Visual discrimination after anterior temporal lobectomy in humans

J.D. Mendola, PhD; J.F. Rizzo III, MD; G.R. Cosgrove, MD; A.J. Cole, MD;
P. Black, MD, PhD; and S. Corkin, PhD

Article abstract—*Objective:* To determine whether right anterior temporal lobectomy (RTL) results in perceptual deficits, and whether the perception of particular stimulus features (i.e., shape, motion, color) is affected differentially. *Background:* RTL results in abnormal visual discrimination, recognition, and recall of pictorial material that cannot be easily specified verbally, such as designs and faces. It is unclear whether stimuli must be conceptually meaningful to elicit perceptual deficits. *Methods:* Tests were constructed to assess a wide spectrum of basic visual discrimination abilities with simple, meaningless stimuli. The performance of nine patients who underwent left temporal lobectomy (LTL) and nine patients who underwent RTL were compared with that of normal control individuals. The mean excision size along lateral cortex was 3.7 cm for the LTL group and 5.6 cm for the RTL group; mean mesial excision size was 5.2 cm for LTL and 4.6 cm for RTL. *Results:* Basic visual discrimination capacities were demonstrated to be essentially intact after LTL and RTL, except for a mild loss of blue color discrimination after RTL. *Conclusions:* There is little evidence that RTL produces perceptual impairments limited to the domain of pattern perception, or generalizable to nonmeaningful stimuli. The perceptual loss after RTL may be largely restricted to extraction of meaning, and related to the disruption of the circuits that connect the outcome of visual analysis to previously stored semantic information.

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Neuropsychological studies have demonstrated that right anterior temporal lobectomy (RTL) results in impaired visual perception.[1-6] The exact nature of these deficits is unclear, however, and no complete description exists of the properties of the stimuli that elicit difficulties. Such stimuli are still often defined by exclusion as nonverbal. The perceptual deficits reported are subtle (excluding the upper quadrantanopia that may occur because of disruption of part of the optic radiations). No central blindness or visual agnosia is present. The stimuli used to elicit impairments are usually made challenging by ambiguity, reduced information, or brief exposure times. Although the evidence is limited, it is generally believed that mild perceptual deficits result from removal of the anterior temporal lobe neocortex rather than the medial limbic structures.[7] Numerous studies in monkeys showing that inferotemporal neocortical lesions impair visual pattern discrimination learning support this assumption.[8] Furthermore, Milner[7] has reported normal performance on the Mooney Closure Faces Test (a test that elicits deficits in patients with RTL) for three patients with selective right amygdalo-hippocampal resections.

One disadvantage of the stimuli that have been used with humans is that they are conceptually as well as perceptually complex (classification of faces, identification of incomplete objects, discrimination of anomalous scenes). These tests require that participants use prior knowledge about the appearance, typical environment, function, and meaning of real-world objects, i.e., semantic knowledge. Three exceptions to this trend are studies that presented simple patterned stimuli under time pressure.[2,5,9] Kimura[2] presented overlapping nonsense shapes for 200 milliseconds and then immediately tested for recognition. Patients with RTL were impaired relative to patients with LTL (control individuals were not tested). In a study by Meier and French,[5] individuals performed an odd-ball-out visual discrimination test on fragmented concentric circle patterns exposed for 4 to 16 seconds. The RTL group was impaired relative to the LTL group (control individuals were not tested). Dorff et al.[9] used letter stimuli (groups of four consonants) that were presented for 150 milliseconds. RTL and LTL groups had impaired recognition, particularly when letters appeared in the visual field contralateral to the lesion. When letters were flashed in both visual fields, only the RTL group showed a bilateral deficit. The results were interpreted as supporting a partially dominant role for the right temporal lobe in visual perception.

These studies suggest that when the visual system of patients with RTL is challenged with briefly

From the Department of Brain and Cognitive Sciences and the Clinical Research Center (Drs. Mendola and Corkin), Massachusetts Institute of Technology, Cambridge; the Department of Ophthalmology, Harvard Medical School, and Massachusetts Eye and Ear Infirmary (Dr. Rizzo); the Departments of Neurosurgery (Dr. Cosgrove) and Neurology (Dr. Cole), Massachusetts General Hospital; and the Department of Neurosurgery, Brigham and Women's Hospital, and Children's Hospital (Dr. Black), Boston, MA.

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Address correspondence and reprint requests to Dr. Janine Mendola, MGH NMR Center, 149 13th Street (2301), Charlestown, MA 02129.

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Table *Characteristics of subjects*

Group	No. M/F	Mean age, y (SD)	Mean education, y (SD)	Mean excision size, lateral cm* (SD)	Mean excision size, medial cm (SD)	Mean mo since operation (SD)
LTL	3/6	32.9 (11.9)	14.4 (2.8)	3.7 (1.2)	5.2 (1.1)	40.4 (27.7)
RTL	2/7	32.7 (11.4)	14.0 (1.8)	5.6 (0.6)	4.6 (1.3)	34.4 (30.7)
Normal controls	9/10	32.8 (8.9)	14.2 (1.3)	—	—	—

* Excision size measured in centimeters from tip of temporal lobe to posterior border.

TL = temporal lobectomy.

exposed patterns, perception is deficient. The selectivity of such a deficit is unknown, however, given that pattern perception has not been compared with performance in other visual domains. To our knowledge, no studies have assessed basic visual discrimination abilities after LTL and RTL with a group of tests that samples a spectrum of perceptual abilities (e.g., color, motion, and pattern perception). Thus, we compared visual discrimination across a range of basic visual capacities using simple, meaningless stimuli. We employed brief exposure times to increase difficulty and minimize the effects of eye movements. Our design also allowed comparison of response accuracy when stimuli were in the visual field contralateral and ipsilateral to the excision.

It may be that simple visual cue discrimination is intact after LTL and RTL, whereas the ability to organize such cues into a coherent shape is compromised. Several studies describe patients who have normal ability to detect the presence of shapes along with an inability to identify the form of such shapes after left or right posterior brain lesions.[10-11] Also, we know that monkey inferotemporal cortex plays an important role in the perception of shape, i.e., the ability to recognize an object's identity despite an infinite variety of viewing angles, sizes, and lighting conditions, and regardless of how visibility is created (including luminance, color, motion, texture, and depth cues).[12-14]

To test the ability of patients with LTL and RTL to perform shape analysis, we directly compared perception of shape from texture cues, shape from limited contour cues, and shape from motion cues. We reasoned that these tests would provide a sensitive assessment because shape was defined by a single cue in each case—a situation more impoverished than typical natural stimuli. Also, these tests required a match between a luminance-defined shape and the same shape defined by the three cues mentioned above. Thus, each test required a type of "recognition invariance" problem to be solved—a task that may depend on temporal neocortex, based on the monkey studies mentioned above. These experiments allowed us to address three questions: Is the semantic content in many previously employed stimuli critical for eliciting impairments after LTL or RTL? Does the dissociation between LTL and RTL still exist when simple meaningless stimuli are used? Is pattern or shape vision selectively vulnerable after RTL?

Methods. *Patients.* Eighteen patients who underwent unilateral anterior temporal lobe resection to treat intractable epilepsy and 19 normal control individuals (NC) were included (table). Nine patients underwent resection on the left side (LTL), and nine on the right side (RTL). The NC group did not differ from the LTL or RTL groups with respect to age ($p = 0.980$ and $p = 0.975$, respectively) or education ($p = 0.742$ and $p = 0.975$) as assessed with *t*-tests (see table). The number of subjects who participated in each test is indicated in figures 2 through 4.

For the patients with LTL or RTL, the operation included removal of anterior temporal neocortex, most of the amygdala, most of the entorhinal cortex, part of the rostral perirhinal cortex, and the rostral part of the hippocampus. Operation reports documented the resection size for lateral neocortex and for mesial structures (see table). *t*-Tests showed that the size of the mesial excision did not differ between the LTL and RTL groups ($p = 0.2$), whereas the lateral excisions in the RTL group were significantly larger than in the LTL group ($p = 0.002$). At the time of testing, the patients varied in time elapsed since operation (range 1 to 7 years), but the two groups did not differ with respect to this variable ($p = 0.7$). Of the 18 patients, 17 were taking therapeutic doses of anticonvulsant medication, and all were either seizure free or experiencing only rare seizures.

All participants gave informed consent for the testing, which was conducted at the MIT Clinical Research Center. Concurrent with the vision testing, all participants received a physical examination that included direct funduscopy, pupillary function, extraocular movement, and visual fields to confrontation. All individuals demonstrated a corrected near Snellen acuity of 20/30 or 20/20.

In addition, five LTL patients and four RTL patients received a further neuro-ophthalmologic examination. This was a random subset of patients who were able to attend this extra testing session at the Massachusetts Eye and Ear Infirmary. It included applanation tonometry to detect glaucoma and nonglaucomatous ocular hypertension, examination of the anterior segment and lens to detect and describe cataract and other lens opacities, determination of refractive error to ensure appropriate correction, funduscopy to inspect the retina and optic nerve, pupillary function, extraocular motility, and Snellen acuity. Goldmann perimetry was performed to detect visual field defects.

Abnormal findings were obtained for two of four patients with RTL and three of five patients with LTL. Spe-

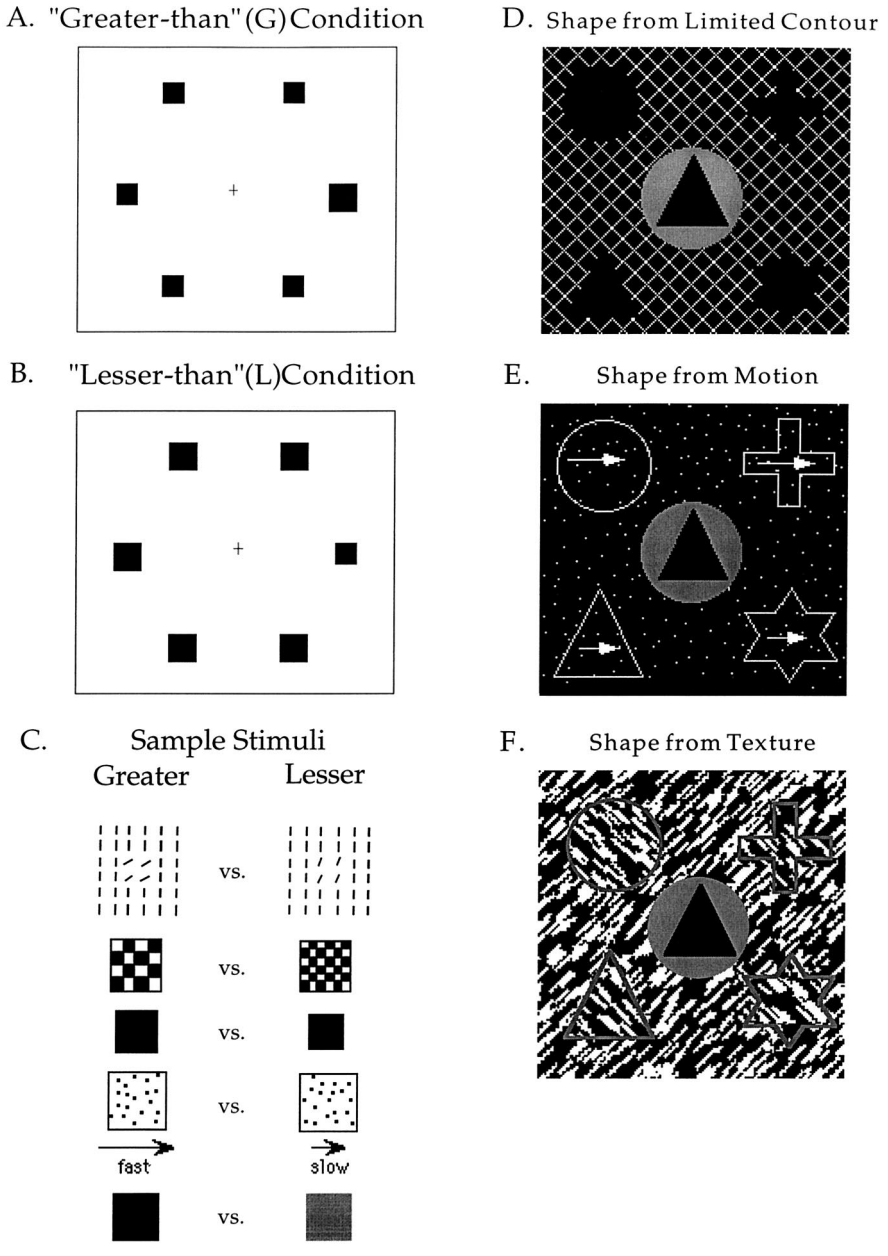

Figure 1. (A, B) Depiction of the stimulus array for the greater-than (G) and lesser-than (L) conditions. Size discrimination is shown as an example. (C) Examples of the G and L stimuli for the visual domains of contrast, speed of motion, size, oriented texture, and pattern. (D–F) Examples of stimuli for the matching tests. The sample stimulus is in the center; the four choice shapes surround the sample. In shape from motion, the dots inside the border of the choice shapes (which is normally not drawn) are set in motion. Also, in shape from texture, the shape outlines are for illustration purposes only.

cifically, two patients with RTL demonstrated a history of congenital "lazy left eye," or amblyopia (not judged to be related to the surgery). Accordingly, visual acuity was reduced unilaterally, and stereopsis was poor or absent. One subject with LTL was judged to have a subtle amblyopia with loss of stereopsis. Finally, the other two patients with LTL had optic neuropathy (moderate constriction and pallor of optic nerves) thought to be related to a period of high intracranial pressure early in life. One of these two patients also had a history of "lazy right eye" that had led to strabismus surgery when the patient was 8 years old. We considered all optic abnormalities as possible confounds in the attribution of visual deficits to the temporal lobectomy; the data were analyzed with this consideration in mind (see Discussion).

All participants performed the Mooney Closure Faces Test,[15] a test of the ability to perceive faces in ambiguous black-and-white images. In earlier studies, patients with RTL were impaired, whereas patients with LTL were not.[6,7] The results of our testing indicated that patients with LTL ($p = 0.012$; $F[1,35] = 7.0$) and RTL ($p = 0.006$); $F[1,35] = 8.8$) were impaired relative to the NC group. The mean number of errors made by NC, LTL, and RTL groups was 12, 19, and 19, respectively. In the studies of Milner,[7] the number of errors made by NC, LTL, and RTL groups was 6, 6, and 9, respectively (an additional group with occipital-temporal excisions averaged 13 errors). It is unclear why our mean scores were lower, and why both LTL and RTL groups were impaired, particularly because our subjects had a smaller mean excision size than in Milner's study (see Discussion). There were, however, several differences in the details of test administration. We conducted the test in a self-paced manner, and subjects made categorization judgments themselves. Milner used a strict time limit for each face, and obtained the categorizations indirectly by asking for a gender and exact age. The sensitivity of the Mooney Test to the exact mode of administration is unfortunate. Nonetheless, these results are im-

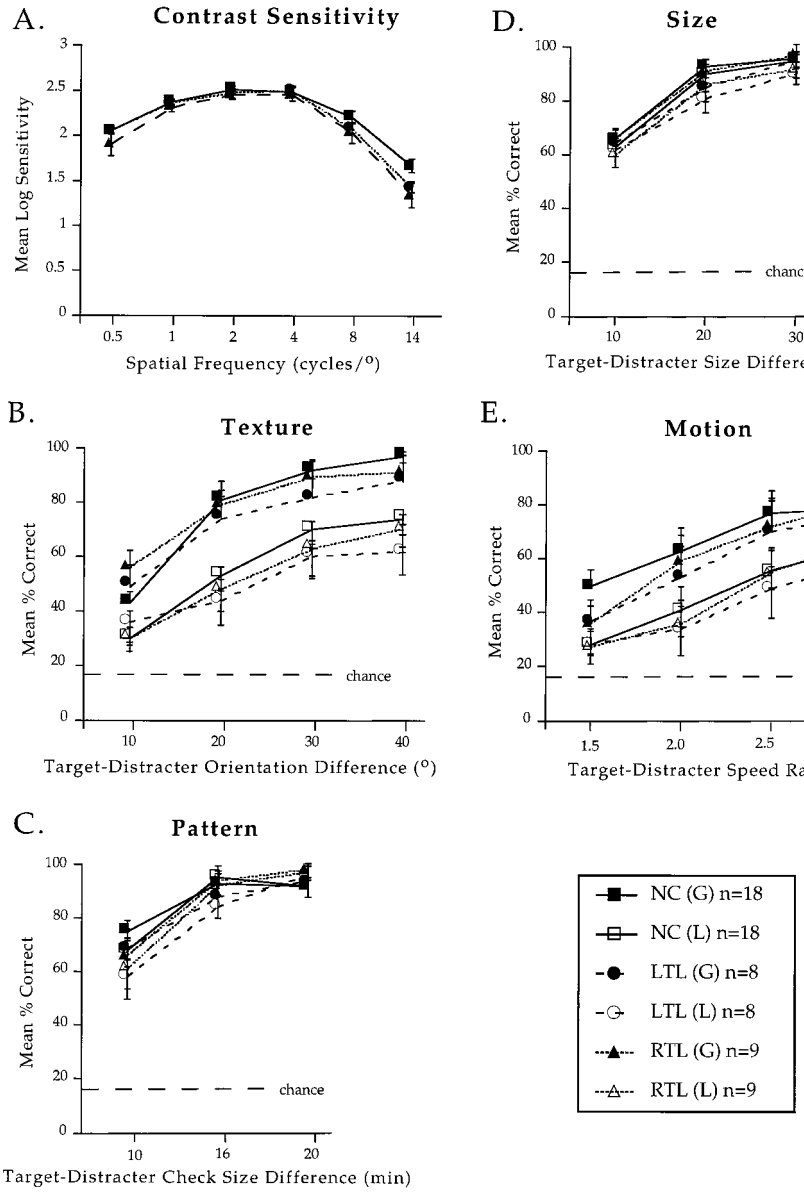

Figure 2. (A) Contrast sensitivity was normal after left temporal lobectomy (LTL) and right temporal lobectomy (RTL) compared with normal control individuals (NC). (B–E) Texture, pattern, size, and motion discrimination are normal after LTL and RTL. Results are shown for the greater-than (G) and lesser-than (L) conditions.

portant because they document at least some perceptual impairments in our patients.

Stimuli. Participants performed 12 tests intended to evaluate a wide range of basic visual capacities. All tests were computerized.

Contrast sensitivity. For this test, individuals sat in a darkened room and viewed an oscilloscope, which subtended 7.1° by 5.7° at a distance of 1 meter. In a two-alternative forced-choice format (Vision Metrics, Berkeley, CA),[16] individuals received trials randomly distributed across six spatial frequencies (0.5, 1.0, 2.0, 4.0, 8.0, and 14.0 cycles/degree). For each trial, a vertical grating filled the screen for one interval, and a homogeneous field, matched in mean luminance (5 cd/m^2), appeared during the other interval; the order was determined randomly. The subject responded "one" if the grating appeared in the first interval and "two" if it appeared in the second interval. A staircase algorithm sought the 75% correct threshold by reducing contrast by 1 dB for each correct response and by increasing contrast by 3 dB for each error, until 20 reversals were completed for each spatial frequency. The performance measure was the log of sensitivity, which was the reciprocal of the threshold contrast.

Oddball target discrimination. The remaining tests have been used extensively in previous research on monkeys[17,18] and were adapted for use with humans. These eight tests used four- or six-alternative forced-choice discrimination paradigms. For each test, the absolute difference between targets and distracters was varied to create several levels of difficulty, so that a range of performance could be assessed. In a typical trial, four or six stimuli appeared following the presentation of a fixation spot. One of the stimuli, the target, was different from the other identical comparison stimuli on any one of several dimensions (e.g., size, color, motion). The stimuli appeared equidistant from the fixation spot between 6° and 8° eccentricity on a polar coordinate system (see figure 1). Difficulty level and target position were randomized.

Although these tests used simple stimuli that assessed basic visual capacities, they also tapped a visual function of a higher level when the prominence of the target was varied. For example, in size discrimination, the target was

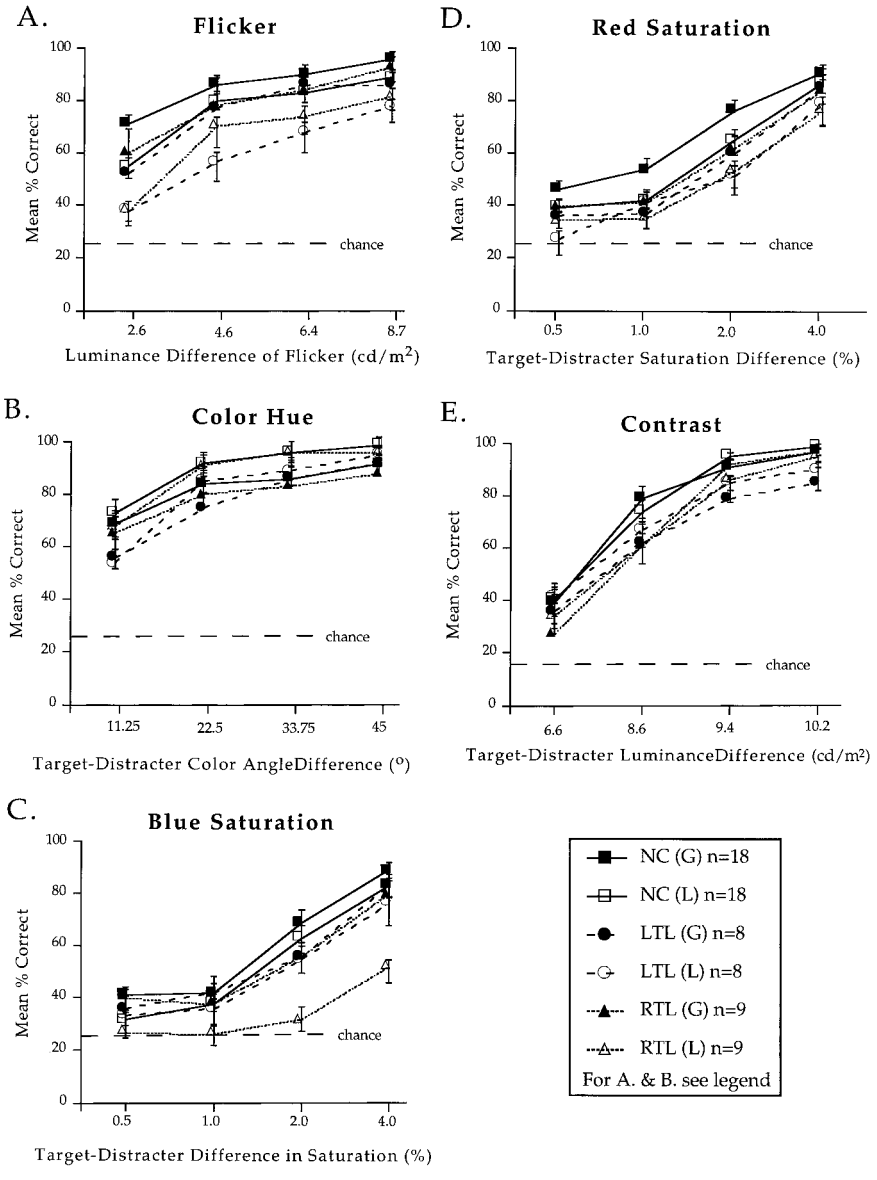

Figure 3. (A) Flicker discrimination was normal after left temporal lobectomy (LTL) and right temporal lobectomy (RTL). Results are shown for the fast (solid symbols) and slow (open symbols) flicker condition. Results are not shown for the greater-than (G) and lesser-than (L) conditions. (B) Red and blue hue discrimination was normal after LTL and RTL. Results are shown for the red color axis (solid symbols) and the blue color axis (open symbols) (no G versus L comparison). (C–E) Blue saturation discrimination was impaired after RTL but not after LTL, whereas red saturation discrimination and contrast discrimination were normal after LTL and RTL. Results are shown for the G and L conditions.

either larger or smaller than the distracters. In a similar fashion, the remaining tests had a target that was either "greater" (G) or "lesser" (L) along the relevant stimulus dimension compared with the distracters (see figure 1, A through C). Previous work in monkeys has shown that the L condition can be especially impaired following a visual cortex lesion.[17] When a discrimination test contained two prominence conditions, they were separated in blocks of trials. Each test comprised 192 to 288 trials.

Texture. Following presentation of a fixation cross, an array of vertical lines filled the screen for 300 milliseconds. The array contained 14 × 14 line elements and subtended 19.2° × 19.2° overall. Each line was 0.64° long and 0.05° wide. In six small areas (1.9° × 1.9°), four lines (2 × 2 array) were tilted toward the diagonal. Difficulty was varied by increasing the amount of tilt difference between the target and distracters (10, 20, 30, and 40°). The absolute tilt of the target and distracter elements was 5, 15, 25, 35, or 45°. In the G condition, the target area lines were more tilted than the distracters; in the L condition, the target area contained lines less tilted than the distracters.

Pattern. Following presentation of a fixation spot, six squares (2.1° × 2.1°) in a hexagonal arrangement were flashed for 250 milliseconds. The squares contained high-contrast checkerboard patterns. The checkered patterns were 3 × 3, 4 × 4, 5 × 5, or 6 × 6, with check size 40, 30, 24, or 20 minutes of arc, respectively. The target check pattern size was either larger (G) or smaller (L) than the distracters.

Size. Following presentation of the fixation cross, six squares in a hexagonal arrangement were flashed for 250 milliseconds. The difficulty levels corresponded to size differences of 30%, 20%, and 10%. The absolute size of the squares' sides was 1.6, 1.76, 1.92, and 2.08°, respectively. The target was either larger (G) or smaller (L) than the distracters.

Motion. Following presentation of a fixation cross, six windows (3.2° × 3.2°), each containing 50 moving dots, were displayed on the screen for 1,000 milliseconds. There were four difficulty levels, with speed ratios between target and distracters of 1.5, 2, 2.5, and 3. The absolute speed of the dots was 1.5, 2.25, 3, 3.75, or 4.5°/s. In this test, each individual moving dot had a limited lifetime of just 100 milliseconds before it was randomly repositioned to a

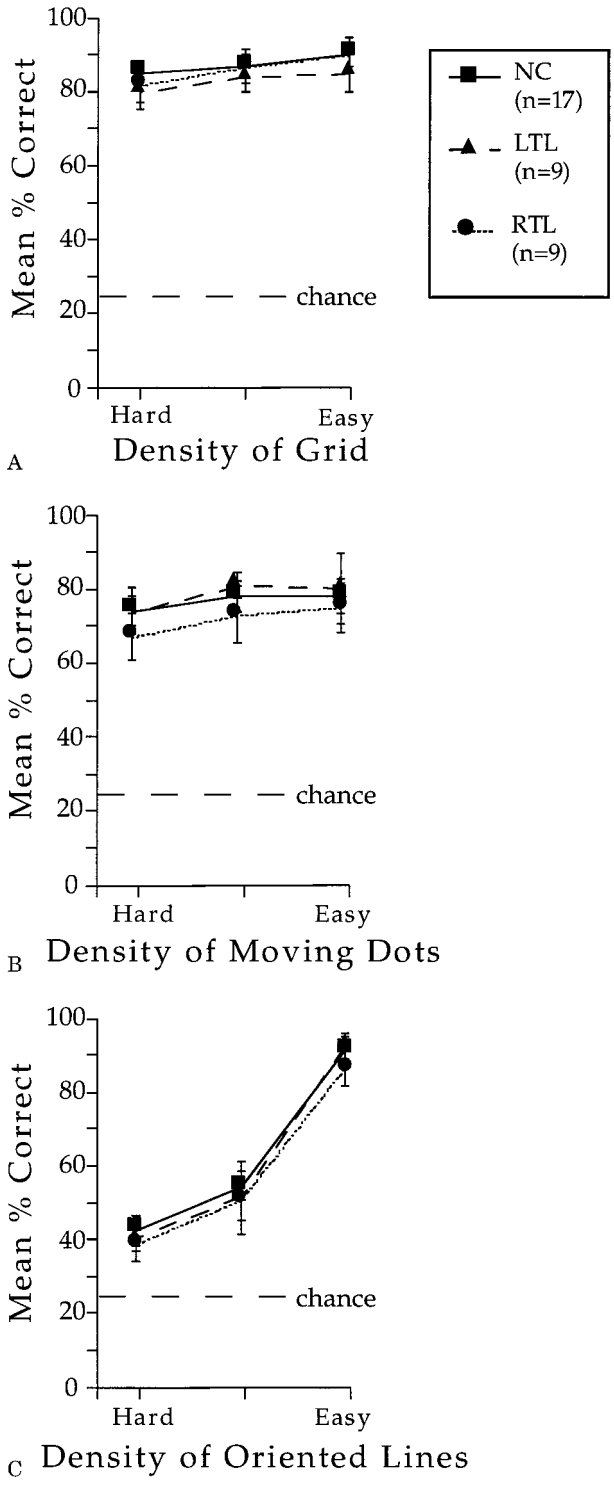

Figure 4. Shape from (A) limited contour, (B) motion, and (C) texture. Matching shape based on selective cues was normal after left temporal lobectomy (LTL) and right temporal lobectomy (RTL).

new location to move for 100 milliseconds. The result was a pure motion signal not confounded by position cues.[19] The target moved either faster (G) or slower (L) than the distracters.

Flicker. Following presentation of a fixation spot, four squares ($1.4^{\circ 2}$) in a diamond arrangement were flashed for 1,000 milliseconds. The luminance of one square (the target) was flickering. The mean flickering luminance equaled the background luminance. Four levels of difficulty corresponded to a ± luminance shift of 2.6, 4.6, 6.4, and 8.7 cd/m^2. Absolute values of luminance levels were 26.6, 29.2, 31.2, 33.0, and 35.3 cd/m^2. The flicker values were 3, 7.5, and 15 Hz. In the single prominence condition (G) in this test, the targets were flickering.

Color hue. Following presentation of a fixation spot, four squares ($1.4^{\circ 2}$) in a diamond arrangement were flashed for 200 milliseconds. The color hue of the target stimuli relative to the comparison stimuli was varied systematically, as described by Schiller.[17] We created two tests that assessed discrimination for two cardinal axes in a McLeod color space. The four difficulty levels corresponded to a color angle difference of 11.25, 22.5, 33.75, and 45° from the cardinal axis. All colors were isoluminant (65.8 ± 1 cd/m^2). Qualitatively, the target appeared slightly more green than the blue distracters in one test, and slightly more pink than the red distracters in the other. There was no sensible G versus L comparison.

Color saturation. Following presentation of a fixation spot, four squares ($1.4^{\circ 2}$) in a diamond arrangement were flashed for 200 milliseconds. In one case, the color of the squares varied systematically from pure white to pale blue. In the other case, the color varied from white to pale red. For both axes, four difficulty levels corresponded to saturation differences of 4, 2, 1, and 0.5%; there was a G version with the targets more saturated, and an L version with targets less saturated.

Contrast. Following presentation of the fixation cross, six squares ($1.8^{\circ 2}$) in a hexagonal arrangement were flashed for 250 milliseconds. The absolute luminance values were 1.41, 2.20, 4.18, and 10.81 cd/m^2 with background luminance at 84.04 cd/m^2. The target was either darker (G) or lighter (L) than the distracters.

Shape matching. The stimuli consisted of four simple geometric shapes: circle, triangle, cross, and star, each subtending 2° of visual angle (see figure 1, D through F). To begin each trial, one of the four possible shapes (the sample) appeared in the center of the screen for 1 second. After a delay of 500 milliseconds, four choice shapes appeared for 1 second at four locations, centered 4° from the center of the entire display. One of the four shapes was identical with the sample; the other three were different shapes. The sample stimulus was defined by luminance and was always presented with full contour information. The choice stimuli were defined by limited contour, motion, or texture information as described below. Each test comprised 144 trials, with difficulty level randomized.

Limited contour test. The screen was filled with a grid of diagonal white lines (5 minutes of arc wide) on a black background. The shapes were also drawn and filled with black, so that they appeared to occlude the white grid. The intersections of the grid with the shapes were the only sources of contour information, which was varied systematically by changing spacing between grid lines (20, 35, 50 minutes of arc) to create three difficulty levels (see figure 1D).

Shape from motion test. The display consisted of randomly placed white dots on a black background. The dots within the boarders of the shapes were moving (5°/s). Thus, the shape contours could be extracted only from the boundaries between moving and stationary dots. Three dif-

ficulty levels were created by systematically altering the density of dots (see figure 1E).

Shape from texture test. The shapes contained a texture of randomly placed line segments (4 minutes of arc wide) oriented 90° from a similar background texture. Shape contours could be extracted only from texture boundaries. The density of the oriented lines was varied to create three levels of difficulty (see figure 1F).

Procedure. Individuals sat 14 inches in front of a computer monitor in a dimly lit room. They were shown sample stimuli and were told to find the oddball target in each briefly flashed picture. Individuals were told when to look for a G or an L target. For the shape matching test, individuals were told to pick the choice shape that matched the central sample. Additionally, they were told that they should try to fixate the cross at the center of the screen, that the difficulty levels were mixed randomly, and that they should guess when unsure of the correct choice. Before the onset of each stimulus, a warning tone was given, and a central fixation cross was presented for 2 seconds. The individuals responded by pressing one of six keys that corresponded to the hexagonal arrangement of stimuli (or one of four keys that corresponded to the square arrangement). During the test, individuals rested at several points, indicated by a "please rest" screen. The order of G versus L blocks was counterbalanced within individuals. Participants required 10 to 15 minutes to complete a block of trials. Testing sessions ranged from 1 to 2 hours and were separated by breaks. Individuals were tested at a comfortable pace over 2 to 3 days of testing.

Results. Overall, the results indicated little impairment of basic visual discrimination capacity after LTL or RTL. For the oddball target discrimination tests (see figure 1, A through C), we demonstrated that the L prominence condition evoked poorer performance than the G condition across all subject groups for all tests, significantly for texture, size, motion, and color saturation. The only significant main effect of group was for blue saturation discrimination (red saturation and gray-level contrast were marginally significant). Given the large number of significance tests that we performed, we must be sensitive to the possibility of finding significant effects caused by chance. Even a conservative interpretation, however, suggests that a subtle weakness for color and contrast discrimination may result after RTL. The increased difficulty of the L condition may have helped to elicit the impairment of the RTL group for blue saturation discrimination. The statistics for individual tests are reported below.

For the contrast sensitivity test, the analysis of variance (ANOVA) comprised the group factor and a spatial frequency factor. For the remaining eight oddball target discrimination tests, we performed a mixed within-individuals and between-individuals ANOVA with two or three factors: group (LTL, RTL, NC); difficulty (three or four levels); and, when applicable, condition (G, L). The shape matching test had two factors: group and difficulty (three levels).

Contrast sensitivity. For this test, there was no main effect of group ($p = 0.144$; $F[2,33] = 2.1$). There was a main effect of spatial frequency ($p = 0.0001$; $F[5,165] = 137.2$), reflecting the well-known decrease in sensitivity at high and low spatial frequencies. No interactions were significant (see figure 2A).

Texture. In this case, there was no main effect of group ($p = 0.653$; $F[2,32] = 0.4$), but there was a main effect of difficulty ($p = 0.0001$; $F[3,96] = 130.0$) and of condition ($p = 0.0001$; $F[1,32] = 66.10$). The L condition produced significantly more errors than the G condition. No interactions were significant (see figure 2B).

Pattern. We found no main effect of group ($p = 0.560$; $F[2,33] = 0.6$). There was a main effect of difficulty ($p = 0.0001$; $F[2,66] = 42.1$). No interactions were significant (see figure 2C).

Size. There was no main effect of group ($p = 0.514$; $F[2,34] = 0.7$). We found a main effect of difficulty ($p = 0.0001$; $F[2,68] = 175.7$) as well as condition ($p = 0.033$; $F[1,34] = 4.9$). The L condition was harder than the G condition. No interactions were significant (see figure 2D).

Motion. In this case, there was no main effect of group ($p = 0.789$; $F[2,27] = 0.2$). We found a main effect of difficulty ($p = 0.0001$; $F[3,81] = 62.2$), as well as condition ($p = 0.0001$; $F[1,27] = 32.3$). The L condition was more difficult than the G condition. No interactions were significant (see figure 2E).

Flicker. Once again, there was no main effect of group ($p = 0.071$; $F[2,31] = 2.88$). We found a main effect of difficulty ($p = 0.0001$; $F[3,93] = 117.4$). We did not use a G versus L condition in this test. In the current analysis, the factor of condition corresponded to fast (15 Hz), medium (7 Hz), and slow (3 Hz) flicker ($p = 0.0001$; $F[2,62] = 101.9$). The slow flicker condition was more difficult than the fast flicker condition. For this test, we found significant interactions between group and difficulty ($p = 0.028$; $F[3,93] = 2.5$), as well as between group and condition ($p = 0.011$; $F[4,62] = 3.56$). The RTL and LTL groups showed somewhat poorer performance with slow flicker than with fast flicker (see figure 3A).

Color hue. Again, we found no main effect of group ($p = 0.302$; $F[2,34] = 1.2$). We found a main effect of difficulty ($p = 0.0001$; $F[3,102] = 127.4$) and condition ($p = 0.011$; $F[1,34] = 7.2$). A prominence condition was not possible for this test. In this analysis, the factor of condition corresponded to the blue axis versus the red axis. The significant effect of condition indicated that the blue and red axis hue discriminations were not equally difficult, although no strong systematic trends were apparent. No interactions were significant (see figure 3B).

Blue saturation. This test was the only one in which we found a main effect of group ($p = 0.012$; $F[2,33] = 4.46$). We also found a main effect of difficulty ($p = 0.0001$; $F[3,99] = 145.4$) as well as condition ($p = 0.0001$; $F[1,33] = 23.1$). Inspection of the data showed that the RTL group was impaired when making L discriminations. Consistently, there was a significant interaction between group and difficulty ($p = 0.004$; $F[6,99] = 3.4$), as well as between group and condition ($p = 0.012$; $F[2,33] = 4.5$). No other interactions were significant (see figure 3C).

Red saturation. In this case, the main effect of group just missed significance ($p = 0.066$; $F[2,31] = 2.96$). The performance of the LTL and the RTL groups was depressed compared with the NC group. We found a main effect of difficulty ($p = 0.0001$; $F[3,93] = 196.7$) as well as condition ($p = 0.0001$; $F[1,31] = 196.7$). The L condition was more difficult than the G condition. No interactions were significant (see figure 3D).

Contrast. Once again, the main effect of group just missed significance ($p = 0.058$; $F[2,32] = 3.1$). The performance of the LTL and RTL groups was depressed. We found a main effect of difficulty ($p = 0.0001$; $F[3,96] = 107.0$). No interactions were significant (see figure 3E).

Effects of target position. Given the generally normal performance after temporal lobectomy, it was not surprising that we observed no differential effects of target position in the oddball tests. We confirmed this impression statistically for the one test in which we found a clear group effect: the case of L discriminations of blue saturation. A mixed within-individuals and between-individuals ANOVA with two factors, group (RTL and NC) and target position (four levels), confirmed the main effect of group ($p = 0.009$; $F[1,26] = 8.05$) and indicated that there was no main effect of target position ($p = 0.559$; $F[3,78] = 0.69$) and no significant interactions.

Shape matching. Despite the more complex tasks used in this experiment, we obtained no evidence of a deficit after RTL or LTL (see figure 4). We performed three mixed ANOVAs and found no main effect of group for the limited contour, motion, or texture tests; the respective p values were ($p = 0.752$; $F[2,29] = 0.5$), ($p = 0.344$; $F[2,29] = 1.1$), and ($p = 0.699$; $F[2,28] = 0.3$). There was a significant effect of difficulty for all of the tests; the respective p values were ($p = 0.003$; $F[2,58] = 6.5$), ($p = 0.003$; $F[2,58] = 6.3$), and ($p = 0.001$; $F[2,56] = 176.0$).

Discussion. In this study, we assessed the performance of patients with LTL or RTL on a wide range of visual discrimination tests. The aim of the study was to determine whether the previously reported mild perceptual deficits after RTL extended to nonmeaningful stimuli, and also whether impairments of pattern or shape perception would dominate. We answered both questions in the negative. Despite the impaired performance of both LTL and RTL groups on the Mooney Closure Faces Test (see Methods), neither group displayed large deficits when making simple discriminations with meaningless stimuli. The following discussion reviews our results and previous studies of the effects of temporal lobe lesions in monkeys and humans.

Visual discrimination after temporal lobectomy. Overall, the performance of patients with LTL and RTL was remarkably good. The lack of main effects of group for so many tests largely allayed our concerns regarding the amblyopia of some patients, as well as any effects of anticonvulsant medication. Amblyopia might have been expected to reduce acuity for patterned stimuli, but we observed no deficits in that domain. One question is how to interpret the single significant effect of group for discrimination of blue axis color saturation, which was restricted to the RTL group when making L discriminations. We have no reason to expect that amblyopia would result in reduced color perception. The considerable size of this deficit, combined with the borderline significance of impairments for red saturation and contrast discrimination, argues for serious attention.

Impaired discrimination of hues at the blue end of the spectrum with relative sparing of the ability to discriminate other hues (incomplete achromatopsia) has been described previously in cortical lesion studies.[20-21] Zeki[22] suggested that this pattern of performance may result from the fact that short-wavelength–sensitive neurons are less common in visual cortex, making blue discrimination capacity more sensitive to partial loss of brain tissue. These lesion studies and PET studies concluded that the fusiform and lingual gyri are most critical for color vision in normal individuals (e.g., references 23 and 24). The cortex removed by LTL or RTL is more anterior to these classically defined color areas. It may be, however, that subtle color defects follow lesions to the more anterior temporal cortex as well.

Consistently, a selective deficit in blue color discrimination has been reported in patients with AD.[25] Given that the cerebral lesions in AD are multifocal, it is difficult to correlate the impairment with any particular visual cortical locus. However, the neuropathologic changes in AD are very prominent in the anterior temporal neocortical regions (areas 20, 21); only the medial temporal lobe structures are more severely affected.[26] Additionally, behavioral experiments suggest that the temporal neocortex and the associated ventral visual information processing pathway are particularly compromised in AD.[27-28] Thus, there is evidence that temporal lobe lesions due to AD or temporal lobectomy may cause some loss of blue color discrimination in humans. Finally, there is evidence from monkey studies that lesions of the anterior middle temporal gyrus (but not lesions of more posterior visual area V4, or more ventral rhinal cortex) cause deficits in color discrimination.[29]

Another issue is the selective impairment for L and not G discriminations of blue saturation. The ability to make such L discriminations appears to be particularly sensitive to the effects of cortical lesions.[17,30] However, we have found that the L condition is generally harder for normal individuals than is the G condition. So, it is possible that the increased difficulty underlies the increased sensitivity to brain lesions. However, we have observed specificity of the effect for color in patients with RTL, which argues against a generalized effect of difficulty. It is possible that discrimination of less prominent elements in a given visual domain requires special mechanisms that are disrupted when the visual cortical areas relatively dedicated to that domain are damaged.

The lack of significant effects of target position is not surprising, given the generally normal performance of patients with LTL and RTL. Even in the case of blue saturation discriminations, where performance was weak after RTL, the errors were not greater for the side of visual space contralateral to the lesion. It is known that the receptive fields of neurons in the inferotemporal cortex of monkeys are bilateral.[12] Information from the ipsilateral visual field is relayed from the opposite hemisphere, through the corpus callosum and anterior commissure.[31] Thus, we would not have predicted a strong

contralateral advantage even if we had discovered greater deficits in the RTL patients. Nonetheless, direct comparison of visual field positions has rarely been conducted in studies of humans with temporal lobectomy, so we considered the question worthy of consideration.

Finally, the shape matching test was our strongest test of shape perception after RTL. Our participants had no problems identifying and matching simple shapes under challenging conditions in which shape could be determined only from a single cue. Additionally, patients with LTL or RTL showed no disadvantage with texture and contour compared with motion cues relative to control individuals. We found this result somewhat intriguing, given the previous association between pattern and shape perception and the temporal neocortex, suggested by the human and monkey studies (e.g., references 7 and 8). We consider some possible explanations in the final section.

Relation to past studies. Given the evidence for perceptual deficits after temporal lobe lesions in humans and monkeys, it is striking that our participants performed normally. One possibility is that the mild "perceptual" difficulties of patients with RTL are tapped only by tasks in which the stimuli have semantic content. The difficulty may lie not in the analysis of basic visual cues but in the extraction of meaning from nonverbal stimuli such as faces, designs, and scenes. The Mooney Closure Faces test appears to require such extraction of meaning, given that a decision regarding the gender and approximate age of the faces is germane to the test. We cannot exclude the possibility, however, that face stimuli constitute a special class of visual stimuli and are processed by (at least relatively) dedicated circuits that are more vulnerable to RTL.[32,33]

Another important factor is that the anterior temporal lobe excisions in our participants may not have extended sufficiently posteriorly to elicit perceptual deficits. Since the 1950s, experience with the therapeutic effects of seizure focus removal has grown, and there has been a tendency to make smaller excisions. The size of the lateral removal in the temporal lobectomy patients studied here (measured posteriorly from the tip of the temporal lobe) ranges approximately from 3 to 6 cm (mean = 3.7 for LTL and mean = 5.6 for RTL) (see table). In the previous studies of temporal lobectomy that have found perceptual impairments after RTL, the lesion size was larger: 5.5 to 9 cm,[4] 5.6 to 9.0 cm (mode = 7 cm),[8] and 4.5 to 8 cm (mean = 5 cm).[6] All the measures cited here refer to surgical reports, which in general may tend to overestimate the size of the resections, compared with postoperative MRI quantification.[34]

Consistently, in monkey studies, it is lesions to the posterior temporal lobe (TEO) rather than lesions to the more anterior area (TE) that typically cause deficits in discrimination of patterns and objects.[35] Also, surgical excisions of the anterior temporal lobe in humans are always unilateral to avoid the dense global amnesia associated with bilateral medial temporal lobe removal, as witnessed in the patient H.M.[36] In contrast, only bilateral temporal lobe lesions in monkeys typically produce visual impairment.[37] Thus, with reference to the literature on monkeys, the unilateral lesions in our patients may help explain the lack of impairment of basic visual discriminations.

A final unresolved issue is whether all human visual areas are homologous (or at least analogous) to visual areas in monkeys and are located in grossly similar regions of the brain. Recent functional imaging studies (e.g., reference 38) indicate that many visual areas are shifted more posteriorly in gross location in humans than in monkeys. In particular, inferior temporal areas specialized for object vision seem to have a more posterior, inferior location in the human brain than do similar areas in monkeys.[39,40] Thus, evidence suggests that the neocortical removal in a typical anterior temporal lobe does not remove the human equivalent of monkey visual areas TEO and TE.

Further work is needed to determine the exact role of anterior temporal lobe structures in normal human perception. The results of the current study emphasize the lack of impairments in basic visual discrimination after anterior temporal lobe lesions in humans. When these results are considered in combination with the previously reported deficits in visual memory and complex perceptual tasks, a dissociation emerges. It seems likely that the semantic, associative component of many previously used tasks is critical for showing a deficit.

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