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Neuropsychological Studies of Object Recognition

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Neuropsychological studies of object recognition

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It is well established that disorders of visual perception are associated with lesions in the right hemisphere. Performances on tasks as disparate as the identification of objects from unusual views or objects drawn so as to overlap, of fragmented letters, of familiar faces, and of anomalous features in drawings, have been shown to be impaired in patients with focal right posterior lesions. A series of investigations are reviewed, directed towards analysing the basis of these deficits. Explanations in terms of primary visual impairment can be rejected, as can an account in terms of faulty figure–ground organization. It is argued that a wide variety of such perceptual deficits – all of which are concerned with meaningful visual stimuli – can be encompassed by the notion of faulty perceptual categorization at an early post-sensory stage of object recognition. Moreover, there is evidence suggesting that some of these various perceptual deficits can be mutually dissociated. The concept of perceptual categorization is discussed in the wider context of a tentative model of object recognition.

Introduction

The complex processes involved in the attainment of a meaningful percept are increasingly being analysed in terms of hierarchical stages. Neurological and neuropsychological data are particularly relevant to the problem of identifying and specifying the component processes of cognitive systems. The analysis of deficits in patients with brain lesions has provided an important source of evidence about object recognition ever since the first descriptions of selective perceptual deficits were reported by neurologists nearly 100 years ago (e.g. by Lissauer 1890; Poppelreuter 1917). But during the last 25 years there has been a marked shift in methodology: reports based on clinical observation, which no matter how insightful are at best anecdotal, have been superseded by experimental investigations, most commonly of group studies of a consecutive series of patients selected according to some anatomical criterion. In this paper I attempt to review those group studies that have contributed to our understanding of the cerebral organization of systems subserving object recognition.

It is now well established that a disorder of visual object recognition occurs in patients with post-rolandic lesions of the right hemisphere. The first quantitative study was reported by Milner (1958). Comparing patients who had undergone temporal lobectomy for the treatment of epilepsy, she found that the right-hemisphere group were significantly worse than a comparable left-hemisphere group on the McGill Anomalies test. This test requires patients to identify an anomaly in a sketchily drawn scene (figure 1) and she suggested that the right temporal lobe 'facilitates rapid visual identification' (a broader spectrum of surgical lesions was not available for investigation).

This finding was followed by a series of reports that patients with cerebral lesions restricted to the right hemisphere were impaired on a variety of visual perceptual tasks. The identification of overlapping familiar objects (figure 2) has been shown to be impaired in patients with lesions in the right hemisphere by De Renzi and his colleagues (De Renzi & Spinnler 1966;

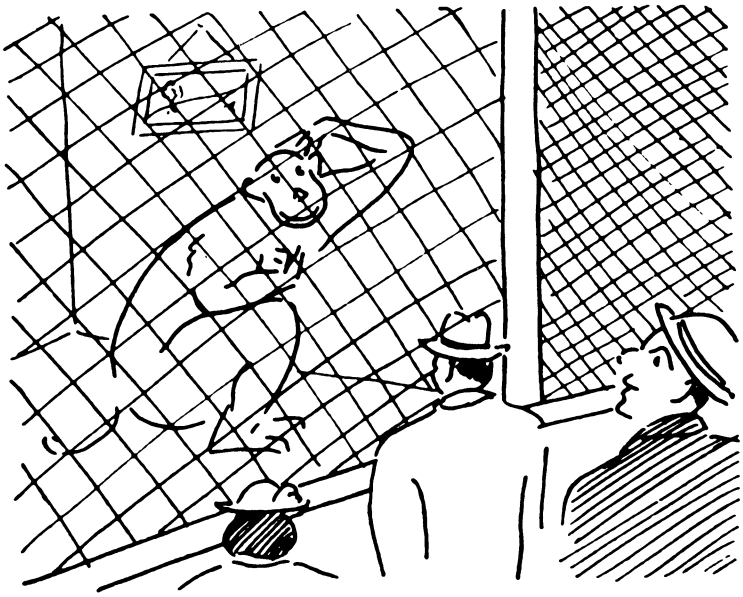

FIGURE 1. Example of an anomalous picture, from the McGill test (Hebb & Morton 1943).

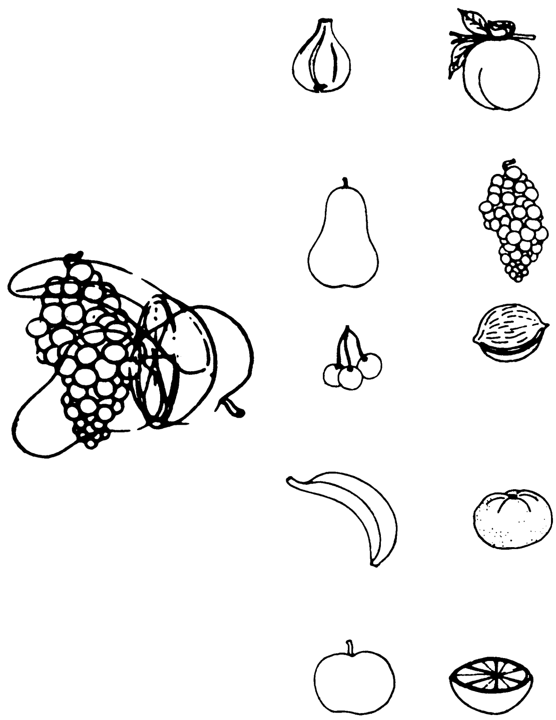

FIGURE 2. Example of an overlapping figure from Ghent's (1956) test.

De Renzi *et al.* 1969). In the absence of more direct evidence, they inferred from the presence of visual field defects that the critical location within the right hemisphere was post-rolandic. A similar result was obtained by using stylized silhouette drawings of objects (De Renzi & Spinnler 1966; Kerschensteiner *et al.* 1972). Warrington & James (1967*a*) tested a consecutive series of patients with verified localized unilateral cerebral lesions on Gollin's picture test, a

FIGURE 3. Example of a Gollin picture (Gollin 1960).

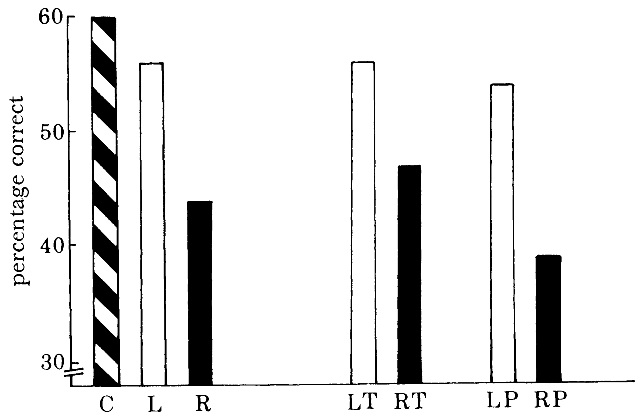

FIGURE 4. Gollin Pictures Test: percentage correct for each patient group. (Adapted from Warrington & James (1967 *a*).)

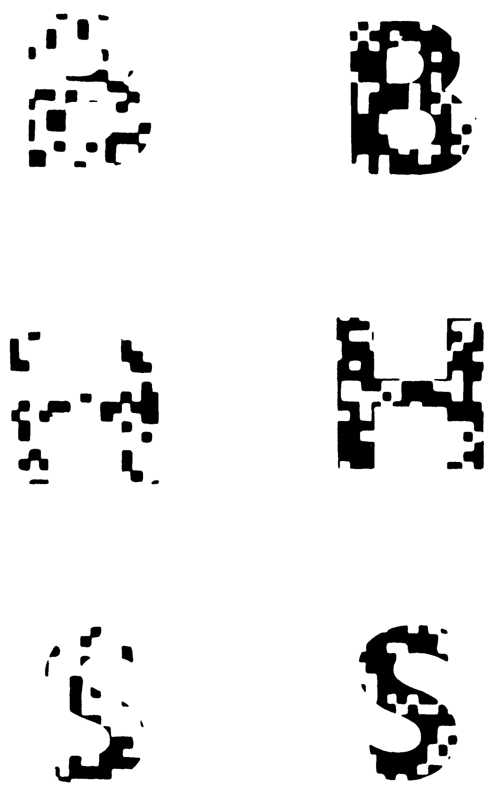

FIGURE 5. Examples from Incomplete Letters Test.

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graded difficulty task of identifying incomplete outline drawings of objects (figure 3). They found that there was an insignificant deficit in the right temporal group compared with the left temporal group, and there was a highly significant deficit in the right parietal group, compared with a comparable left parietal group (figure 4). This result was later replicated by Warrington & Taylor (1973): there was a significant right posterior deficit, but no trace of an impairment in the right temporal group compared with the left temporal group.

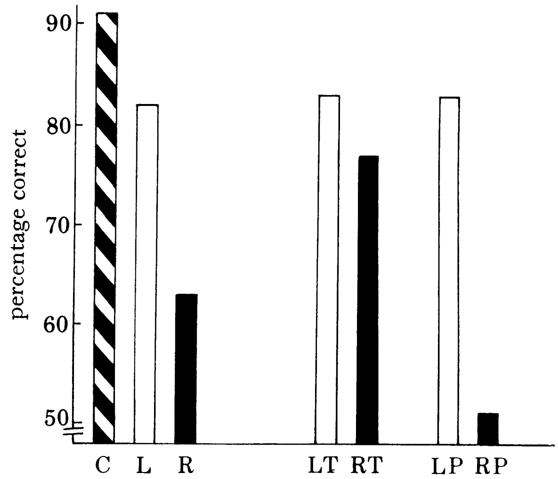

FIGURE 6. Incomplete Letters Test: percentage correct for each patient group. (Adapted from Warrington & James (1967*a*).)

The perception of other classes of stimulus material has also been shown to be impaired by a right posterior lesion. An impairment in the perception of photographs of faces was first noted by De Renzi & Spinnler (1966) and their findings were essentially replicated by Warrington & James (1967*b*) and Benton & Van Allen (1969). Newcombe & Russell (1969) obtained a similar result by using schematically drawn faces (the Mooney Closure test) in patients with unilateral missile injuries of the post-rolandic region of the right hemisphere.

Letters, too, if degraded along a perceptual dimension (figure 5) give rise to a right hemisphere deficit (Warrington & James 1967*a*). The task was simply to name, or to identify by tracing, each of 24 incomplete letters. Notwithstanding the fact that many of the patients in the left hemisphere group were dysphasic there was a striking deficit in the right parietal group compared with the comparable left parietal group (see figure 6). A similar result was reported by Faglioni *et al.* (1967).

These and other studies provide overwhelming evidence of a syndrome of faulty visual recognition associated with right hemisphere lesions. These effects are robust and have been replicated in patient groups with very different aetiologies. The hallmark of this syndrome appears to be a difficulty in perceiving meaningful visual stimuli when the redundancy normally present within the figure is reduced or degraded.

ANALYSIS OF THE SYNDROME

Given this evidence that performance on a wide range of apparently dissimilar tests of object recognition is impaired in patients with posterior right hemisphere lesions, the questions arise: What functional deficit or deficits would account for these impairments? Can we identify the critical component or components of the cerebral systems subserving object recognition that are damaged in these patients?

Visual sensory efficiency

It has been repeatedly demonstrated that the recognition deficit observed in patients with posterior right hemisphere lesions is not a trivial consequence of visual field defects. In all the group studies cited, the right hemisphere lesion groups were compared with comparable left hemisphere groups and it is a common finding that the incidence of visual field defects is much the same in the two groups. More pertinent, it has been well documented that this syndrome cannot be accounted for by raised sensory thresholds in supposedly intact parts of the visual field. For example, Ettlinger (1956) assessed the incidence of sensory deficits examining a number of psychophysical measurements in patients with localized cerebral lesions. Although he recorded substantial impairments of visual sensory efficiency in perimetrically intact sectors of the visual field, such changes were not correlated with the presence of clinically identified cognitive disorders of perception. Similarly, Warrington & Rabin (1970) found that while tachistoscopic threshold measurements for detecting the presence or absence of a 'black dot' or identifying a letter (not degraded) in the central visual field were impaired in all brain-damaged groups, the critical right parietal group were not selectively impaired. In this and in subsequent experiments to be reviewed a consequentive series of patients with unilateral cerebral lesions were tested. These patient groups were further subdivided into 'anterior' and 'posterior' subgroups. A normal control group (patients with extracerebral lesions) were tested to obtain an estimate of task difficulties.

Contour discrimination

We considered next the hypothesis that the impairment of object recognition in these patients could be accounted for by a deficit at the level of contour discrimination (Taylor & Warrington 1973). Subjects were required to discriminate between two lines of different length, between two circles of different sizes and between two triangles with straight or curved sides (see figure 7). The performance of the right hemisphere group was very similar to that of the left hemisphere group and not significantly impaired compared with the normal control group, and in particular the right posterior group were not impaired compared with the controls on any of these three tasks (figure 8). These results are unlikely to be due to an artefact of task difficulty or of patient selection since on an equally simple task of similar difficulty, namely position discrimination, a highly significant deficit was found in this same right posterior group (Taylor & Warrington 1973).

This is not an unimportant negative finding because of course an inability to discriminate contours does indeed give rise to difficulties in the perception of meaningful stimuli. For example, Efron (1968) has described in some detail a patient recovering from cortical blindness (bilateral lesions) who was unable to judge whether two distinctive shapes (square or oblong) were the same or not, in spite of having intact brightness and hue discrimination. We have recently replicated his findings in a patient, J.A.F., with bilateral occipital lobe lesions (Warrington, unpublished observations). Moreover, J.A.F. was quite unable to do the 'triangles' test. Both of these patients were very impaired in their ability to recognize objects by sight and it seems plausible to suggest that their deficits were at the level of contour discrimination. But the point remains that recognition impairments can still occur even when contour discrimination is preserved.

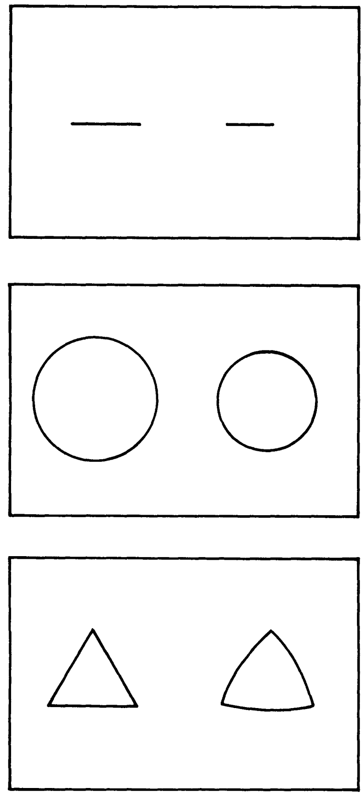

Figure 7. Contour discrimination stimuli: examples of lines, circles and triangles.

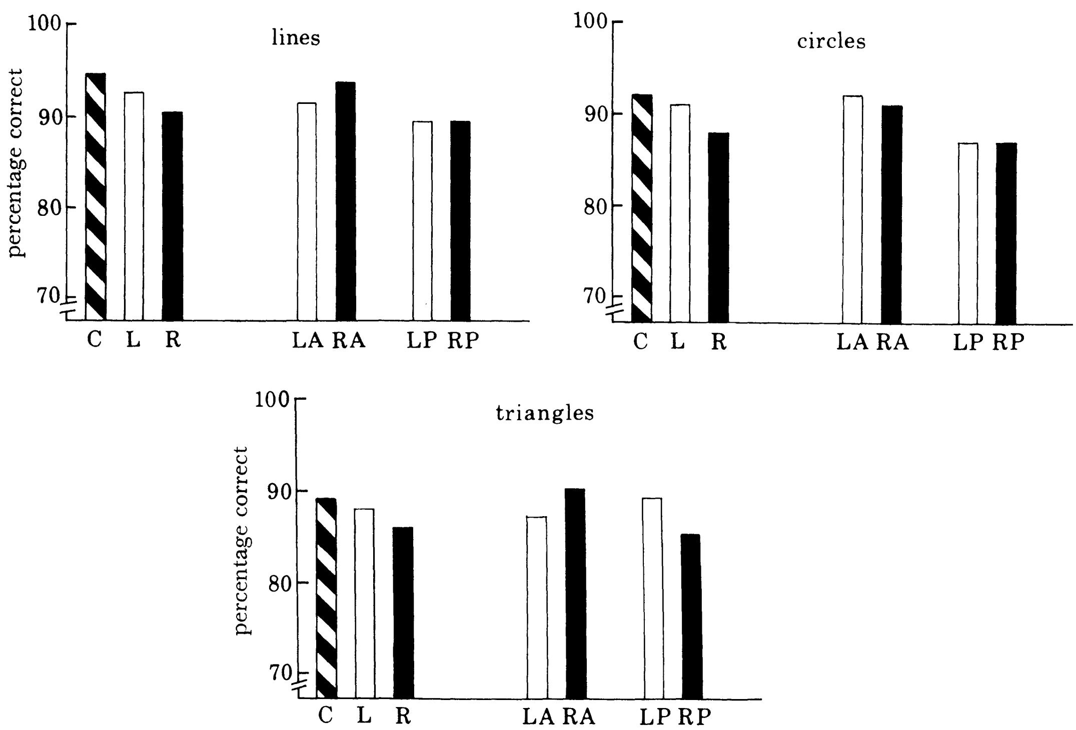

Figure 8. Contour Discrimination Test: percentage correct for each patient group. A, anterior lesion; P, posterior lesion. (Adapted from Taylor & Warrington (1973).)

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Figure–ground discrimination

A deficit at the level of figure–ground discrimination seemed a plausible candidate to consider. It could be argued that the normal redundancy of the figure or the signal: noise ratio is reduced in the type of visual stimuli that were first used to identify the object imperception syndrome. In order to test whether this was a critical variable, it seemed appropriate to devise a task in which there was no identification component, but at the same time in which the signal: noise ratio could be altered so as to vary the difficulty of the figure–ground discrimination.

FIGURE 9. Example of figure–ground stimulus.

The test stimuli comprised a fragmented letter (an X or an O) superimposed upon a fragmented background (figure 9) and they were graded in difficulty by varying the relative ratio of black to white in the figure and the background.

The subject was thus required to detect the presence or absence of a *known* letter stimulus. He was asked 'is the "X" there or not'? Although the right hemisphere group was significantly worse than the control group, there was not a significant difference between the right and left hemisphere groups, and in particular the right posterior group was not selectively impaired (figure 10). Since there was neither a floor effect nor a ceiling effect in the control group on this task, it seems unlikely that the absence of a significant deficit in the right parietal group can be attributed to an artefact of task difficulty or, for that matter, to a selection artefact, as this same group of patients was impaired on two tasks of object identification (Warrington & Taylor 1973). I would therefore argue from this result that the organization of contour information into coherent forms or gestalts is not the critical factor and that the patients in the right posterior group can achieve an adequately structured percept.

However, this negative finding does not deny the possibility of the existence of a disorder of figure–ground perception in other classes of patients. Indeed, I have some preliminary evidence that such a deficit is associated with bilateral occipital lobe lesions.

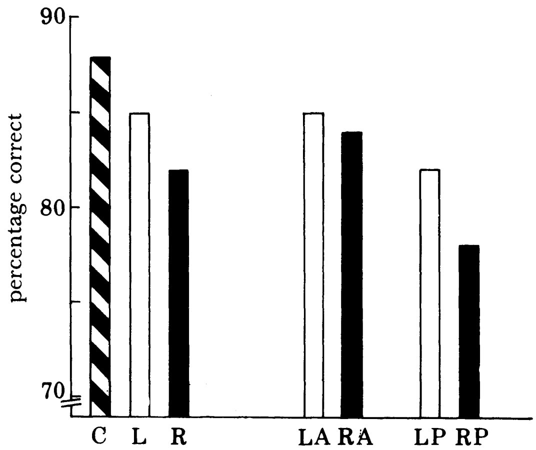

FIGURE 10. Figure–Ground Test: percentage correct for each patient group. (Adapted from Warrington & Taylor (1973).)

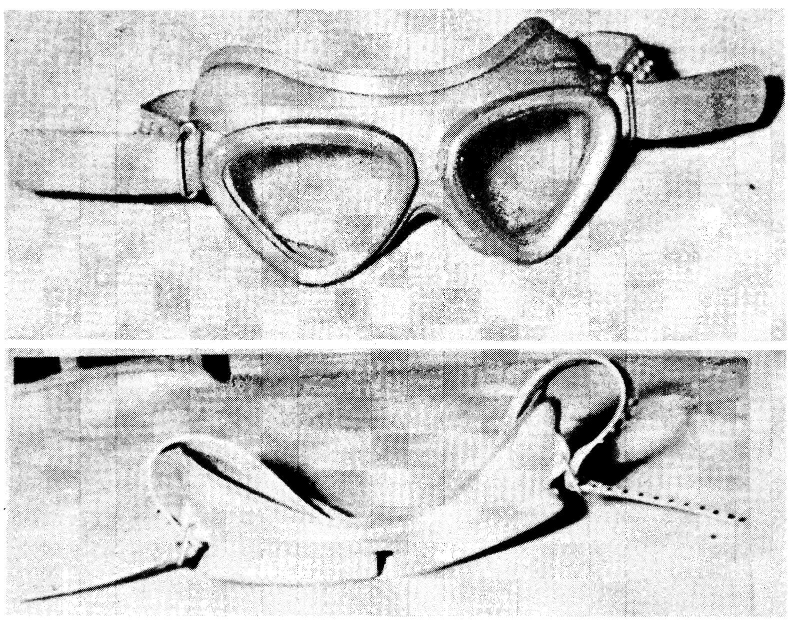

FIGURE 11. Example of prototypical and 'unusual' views of an object.

Perceptual categorization

If our analysis is accepted that the right parietal imperception syndrome cannot be accounted for in terms of disorders in contour or figure–ground discrimination, then by elimination a perceptual categorization hypothesis becomes plausible. Efficient object recognition requires a mechanism whereby a set of two or more stimulus inputs are allocated to the same perceptual category. For example, we have the capacity to identify an object from an infinite variety of orientations, distances and luminances.

To pursue this question we devised a test of object recognition in which the angle of view was varied. We contrasted identification of a prototypical or iconical view with a view which, though not necessarily unfamiliar, was considered to be a non-prototypical view, an 'unusual' view (Warrington & Taylor 1973). The designation of prototypical and non-prototypical was at this stage determined entirely arbitrarily (I decided) (figure 11). This technique has the advantage that the conditions of the task are constant except for angle of view. The test stimuli comprised photographs of 20 common objects, each photographed from two angles of view. Subjects were first required to name or identify each of the unusual view photographs and secondly each of the prototypical views. It was found that the error rate on the prototypes was

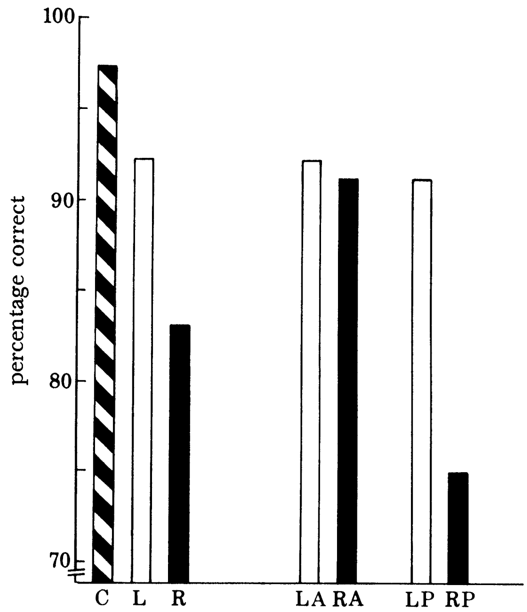

FIGURE 12. Unusual Views Object Test: percentage correct for each patient group. (Adapted from Warrington & Taylor (1973).)

very low and there was no deficit in any patient group, including the right posterior group. However, identification of the unusual views was very significantly impaired in the right hemisphere group compared with the left hemisphere group, and this deficit was selective to the right posterior group (figure 12).

Although in everyday life objects are seen from an infinite number of orientations, admittedly some will be more familiar than others; these findings suggest that for efficient object recognition there is a favoured view and it is the right posterior lesion group that are less able to tolerate a deviation from this prototypical representation. We interpreted this deficit in terms of a failure of perceptual categorization.

Other transformations from the prototypical view are also important. It was observed that changing the direction of illumination is as effective as changing the angle of view for eliciting a right hemisphere deficit. A prototypical view of an object that was evenly illuminated was contrasted with the identical prototypical view unevenly lit, so that it was partly obscured by shadows (figure 13). The test stimuli comprised photographs of ten common objects each photographed under two lighting conditions. It was found that there was a significant effect of uneven lighting for the right hemisphere group compared with the left hemisphere group, and again the deficit was especially conspicuous in the right posterior group (figure 14) (E. K. Warrington & C. Ackroyd, unpublished). This finding too we would interpret in terms of a

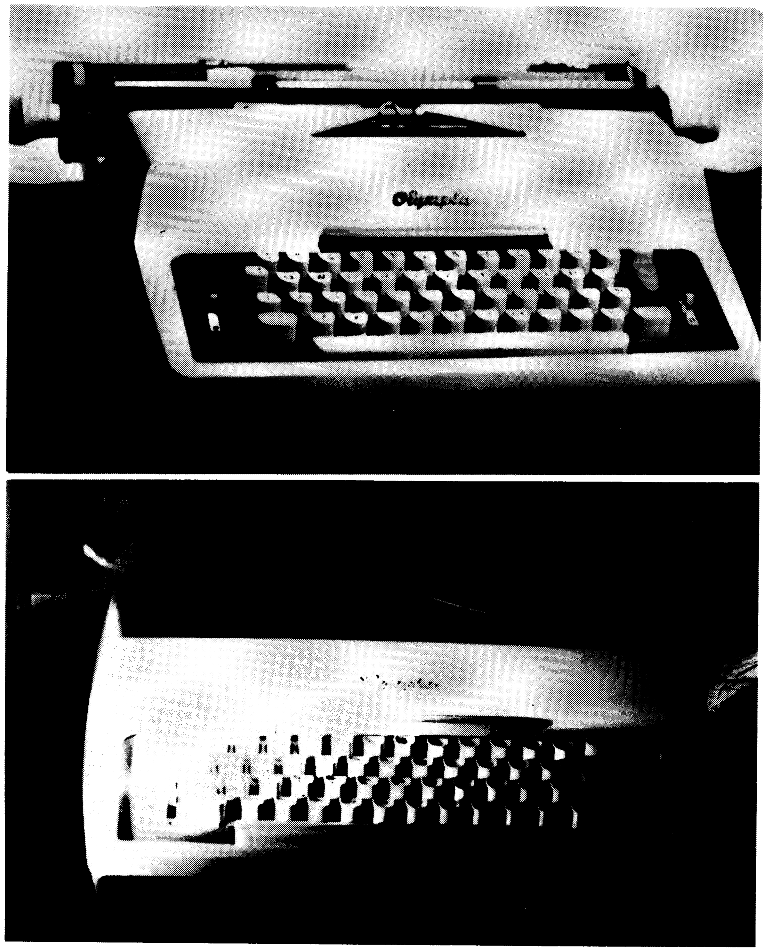

FIGURE 13. Example of evenly and unevenly lit object.

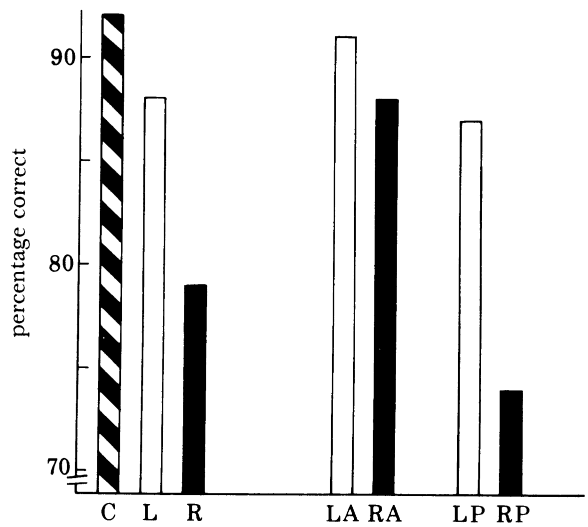

FIGURE 14. Lighting–'Shadows' Test: percentage correct for each patient group.

failure of perceptual categorization, the right posterior group being unable to tolerate the normal degree of deviation from the prototypical representation of the objects that causes no difficulty for normal subjects.

A more direct test of the perceptual categorization hypothesis was devised by pairing a prototypical view of an object with an 'unusual' view. In this test the subject was not required to identify either representation of the object, but merely to judge whether or not they were photographs of the same object taken from different angles of view. The test stimuli consisted

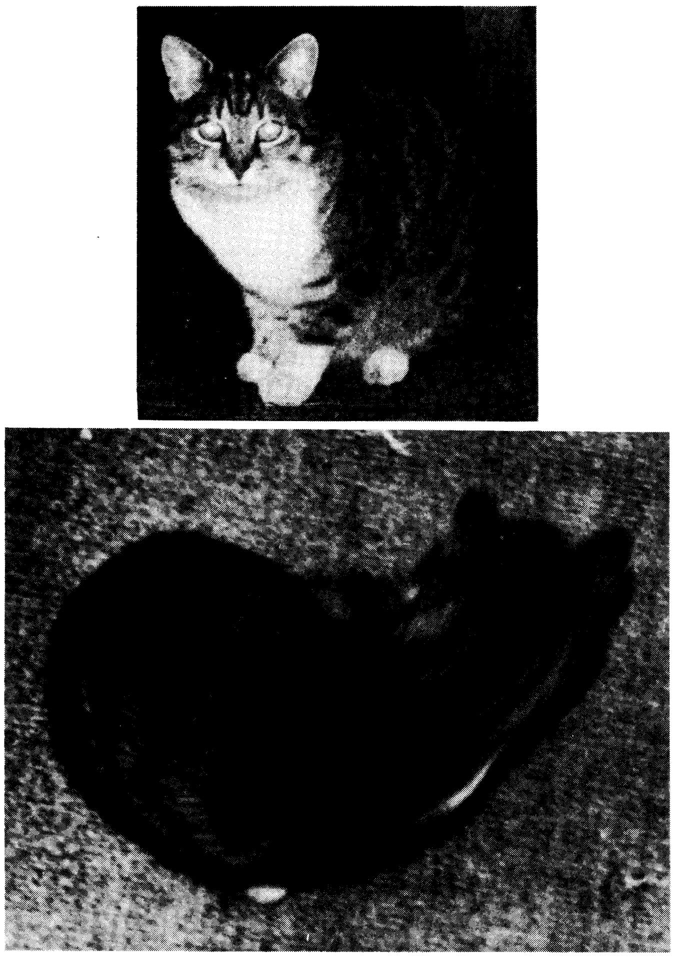

FIGURE 15. Example from Same–Different Unusual Views Object Test.

of 20 pairs of photographs in which 10 pairs were photographs of the same object and 10 pairs were of different objects (figure 15). It was found that the right hemisphere group were significantly worse than the left hemisphere group and, furthermore, the right posterior group were selectively impaired on this task (figure 16). It had already been established that the prototypical view could be identified by the right posterior group, at least as well as the other lesion subgroups, yet given an explicit perceptual hypothesis (a photograph that they succeeded in naming and identifying) they still failed the task (Warrington & Taylor 1978).

This matching by physical identity task demands that the subject allocate to the same

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category different representations of the same object. The detection of similarity breaks down in the right posterior group of patients, and the categorization of percepts by physical identity is impaired. I would therefore argue that this result reinforces our interpretation of this syndrome and that we have identified an impairment of object recognition at the level of visual processing at which perceptual categorization is normally achieved.

The mechanism that achieves perceptual categorization is at present obscure. Two major contenders in the experimental literature are theories of template matching and of feature

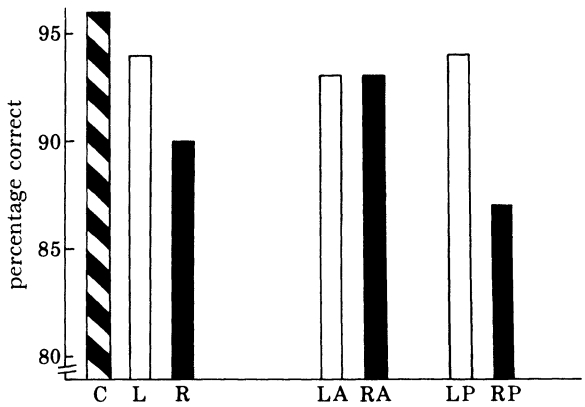

FIGURE 16. Same–Different Unusual Views Object Test: percentage correct for each patient group. (Adapted from Warrington & Taylor (1978).)

analysis (see, for example, Neisser 1967). However, it is possible to bridge the differences between these concepts by the superordinate hypothesis suggested by Sutherland (1973) that an abstract structural description is stored. In line with this view, Marr & Nishihara (1978) state, 'shape recognition involves: (i) a collection of stored shape descriptions and (ii) various indexes with the collection that allow a newly derived description to be associated with an appropriate stored description'. Indeed, they draw on the evidence of the 'unusual views' finding to support their formulation. From such a perspective, perceptual categorization would fail if either the stored abstract structural description were damaged or access to it were impaired.

At any rate an appeal to a spatial factor to explain the unusual view finding fails. Rotation either of the image or of the central representation begs the question. Before identification, except for two-dimensional objects such as geometrical shapes or letters, rotation would yield no useful information. Furthermore, orientation is not the only transformation that is effective. Changing the lighting conditions of the prototype gives rise to the same class of deficit. I would argue that if we could identify the crucial characteristics of a prototypical view, this would provide direct evidence as to the properties of the central representation of the stored description of an object at a perceptual level (see below).

So far I have applied the concept of perceptual categorization to photographs of real objects. But of course I would argue that this formulation is equally applicable to other classes of visual stimuli that give rise to this right hemisphere syndrome: overlapping figures, faces, fragmented objects, incomplete letters, and so on. However, although I would accept that a unitary mechanism links these deficits, some evidence is now emerging that suggests a degree of material specificity in their organization.

Material specificity of perceptual categorization

Whiteley and I were alerted to the possibility of a double dissociation between different classes of visual stimuli when we were investigating three patients with prosopagnosia (a failure to recognize faces well known to them). These patients were tested on a wide range of visual and perceptual tasks and we attributed their deficit to impaired perceptual categorization – a categorization failure selective for faces (Whiteley & Warrington 1977).

Figure 17. Example from Same–Different Faces Test.

Table 1

(Percentage correct; $N = 20$.)

	unusual views	incomplete letters
case 1	30	83
case 2	95	42

Modified from Whiteley & Warrington (1977).

These patients, each having a unilateral right hemisphere lesion, were alike in so far as their perception of faces was impaired, i.e. on a same/different matching test for faces (see figure 17). Yet, one of these patients (case 1) had no difficulty whatever in identifying unusual views and one (case 3) had no difficulty in identifying incomplete letters (see table 1). Thus here we have on these two tests a double dissociation of deficits.

We were therefore interested in the incidence of such dissociations and in particular double dissociations between perceptual skills for different classes of visual stimuli, namely objects, letters and faces, and because of the possible role of the right posterior hemisphere for topographical skills (De Renzi, this symposium) we included a test of perception of buildings. In the context of a more comprehensive investigation of visual perceptual and visual memory skills in patients with unilateral right hemisphere lesions, the following four perceptual tests were administered to a group of patients with right hemisphere lesions and to a normal control group.

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1. *Unusual views.* The test stimuli consisted of 20 photographs of common objects photographed from an angle considered to be non-prototypical (see figure 11). Subjects were required to name or identify each object.

2. *Incomplete letters.* The test stimuli consisted of 24 incomplete letters in which the ratio of black to white was 30:70 (see figure 5 above). Subjects were required to name or identify each letter.

3. *Faces matching.* The test stimuli consisted of 20 pairs of photographs of faces taken from different views (a profile was paired with a full face), 10 pairs being of the same person and 10 pairs of different people. The subjects were required to judge whether or not the photographs were of the same person (see figure 17).

4. *Buildings matching.* The test stimuli consisted of 20 pairs of photographs of buildings photographed from different angles, 10 pairs being of the same building and 10 pairs of different buildings. The subjects were required to judge whether or not the photographs were of the same building (see figure 18).

FIGURE 18. Example from Same–Different Buildings Test.

It was found that there was a highly significant deficit in the right hemisphere group on all four perceptual tests (see figure 19) (Whiteley & Warrington, in preparation). We attempted to assess the incidence of selective deficits by comparing an individual's performance on each pair of tests and counting the number of instances of normal performance on the one test and severely impaired performance on the other test. A 'normal' score was defined as being within 1 s.d. of the mean score of the normal control group and an impaired score as being more than 3 s.ds below the mean score of the normal control group. The number of dissociations for each comparison is given in table 2 (in brackets are the number of dissociations for an even more stringent criterion, namely a cut-off for impairment of 4 s.ds below the mean). Double dissociations of performances occurred for three of the six comparisons, unusual views *v.* letters, letters *v.* faces and buildings *v.* unusual views. The result of the first of these comparisons replicates our earlier finding of a double dissociation of deficits on unusual views and incomplete letters in two of our prosopagnosic patients. There were instances of single dissociations for the other three comparisons, namely faces normal but buildings impaired, faces normal and unusual views impaired, and unusual views normal and buildings impaired. I would stress that we have

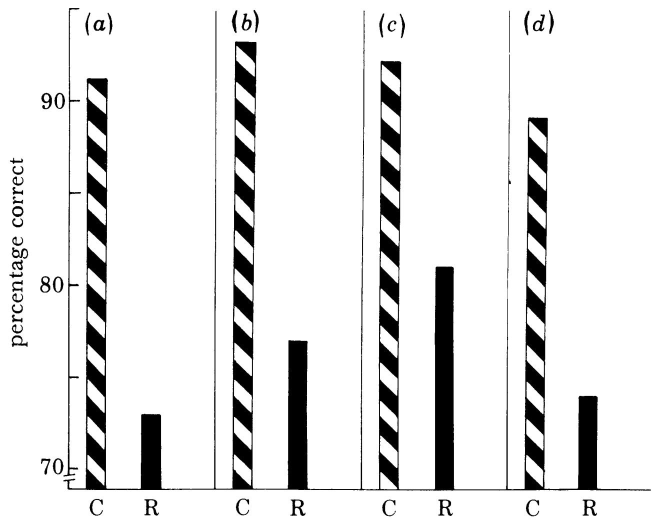

FIGURE 19. (*a*) Unusual Views, (*b*) Incomplete Letters, (*c*) Same–Different Faces, (*d*) Same–Different Buildings Tests: percentage correct for the control group and the right hemisphere group on each test (Whiteley & Warrington, in preparation).

TABLE 2. INCIDENCE OF DISSOCIATIONS

		normal performance			
		unusual objects	incomplete letters	faces	buildings
impaired performance	unusual objects	—	3 (3)	4 (2)	—
	incomplete letters	1 (1)	—	7 (5)	1 (1)
	faces	—	2 (2)	—	—
	building	1 (0)	1 (0)	2 (0)	—

used a stringent criterion for dissociation of deficit. Yet in a population (namely the right hemisphere group) that is significantly impaired on all these tasks, 22 instances of dissociation have occurred in 12 out of 50 patients tested. Whatever method or assumptions one makes to calculate an expected chance value, our observed values are strikingly high. (By one conservative estimate the chance expected values are less than three instances for the 3 s.d. cut-off and less than one instance for the 4 s.d. cut-off (Whiteley & Warrington, in preparation).)

A NEUROPSYCHOLOGICAL MODEL OF OBJECT RECOGNITION

Finally, I shall attempt to place the concept of perceptual categorization in a wider context. This stage of visual processing is evidently independent of language and verbal hypothesis since it is the right, not the left, hemisphere that is implicated. But the more pertinent questions are: Is it a pre-semantic stage of visual processing? Is object recognition at the level of knowledge of meaning achieved by right or left hemisphere systems? Evidence from single case studies indicates that perceptual categorization can be achieved without knowledge of meaning (Taylor & Warrington 1971; Warrington 1975; Hécaen *et al.* 1974) and, moreover, that a failure of object recognition can occur in patients with lesions lateralized to the left hemisphere (Hécaen & Ajuriaguerra 1963; Hécaen *et al.* 1974; Nielsen 1937). There is also evidence from group studies that semantic categorization of visual objects is a system lateralized to the left hemisphere. De Renzi *et al.* (1969) reported the first quantitative evidence of a double dissociation between what I have termed perceptual categorization and semantic categorization.

Figure 20. Example from Matching-by-Function Test.

Following their procedures, we devised a task in which perceptual categorization skills were minimized and semantic categorization skills maximized. Instead of requiring the subject to match photographs by physical identity we required matching by functional similarity (Warrington & Taylor 1978).

The test stimuli consisted of 20 sets of photographs of common objects, all of which were intended to be prototypical views. Each set consisted of two objects with the same function although being physically dissimilar (e.g. an open and closed umbrella) and one object being functionally somewhat different (e.g. walking stick). The two dissimilar-function object photographs were arranged as a pair, and the subject was required to match the third object with the one of the pair having the same function (see figure 20). The subjects were subsequently required to identify either by naming or by description each individual photograph used in the matching-by-functions test. On the matching-by-function task there was a significant deficit in both the right and the left hemisphere groups. A plot of the function-matching error score as a

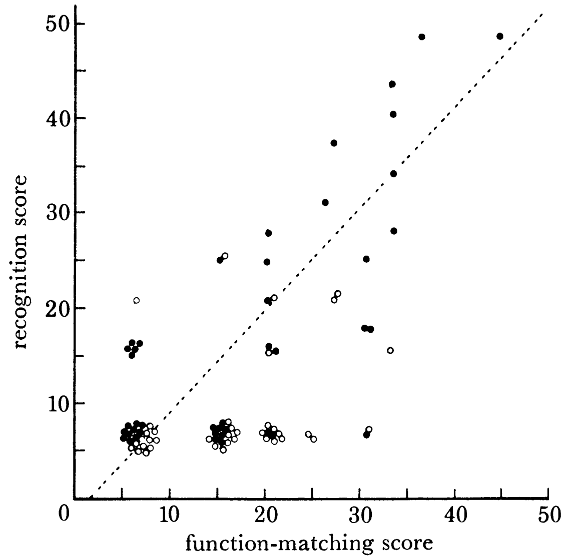

FIGURE 21. Individual patient scores (arcsin transformed) on the two measures of the Function-Matching Test: ●, right hemisphere group; ○, left hemisphere group. The dotted line represents the regression of the matching-error scores on the error scores obtained from the control group. (From Warrington & Taylor (1978), reproduced by permission.)

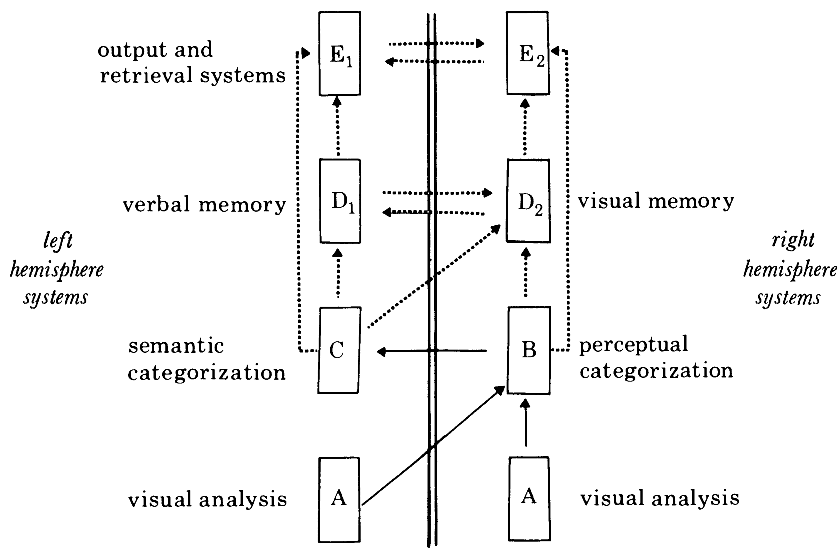

FIGURE 22. Model of the stages of object recognition. (From Warrington & Taylor (1978), reproduced by permission.)

function of the identification error score is given in figure 21. The performance of the right hemisphere group appears to be determined directly by the incidence of misrecognition errors whereas the left hemisphere group were impaired on the function-matching test in spite of a very low incidence of errors of recognition. If one partials out the effects of perceptual impairments, there is on this task a significant deficit in the left hemisphere group compared with the right hemisphere group and this deficit is selective to the left posterior group. I would argue that this deficit reflects a failure of object recognition at the level of semantic categorization.

A tentative model of the cerebral organization of object recognition is indicated in figure 22. This model stated in its strong form would postulate complete lateralization of function but stated in a weaker form would merely postulate hemispheric specialization. For the present exposition no commitment as to the relative degree of lateralization is made, nor is it assumed that there is the same degree of hemispheric specialization for the different stages of the model. This model specifies two serially ordered post-sensory categorical stages of visual object recognition. It is assumed that visual analysis resulting in a structured percept is achieved by the visual cortices (system A), there being no lateralization of function at this level of analysis. The first categorical stage that achieves perceptual categorization (system B) is viewed as a post-sensory pre-semantic system. The input to this first categorical system is held to be from bilateral structures in the occipital lobes, this perceptual categorization system being lateralized to structures within the right posterior cortex. The second categorical stage that achieves semantic categorization (system C) is lateralized to structures within the left posterior cortex, and is held to operate on the categorized output from the perceptual categorization system. According to this formulation the integrity of both hemispheres is necessary for the recognition of meaningful visual stimuli.

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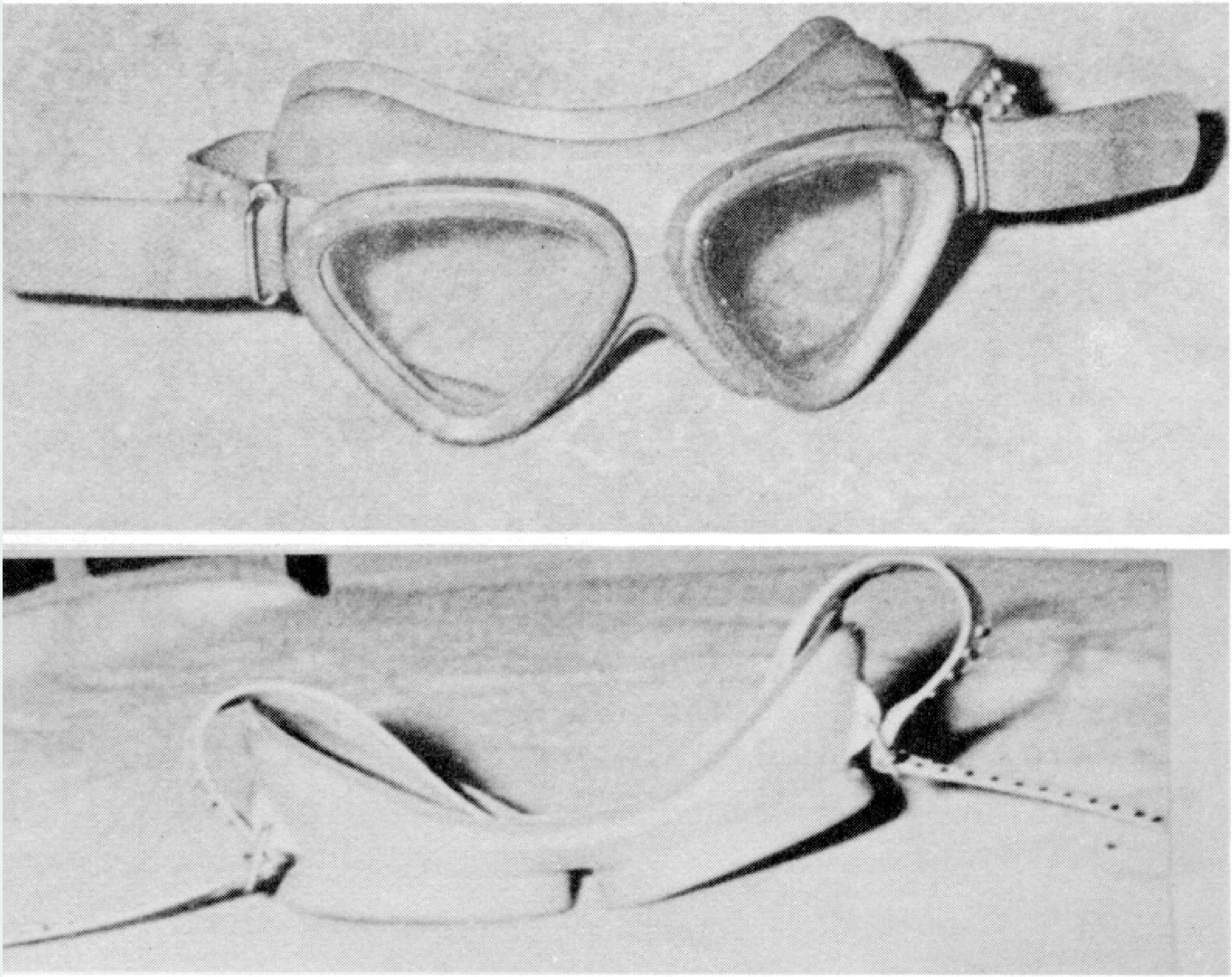

FIGURE 11. Example of prototypical and 'unusual' views of an object.

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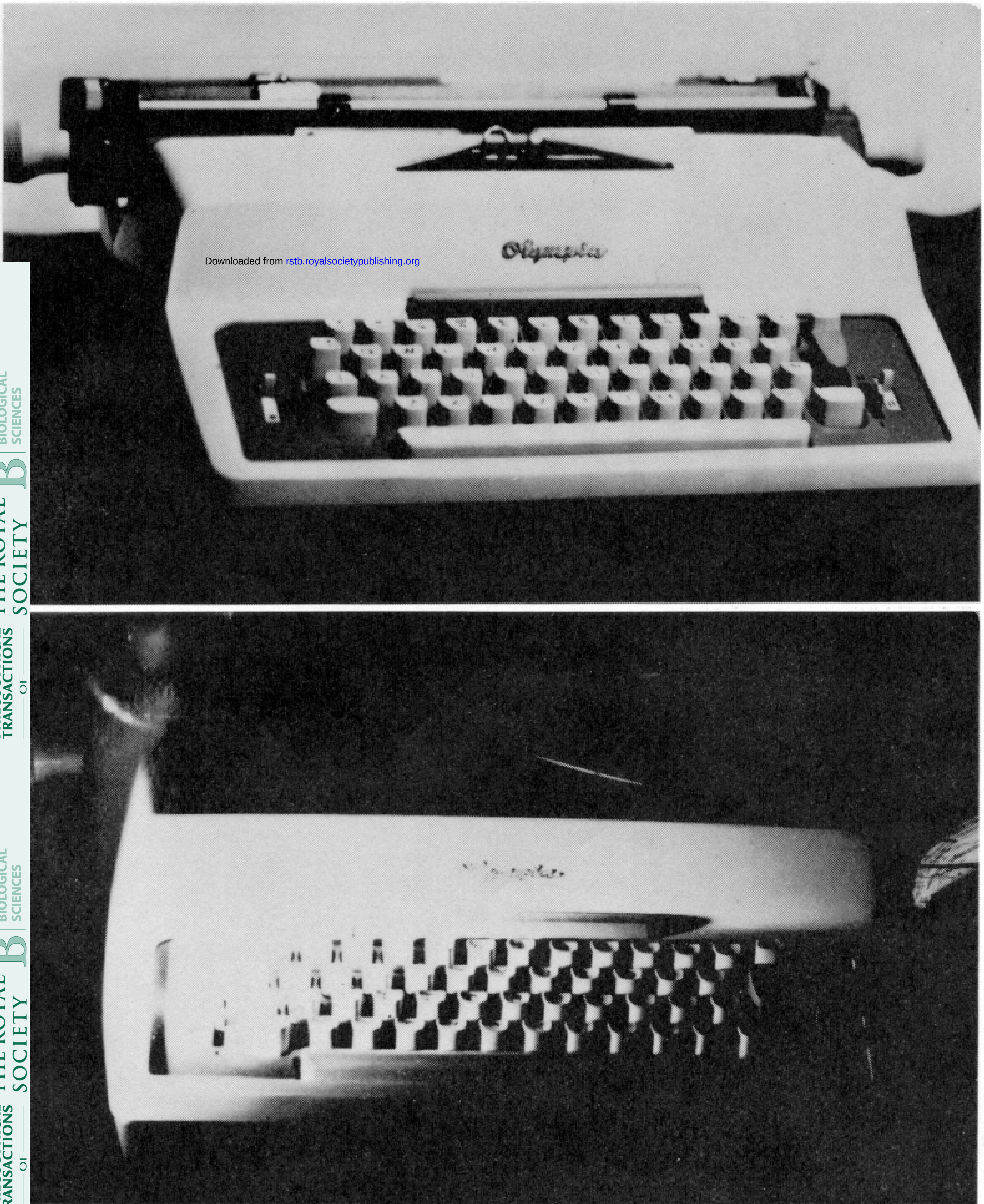

FIGURE 13. Example of evenly and unevenly lit object.

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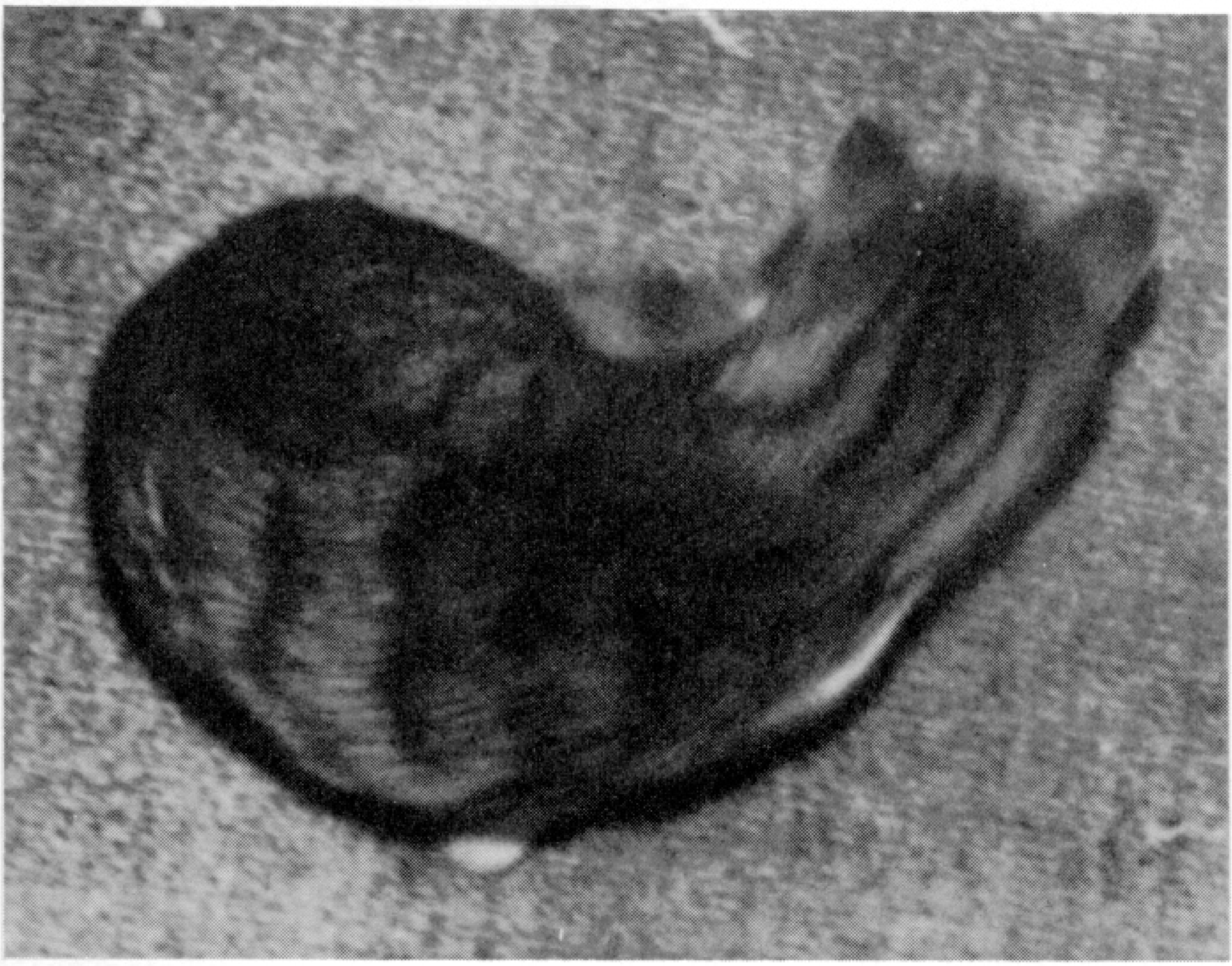

GURE 15. Example from Same–Different Unusual Views Object Test.

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FIGURE 17. Example from Same–Different Faces Test.

FIGURE 18. Example from Same–Different Buildings Test.

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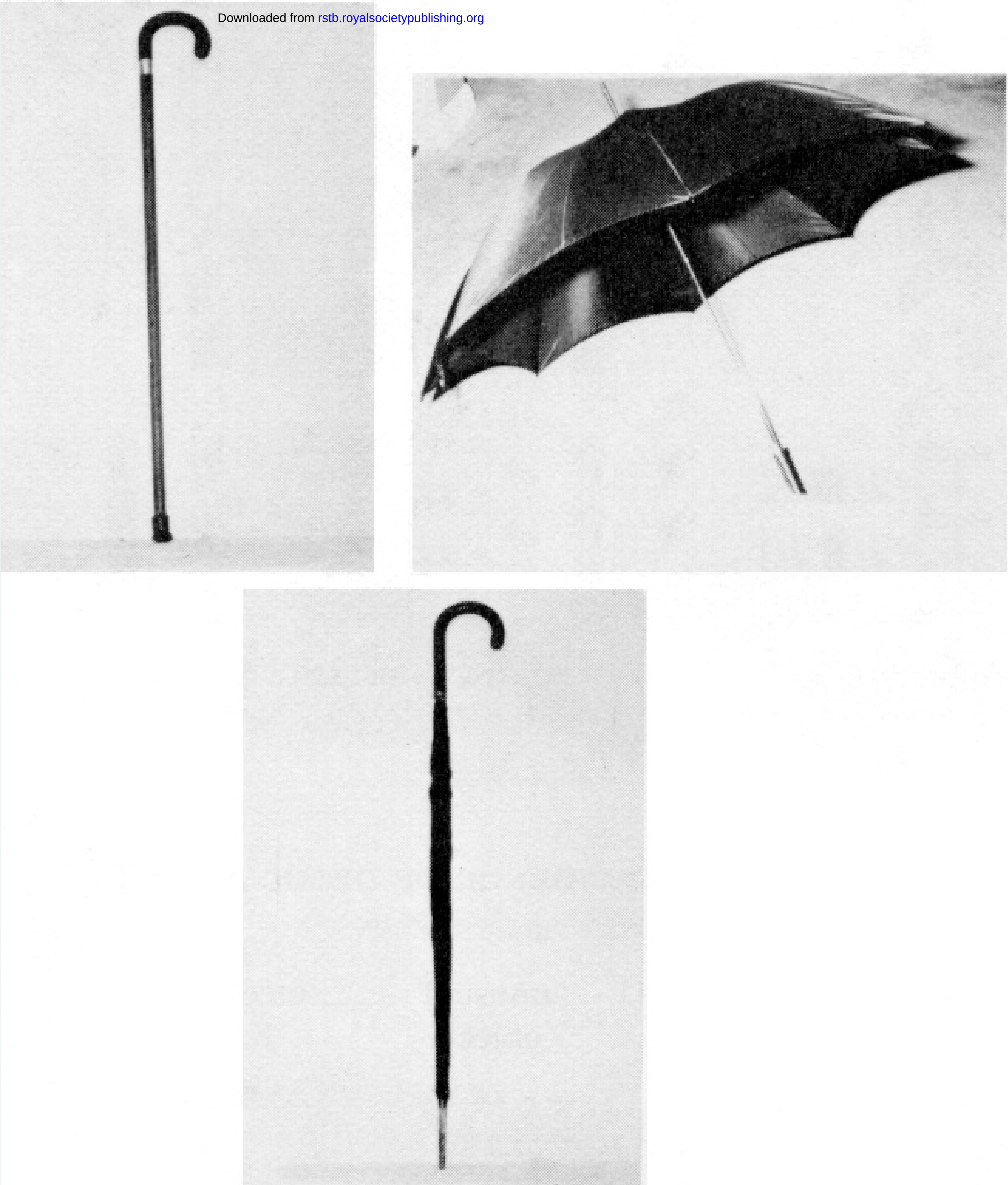

FIGURE 20. Example from Matching-by-Function Test.

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