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Intact Visual Imagery and Impaired Visual Perception in a Patient With Visual Agnosia

Marlene Behrmann, Morris Moscovitch, and Gordon Winocur

Although it is now well accepted that visual mental imagery and visual perception share common underlying mechanisms, there are several reports in which they are dissociated. Evidence for the separability of these processes is provided by a patient, C. K., who has a profound visual object recognition deficit attributable to an impairment in grouping or segmenting visual images. Despite this perceptual deficit, C. K. was able to draw objects in considerable detail from memory, and his knowledge of the visual appearance of objects was preserved on a variety of mental imagery tasks. Together with previous cases, these findings confirm the double dissociation between object recognition and perception. Interestingly, C. K. could also recognize newly constructed objects in his internal imagery. To accommodate these results, we propose a model in which imagery and perception are strongly associated but are also functionally specialized.

During object recognition, the retinal image is processed and then mapped onto a stored long-term canonical representation that captures some of the invariant properties of the object (Pinker, 1984, 1985). During mental imagery, the visual appearance of an object is reconstructed from a canonical mental representation that is retrieved from long-term memory (Farah, 1984, 1985; Finke, 1985; Kosslyn, 1987). Although it has been suggested that mental imagery resembles the actual perception of an object or event (Finke, 1989), it is unclear to what extent visual perception and mental imagery use common mechanisms. Researchers (Farah, 1984, 1988; Kosslyn, 1980, 1987) have argued that input (perception) and output (imagery) processes draw strongly on the same set of stored representations or underlying codes. Some have gone even further, proposing that visual imagery and perception also share a common neural substrate and that imagery uses neural mechanisms that are ordinarily dedicated to visual perception. According to these views, during object recognition, an external image is projected onto the retina and passes through a visual buffer and various stages of early visual processing in the parietal and temporal lobe until it is recognized through the activation of stored associative memories. During mental imagery, stored associative memories are activated and projected down the same visual pathways onto the same visual buffer that is used in object recognition. The generated image is then subject to inspection and further processing. This bidirectional flow of information is made possible by the direct cortico–cortico connections from higher level visual areas to lower level areas (Douglas & Rockland, 1992) and by the presence of afferent and efferent connections from each visual area to a second visual area (Van Essen, 1985).

In addition to having the appeal of parsimony, the view of common representations and neural substrate for visual imagery and perception has garnered much support from empirical research. Findings from a variety of studies on both normal and brain-damaged people have confirmed that perception and mental imagery are strongly associated. Notwithstanding this overwhelming positive evidence, there are reports of patients who have deficits in imagery despite having intact perception or object recognition (Farah, 1988; Riddoch, 1990). A critical question is how to accommodate this pattern of dissociation in the context of a model that proposes shared mechanisms for imagery and perception. One possible explanation for this single dissociation might be that imagery is just a more complex and demanding operation and, as such, is more vulnerable to the effects of brain damage than is perception (see Tippett, 1992, for a review; also Kosslyn et al., 1993). This would imply that there is a single common system, but that imagery and perception are not equally complex and demanding processes. If this were indeed the case, however, one would not expect to find a case of the converse pattern with the more complex imagery task preserved and the simpler perception task impaired.

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In this article, we present data from a patient, C. K., who has a profound visual object recognition deficit or object agnosia following a closed-head injury. We rule out the explanation of differential complexity of imagery and perception by demonstrating that C. K. shows the complementary pattern of preserved imagery in the context of a profound visual recognition deficit. Although the pattern of intact imagery and impaired perception has been reported previously (Jankowiak, Kinsbourne, Shalev, & Bachman, 1992; Riddoch & Humphreys, 1987), we argue that C. K. shows the most clearcut example of this dissociation. That the supposedly "more complex" task (imagery) is preserved whereas the less demanding task (perception) is impaired seriously undermines the view that imagery and perception are hierarchically arranged in complexity. Instead, the existence of a double dissociation between imagery and perception is established and demands explanation in the context of shared mechanisms. In the rest of the article, we focus on the relationship between imagery and perception.

Because considerable data favor the strong association between the representations and neural substrate used in imagery and perception and because it is within this context that the current investigation is undertaken, we provide an overview of this evidence. We also outline the existing data showing the dissociations between imagery and perception in neuropsychological cases.

Common Systems for Perception and Imagery

In this section, we review the evidence that supports the view that common representations and common neural substrate mediate visual imagery and perception.

Common Representations for Perception and Imagery

The view that perception and imagery share representations is borne out by results from numerous studies that demonstrate the functional equivalence between perception and imagery (see Finke, 1985; Kosslyn, 1987; Kosslyn et al., 1993; Saariluoma, 1992). For example, Finke and his colleagues (Finke, 1979, 1980; Finke & Kosslyn, 1980; Finke & Schmidt, 1978) found that visual–motor and orientation-specific adaptation (McCollough effect) are equivalent for images and percepts. This also applies to the relation between eccentricity and resolution. The close relationship between images and percepts is further demonstrated by studies that have found facilitation between these two processes. For example, Farah (1989) found that when subjects formed a mental image of a letter, the imaged prime facilitated detection of the subsequent target letter. In her experiment, subjects were instructed to detect the shape of a stimulus (H or T) that was preceded by an imaged prime stimulus (H or T) in the same or in a different location to the target. When the imaged prime and the target stimulus shared both shape and location, the subjects were better at detecting the subsequent target letter. These findings led to the conclusion that priming between imagery and visual perception is mediated through a common set of representations shared by the two processes (see also Stadler & McDaniel, 1990).

The representational commonality between imagery and perception is also noted in studies of patients with impaired perception (visual agnosia) who have similar imagery deficits (Goldenberg, 1993; Ogden, 1993; Wilson & Davidoff, 1993). Even more compelling evidence for the representational commonality comes from patients whose imagery and perception deficits affect the same domain. There are, for example, reports of agnosic patients who are unable to perceive and image only faces and colors (Levine, Warach, & Farah, 1985), only facial emotions (Bowers, Blonder, Feinberg, & Heilman, 1991), only spatial relations (Farah, Hammond, Levine, & Calvanio, 1988; Levine et al., 1985), only object shapes and colors (Goldenberg, 1992), or only living things (Mehta, Newcombe, & De Haan, 1992). The consistency between perception and imagery across particular domains endorses the claim that mental imagery activates the same stored representations that are engaged by an external stimulus during perception. When the common representations are affected, parallel deficits in imagery and perception are observed.

Common Neural Substrate for Perception and Imagery

In addition to the evidence for shared representations, there is also considerable empirical support for the view of a shared neural substrate for imagery and perception. Studies measuring regional cerebral blood flow using single photon emission computerized tomography (SPECT), for example, have found higher rates of blood flow in visual areas of the inferior occipital region (particularly in the left hemisphere) when the subjects were required to answer high-imagery questions (e.g., "Is the green of pine trees darker than the green of grass?") compared with when they answered equally difficult low-imagery questions (e.g., "Do leap years have 366 days?") (Goldenberg, Podreka, Steiner, & Willmes, 1987; Goldenberg, Podreka, Steiner, Willmes, Suess, & Deecke, 1989; Goldenberg, Steiner, Podreka, & Deecke, 1992; see also Charlot, Tzourio, Zilbovicius, Mazoyer, & Denis, 1992). Similar results were obtained in a study using positron emission tomography (PET), in which activation of primary visual cortex (Areas 17 and 18) was noted during imagery tasks as well as during equivalent perception tasks (Kosslyn et al., 1993; but see Roland and Gulyas, 1994, for a different view). Finally, the selective involvement of the occipital regions in the generation of mental images has been demonstrated by electrophysiological measures (Davidson & Schwartz, 1977; Farah & Peronnet, 1989) in which specific activation was shown at the occipital electrodes in imagery tasks. The observation that increased activation could be seen on imagery tasks in areas thought to be dedicated to visual perception lends further credibility to the view of a shared neural mechanism for these two processes.

A final source of evidence showing the close neural correspondence between imagery and perception comes from studies of patients with brain damage (see Levine et al., 1985, for overview). For example, patients with cortical blindness due to destruction of the occipital cortex (Brown 1966; Symonds & Mackenzie, 1957) have been reported to have an associated loss of imagery, whereas patients with scotomas (blind spots) have been reported to show equivalent blind spots in their mental imagery (Head & Holmes, 1911). In a similar vein, Farah, Soso, and Dasheiff (1992) showed that, in a single subject who had undergone unilateral occipital lobectomy, the visual angle of the patient's "mind's eye" was reduced in much the same way as was the visual angle of perception. On the basis of the associated imagery and perceptual deficits that arose from removal of the same cortical substrate, Farah et al. concluded that images occur in a spatially mapped representational medium that is shared with visual perception (see also Kosslyn et al., 1993). Taken together, the findings of these studies strongly favor the view that imagery and perception share a common neural substrate.

Evidence for Dissociations Between Perception and Imagery

The empirical data outlined so far from both brain-damaged and normal subjects provide strong support for the view that mental imagery and visual perception share a common neural substrate and common representations. The next section outlines the existing evidence for dissociations between the two processes.

Imagery Deficits With Intact Visual Perception/Recognition

Evidence favoring a dissociation between imagery and perception comes from several neuropsychological case studies of patients in whom imagery is impaired relative to recognition. The first case of sudden loss of mental imagery, reported by Charcot and Bernard in 1883, described a patient who could not image even those objects he could identify in visual perception (Goldenberg, 1993). The same pattern has been reported in two, more recent cases. R.M. (Farah, 1988; Farah, Levine, & Calvanio, 1988) was unable to draw from memory, had lost his dream imagery, and was unable to describe objects from memory. Furthermore, he was unable to answer yes–no questions that were verifiable only through the use of imagery. In contrast, his performance in the recognition control conditions was perfect, as were his picture and object identification. These results led to the conclusion that R.M.'s deficit selectively affected image generation, the process by which stored representations from long-term memory are created in a short-term visual buffer.

The second patient, D.W. (Riddoch, 1990), also showed a selective impairment in image generation. D.W. was unable to draw from memory and was also unable to generate items from long-term memory. For example, he was unable to determine whether animals have long or short tails or whether letters have curved or straight sides when the names of the items were presented auditorily. In contrast, he was successful at recognizing objects, at copying visually presented stimuli, and at accessing the semantic system from vision. The findings from patients R.M. and D.W. have been interpreted in the context of a model (Farah, 1988; Farah, Levine, & Calvanio, 1988; Kosslyn, 1987, 1988) in which there are some component processes that are unique to imagery and that may be selectively affected without any consequences for recognition.

Perception/Recognition Deficits With Preserved Imagery

Whereas the pattern of an imagery deficit associated with good recognition seems to be clearly established, the existing evidence for the converse pattern is less definitive. The first report of such a case is that of Wilbrand's patient, who could conjure up vivid images of buildings that she was unable to recognize in reality (Goldenberg, 1993). More recently, support for this dissociation comes from reports of patients with impaired object recognition or agnosia who are able to draw from long-term memory the very objects they typically misidentify. H.J.A., a patient with agnosia (recognition deficit), showed relatively good drawing skills compared with his perceptual ability (Humphreys & Riddoch, 1987a, 1987b; Riddoch & Humphreys, 1987). Although the evidence is highly suggestive in this case, it is still not conclusive. Drawing ability alone is not necessarily indicative of preserved mental imagery (Van Sommers, 1989), and there is at least one report of a patient who can draw the uppercase equivalent of a lowercase target letter in the absence of any imagery ability (Kosslyn, Holtzman, Farah, & Gazzaniga, 1985). Because we do not know the degree to which H.J.A.'s mental imagery is preserved on tests other than drawing, the extent to which imagery and perception are truly dissociated in this case remains unclear.

Data from a second agnosic patient, M.D. (Jankowiak et al., 1992), are also suggestive but not conclusive. M.D. displayed reasonably good (but not perfect) drawing of objects and also performed remarkably well on a range of tests of mental imagery. The lack of clarity in this case comes from the finding that his object recognition ability was reasonably well preserved under some conditions. Although M.D. could only correctly identify 50% of black-and-white sketches of objects and symbols (e.g., $, %), his identification of real objects was good (91% accuracy), and he could interpret five out of six photographs of complex visual scenes. That M.D. could recognize visual stimuli well under some conditions undermines the claim of a clear dissociation between imagery and perception in his performance (see Servos, Goodale, & Humphrey, 1993, for a similar case). C. K., the patient presented in this article, is an agnosic patient who showed a remarkably clear dissociation between visual object recognition and mental imagery (see also Behrmann, Winocur, & Moscovitch, 1992) and therefore provided the necessary evidence for the complement of the double dissociation between imagery and perception.

Case Report

C. K. is a 33-year-old, right-handed man who emigrated from England to Canada in 1980. In January 1988, he sustained a closed-head injury (acceleration–deceleration whiplash) in a motor vehicle accident. C. K. had no premorbid neurological problems, but following the accident, he exhibited motoric weakness of the left side and a left homonymous hemianopsia. Neuropsychological testing conducted soon after the accident revealed major cognitive deficits including visuomotor slowing, limited learning ability, poor planning and organization, and distractibility. Memory was also poor initially, but it improved markedly. Personality changes were noted including frequent mood swings and temper outbursts. Following the accident, C. K. received extensive rehabilitation training, focusing on planning and organization as well as on improving his memory.

Neuropsychological testing conducted in September 1989 revealed a full-scale IQ score at the 20th percentile, a verbal score at the 40th percentile, and a low-average nonverbal score at the 10th percentile. In April 1991, a full Wechsler Adult Intelligence Scale–Revised (WAIS–R) was administered, and C. K. obtained a verbal IQ of 96 and a performance score of 74. Prior to the accident, C. K. was an exemplary student enrolled in a master's degree program in history. He made a remarkable recovery from his injuries and, in 1991, completed his degree with the aid of multitrack tape recorders and a voice-activated computer. C. K. now works as a manager in a large organization; after an initial period of adjustment and despite his deficit, he has adapted quite well.

The results of a computerized tomography scan (with transaxial scans performed in the temporal lobe and standard basal planes) in December 1991 and of a magnetic resonance imaging scan in June 1992 revealed no focal mass or abnormality. There was, however, a suggestion of thinning of the occipital lobes bilaterally on the magnetic resonance imaging scan. An electroencephalogram (September 1991) showed some abnormality over the left frontotemporal area (low-voltage theta activity of 6 to 7 cps). Although this is an unusual finding in a patient with object agnosia, because the abnormality from the head injury is nonspecific, diffuse cortical changes are not unusual. At present, C. K. suffers from seizures of the partial complex form and takes anticonvulsant medication (Tegretol). Goldmann perimetry testing (December 1990) showed that the left field defect had resolved to a partial homonymous hemianopsia. Visual acuity was 6/7.5 ou, with −1.00 lenses for distance vision and +1.00 for near visual tasks. Following the accident, C. K.'s ocular motility was normal, as were his pupils. Anterior segments and fundi were normal. There was some evidence of accommodative or convergence insufficiency, but this has been corrected by lenses.

The testing reported here was conducted between October 1991 and June 1993. C. K.'s language comprehension and spontaneous speech expression were normal as revealed by his performance on the subtests of the standardized Western Aphasia Battery, which do not require visual input (Kertesz, 1982). C. K. served as the subject in all the experiments reported below. A group of 10 graduate students and research associates of approximately the same age as C. K. served as normal control subjects where necessary unless otherwise specified. The experiments in the first section (Experiments 1 to 3) are designed to characterize the nature and severity of C. K.'s object recognition deficit, whereas the experiments in the second section (Experiments 4 and 5) examine his imagery abilities. In the final section (Experiment 6), the experiments are designed to investigate whether the mechanism used for the internal recognition of an object is the same as that used for the recognition of an externally presented visual stimulus.

Experiment 1: Object Recognition

Experiment 1a: Visual Recognition of Three-Dimensional Objects

Method. Twenty-three real objects were selected and presented for recognition. Twelve objects were their actual size (e.g., a 3-cm safety pin), and 11 were miniature versions (e.g., a 6-cm hammer). The objects were placed individually on a table in front of C. K. for an unlimited exposure duration, and he was required to identify each one. He was not allowed to touch or pick up the object.

Results and discussion. The normal control subjects recognized all 23 objects with perfect accuracy. In contrast, C. K. named only 16 out of 23 (70%) correctly, reflecting a significant difference compared with the control subjects, $\chi^2(1) = 8.3, p < .01$. Size of the objects did not influence performance; C. K. made four errors with full-size objects and three errors with small objects, $\chi^2(1) = 0.3, p > .05$. The seven errors include the following: identifying a smoking pipe as a straw, a box of matches as a card with writing, a padlock as an earring, a saw as a knife, pliers as a clothes peg, and giving no responses to a paper clip and a toothbrush.

Experiment 1b: Tactile Recognition of Objects

One possible reason that C. K. failed to recognize the objects might be that he no longer possesses the fundamental conceptual or semantic knowledge required to identify them. In this next experiment we presented the same 23 objects for recognition through a modality other than vision. If C. K. has retained knowledge of the objects but is unable to access that knowledge from vision, he should be able to recognize the objects when they are presented in the tactile modality. Additionally, when asked to provide verbal definitions of these objects in response to their auditorily presented name, he should demonstrate preserved knowledge.

Method. The same 23 objects used in Experiment 1a were used here. On one occasion, C. K. was given each of the objects to identify from tactile input. The object was given to him to hold and palpate with his eyes closed, and he was required to identify it. On a second occasion, C. K. was asked to provide definitions for each of the objects when the name of the object was read aloud to him.

Results and discussion. C. K. was able to identify all 23 objects with tactile presentation, suggesting that the object recognition deficit is restricted to the visual modality. He also defined correctly and in detail all the objects when presented with the name auditorily. For example, he defined a duck as "an animal, marine life, with webbed feet and a bill"; a card of matches as "a cardboard container, the container flipped open, the log sticks are struck against the cordite strip"; and a pipe as "a long cylindrical hollow object to convey liquid or gas." When C. K. was asked by the examiner to define a pipe for smoking, he continued, "a short, hollow object, larger on one end, 120° angle, for leisurely smoking using tobacco." The detailed and descriptive definitions that he was able to provide reflect the preservation of his knowledge of objects. Furthermore, the results from the tactile naming task establish that C. K.'s inability to recognize an object is restricted to the visual modality.

Experiment 1c: Visual Recognition of Line Drawings

In this experiment, we investigated whether the recognition deficit shown by C. K. for real objects also extends to black-and-white two-dimensional line drawings. M.D., the agnosic patient of Jankowiak et al. (1992), was able to recognize three-dimensional objects with surprising accuracy (91% correct), although he was able to recognize only 50% of the line drawings. A superiority in object over line drawing recognition has been documented repeatedly both for brain-damaged and normal subjects (Biederman & Ju, 1990; Humphreys & Riddoch, 1987a, 1987b; Servos et al., 1993; Thaiss & De Bleser, 1992; Ullman, 1989) and is usually attributed to the presence of surface, edge-based, and depth cues available for recognizing real objects but not for line drawings.

We also examined whether C. K.'s inability to name visually presented objects was truly attributable to a recognition deficit or whether it arose from an impairment in retrieving the label for an object presented in the visual modality. There are now many reported cases in which patients misname visual objects that have been correctly recognized (Iorio, Falanga, Fragassi, & Grossi, 1992; Plaut & Shallice, 1993), a disorder known as optic aphasia. Although there still exists considerable debate about the relationship of visual agnosia to optic aphasia, there is general agreement that the differentiating feature between them is whether the patient possesses any semantic knowledge of the unnamed or misidentified visual stimulus as revealed by either verbal or gestural response. If so, this would be consistent with the pattern of optic aphasia. In contrast, if the patient is unable to demonstrate any higher level information, this would be more consistent with visual agnosia.

Method. Sixty black-and-white line drawings of objects were taken from the Boston Naming Test (Kaplan, Goodglass, & Weintraub, 1983). Each drawing (average size 9 cm × 9 cm) appeared on a single 15 cm × 15 cm page. The drawings were presented individually for an unlimited time, and C. K. was required to name each one. When he failed a trial, he was encouraged to describe the item or to express any semantic information he possessed about the stimulus either verbally or gesturally, to ensure that his inability to name the object was attributable to a visual recognition deficit rather than to a problem in retrieving the label for the item.

Results and discussion. C. K. named 18 out of 60 (30%) line drawings correctly, a significant impairment relative to the standardized norm of 56.6 obtained by age- and schooling-matched controls (Kaplan et al., 1983), $\chi^2(1) = 54.08$, $p < .001$. There was no evidence from the verbal protocol (see Appendix A) or from his gestures that visual analysis was sufficiently good to gain access to semantic information but not adequate to retrieve the correct verbal label. Further evidence to support this view comes from examining the nature of C. K.'s naming errors. If the errors are predominantly semantic, then one might conclude that the visual information had accessed semantics and that the errors occurred because of a deficit at more central stages of processing; in contrast, if the errors are predominantly visual, then one might infer that the deficit disrupted the more peripheral stages of visual processing (Iorio et al., 1992; but see Hinton & Shallice, 1991, and Plaut & Shallice, 1993, for alternative views on "mixed errors"). C. K.'s errors included the following: naming a picture of a dart "a feather duster," a tennis racquet "a fencer's mask," and an asparagus "a rose twig with thorns." All of these errors reflect predominantly visual confusions. (See Figure 1 for examples of the stimuli.)

These visual errors indicate that although he is able to perceive parts of an object, C. K. is unable to integrate them into a meaningful whole. In addition to the visual errors, many of C. K.'s errors do bear some semantic relationship to the target; for example, he identified a rhinoceros as a "dinosaur" and a beaver as an animal, "hamster." These responses, however, are also visually related to the targets, and there are no items in which the error response is only semantically but not visually related to the target. It seems unlikely that C. K. is able to access semantics for the presented item but fails to retrieve the label; rather, it appears that he is able to pick out some elements of the object and, in some cases, the impoverished representation is sufficient to get reasonably close to the correct target. For example, noting the presence of four legs on the object is sufficient to place it in the category of animal, or perceiving the shape of the rhinoceros may be sufficient to generate the response "dinosaur" or "hippopotamus," both of which are semantically as well as visually related to the target. The absence of pure semantic errors suggests that C. K. did not

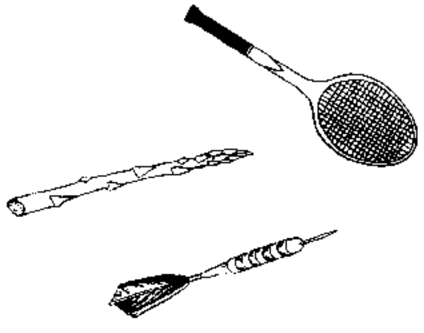

Figure 1. Examples of stimuli from the Boston Naming Test that C. K. misnamed.

gain access to semantic information about the item on which the visual misidentification occurred.

Discussion of Experiment 1

The results of Experiment 1 are straightforward: C. K. has object agnosia and is severely impaired in his ability to recognize objects, presented either in three dimensions or as line drawings in the visual modality. His failure to recognize objects is not attributable to a loss of knowledge or to a failure to retrieve the verbal label for the visually presented item. Instead, the deficit is one in which the appropriate semantic information cannot be accessed for items presented in the visual modality. Although we have demonstrated that C. K. has a modality-specific deficit in which he is unable to recognize visually presented objects, it is still unclear whether all classes of visual stimuli are implicated or whether the deficit is domain specific and restricted to certain classes of objects. Deficits in face recognition, for example, or in printed word recognition along with preserved recognition of other forms of visual stimuli are now well documented (Farah, 1991, 1992).

Experiment 2: Visual Processing of Letters and Faces

Experiment 2a: Discrimination of Visually Presented Letters

This experiment evaluated C. K.'s ability to discriminate the forms of letters; later experiments assessed his ability to identify and assign meaning to the letter forms.

Method. A single letter appeared either in its normal orientation or in reflected form. Half the letters were uppercase and half lowercase. There were a total of 52 trials. Stimuli for this and the following experiments were drawn up in 18-point black Geneva type and were laser printed on white paper. Each item was presented on the table in front of C. K. for an unlimited exposure duration, and he was required to decide whether the stimulus was a possible (normally oriented) letter or whether it was reversed. He was not required to identify or name the letter.

Results and discussion. C. K. was correct on 29 out of 52 trials, a score reflecting performance that is not significantly different from chance, $\chi^2(1) = 0.154$, $p = .7$. The results suggest that he has a marked deficit in processing letters that are presented visually.

Experiment 2b: Cross-Case Matching of Printed Letters

To confirm that C. K.'s deficit is in recognizing letters (and not in rotation or transforming reversed items as might be the case from the previous experiment), we designed this next experiment to examine whether, for normally oriented letters, C. K. was able to identify letters by matching a lowercase instance of a letter (e.g., *a*) with its uppercase, visually dissimilar counterpart (e.g., *A*).

Method. The stimuli consisted of 14 letters for whom the uppercase and lowercase counterparts were visually different (e.g., Aa, Bb, Hh, Rr). Half the trials consisted of a lowercase target and half an uppercase target. For each target (e.g., *d*) two choices (e.g., *D* and *O*) were available. The choices were presented to the right of the target. They appeared vertically one above the other with the position of the correct response counterbalanced. C. K. was required to decide which of the two choices matched the target and to point to that item.

Results and discussion. Once again, C. K. was impaired in letter processing (correctly identifying 17 out of 28, or 57%), lending further support for the view that his recognition deficit extends to a problem in processing letters. However, because neither of the above experiments tested C. K.'s ability to recognize a letter explicitly, we designed the next experiment to examine C. K.'s naming of letters.

Experiment 2c: Recognition of Single Letters

Method. The 26 letters of the alphabet were printed in lowercase first and then in uppercase, making a total of 52 stimuli. C. K. was instructed to name the letters that were presented individually and for an unlimited time. The set of randomly mixed lowercase letters appeared first, followed by the set of uppercase letters. By blocking on case and narrowing the set of potential items, we expected to elicit the best possible performance from C. K.

Results and discussion. C. K. was able to name 36 out of 52 (70%) of the letters correctly. Although this indicates a severe deficit, his performance was somewhat better than that on recognizing line drawings. One possibility is that because letters of the alphabet form a closed class of potential responses (and the stimuli were blocked on case), this letter recognition task was made easier (see also Experiment 2a).

As in Experiment 1, it was important to demonstrate that C. K.'s failure on 30% of the letters was not attributable to a loss of knowledge of letters. Therefore, the letters C. K. failed to identify were presented to him in the tactile modality for tracing before identifying the letter. Of the 16 visual items he failed to recognize, he misidentified only 4 when tracing. In all these cases, his tracing was incorrect; for example, he stopped short on the *O* and called it a *C* or extended the tracing and called an *n* an *h*. C. K.'s good performance in the tactile modality and poor performance with visually presented letters suggests that his recognition deficit extends beyond objects.

Experiment 2d: Recognition of Single Words

Although the results from the previous experiments point to a fundamental deficit in visually recognizing printed letters, there are occasional reports of patients who are able to read words without being able to identify the component letters (Shallice & Warrington, 1977). Because the above experiments only examined letter and not word processing, for the sake of completeness, this experiment examined C. K.'s ability to read aloud visually presented words.

Method. Twenty-four words were taken from Kay, Lesser, and Coltheart (1992, Subtest 30) and were printed individually in 24-point Times type in black lowercase letters on a white card. Each card was placed in front of C. K. for an unlimited exposure duration. C. K. was required to read aloud each word. He was not allowed to trace or touch the letters.

Results and discussion. C. K. was unable to read any of the words aloud. He could identify some of the letters individually; for example, for the stimulus *beard*, he said "it is *b* and there is a *r* in it, too." These findings, along with those of the previous experiments, provide clear evidence that C. K. is severely alexic and that his object recognition deficit includes a profound impairment in processing printed letters or words.

Experiment 2e: Discrimination of Unfamiliar Faces

C. K. is impaired at dealing with orthographic visual material; the following task examined whether he is also impaired at processing visual stimuli from another domain (i.e., faces).

Method. The Face Recognition test (Benton, de Hamsher, Varney, & Spreen, 1983) was used to determine whether C. K. is able to discriminate between faces. In each display, a single front-view photograph of a face is presented above a display of six faces. On the first 6 trials, the six possible choices are all front-view photographs. On a further 24 trials, the six choices are three-quarter view photographs. This condition ensures that the identification is not done on a simple matching of features in the photographs. On the remaining 24 trials, the six choices include the target under three different lighting conditions together with three distractor items. Male and female faces appear equally often.

The target photograph is presented with the six choices for an unlimited exposure duration. On the first 30 trials, the subject matches the single target face with its counterpart from the array, and on the remaining 24 trials, the subject identifies all three choices in the array that correspond to the target.

Results and discussion. There was no significant difference between the performance of C. K. (a scaled score of 49 out of 54) and the mean for normal men (45.6 out of 54), $\chi^2(1) = 0.8, p > .05$. Instead, C. K.'s preserved face perception reveals that he can discriminate between and match faces even under difficult conditions such as poor lighting. The results, though provocative, do not allow us to conclude that C. K. can recognize faces. The next experiment remedied this by examining whether C. K. can assign meaning and identity to a face.

Experiment 2f: Recognition of Famous Faces

Whereas the previous experiment was concerned with C. K.'s ability to discriminate faces, this experiment tested face recognition per se.

Method. Photographs of 17 currently famous people were cut out of magazines. These included obscure photographs of Imelda Marcos, Boris Yeltsin, and Oliver North as well as a picture of the Queen of England and the Queen Mother with scarves over their heads and in profile. Ten of the trials consisted of color pictures, whereas the remaining 7 trials consisted of black-and-white pictures.

The photographs were presented individually for an unlimited exposure duration, and C. K. was instructed to name the person(s) in the picture.

Results and discussion. The normal subjects recognized a mean of 16.4 photographs correctly with a single error on the Queen, 2 on the Queen Mother, and 3 on Terry Anderson. C. K. was able to identify correctly the individuals in all 17 photographs, showing preserved face recognition ability. The preservation of face recognition in some patients with severe visual agnosia has already been documented (Farah, 1992; Young, 1992), and although this seems paradoxical on the surface, several explanations have been advanced to explain this pattern of results. Although some have argued that face recognition is mediated by a dedicated, specialized module (see Gurd & Marshall, 1992, for brief overview), others suggest that face recognition relies on a different form of processing from that used in object recognition, and that the dissociation comes from selective sparing of the processes used in face recognition (Farah, 1992). The remarkable preservation of face recognition alongside the profound object recognition deficit is the topic of other research on C. K. and will not be discussed in great detail here. That he can recognize faces, however, in the context of such a severe object recognition deficit must be accounted for by any model of the mechanisms underlying visual cognition.

Discussion of Experiment 2

The results of Experiment 2 show that C. K. is impaired at recognizing letters and that he is severely alexic. In contrast to the profound object and letter recognition deficit, however, he retains the ability to recognize faces, visual stimuli that are at least (if not more) complex than other stimuli he failed to recognize.

Because C. K. could name all the objects (Experiment 1) and letters (Experiment 2) without visual input when permitted to palpate or trace them and could provide definitions to auditory input, the recognition deficit cannot be explained by a difficulty in recalling the names of the visually presented items, nor can it be attributed to a loss of object knowledge. The impairment in the recognition of visual stimuli despite intact elementary perceptual abilities such as acuity and luminance discrimination is known as "visual agnosia." Lissauer (1890) originally delineated two forms of visual agnosia: *apperceptive agnosia,* or a deficit in early stages of visual processing in which patients fail to recognize objects because of faulty perception, and *associative agnosia,* in which patients seem to have virtually normal perception but cannot associate the percept with meaning. The ability to copy a visually presented stimulus often serves as a differential diagnostic indicator between these two types of agnosia: Because apperceptive agnosics cannot form an adequate visual percept, they fail to copy correctly, whereas associative agnosics derive an adequate structural representation and demonstrate preserved copying.

This simple classification has undergone considerable revision recently, and attempts have been made to develop a fuller conceptual account of visual perceptual disorders. Although the basic Lissauer classification is preserved in most cases (but see Farah, 1990), the stages of processing required for identifying a visual object have been elaborated and fractionated. Warrington, for example, has distinguished between the processes involved in shape coding, figure–ground segmentation, perceptual classification, and semantic classification (Kartsounis & Warrington, 1991; Warrington, 1982), whereas Humphreys and Riddoch and their colleagues have distinguished between the coding of visual features at various spatial scales, the integration and grouping of these features, the mapping of these features to stored representations of objects, and the accessing of structural and of semantic information about the objects (Humphreys et al., 1993; Riddoch & Humphreys, 1987).

An important aspect of the revised taxonomies is that they expand the simple Lissauer dichotomy to include many intermediate stages of visual processing, such as feature grouping and figure–ground segmentation. A critical source of support for these stages of processing comes from neuropsychological studies of agnosic patients in whom the deficits have been localized to these intermediate stages. For example, Riddoch and Humphreys (1987) reported that their visual agnosic patient, H.J.A., had a specific deficit in integrating form information; whereas he could identify letters, line drawings, and geometrical shapes reasonably well, he was differentially impaired, relative to control subjects, when these same stimuli were presented overlapping with other stimuli. H.J.A. also failed on tasks in which grouping conjunctions of form features was required (Humphreys, Riddoch, Quinlan, Price, & Donnelly, 1992) and on tasks requiring grouping through collinearity and good configuration (Humphreys et al., 1993). This problem in grouping features and encoding their relations has been termed *integrative agnosia*.

In addition to H.J.A., there are several other patients who seem to be impaired at the intermediate integrative stages of visual processing. De Renzi and Lucchelli (1993) described a patient, Annalisa, who was able to match complex objects but failed on tasks requiring the extraction of the form from a noisy background. Thaiss and De Bleser (1992) reported a similar case of a patient, T.K., who failed to bind together local features into a perceptual whole. The patient could copy the individual lines of a shape but was unable to relate these to the global form. She also failed to identify objects when they were overlapping and often recognized a part of an object without appreciating that it formed a part of a larger object. This led Thaiss and De Bleser to suggest that T.K.'s impairment arose at intermediate stages of processing and that the disorder was attributable to a reduction of the attentional spotlight that facilitates global processing and shape integration (for examples of other similar cases, see Grailet, Seron, Bruyer, Coyette & Frederix, 1990; Case G.K. in Humphreys et al., 1993; Sparr, Jay, Dreslane, & Venna, 1991). It is interesting that many, although not all, of the patients with deficits in intermediate stages of processing can produce a reasonable copy of the stimulus. On the Lissauer dichotomy, this would qualify them as having associative agnosia. Qualitative analysis of the copying, however, often reveals that it is done line-by-line in a piecemeal fashion without appreciation of the global shape of the object. This slavish and segmental approach is consistent with the view that these patients are unable to derive a coherent structural description of the stimulus. Thus, whereas the failure to copy may be informative, an accurate end product does not guarantee that perceptual processing is normal.

The question is, what is the nature of the underlying perceptual deficit that gives rise to C. K.'s impaired performance. The next set of experiments was designed to characterize his visual perceptual deficit in more detail. We first demonstrate that he can copy reasonably well but that the process by which this is achieved is not normal. Thereafter, we present a series of experiments localizing the functional lesion in the visual processing system. The findings suggest that C. K. has a deficit in integrating features of a visual stimulus and that his performance is similar to that of patients with deficits in intermediate stages of visual processing.

Experiment 3: Perceptual Processing

Experiment 3a: Copying of Visual Stimuli

This experiment examined C. K.'s ability to copy a visually presented stimulus.

Method. The stimuli consisted of 10 configurations of geometric shapes printed in black ink on single sheets of white paper. Each stimulus configuration was placed in front of C. K., and he copied each on a separate sheet of blank paper. He was allowed unlimited time, and a new configuration was introduced when he indicated that he had completed his copy.

Results and discussion. C. K. made no errors on this task, copying each configuration correctly. His performance, however, was slow and slavish, and he reproduced the components of the configuration segmentally. The numbers (see Figure 2) reflect the order in which he copied the figure and reveal that, although he copied the configuration correctly, he drew the segments line-by-line and in an unusual sequence. Even though he could copy the figure, he was not aware of the identity of the objects. The ability to copy without appreciating the identity of the target was also seen in C. K.'s copying of a line of text from the Western Aphasia Battery (Figure 3i). He was able to copy the text accurately (Figure 3ii) but produced each letter in a fashion that directly replicated the input. For example, his production of the letter *a* in the figure is in the identical font and script to that of the target sentence. His copy of the text also differs markedly from his own spontaneous writing of the identical material (Figure 3iii), indicating that the copying was done segmentally and piecemeal and probably without knowledge of the target.

Experiment 3b: Perception of Overlapping Shapes

A hallmark feature of many patients with deficits at intermediate processing stages is that they are unable to extract overlapping objects from the background. In Experiment 3b, we examined whether C. K. could group together components of a black-and-white line drawing where the objects overlap and the lines intersect. The task was modeled after Ghent's (and Poppelreuter's) overlapping figure test, and versions of it have been used to reveal the grouping and parsing deficits in other agnosic patients (De Renzi & Lucchelli, 1993; McCarthy & Warrington, 1986; Riddoch & Humphreys, 1987; Thaiss & De Bleser, 1992).

Method. Ten displays were created in which 4 line drawings (taken from Snodgrass and Vanderwart, 1980) were drawn such that they overlapped each other (maximum 40 objects). (An example of the display is provided in Figure 4.) Each display occupied a full sheet of 18.9 cm × 27.5 cm (8.5 × 11 in.) paper. For the matching version of the experiment, an array of 6 individual pictures accompanied the display. Three of the pictures in the array appeared in the overlapping display, and the remaining three were distractors. Where possible, one of the distractors was visually similar to one of the targets. The position of the targets and distractors was randomized.

The experiment was conducted twice. In the tracing task, each display was presented to C. K. along with a set of colored crayons, and he was instructed to draw around the boundary of each object in a single color. He was not required to identify the objects. On a second occasion, several months later, in the matching task, the 10 displays were presented with the array of choices. C. K. was instructed to point to the pictures in the array that also appeared in the overlapping display. The control subjects also completed this experiment.

Results and discussion. In the tracing task, C. K. was completely unable to demarcate the boundaries of individual objects when presented in the overlapping array. First, he marked in separate colors those components of the objects that jutted out from the central mass. When he reached an intersecting line, he was unable to decide how to continue and most often refused to carry on. None of the 40 objects was traced correctly. The failure to discriminate the figures from the overlapping display was also seen in his matching performance. C. K.'s performance (23 out of 40 correct) was significantly poorer than the normal subjects' 39.8 out of 40; $\chi^2(1) = 16.1, p < .0001$. His predominant strategy was to select out some contour from the overlapping display and to try and match it with the set of choices in the array. So, for example, on the stimulus shown in Figure 4, he correctly matched the flag (by the stick jutting out) and the jug (which he called a cup). He then pointed to the center of the envelope with the lines projecting downward and matched it to the bow, stating that "here there is a central section with parts coming down from it." These findings are consistent with the view that he is unable to segment or parse a complex display. Whereas he is able to match local information or components, he is unable to extract and integrate entire objects from the mass of intersecting lines.

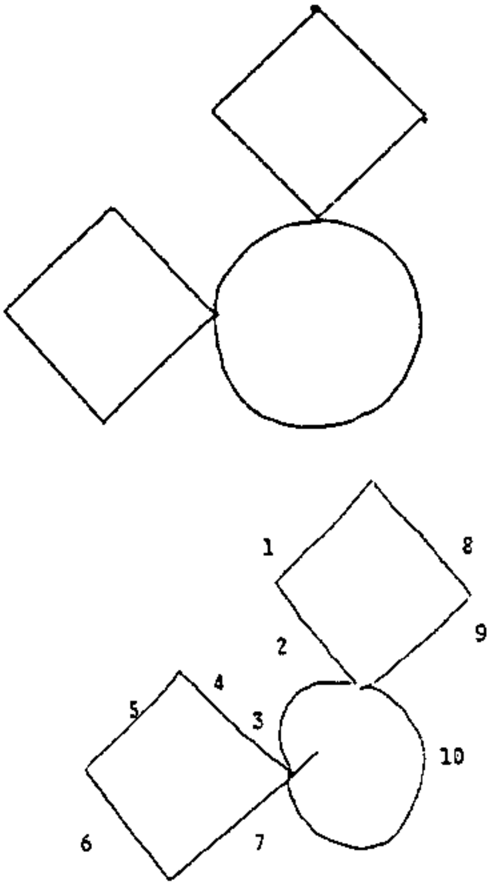

Figure 2. C. K.'s copying of geometric configurations. The numbers indicate the sequential order of the strokes.

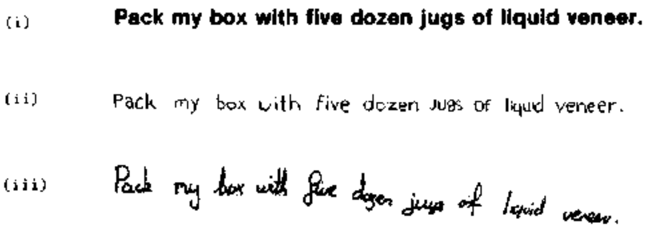

Figure 3. C. K.'s copying (middle) and spontaneous writing (bottom) of the target line of text (top) from the Western Aphasia Battery.

Experiment 3c: Figure Extraction From Noisy Background

The overlapping figures task, however, is complicated, and many shapes whose identities are unknown appear simultaneously. If the deficit is indeed in extracting and integrating the elements of an object in the presence of other distracting visual information, then C. K. should also fail to detect the presence of a single shape even when its identity is known ahead of time. Some patients who fail to integrate features of an object also fail to identify the presence of a shape when it appears against a noisy background of extraneous lines, even if only a single shape is present at any one time and even if the subjects know the identity of the shape. For example, when De Renzi and Lucchelli (1993) and Warrington (Kartsounis & Warrington, 1991; Warrington, 1982) instructed their patients to detect an *X* from a fragmented background, the agnosic patients were not able to do so reliably. These findings led them to suggest that figure–ground segmentation is another instance in which object features need to be segmented and grouped away from the background. To examine figure–ground segmentation in

C. K., we used a modified version of the shape detection task from the Warrington and James (1991) Visual Object and Space Perception battery. (Examples of the stimulus are presented in Figure 5.)

Method. In this task, a fragmented letter (*X*) was superimposed on a background in which the amount of noise in the background was varied. The *X* was present on half the trials. To examine whether C. K.'s performance varied as a function of background noise, we divided the "present" trials in half, with one half consisting of trials with more noise in the background than in the second half (see Figure 5). C. K. was instructed that on some trials, there was an *X* superimposed on the background whose presence he had to detect. Two blocks of 20 trials were run.

Results and discussion. Whereas normal subjects' mean score on this test is 19.9 (one block; Warrington & James, 1991), C. K. scored 26 correct out of 40 across the two blocks. He was able to detect the absence of the *X* on all trials (20 out of 40) and the presence of the *X* on 6 out of 10 trials where the background was less noisy, but he was unable to pick out the figure when the background was more fragmented (0 out of 10). This finding is consistent with the view that C. K.'s difficulty in extracting the features or elements of an object becomes more marked as the amount of background distracting information increases. Having shown that C. K. was unable to segment overlapping objects or figures from the ground, and that this might be the source of the agnosia, it was important to demonstrate that lower stages of visual processing that do not require feature integration were preserved.

Experiment 3d: Color Discrimination

Method. The Farnsworth–Munsell 100-hue test for color discrimination was administered. The standardized procedure was followed. In addition, a further 25 caps for the testing of the black–white continuum were administered.

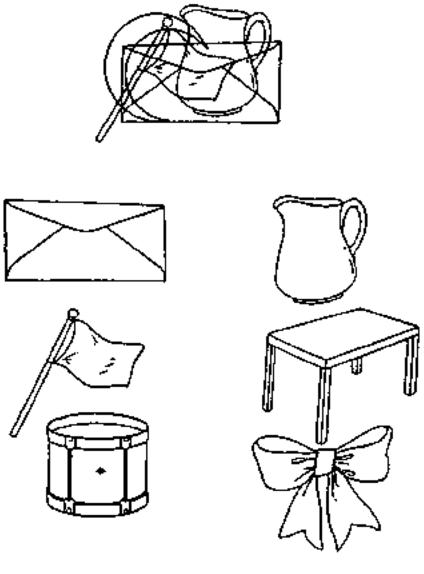

Figure 4. Example of an array of 4 overlapping objects used in the tracing and matching task.

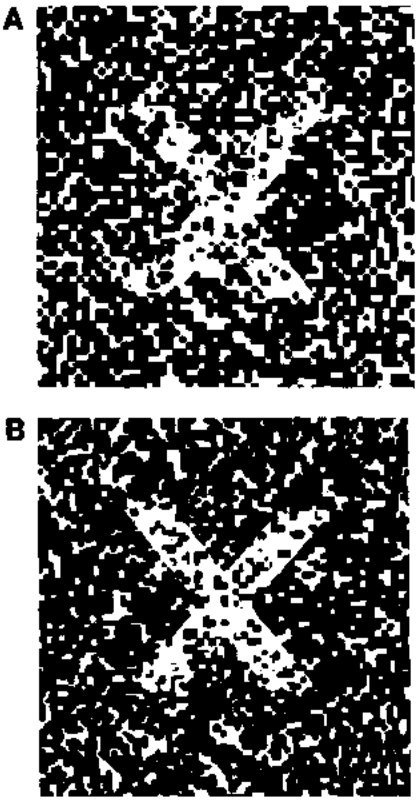

Figure 5. Example of trials from the shape detection test, one with more background noise (top) and one with less background noise (bottom).

Results and discussion. C. K.'s error score was 52, which places him in the 50th percentile of an unselected group of subjects. On the first test, 68% of the normal population achieved a total error score of between 20 and 100. C. K. made only a single error on the gray-scale black-and-white caps. Taken together, these results suggest that color and brightness discrimination is well within normal limits.

Experiment 3e: Shape Coding

The Efron shape matching test, in which subjects have to determine whether a solid black object is a square or an oblong, was given to C. K. This task does not require the integration of features or segmentation; rather, the shape of the object must be coded, and the variation of one dimension (length) must be discerned (De Renzi & Lucchelli, 1993).

Method. Forty figures were created, 20 black squares (50 mm^2) and 20 oblongs (55 mm × 48 mm), printed on white A4 paper. The task generally required subjects to match pairs of objects and to decide whether they are the same or different. To minimize task demands, a single object was presented to C. K., and he had to say whether it was a square or an oblong.

Results and discussion. C. K. was able to label shapes correctly on 38 out of 40 trials. Although there are no norms for this version of the task, C. K.'s performance probably fell within the limits of normal performance (see De Renzi & Lucchelli, 1993).

Experiment 3f: Judgment of Line Orientation

If C. K.'s deficit affects the integration and grouping of individual elements of the display, then he should still be able to detect the orientation of single lines when they do not overlap or intersect.

Method. C. K. performed the Judgment of Line Orientation test (Benton et al., 1983, Form V). A single black target line printed on a white page was presented at various orientations from vertical to horizontal. Above the target appeared a display of 11 lines at different orientations, each of which was marked with a number from 1 through 11. C. K. was required to point to the line that corresponded with the target in orientation. (Normal subjects are asked to provide the number of the matching line, but the task was modified because C. K. cannot read).

Results and discussion. C. K. was impaired (17 out of 30 correct) in contrast to normal performance for males of his age, whose mean score is 25.6, $\chi^2(1) = 5.3, p < .05$. Although these findings are surprising given his performance on copying (where he copied the orientation of individual lines well) and shape coding, the failure may be consistent with the deficit in feature segmentation. Because the choices for the response appear as part of an array of 11 lines, it is possible that even if C. K. had encoded the orientation of the target correctly, he may have failed to segment the corresponding line from the multi line choice array. The task demands of the test may thus have obscured his line orientation ability.

Discussion of Experiment 3

The results of Experiment 3 show that although C. K. was able to produce a reasonable copy of the visually presented figure, he was not able to derive a coherent and full structural description of the visual image. He copied feature-by-feature and performed poorly on tasks requiring segmentation or parsing of a visual stimulus. He did, however, seem to perform normally on tasks that did not require grouping or binding of features. C. K.'s failure to integrate parts of an object is consistent with the pattern of performance observed on object recognition. His errors (e.g., calling a tennis racquet a fencer's mask) suggest that he activates some partial representation of the input but, like other patients with integrative visual agnosia (Grailet et al., 1990; Humphreys & Riddoch, 1987a; Riddoch & Humphreys, 1987; Thaiss & De Bleser, 1992), is unable to integrate these parts into a coherent whole. The results of the tasks in Experiment 3 locate the functional deficit underlying the agnosia to an intermediate stage of visual processing. Having established that C. K.'s object recognition is profoundly impaired and that he is unable to derive a coherent percept of the visual stimulus, we designed Experiments 4–5 to assess his visual imagery abilities.

Experiment 4: Imagery for Object Size, Color, and Form

The critical question addressed in this article is, to what extent do imagery and perception overlap. Having shown that C. K. has profoundly impaired perception of visually presented stimuli, we administered to him a series of tests for which normal adults are known to rely on visual imagery (Farah, Hammond, et al., 1988; Farah, Levine, & Calvanio, 1988). These tests have also been used in several previous studies to demonstrate deficits in mental imagery (Farah, Levine, & Calvanio, 1988; Kosslyn, 1975, 1987; Kosslyn et al., 1985; Riddoch, 1990). Not all tests of imagery are suitable for the current study; Whereas some tests examine object imagery with which we are concerned, some are constructed to test spatial imagery. Indeed, Farah, Hammond, et al. (1988) showed that visual and spatial forms of imagery are functionally dissociable entities and argued that a deficit in visual imagery, but not spatial imagery, should accompany visual object agnosia. For this reason, we report only the results of those experiments that test knowledge of the physical appearance of objects such as their size, color, and form. However, we have also tested C. K.'s spatial imagery abilities on a number of tests that have been used by others, including determining the angle between hands on an imaged clock (Craik & Dirkx, 1992; Paivio, 1978), determining distance in imagery by choosing which of three cities is furthest from the other two (using, for example, Manchester, Leeds, and Birmingham), and determining direction in an imaged navigation task (Brooks, 1968). C. K. performed normally on all these tasks, ruling out any deficit in spatial imagery (Behrmann et al., 1992).

Experiment 4a: Imagery for Object Color

Method. Twenty objects whose characteristic color is not verbally associated with the item (e.g., a football, the inside of a cantaloupe) were selected. The examiner presented the name of the object auditorily, and then C. K. stated aloud its color.

Results and discussion. C. K. was able to produce the correct color for all 20 objects.

Experiment 4b: Imagery for Object Shape

In this experiment, we used a task used previously to test subjects' knowledge of parts of animals. This test is considered to be a sensitive indicator of imagery ability, because facts about body parts and animals are usually only coded visually and are not represented in verbal memory (Farah, Hammond, Mehta, & Ratcliff, 1989; Kosslyn, 1975).

Method. Forty animals whose tail (e.g., kangaroo, pig) or ears (e.g., Doberman, dachshund) are not characteristically associated with the animal were selected. The name of an animal was read aloud to C. K. On the first 20 trials, he was required to judge whether the animal has a long tail proportional to its body size, and on the second 20 trials, he judged whether the ears of the animal were floppy or upright.

Results and discussion. C. K. showed preserved knowledge of body parts, responding correctly on all trials of animal tails and animal ears.

Experiment 4c: Imagery for Object Size

Method. Sixteen pairs of similar-sized objects (e.g., a popsicle and a pack of cigarettes, a thimble and an eraser, a regular TV and a microwave) were constructed. The names of two objects were read aloud to C. K., and he judged which of the two similar-sized objects was larger, producing a verbal response for each pair.

Results and discussion. C. K., like the 10 normal subjects, was able to make the correct size comparison judgments in all 16 pairs.

Experiment 4d: Verification of High- and Low-Imagery Sentences

Experiments 4a–4c show that C. K. performed well on various tests that probe knowledge of the visual appearance of objects. In Experiment 4d, we assessed C. K.'s mental imagery on a slightly different form of imagery task. In this task, a subject is required to verify sentences that are rated as being high on visual imagery (e.g., *The letter W is formed by three lines*) or low on visual imagery (e.g., *There are seven days in a week*). Such a task has been shown to be a sensitive indicator of mental imagery in normal and brain-damaged subjects. Eddy and Glass (1981), for example, found that normal subjects showed equivalent reaction times to verify the two types of sentences. This was not so, however, under dual-task conditions. When subjects were given a second task (reading) to be carried out while verifying the sentences that were presented auditorily, performance on only the high-imagery sentences was adversely affected. Because reading, a visual task, interfered more with the verification of high- than low-imagery sentences, Eddy and Glass concluded that visual imagery played a critical role in the verification of the high-imagery but not low-imagery sentences. Consistent with this is the finding that R.W., the patient with a selective imagery deficit (Farah, Levine, & Calvanio, 1988), performed significantly worse on the high- than on the low-imagery sentences. If C. K. has normal imagery, he should perform as normal subjects do and show equivalent performance in the verification of high- and low-imagery sentences.

Method. The sentences used by Eddy and Glass (1981) were used in this experiment. One high- and one low-imagery sentence were inadvertently omitted, making a total of 34 out of the original 36 items. Half the sentences were high imagery and half low. Each sentence had both a true and a false completion (e.g., *The accelerator on a car is the right/left pedal*), making a total of 68 sentences. The two completions and the high- and low-imagery sentences were randomly intermixed. C. K. was required to say "yes" or "no" to each sentence that was presented auditorily.

Results and discussion. C. K. verified correctly 59 out of 68 sentences, with no difference in true–false completions $\chi^2(1) = 1.15$, $p > .05$, and no difference between high- and low-imagery sentences $\chi^2(1) = 1.12$, $p > .05$. Only one of C. K.'s errors was consistent across both versions of the sentence—he responded "true" to the sentence "the hot water handle on a sink is on the right" and "false" to the sentence "the hot water handle on a sink is on the left." This sentence probably unduly penalizes C. K. as it appears that there is no obvious convention in the United Kingdom for placement of the hot water tap on the sink. The finding of equivalent performance with high- and low-imagery sentences suggests that, when mental imagery is involved, C. K.'s performance is as good as when imagery is not required.

Discussion of Experiment 4

The results of the sentence verification task are consistent with the data from the three tests of object imagery. These data show that C. K. retained detailed knowledge of the physical characteristics of many objects including their size, shape, and color, and that C. K. can use this knowledge when sentences require imagery for verification. Because we do not have equivalent perceptual analog tasks for the imagery tests, the data from these tasks provide compelling but not definitive evidence for the dissociation between imagery and perception. To make the argument even more convincing, it would be important to show that whereas C. K. was impaired on a perceptual form of the task, performance was intact when the same task was carried out in imagery.

Experiment 5: Comparison of Perception and Imagery

Experiment 5a: Imagery for Letter Shape

The results of Experiment 2 revealed that C. K. has poor discrimination and recognition of letters. To determine whether he knows the shape of letters and can image them, we asked him to generate letters of the alphabet and judge their form.

Method. The stimuli consist of the 26 letters of the alphabet. Two tasks, previously used to test imagery (Kosslyn, 1987; Kosslyn et al., 1985; Riddoch, 1990, Sergent, 1989), were administered to C. K. In the first task, C. K. was asked to imagine an uppercase letter and to judge whether it has any curved lines (e.g., *C* vs. *L*). In the second task, he was asked to imagine a lowercase letter and to decide whether the letter has a line ascending or descending from the body (e.g., *b* vs. *p*). The letters were presented auditorily one at a time by the experimenter in random order, and the uppercase and lowercase versions were blocked.

Results and discussion. C. K. performed perfectly on both tasks, scoring 26 out of 26 as do normal subjects.

Experiment 5b: Imagery for Object Size

This experiment assessed C. K.'s ability to compare the size of two objects when, on the imagery version, the names of the objects were given to C. K. and, on the perceptual version, line drawings of the same objects were presented.

Method. This task used the material developed by Schwartz and Chawluk (1990), in which 30 pairs of familiar objects were drawn up for size comparison. Examples of pairs include "banana–

spider" and "scissors–kite." In the imagery form of the experiment, the names of the two objects were read aloud, and C. K. was instructed to decide which of the two objects was larger. In the perceptual form of the experiment, pictures of the two objects, drawn as black-and-white line drawings, were presented to C. K., and he was required to make the size judgment. The two objects were drawn to the same scale in the pictures.

Results and discussion. Whereas C. K. was able to make the size judgments without error in imagery, he made the correct judgment in perception on only 19 of the 30 trials, a score not significantly different from chance $\chi^2(1) = 0.6$, $p = .43$.

Experiment 5c: Imagery Through Drawing

One way of assessing whether C. K. knows the figural appearance of objects he fails to identify from visual input is to have him draw the item in response to the label. Drawing is assumed to involve imagery and the generation of items from stored knowledge (Servos et al., 1993; Trojano & Grossi, 1992; Van Sommers, 1989); if C. K. can draw the objects he fails to recognize, this would provide further evidence for the dissociation between imagery and recognition. An initial observation made during preliminary testing showed that C. K. was able to draw objects from long-term memory in rich detail (see examples in Figure 6). C. K.'s drawing ability was particularly good; he had taken several art classes at school.

Method. Thirty of the 42 objects that C. K. could not identify in Experiment 1c (recognition of line drawings) were selected randomly. The name of each item was read aloud, and C. K. took as much as time as he required to complete each drawing. Each drawing was done on a separate sheet of blank paper.

Figure 6. Examples of C. K.'s spontaneous drawings of items from memory. Top: a map of the United Kingdom with *x* marking London, bottom: an electric guitar.

Results and discussion. C. K. drew easily recognizable pictures of 29 of the 30 objects (see Figure 7). His single error was on the item "seahorse" (see Figure 7). He commented that he did not really know what a seahorse looked like as he had not seen one for a long time. It is interesting that his rendition has a head of a horse but he stopped when he could not think of the shape of the body. When shown his own drawings on a subsequent occasion, he was not able to identify any of them.

Discussion of Experiment 5

C. K.'s ability to draw suggests that he has retained considerable knowledge about objects. Drawing, however, only taps an impoverished representation of knowledge (Van Sommers, 1989) and, on its own, is not a definitive test of the extent to which imagery is preserved (Trojano & Grossi, 1992). The results of the more detailed and controlled imagery tests, however, demonstrate that C. K. is able to generate mental images that contain detailed knowledge of the visual appearance of the very objects that he fails to recognize when they are presented to him perceptually. The data thus far clearly demonstrate that despite the profound object recognition deficit, C. K.'s visual mental imagery remains intact.

Experiment 6: Mechanisms for Perceiving the Internal Visual Image

The imagery experiments described above all required that C. K. make single judgments (size, shape, color) on a static image that had been generated from a long-term representation in response to a given label. For example, when C. K. was asked to determine whether the ears of a Doberman stick up or down, the identity of the internally generated object was already given by the label and the image was generated top–down from a long-term store of representations. In contrast, consider the following task, in which subjects are required to take the letter *H*, and to turn it on its side, drop off the bottom line, and report the identity of the image. In this task, the initial item is generated from the long-term store but is then transformed and altered. The subject is required to reinterpret the newly created image, to recognize it internally, and to assign it an identity. Are the mechanisms used for perceiving this new image the same as those used for perceiving the target letter *T* when it is visually presented? If internal perception shares the same pathway as external perception, then one might expect that C. K. would be impaired in both cases. If, however, the mechanisms used for seeing in the mind's eye are not equivalent to those used for perceiving a veridical object, then C. K. might succeed on the former and fail the latter. These findings would provide a strong constraint on any model of the relationship between imagery and perception.

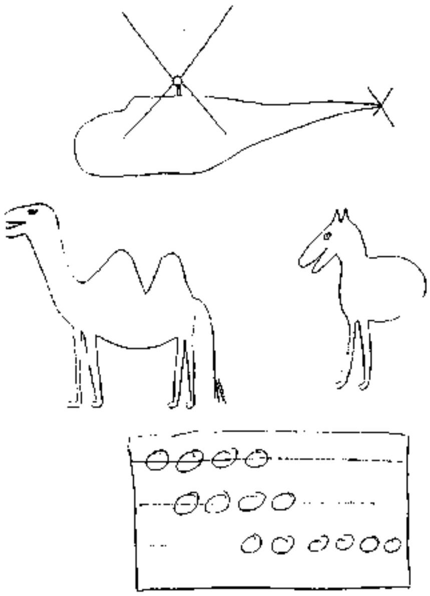

Figure 7. Examples of C. K.'s drawing items from the Boston Naming test from long-term memory. His error (the seahorse) is included. Top: helicopter; middle row: camel (left) and seahorse (right); bottom: abacus.

Experiment 6a: Perception of Objects Generated in an Internal Image

To examine whether C. K. could assign an identity to a newly created image, we used the tasks described by Finke, Pinker, and Farah (1989, Experiments 2 and 3), in which subjects are asked to generate a familiar pattern in imagery, alter it in some fixed way, and then to identify the transformed image. These tasks were initially designed to determine whether visual patterns can be reinterpreted in visual imagery. An example of a trial from these tasks is as follows: "Imagine the letter *B*. Rotate it 90° to the left. Put a triangle directly below it having the same width and pointing down. Remove the horizontal line." (The target response is "heart"). The method used by Finke et al. was as follows: Subjects were instructed to close their eyes, to listen to the instructions, and then to report the target. If the subjects failed to identify the item from imagery, they were asked to draw it to determine whether the transformation was correctly carried out and then to identify it from the drawing. An appropriate construal of the image was made on approximately 70% of the trials (pooled across the two experiments) by the normal subjects (undergraduate students). An additional 10% of the trials (approximately) were correctly drawn and then identified.

Method. The 12 trials used by Finke et al. (1989), 6 from Experiment 2 and 6 from Experiment 3, were run. The targets to be identified included the letter *T*, a heart, a stick figure of a person, the letter *F*, a TV set, and a sailboat (Experiment 2), as well as a musical note, a wine glass, a clock, an hourglass, an umbrella, and a tree (Experiment 3). The instructions were read aloud to C. K., and he was required to identify the transformed image. If he failed to do so, he was asked to draw it (to determine whether he had carried out the correct transformation) and then to identify what he had drawn, if possible.

Results and discussion. C. K. was able to identify 11 out of the 12 objects from imagery. He was unable to identify the wine glass from imagery but drew it correctly (see Figure 8i), demonstrating that he had generated the image correctly. He was then unable to identify his drawing from vision, possibly because the triangle is too small relative to the stem.

These data suggest that he was able to perceive and recognize a newly created mental image. That C. K. could recognize items from "internal" input but not from "external" input suggests that these two forms of perception are mediated by different mechanisms. The number of trials on this experiment are few, however, and normal performance is not at ceiling. In addition, the line drawings used for perception are highly schematized and simplified and as such, may not be a very stringent test of perception or of imagery.

Experiment 6b: Identification of Recreated Letters in Imagery

In the final experiment, we again examined C. K.'s ability to identify a newly generated image using a larger number of trials and using items that, in their written form, were full representations of the stimulus. In this case, alphabetic letters were used. The starting patterns in this experiment were all items that C. K. could generate correctly (as was

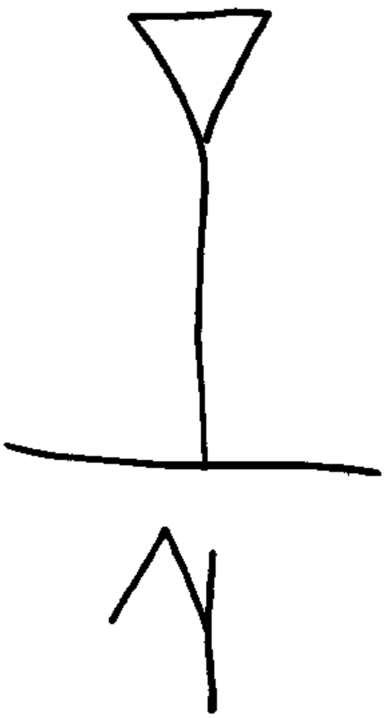

Figure 8. C. K.'s drawing of a wine glass (top) and the letter N (which he failed to identify from imagery).

demonstrated in Experiment 5). This experiment followed the same procedure as Experiment 6a. Prior to testing C. K., we tested 5 normal subjects (research assistants and graduate students, 4 of whom were women).

Method. The stimuli consisted of 24 trials, each of which contained a letter of the alphabet as the target stimulus. (See Appendix B for instructions for each trial.) The procedure was identical to that of the previous experiment.

Results and discussion. The normal subjects scored a mean of 21.6 out of 24 correct ($SD = 2.3$). Four of the 5 subjects made an error on one particular item (see Appendix B, Trial 7), but all were able to interpret their drawing correctly afterwards. C. K. made two errors, one on Trial 7 and one on Trial 14, where he misplaced one of the elements (see his drawing of the letter N in Figure 8) and was then unable to recognize the image. In contrast to his ability to perceive these newly generated images of letters, his ability to recognize letters of the alphabet presented to him visually was poor (see Experiment 2c).

Discussion of Experiment 6

C. K. was able to generate an item, transform it, and recognize it from the internal image, as shown in both Experiments 6a and 6b. On the few trials in which he failed to identify the image, he was able to draw it in a manner consistent with the instructions but still failed to identify it from the drawing.

General Discussion

The focus of this article is on the relationship between visual imagery and visual perception. Compelling evidence from a number of sources supports the view that imagery and perception share common representational and neural mechanisms. This evidence, from previous behavioral studies with normal and brain-damaged subjects and from recent neuroimaging and electrophysiological studies, provides the framework within which the current investigation is undertaken. The question addressed in this article is whether imagery and perception can be doubly dissociated and, if so, how such dissociations can be accommodated within a model of shared mechanisms. The first half of the imagery–perception double dissociation, in which imagery is impaired but recognition is reasonably well preserved, has already been documented in several cases (Farah, 1988; Farah, Hammond, et al., 1988; Riddoch, 1990). Although there are existing data favoring the converse dissociation of impaired recognition and preserved imagery, the data are highly suggestive but not conclusive (see cases of Humphreys & Riddoch, 1987a, 1987b; Jankowiak et al., 1992; Riddoch & Humphreys, 1987). The first goal of this article, then, was to establish clearly the existence of the pattern of impaired recognition but preserved imagery, thereby confirming both sides of the double dissociation. The second goal was to examine the bounds of the relationship between imagery and perception and to suggest a model in which both the observed associations and dissociations might be explained.

C. K. is a 33-year-old male who has a profound object recognition deficit (visual object agnosia) following a head injury. He is poor at recognizing visually presented objects, both black-and-white line drawings and three-dimensional objects. The deficit in identifying objects from vision cannot be attributed to a loss of knowledge about the objects or to a difficulty in retrieving the label for the object. He is able to recognize and name these same objects presented to him through the tactile modality and can define the objects in detail in response to their auditorily presented name. C. K. also has a marked alexia; he is poor at recognizing letters of the alphabet (although he can do so by tracing them) and cannot read even single words. It is interesting that despite the severe agnosic deficit, C. K. is able to discriminate novel faces and to recognize famous ones. C. K.'s remarkable preservation of face recognition is the focus of a separate article and speaks to the much-debated issue of modularity or separation of the processes required for face recognition and for object recognition (Farah 1991, 1992). It should be noted, however, that C. K. is one of a small number of reported patients who have object agnosia and alexia along with preserved face recognition.

C. K.'s deficit in object processing appears to arise from a problem in intermediate stages of visual processing, an impairment that has come to be called "integrative agnosia" (Riddoch & Humphreys, 1987). He is unable to segment and group elements of an array. For example, he cannot match or trace items that are overlapping and cannot segment a figure from the ground as the visual noise is increased, despite the finding that lower level perceptual processes are mostly intact. As demonstrated in his errors in naming objects (e.g., referring to a dart as a feather duster and a tennis racquet as a fencer's mask), he is able to pick up local and isolated visual features of the individual object but is then unable to form a coherent, meaningful whole from the parts. This is also reflected in his copying performance—although C. K. copies geometric configurations correctly, he does so in a slavish, piecemeal fashion without appreciating the identity of the object or text being copied. This fundamental impairment in segmentation or grouping affects the process by which a coherent structural description of the object is derived and has been identified as the critical deficit in a number of other recent patients with agnosia (De Renzi & Lucchelli, 1993; Grailet et al., 1990; Humphreys et al., 1993; Sparr et al., 1991; Thaiss & De Bleser, 1992).

Despite his severe object recognition deficit, C. K. demonstrates remarkably intact mental imagery. He possesses detailed knowledge about the size, color, and shape of objects and letters, even for those items that he fails to identify from visual presentation. He can also verify sentences that rely on mental imagery as well as normal subjects. The integrity of the long-term representations of objects is demonstrated further by his ability to draw in considerable detail from memory the very objects he fails to recognize. Finally, and critically, C. K. can access semantics for items that are constructed in his mental image, and he can generate a stimulus from component parts, process this newly created image, and assign an identity to it. Thus, he can perceive items in imagery even though he cannot do so from veridical external input. These results indicate that C. K. still possesses the long-term representation of the objects he fails to recognize and is able to generate an image from these representations in a "top–down" fashion. Once an image is generated "top–down," he can also manipulate it and then use it successfully as "bottom–up" input to the stored representations of objects.

C. K.'s performance provides the most clear-cut example of a patient with preserved imagery and impaired recognition and, as such, provides the complement for the double dissociation between imagery and perception. That imagery and perception can each be selectively impaired while leaving the other process reasonably intact argues against a simple explanation of hierarchical ordering in which one of these processes is inherently more difficult than the other. Instead, this form of double dissociation has been taken to mean traditionally that there is some independence or separation between the two processes. The paradox, then, is how to reconcile the findings of separation with the overwhelming evidence supporting the shared substrate for imagery and perception. In the next section we consider a range of possible models that can accommodate both the association and dissociation results and then adopt them to explain the specific results shown by C. K.

Because the separability or independence suggested by the double dissociation between imagery and recognition is difficult to reconcile with the evidence showing a common underlying mechanism, we need to examine what type of architecture can account for these data (see Shallice, 1988, for a full discussion of the inferences from double dissociations). One possible scheme is one in which imagery and recognition are not completely isolable nor completely integrated, but rather overlap partially and still retain some unique components. It is obvious that there are some components of the system that are not shared by imagery and recognition. For example, the retina, though critical for recognition, is hardly likely to be involved in imagery. Thus, damage to early stages of visual processing has little impact on imagery, and congenitally blind people can generate images (Cornoldi, Cortesi, & Preti, 1991).

The idea of some components being unique to imagery or recognition can be extended to argue that there are subprocesses that are dedicated to imagery and of no functional relevance for perception. This interpretation has already been proposed to explain the behavior of those patients with imagery deficits who have preserved recognition. According to componential theories of visual imagery (e.g., Kosslyn, 1980; Kosslyn, Flynn, Amsterdam, & Wang, 1990), the generation component is the means whereby an image is created in the visual buffer from information stored in long-term visual memory. The generation component, in turn, can be subdivided into subprocesses such as *picture*, *put*, and *find*. Because generation is selectively involved in imagery and has no role in perception, it can be damaged without any consequences for perception. Farah (1984) used this idea of a unique imagery component to infer the locus of damage in a post hoc analysis of 37 patients with loss of imagery, 8 of whom had grossly intact perception and recognition. Farah concluded that in all these 8 cases the deficit arose in the image-generation process, as this was the only component that was needed exclusively for imagery and not for perception. The same conclusion was reached more recently with the patients who had undergone more formalized, experimental testing. In these later cases (Farah, 1988; Farah, Levine, et al., 1988; Riddoch, 1990), the deficit was also localized to the generation process (see Goldenberg, 1993, for discussion of other, similar cases). Whereas this explanation may hold and account for the selective impairment in imagery, it still does not shed light on the complementary pattern or suggest what unique recognition processes may be selectively damaged, leaving imagery intact. In its current form, then, this model does not account for C. K.'s pattern of deficits. In fairness, because the pattern of impaired recognition and intact imagery shown by C. K. has only been described in detail recently, the model has not had to address this issue.

A conceptualization similar to the model of unique components is that of unique pathways of access to the shared long-term representations. Studies of primate visual systems indicate that pathways to and from visual areas are instantiated independently (Van Essen, 1985). Thus, even if representations for imagery and recognition are shared, access to and projections out of the common store may be different. Damaged feedforward projections in which the intact representations cannot be accessed may impair object recognition, whereas damaged "back-projection" or "top–down" pathways from the stored representations may selectively impair imagery. Applying this logic to the case of C. K., one might argue that it is the feedforward projections that are affected, precluding access to the stored semantic representation. Although this view might account for some of the findings, it does not provide an adequate explanation of all the results. Consider the task of recognizing a newly constructed stimulus in mental imagery (as in Experiment 6). In this task, C. K. was required to generate an image top–down, project it on the visual buffer, transform it in some prescribed way, and then, through the feedforward connections, access the long-term store bottom–up to assign an identity to the item. If the same set of pathways are used for the recognition of internal bottom–up and external bottom–up stimuli, one might predict that C. K. would fail to recognize the altered visual images, but this is not the case. To account for these data, then, one might have to postulate a third pathway: one for top–down image generation and two for bottom–up access, one from an internal and one from an external object. Such an account does not seem parsimonious, and as more dedicated pathways are proposed, the less likely it will be that the strong association between imagery and perception can be explained.

Neither the unique component view nor the dedicated pathways model provide a satisfactory account of the data. The model that we propose takes as its starting point the idea of a shared system and, consistent with the empirical data, we argue that imagery and recognition are strongly associated. As in many cognitive and computational models of visual object processing, we assume that there are a series of component stages through which an object is passed prior to recognition (see Farah, 1990; Humphreys et al., 1993; Kosslyn et al., 1990; Marr, 1982; McCarthy & Warrington, 1990). At early stages, primitive features are registered and edge-detection and orientation are carried out. At intermediate stages, processes involved in figure–ground segregation and feature grouping come into play, and processes involved in activating stored knowledge are operational at late stages. We have argued that C. K.'s deficit affects intermediate stages of processing that are required for grouping and segmentation of elements or features and, as in other patients with "integrative agnosia," this precludes the derivation of a coherent structural description. The impairment, therefore, disrupts the access to higher level processes that are, in themselves, fully functional. It is these intact, higher level processes that operate in imagery and that access the stored representations. Thus, imagery of object size, shape, and color is preserved.

What remains to be explained is how C. K. can recognize an internally generated object if the deficit affects bottom–up access to the higher order representations. One possibility is that the task of recognizing an internally generated image is not as reliant on the intermediate stages of parsing and integration of features as is the case for an object presented externally. When asked to image the letter *K*, for example, all the features and their relations to each other are specified top–down from the long-term representation. A by-product of this top–down generation, therefore, is that the parts of the item and the spatial relations between them are known. Because the integration of the parts is given top–down, shifting the parts around to transform the image may be accomplished without the involvement of segmentation processes. In this way, perceiving an internally generated object avoids the bottom–up disruption and involves only processes higher than the figure–ground segmentation and grouping. Therefore, a shared system for imagery and recognition may exist but may be used differently for different tasks and functions. Such a model would not only explain the associations but, by virtue of the different functional reliance, would account for the dissociations in the system.

By proposing a unifying framework and by showing how selective impairments can be observed in the context of a shared mechanism, we have been able to accommodate both the associations and dissociations between visual mental imagery and visual recognition. The thrust of this argument is that it is possible to observe double dissociations in the context of a shared system. Although common representations and neural mechanisms may subserve both imagery and recognition, there may still be components of the shared system that are functionally specialized. Damage to these shared components or processes may give rise to the observed dissociations.

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Appendix A

Errors on the Boston Naming Test

Target picture	Response	Classification
tree	plant	S/V
octopus	plant	V
wheelchair	chair	S/V
mask	face	S/V
bench	double chair	S/V
volcano	explosion or something	V
dart	feather duster	S/V
globe	trophy	V
beaver	an animal, hamster	S/V
rhinoceros	dinosaur	S/V
igloo	bricks and a dome	V
dominoes	bricks with holes in them	V
harp	don't know	—
knocker	brooch	V
pyramid	a triangle shape	V
funnel	glass	V
noose	piece of rope	S/V
compass	don't know	—
tripod	three spears	V
tongs	has teeth	V
trellis	squares and dots	V
protractor	measuring instrument in cockpit	V
helicopter	rotary wing aircraft of some sort	S/V
hanger	hook	V
camel	animal (not specific)	S/V
pretzel	snake	V
racquet	fencer's mask	V
seahorse	scorpion	V
canoe	boat	S/V
wreath	don't know	—
harmonica	has holes in it like pigeon holes	V
acorn	some kind of fruit	V
stilts	don't know	—
escalator	stairs you push up to plane	S/V
hammock	tennis court net	S/V
pelican	bird, water bird, a duck	S/V
muzzle	a map with coasts and roads	V
accordion	don't know	—
asparagus	a stick, a rose twig with thorns	V
latch	not sure, some metal	V
scroll	some writing on paper	V
yoke	don't know	—
palette	abstract drawing	V
abacus	grill with food, corn on the grill	V

Note. The errors are classified according to whether they are related visually (V) or semantically (S) to the target or both (S/V). A dash indicates no response.

Appendix B

Trials for Imagery/Perception Experiment (Designed by Moscovitch)

1. Take the letter *V*, turn it upside down. Put a horizontal line through the middle of it. **A**

2. Take the number 3, put a vertical line touching the open end. **B**

3. Take the letter *O*, cut it in half vertically. Throw away the left half and rotate the remainder 180 degrees. **C**

4. Take the letter *C*, rotate it 180 degrees. Add a vertical line connecting the two open ends. **D**

5. Take the letter *H*. Drop off the right vertical line. Add a horizontal line to the top and to the bottom. **E**

6. Take the letter *L*. Flip it from top to bottom and add a horizontal line in the middle. **F**

7. Take the letter *C*. Add a small vertical line to the bottom and attach another small horizontal line on top of the vertical line. **G**

8. Take the letter *F*. Drop the top line. Add a vertical line to the right of the figure. **H**

9. Take the letter *T*. Drop off the horizontal line. **I**

10. Take the letter *L*. Drop off the bottom horizontal line. Now take the letter *C* and rotate it 180° so that the open end is facing left. Attach the right half of the open end to the bottom of what is left of the *L*. **J**

11. Take the letter *I*. Add the sharp vertex of the letter *V* to the middle of the right side of the line. **K**

12. Take the letter *T*. Turn it upside down. Drop off the left half of the horizontal line that is sticking out. **L**

13. Take the letter *V*. Turn it upside down. Now take another *V* and turn it upside down and bring it next to the first upside down *V* on its right until they touch. **M**

14. Take the letter *V*. Turn it upside down and bring the letter *I* until it touches the right end. **N**

15. Take two *C*s. Turn one backwards and bring them together until they touch. **O**

16. Take the letter *T*. Drop off the horizontal line. Add a backwards *C* to the right side of what remains. **P** (this could plausibly be a **D**)

17. Take two *C*s. Turn the right one backwards and make it touch the left one. Now add a small diagonal line to the bottom right edge. **Q**

18. Take the letter *B*. Drop off the bottom semicircle. Add a diagonal line (tilted to the left) to where the top semicircle touches the vertical line. **R**

19. Take two *C*s. Turn the right *C* backwards. Lower it so that the top edge of the backward *C* touches the bottom edge of the normal *C*. **S**

20. Take the letter *H*. Turn it on its side and drop off the bottom line. **T**

21. Take the letter *C*. Turn it facing up. **U**

22. Take the letter *M*. Cut it in half. Drop off the right side and turn whatever remains upside down. **V**

23. Take the letter *M*. Turn it upside down. **W**

24. Take the letter *V*. Add a vertical line to the vertex. **Y**

Note. Trials were randomized. Correct responses are indicated in bold.

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