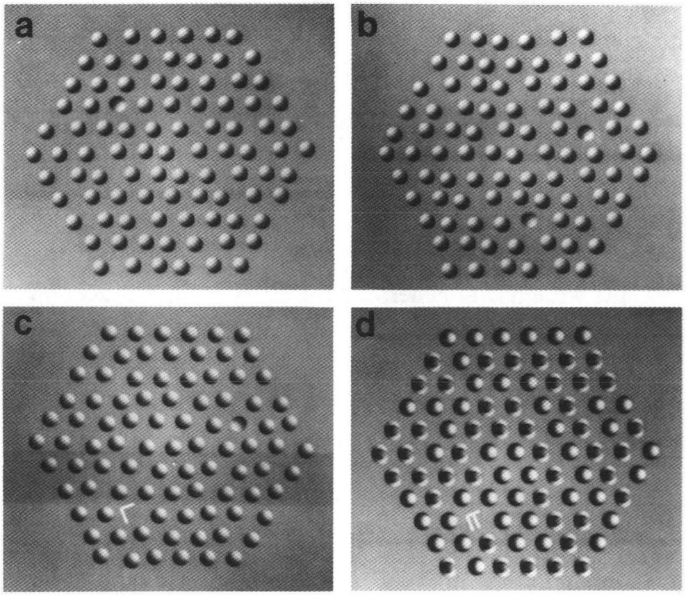

Figure 1. Stimulus and mask patterns: (a) stimulus pattern for high-shadow target localization; (b) top and bottom high-shadow target detection; (c) T/L discrimination and high-shadow target detection; and (d) mask pattern for (c).

element to the source of light (θ_i, α_i). Each vector is specified in a spherical coordinate system: θ is the angle formed with the line of sight, and α is the orientation of the projection onto a plane perpendicular to the line of sight. The line of sight is defined as a unit vector pointing from the surface element to the observer. $I_{\max}$ is the maximal intensity.

Four shading elements were used, with $\alpha_i = 45, 135, 225, 315$ deg, and $\theta_i = 60$ deg. Accordingly, the shaded region in these elements was situated in the lower left, lower right, upper right, and upper left of each element, respectively. For this reason, elements with $\alpha_i = 45$, 135 deg are sometimes referred to as 'high shadow' elements, and elements with $\alpha_i = 225$, 315 deg as 'low shadow' elements. In any given trial, the stimulus contained either elements with α_i equal to 45 and 225 deg, or with α_i equal to 135 and 315 deg. Using two sets of elements produced a more varied ensemble of stimulus patterns. The luminance contrast of shading elements was 30%.

Stimulus and mask patterns

Stimulus and mask patterns were composed of 91 pattern elements, spaced 1.4 deg apart in a hexagonal array. The entire array comprised a central element and five concentric shells of elements around it. In the stimulus, almost all elements were identical so that the array formed a relatively uniform background texture. In most experiments, the background consisted of 'low shadow' elements (Fig. 1a–c). Only in part of Experiment 1 was the background formed by 'high shadow' elements (turn Fig. 1a upside down). To introduce some variability in the background, elements were displaced randomly by up to 0.32 deg in both the vertical and horizontal direction.

Two types of target elements, dubbed 'shadow' and 'letter' targets, appeared in the third concentric shell of the array, at approximately 4.2 deg eccentricity. In those experiments with a 'low shadow' background, the target was of the 'high shadow' type ($\alpha_i = 45$ deg for background elements with $\alpha_i = 225$ deg, and $\alpha_i = 135$ deg for background elements with $\alpha_i = 315$ deg, Fig. 1a–c). In the experiment with a 'high shadow' background, the target was of the 'low shadow' type (Fig. 1a upside down). The 'letter target', used only in Experiment 3, exhibited the shape of T or L with equal probability (Fig. 1c).

For the mask pattern, different elements were used. To mask shading elements, two composite elements were newly generated for every trial. These composite elements contained one 'high' and one 'low shadow' element superimposed, each with a random offset of up to 0.32 deg in both the vertical and horizontal direction (Fig. 1d). Letter elements were masked by a ∏-shaped element which was randomly rotated (Fig. 1d).

Procedure

Observers were instructed to fixate a mark at the center of the display before initiating each trial. The trial sequence began with a blank interval (54–180 ms, chosen randomly for every trial), continued with the stimulus (36 ms), a second blank interval (36–144 ms, constant during each block of trials), and concluded with the mask (90 ms). The randomly variable blank interval at the beginning of the trial sequence prevented planned saccades, and the short presentation time of the stimulus prevented a second fixation. The interval between stimulus and mask onset (stimulus onset asynchrony, or SOA), ranged from 72 to 180 ms. The mask was assumed to limit visible persistence of the stimulus (Coltheart, 1980).

In parts of Experiments 2 and 3, observers judged only one attribute of the stimulus and ignored others. In this *single task* condition, observers produced one response after every trial and the resulting success rate was termed *separate performance*. In the remaining parts of Experiments 2 and 3, observers attempted to judge two attributes of the stimulus concurrently. In this *double task* condition, observers produced two responses after every trial and the resulting rates of success were termed *concurrent performances*. Note that single and double task situations employed identical stimulus ensembles. A mistaken response always elicited immediate auditory feedback.

Trials were performed in blocks of 50. Experimental sessions lasted between 1 and 2 hr and, during one session, observers performed several blocks of trials at one SOA, and then proceeded to another SOA, beginning with the highest and ending with the lowest SOA. In Experiment 1, alternating sessions were devoted to 'high' and 'low' shadow targets. In Experiments 2 and 3, alternating sessions were devoted to single and double task conditions. The three experiments were performed in the order reported (i.e., 1, 2, 3), sometimes separated by an interval of several weeks.

Statistics

Threshold SOA values were estimated fitting the psychometric function

$$P_{(t)} = 1 - \tfrac{1}{2}2^{-(t/T)^{\gamma}}$$

to each data set, where $P_{(t)}$ is performance, t is SOA, and T, γ are the parameters of the least-squares fit. The resulting values for γ (slope of the psychometric function) ranged from 2 to 5. The values for T (threshold SOA of the psychometric function) are listed in Tables 1–3. Confidence intervals for T were computed on the basis of γ and the average standard error of $P_{(t)}$.

RESULTS

Experiment 1: Replication of performance asymmetry observed by Kleffner and Ramachandran (1992)

In many search tasks, a performance asymmetry is observed when the roles of target and distractor elements are reversed (e.g., Treisman and Gormican, 1988). Several groups have reported search asymmetries in transient, masked displays (Gurnsey and Browse, 1987; Sagi and Julesz, 1987; Rubenstein and Sagi, 1990; Braun, 1993). Many, but not all, instances of search asymmetry are well understood in terms of signal detection theory (Malik and Perona, 1990; Rubenstein and Sagi, 1990). A peculiar type of asymmetry has been observed for search among targets and distractors which exhibit shape-from-shading: search for a 'high shadow' target among 'low shadow' distractors yields significantly shorter reaction times than the opposite, especially with naive subjects (Ramachandran, 1988; Enns and Rensink, 1990; Kleffner and Ramachandran, 1992). Apparently, 'high' and 'low shadows' generate signals of different amplitude.

The present experiment used stimulus displays almost identical to those of Ramachandran and colleagues (Ramachandran, 1988; Kleffner and Ramachandran, 1992). However, stimulus presentation was transient and masked, rather than static. Because of this difference, it seemed desirable to verify that a performance asymmetry is observed under the present conditions as well. To this end, the first experiment compared performance on the stimulus shown in Fig. 1a with the same stimulus turned upside down. In one case, the target element was of the 'high shadow' and the background elements of the 'low shadow' type. In the other case, these roles were reversed. The target was located at least 1.4 deg away from the midline, as well as at approximately 4.2 deg of eccentricity, and was equally likely to appear in the top and bottom half of the display. Observers reported target location by pressing keys labeled 'top' and 'bottom'.

Localization performance was established at several SOAs for 'high' and 'low shadow' targets. The results are shown in Fig. 2 and Table 1 (observers SW, JB). Both observers exhibited significantly better performance in locating the 'high shadow' target. On average, the two observers reached threshold performance at 76.5 ± 7.0 ms with the 'high shadow' target, but only at 127 ± 29.4 ms with the 'low shadow' target. Thus, a paradigm using transient, masked displays yields the same asymmetry as a paradigm using static displays, demonstrating that both paradigms assess the same phenomenon, namely, shape-from-shading.

In the experiments described below, results are reported only for 'high shadow' targets. 'Low shadow' targets appear to be perceived differently by naive and by practised observers (Kleffner and Ramachandran, 1992; Braun, unpublished observations), which made it impractical to conduct Experiments 2 and 3 with naive observers. For a practised observer (JB), 'high' and 'low shadow' targets produced qualitatively identical results in Experiments 2 and 3.

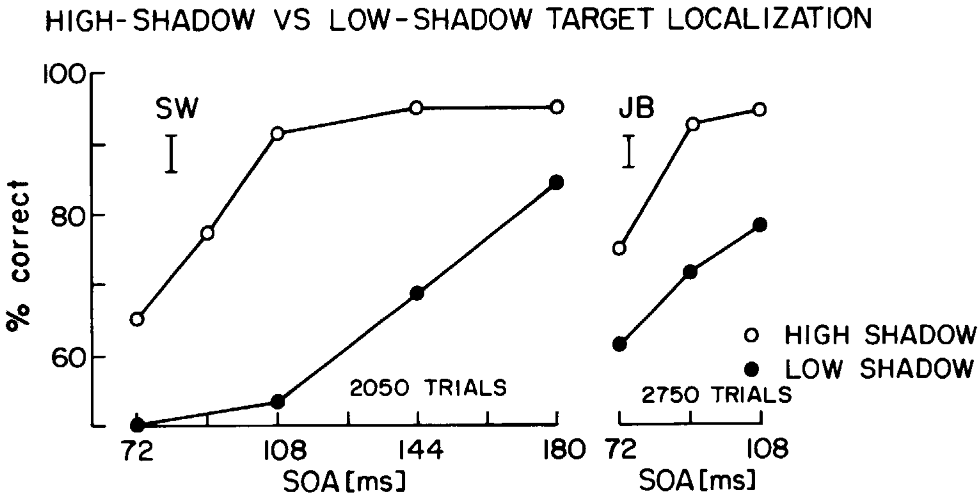

Figure 2. Results of Experiment 1. Comparison of the psychometric functions obtained by observers SW and JB for high-shadow and low-shadow target localization. A representative error bar (average standard error) and the number of trials are also given. The high-shadow target was significantly easier to locate (cf. Table 1).

Experiment 2: Is shape-from-shading perceived in parallel?

In visual search for a 'high shadow' target among 'low shadow' distractors, reaction times are largely independent of the number of distractors (Enns and Rensink, 1990; Kleffner and Ramachandran, 1992; Sun and Perona, 1993), demonstrating that shading is processed in parallel across the visual field. An alternative way to establish parallel processing is to investigate concurrent tasks (Kahneman, 1973; Braun and Sagi, 1990). This method has the advantage of assessing *perception* rather than mere *processing*, and the disadvantage of assessing only a small number of targets (usually two), rather than a large number of distractors.

Here, the method of concurrent tasks is used to investigate whether shape-from-shading is perceived simultaneously at two locations of the display. The stimulus is illustrated in Fig. 1b. Embedded in a background of 'low shadow' elements, one 'high shadow' target could appear in the top half of the display and, independently, another 'high shadow' target could appear in the bottom half. Targets were located at least 1.4 deg away from the midline, as well as at approximately 4.2 deg eccentricity. Otherwise, target location was random, and in each half of the display a target was present or absent with equal probability. This stimulus was investigated

Table 1
Threshold SOAs from Experiment 1

	High-shadow vs low-shadow target localization, T (ms)			
	High-shadow target	Low-shadow target	Difference	Significance
Observer SW	83.4 ± 3.3	157.3 ± 6.9	74.0 ± 7.6	$p < 0.0001$
Observer JB	69.5 ± 2.7	98.5 ± 2.5	28.9 ± 6.5	$p < 0.0001$
Average	76.5 ± 3.0	127.9 ± 4.7	51.5 ± 7.1	$p < 0.0001$

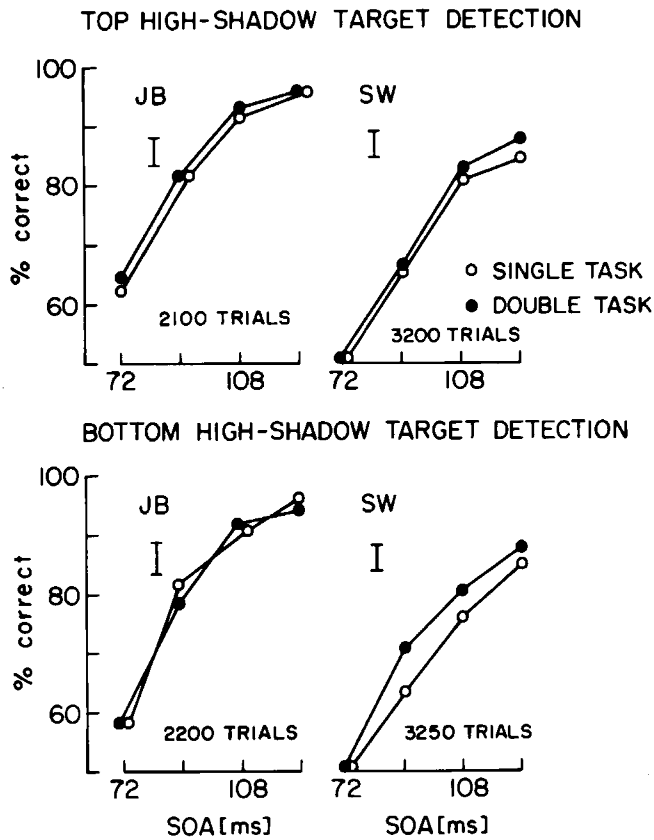

Figure 3. Results for Experiment 2, combining high-shadow target detection tasks in the top and bottom halves of the display, observers SW and JB. The graphs compare psychometric functions for separate performance (single-task situation) and concurrent performance (double-task situation). No significant differences were observed (cf. Table 2).

Table 2
Threshold SOAs from Experiment 2

	Top high-shadow target detection, T (ms)			
	Single task	Double task	Difference	Significance
Observer SW	108.6 ± 5.5	103.4 ± 4.4	−5.2 ± 7.1	ns
Observer JB	68.9 ± 5.3	66.6 ± 3.2	−2.3 ± 6.2	ns
Average	88.8 ± 5.4	85.0 ± 3.8	−3.75 ± 6.6	ns
	Bottom high-shadow target detection, T(ms)			
	Single task	Double task	Difference	Significance
Observer SW	114.2 ± 3.7	106.4 ± 4.6	−7.8 ± 5.9	ns
Observer JB	71.0 ± 4.1	72.7 ± 3.3	1.6 ± 5.2	ns
Average	92.9 ± 3.9	89.6 ± 4.0	−3.1 ± 5.6	ns

under two single-task and one double-task conditions. In the two single-task conditions, observers detected a 'high shadow' target in the top or bottom half of the display, respectively, ignoring any target in the other half. In the double-task condition, observers concurrently detected targets in both halves of the display. Observers responded by pressing keys labeled 'present' and 'absent'.

Separate and concurrent performance levels were established at SOAs ranging from 72 to 136 ms. The results are shown in Fig. 3 and Table 2 (observers SW, JB). Separate and concurrent detection produced essentially identical performance. On average, the two observers reached threshold at an SOA of 90.9 ± 20.8 ms for detecting one target, and an SOA of 87.3 ± 17.6 ms for detecting both targets (Table 2). This outcome provides additional evidence that shading is *processed* in parallel (Enns and Rensink, 1990; Ramachandran and Kleffner, 1992; Sun and Perona, 1993). In addition, it shows that shape-from-shading occurs simultaneously at two locations in the display. Note that analogous results obtain for the detection of two textural singularities (Braun and Sagi, 1990, 1991).

It seems possible that this outcome could be extended to three, four, or even more targets. To do so, one could ask observers to report the 'figural attributes' of several 'high shadow' elements in a background of 'low shadow' elements (Kleffner and Ramachandran, 1992), as this would reduce the number of responses required.

Experiment 3: Does shape-from-shading involve visual attention?

Several concurrent task experiments show that form discriminations compete for visual attention (Duncan, 1980, 1984; Treisman *et al.*, 1983; Sagi and Julesz, 1985; Kröse and Julesz, 1989; Braun and Sagi, 1990; Braun and Julesz, in preparation), and the T/L discrimination used here is no exception. In an experiment combining two T/L discriminations, I found that this task engages visual attention for approximately 60 ms (Braun and Sagi, 1991). Thus it seems safe to assume that successful execution of this task will draw a significant fraction of visual attention away from any other task that the observer may be performing at the time.

Here, the T/L discrimination was combined with detecting a 'high shadow' target. The stimulus is shown in Fig. 1c. In a background of 'low shadow' elements, there appeared a letter target and a 'high shadow' target. The letter target exhibited the shape of either T or L, and the 'high shadow' target was either present or absent. Both targets appeared at approximately 4.2 deg of eccentricity, and were never closer than 4.2 deg to each other. Otherwise, the position of both targets was random. As in the previous experiment, this stimulus was investigated under two single-task and one double-task conditions. In one single-task condition, the observer discriminated the letter target and ignored the shadow target; in the other the observer detected the shadow target and ignored the letter target. In the double-task condition, the observer concurrently discriminated the letter target and detected the shadow target. The observer pressed keys labeled 'T' or 'L' (letter target), and/or 'present' or 'absent' (shadow target).

Separate and concurrent performances were established for both tasks at SOAs ranging from 72 to 144 ms. The results are shown in Fig. 4 and Table 3 (observers JB, SW, NA). Again, separate and concurrent performance levels did not differ significantly. On average, observers performing only shadow target detection reached threshold at an SOA of 111.2 ± 7.66 ms. When observers performed the

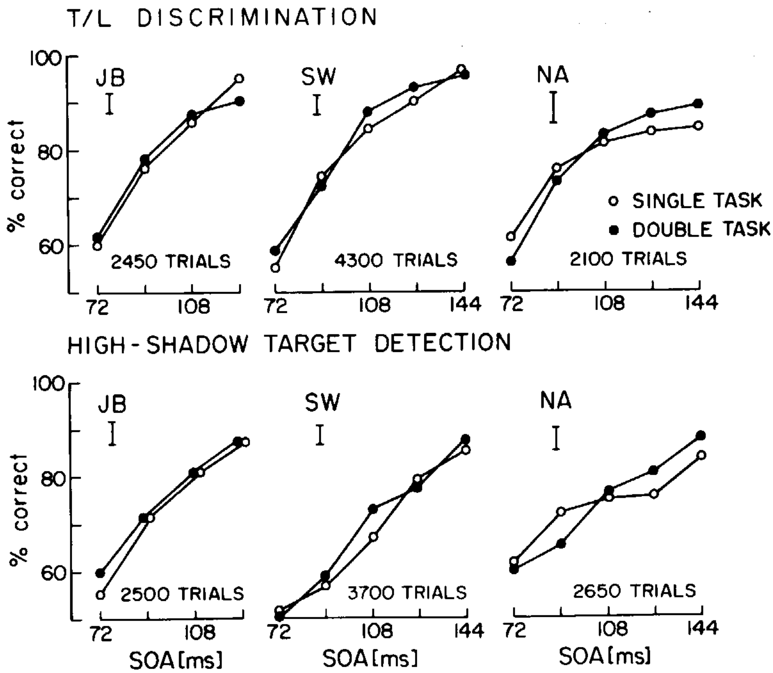

Figure 4. Results for Experiment 3, combining T/L discrimination with high-shadow target detection, observers JB, SW, NA. The graphs compare psychometric functions for separate performance (single-task situation) and concurrent performance (double-task situation). No significant differences were observed (cf. Table 3).

Table 3
Threshold SOAs from Experiment 3

	T/L discrimination, T(ms)			
	Single task	Double task	Difference	Significance
Observer SW	101.8 ± 4.5	95.9 ± 4.7	−5.9 ± 6.5	ns
Observer NA	99.6 ± 10.2	100.5 ± 8.0	1.0 ± 13.0	ns
Observer JB	92.6 ± 3.3	90.4 ± 3.8	−2.2 ± 5.0	ns
Average	98.0 ± 6.0	95.6 ± 5.5	−2.37 ± 8.2	ns
	High-shadow target detection, T (ms)			
	Single task	Double task	Difference	Significance
Observer SW	119.8 ± 5.4	120.2 ± 5.2	0.5 ± 7.5	ns
Observer NA	112.6 ± 7.9	110.3 ± 6.7	−2.2 ± 10.4	ns
Observer JB	101.2 ± 4.7	97.3 ± 5.7	−3.9 ± 7.4	ns
Average	111.2 ± 6.0	109.3 ± 5.9	−1.9 ± 8.4	ns

letter discrimination concurrently, the corresponding value was 109.3 ± 9.4 ms (Table 3). With respect to shadow target detection, observer JB performed more poorly in Experiment 3 (single task threshold SOA 101.2 ± 4.7 ms) than in Experiment 2 (71.0 ± 4.1). This may have had to do with the fact that Experiment 3 was conducted several weeks after Experiment 2.

Given that T/L discrimination places a significant demand on visual attention, the observed outcome implies that detecting a shadow target does not. Note that the two tasks exhibit comparable psychometric functions (when performed separately), showing that perceptual difficulty does not predict attentional requirements. However, the main point is that detecting a shadow target is comparable to detecting a textural singularity: for both tasks performance does not depend on attention being fully available (Braun and Sagi, 1991).

DISCUSSION

A two-dimensional luminance pattern which reproduces the reflectance pattern of an obliquely illuminated, three-dimensional scene often induces a vivid perception of depth. Observers often perceive a pattern in which light is placed above dark as *convex*, and a pattern in which dark is placed above light as *concave*. Sometimes the illusion is bistable and the perceived shape changes with the presumed direction of illumination.

The task studied here was a 'pop-out task', in which observers detected a concave-appearing target in a dense array of convex-appearing distractors. This task was modeled after that used by Ramachandran and colleagues (Ramachandran, 1988; Kleffner and Ramachandran, 1992), with one important difference: the present experiments used a transient, masked display. As the introspective experience of shape-from-shading is less striking under these conditions, it seemed important to replicate some of the results which Ramachandran and colleagues obtained with static displays. To this end, the asymmetry between concave-appearing and convex-appearing targets (embedded in convex- and concave-appearing distractors, respectively) noted by Ramachandran and colleagues was replicated with transient, masked displays, validating the 'pop-out task' as an assay for shape-from-shading.

To determine whether shape-from-shading occurs simultaneously in different parts of the visual field, 'pop-out' performance was measured concurrently with respect to targets in the top and bottom halves of the display. Indistinguishable psychometric functions were obtained for the concurrent detection of both targets and the separate detection of only one target. This showed not only that shading is *processed* in parallel, for which there is evidence from other studies (Enns and Rensink, 1990, 1991; Kleffner and Ramachandran, 1992; Sun and Perona, 1993), but that shape-from-shading is *perceived* in parallel at two locations in the visual field.

In addition to establishing parallel perception, concurrent task experiments can be used to assess limited perceptual resources (Kahneman, 1973). Here, a concurrent task experiment was used to investigate the dependence of 'pop-out' performance on *visual attention*. A concurrent form discrimination task was used to draw visual attention away from the 'pop-out task'. Form discriminations are known to compete for visual attention in concurrent task situations (Duncan, 1980, 1985; Sagi and Julesz, 1985; Kröse and Julesz, 1989; Braun and Sagi, 1990; Braun and Julesz, in preparation). The particular task used here is known to compete for visual attention during approximately 60 ms (Braun and Sagi, 1991). Indistinguishable psychometric functions were obtained for the concurrent and separate performance of both tasks. In other words, 'pop-out' performance was the same, whether visual attention was available or otherwise engaged, demonstrating that shape-from-shading does not measurably depend on visual attention.

The processing of visual cues to three-dimensional shape has been investigated in several ways: (i) measurements of reaction time for visual search in static displays (Enns and Rensink, 1990, 1991; Kleffner and Ramachandran, 1992); (ii) measurements of percentage correct for visual search in transient, masked displays (Sun and Perona, 1993); and (iii) measurements of percentage correct for two concurrent tasks in transient, masked displays (present work). That *shading* is processed in parallel across the visual field is supported by all three methods. Conflicting evidence exists with respect to *perspective* and *occlusion*, two other clues to three-dimensional shape. For example, for line patterns without shading, parallel processing is observed with method (i) (Enns and Rensink, 1990, 1991), and serial processing with method (ii) (Sun and Perona, 1993). Perhaps experiments with method (iii) could help resolve this kind of conflict.

It should be stressed that concurrent visual tasks are rarely compatible to the degree observed here. In fact, it is often thought that tasks involving voluntary reports about the attributes of different objects are never compatible, as bringing each attribute to awareness would normally require a shift of visual attention (Duncan, 1980, 1984; Treisman *et al.*, 1983; Treisman, 1993). Over the past several years, I and others have argued that tasks involving reports about textural discontinuities constitute an exception to this rule (Braun and Sagi, 1990, 1991; Ben Av *et al.*, 1992; Rock *et al.*, 1992; Braun, 1993; Braun and Julesz, in preparation), affirming the validity of Julesz' original insight that 'texture is special' (Julesz, 1981). The present experiments show that a discontinuity in shading behaves just like a textural discontinuity—i.e. a discontinuity in luminance, orientation, spatial frequency, or some other 'texton'—in concurrent task situations.

There is considerable evidence that textural features interact over a limited range and that only a sufficiently dense distribution of features form a texture (e.g., Malik and Perona, 1990; Rubenstein and Sagi, 1990; Sagi, 1990; Nothdurft, 1991). At present, it is not known whether similar interactions exist for shading. However, as Leonardo Da Vinci and many '*trompe l'oeuil*' painters (e.g., Milman, 1986) have realized, shape-from-shading appears to become more compelling when a scene contains many shaded objects. Ramachandran (1988) observed that multiple shaded objects are always interpreted consistently, and attributed this fact to inhibitory interactions. Thus, future work might profitably investigate interactions between shape-from-shading at neighboring locations.

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