

LOSS OF VISUAL IMAGERY AND LOSS OF VISUAL KNOWLEDGE—A CASE STUDY

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Abstract—As a sequel of a left posterior cerebral artery infarction a patient had severely defective mental imagery of shapes and colours of objects. Imagery of faces, letters, and topological relationships was preserved. The impairment of imagery of object colours was associated with colour agnosia and colour anomia. For colours, there was no difference between performance on tasks calling for imagery of object colours and tasks affording a distinction between correctly and incorrectly coloured objects. For shapes of objects, imagery appeared to be below the level of the patient's knowledge about the visual appearance of objects as manifested by the ability to identify objects and to distinguish correctly from incorrectly drawn pictures. The apparently selective image generation deficit for shapes of objects could be a sequel of loss of knowledge about visual attributes of objects, if superior performance on shape recognition tasks was afforded by perceptual entry level representation which enable a rapid identification of objects but are inaccessible to introspective consciousness.

INTRODUCTION

NEUROPSYCHOLOGICAL CASE studies have shown both associations and dissociations of visual imagery and visual recognition deficits. Visual agnosia is frequently accompanied by a loss of visual imagery [1, 2, 8, 18, 32, 44, 46, 51, 61, 73, 75], and selective disturbances of single aspects of visual recognition can be associated with an equally selective imagery deficit. For example, patients who fail to report the left half of perceived stimuli may also fail to report the left half of imagined stimuli [3, 9–11, 33, 53, 56]. Defective apprehension of spatial relationships can be accompanied by defective spatial organization of mental images [46, 55]. Conversely, object agnosia with preserved apprehension of spatial relationships can be complemented by an imagery deficit which affects imagery of single objects but not imagery of topological relationships [46, 69]. Recognition and imagery of object colours can be disturbed in the presence of intact recognition and imagery of object forms [20, 47, 49, 72], and conversely [1, 2]. Impaired recognition of faces [50, 66] or living things [23, 69] has been reported in association with imagery deficits restricted to the same classes of visual entities.

Whereas these dissociations affect visual recognition and imagery equally, there are also dissociations between recognition and imagery. There are patients who cannot recognize seen objects but appear to have intact or at least much better preserved imagery [25, 37, 45, 54, 64, 68, 77]. This dissociation can interact with that between different aspects of visual apprehension. There are cases in whom both recognition of object colours and object forms was defective, whereas the imagery deficit affected only object colours and not object forms [25, 54].

The reverse dissociation, loss of imagery with better preserved recognition of objects, has

also been described in a number of cases [4, 12, 13, 16, 19, 24, 34, 58, 65]. Again, the disturbance can be selective for single aspects of vision, as there were patients who could not imagine the forms of objects but could imagine their colours [12, 19, 34, 58] or topological relationships [19, 24].

The observed associations and dissociations fit into cognitive theories of mental imagery which assume that some cognitive processes are shared by visual perception and visual imagery while others are specific either to perception or to imagery [22, 40–42, 59]. Both recognition and imagery require knowledge about the visual appearance of the world that is stored in long-term memory. In perception, visual input is matched to stored knowledge for recognition, and in imagery the content of the mental image is derived from the same knowledge. Both imagined and perceived images can further be evaluated and processed by identical cognitive mechanisms.* To enable a match between percepts and knowledge in long-term memory, perceptual preprocessing of visual input is necessary. By contrast, imagery calls for an image generation process which converts knowledge into the “quasi-perceptual” format that permits further processing.

Associated deficits of perception and imagery which are restricted to one domain or to one aspect of vision can be caused either by deficits in long-term memory which affect knowledge about single categories (e.g. living things) or single visual attributes of objects (e.g. colour), or by deficient further processing of one aspect of images (e.g. when one half of them is not attended to). Impaired recognition with spared imagery would be ascribed to defective perceptual processing at stages which precede the access to long-term memory. Finally, spared recognition in the presence of impaired imagery would indicate damage to the image generation process [22].

The analysis of image generation deficits could permit insights into the nature of the image generation process. Models have been proposed which conceive of image generation as being performed by cognitive modules which can be impaired independently from a loss of visual knowledge [22, 40–42]. An alternative assumption would be that image generation is equivalent to the activation of modality-specific visual knowledge, and that there are no additional processes which compose the quasiperceptual image out of retrieved knowledge [30, 57]. To account for cases whose visual imagery is worse than visual recognition it has been hypothesized that these patients have lost parts of visual knowledge which are more important for imagery than for recognition [30]. In this way, the image generation deficit would ultimately be referred to a selective loss of knowledge about visual attributes of objects.

Both views make different predictions concerning possible constellations of associations and dissociation between impaired imagery and impaired recognition. If image generation can be damaged independently from loss of visual knowledge, its breakdown may follow patterns determined by the subcomponents of the image generation process, but should not necessarily respect dissociations determined by the organization of visual knowledge. Image generation deficits should be manifest across the boundaries between different domains of visual knowledge. On the other hand, if the image generation deficit stems from a selective loss of visual knowledge, a close examination of patients whose imagery is worse than recognition should reveal impairment in the recognition of those visual attributes which are more important for imagery than for recognition of objects [30].

*A visual buffer, where both perceived and imagined images are retained for further processing, is omitted from that account. All the effects to be analysed in this study can be explained without it.

The following report presents a patient who had lost visual imagery as a sequel of left posterior cerebral artery infarction, and in whom the relationship between imagery and recognition was assessed for different kinds of visual entities.

CASE REPORT

K.Qu. was a 83-year-old right-handed man who had graduated from a technical college and was still directing a plumber's workshop with several employees. Because his wife suffered from Alzheimer's disease, he had been familiar to the Neurological Department before the start of his own illness. He was known as an active and well-informed person who successfully managed family and business affairs. In July 1990 he sustained a left posterior cerebral artery infarction with secondary haemorrhage, probably caused by embolism from atrial fibrillation. On the initial examination right upper quadrantic anopia and aphasia with anomia and reduced comprehension were noted, while the remainder of the neurological examination was reported to be normal.

When neuropsychological investigations commenced in August 1990, there were still quadrantic anopia and word-finding difficulties in spontaneous speech, but in conversation language comprehension appeared normal. He was alexic but not agraphic. He was oriented to time, place, and day-to-day events, but forgetful.

CT scan (see Fig. 1) showed an extensive infarction of the territory of the temporo-occipital branches of the left posterior cerebral artery. In addition there were small and apparently older infarctions in the right-frontal lobe and right cerebellum.

During the further course, word-finding improved and after 2 months there was only mild anomia in spontaneous speech. Likewise, reading improved to the degree that he could slowly read words and sentences.

NEUROPSYCHOLOGICAL EXAMINATIONS

Neuropsychological investigations were carried out mainly in August and September 1990. Examinations concerning reading, naming, visuo-perceptual abilities, and imagery for colour and shapes were repeated and completed during the following 1½ years, when no major evolution of deficits was observed any more.

Report of neuropsychological examinations will be divided in two parts. In the first, general neuropsychological findings pertaining to intelligence, memory, language and perceptual functions will be reported, and in the second investigations concerning visual imagery and knowledge about the visual appearance of objects. Knowledge about colours will be treated in the first section, and knowledge about the colours of objects in the second.

GENERAL NEUROPSYCHOLOGICAL FINDINGS

Intelligence and memory

K.Qu. scored above the 95th percentile of his age group on the Coloured Progressive Matrices (30/36). Digit Span was 7 forwards and 5 backwards, and Corsi Block Span 5. On the Rey Auditory Verbal Learning Test he recalled 2-3-4-3-3 words on immediate, and none on delayed recall. By contrast, memory for faces, as assessed by the Warrington Face

Recognition Test [76] was at the 50th percentile of the control group (42/50). At the beginning of August, immediate recall of the Rey Osterrieth figure was restricted to a few fragments. At the end of August both immediate and delayed reproduction of the Taylor-figure preserved the basic structure but were impoverished (13/36 and 14/36, 10th percentile of normal group = 15/36).

Oral language

Phonemic and syntactic structure of spontaneous speech were normal, and repetition was flawless. In September 1990 naming was assessed from line drawings and from verbal description with half of the items presented first for picture naming and later for naming from description, and the other half in the reverse order. Naming from description was only moderately better than from pictures (45/64 vs 39/64), and there was a high consistency of errors between both modes of naming: out of 25 items failed on picture naming, 18 were also failed on naming from description, and out of 39 items correctly named on picture naming, 37 were also named from verbal description ($\chi^2 = 31.7$, d.f. = 1, $P < 0.0001$). On this and other examinations fruits and vegetables were named consistently worse than any other category examined. Across all examinations K. Qu. named correctly 9/73 (12%) fruits and vegetables, 40/76 (53%) other aliments, 34/82 (42%) animals, 19/32 (59%) household-items, 41/60 (68%) small manipulable objects, 42/62 (68%) larger objects, and 17/30 (57%) body parts.*

Comprehension of single and multiple step commands was good, and the patient correctly distinguished semantically impossible from possible sentences. When auditory comprehension of object names was assessed by presenting each of the pictures used in a naming examination together with three distractors from the same semantic category, pointing to the named picture was markedly better than picture naming (55/60 vs 31/60).

Writing and reading

Initially, the patient committed some literal paraphasias on writing to dictation of single letters or non-words, but not on writing of real words. He could without hesitation distinguish real letters from similar shapes. He correctly read only 13 out of 26 letters, but pointed correctly to 21 out of 26 letters spoken to him. Neither tracing letters with the fingers nor copying the letter helped his reading. In the latter case, he continued to misname the letter he was writing, although he could write it correctly on dictation. He himself had found another more successful reading strategy based on the intact recognition of letters spoken to him: He recited the alphabet until he came upon the letter that he wanted to read. Out of the above-mentioned 13 correctly read letters, five had been recognized in this way. He frequently could say whether a letter was close to the beginning or to the end of the alphabet before he started his reading strategy and sometimes even if he eventually failed to recognize it.

In the further course, reading improved to letter-by-letter reading. Eventually, he read words slowly and with rare literal paralexias but without overt spelling. In November 1991 reading was assessed with triplets of words of increasing length. From 3-letter to 8-letter words there was a fairly linear relationship between word-length and reading time ($R = 0.98$, $P = 0.001$, mean increase per letter 3.2 sec) betraying covert letter-by-letter reading [6], while

*Naming of some items was examined repeatedly. The categories of small and larger objects overlapped with that of household items. They were examined in separate sessions.

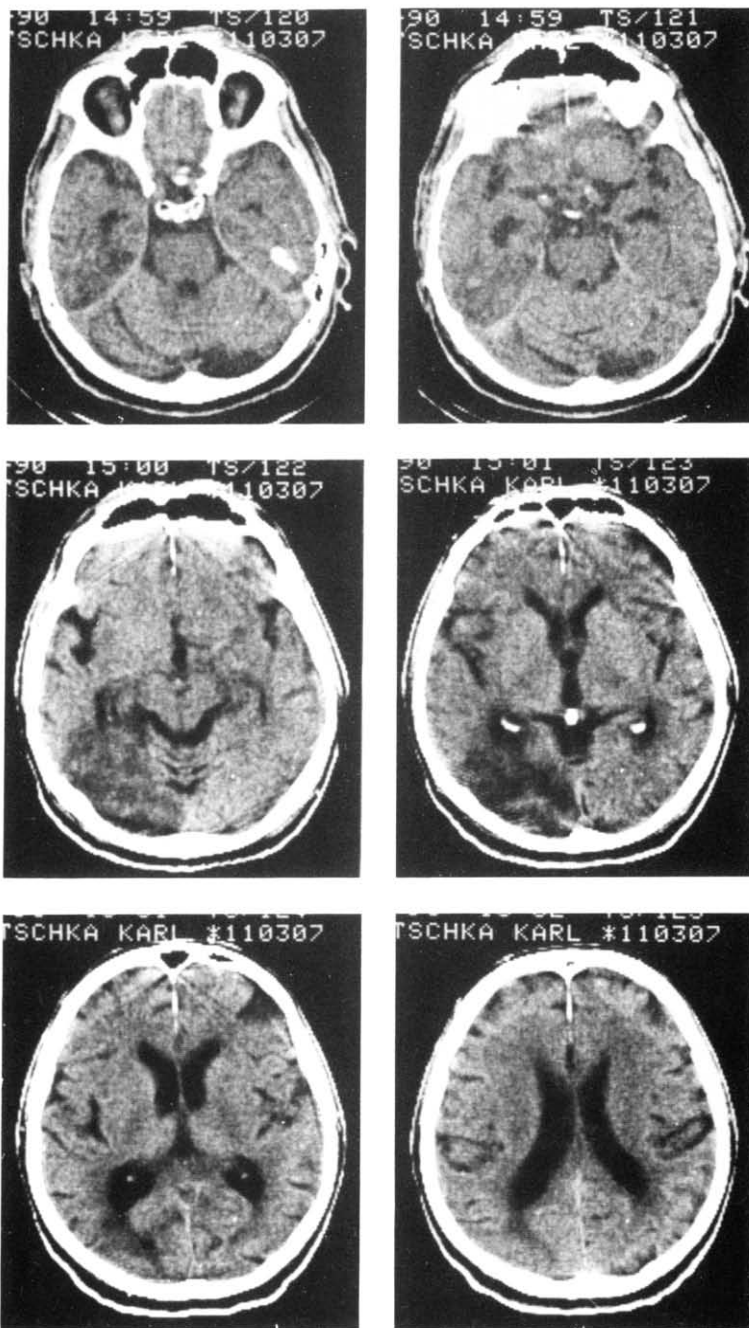


Fig. 1. CT scans showing extensive infarction of the territory of the temporo-occipital branch of the left posterior cerebral artery. In addition, there are small infarctions in the right frontal lobe and cerebellum. The left side of the slices corresponds to the left side of the brain.

with longer words the relationship became irregular, and the patient volunteered that he tried to guess the whole word from one or two syllables.

Visuoperceptual and visuospatial abilities

Binocular corrected visual acuity was 5/18. On a shape discrimination test which requires comparisons between slightly different curvatures [30] K.Qu.'s performance was in the upper range of the control group (see Table 1). He correctly identified photographs of famous personalities and of Viennese monuments. On the Benton Test of Facial Recognition [7] his performance was classified as "borderline" (age corrected score 39). By contrast, recognition of incomplete line drawings was clearly defective: On part one of Read's Visual-Closure Task [63] he committed 27 errors which is 4.8 S.D. more than the mean of the age-appropriate control group, although he identified all drawings when shown with complete contours. On the second part he showed a procedural learning effect which was, however, inferior to that of the control group (37%, controls: mean = 72%, S.D. = 17). On the practice items of the subtest "Speed of Closure" of Horn's Primary Factors Test Battery (35) he saw "only lines" and none of the objects demonstrated to him by the examiner. On the test, he eventually resolved two pictures in one minute (T-score = 35).

Table 1. Perceptual discrimination, low- and high-imagery sentences, and perceptual access to visual knowledge

	K.Qu.	Controls		Range
		Mean	S.D.	
Shape discrimination	36	23.5	2.5	19-27
Colour discrimination	26	25.9	1.9	21-29
Low-imagery sentences	22	22.2	2.0	18-25
Shape imagery sentences	18	21.6	1.8	19-24
Colour imagery sentences	13	22.6	2.3	18-25
Visual shape questions	17	22.9	1.9	20-25
Visual colour questions	18	23.7	1.4	21-25

There were 27 controls. Their mean age was 53.6 with a range from 31 to 77, but the only significant correlation with age concerned shape discrimination which got worse with increasing age ($R = -0.47$). Correlations for verbal and visual knowledge questions were between -0.08 and -0.40 and not statistically significant.

In August 1990 his copy of the Rey-Osterrieth figure showed some inaccuracies and yielded a score of 32/36 which corresponds to the published mean score of adults [48]. In September 1990 he copied the Taylor figure perfectly. He correctly placed the major towns into an empty map of Austria, and he could draw from memory an accurate layout of his room on the ward. He could without difficulties discriminate whether rotated letters were correct or mirror images, but denied to have mentally rotated them to the upright position. Instead, he claimed that by simply looking at the letter he could see whether it was correct or not. On the Mannekin Test of mental rotation which requires a distinction between right and left of upright and inverted mannekins [29, 62] he did not commit a single error with upright mannekins (16/16), but scored at chance level (8/16) with upside-down figures. On the Older Adults Form of the Schaie-Thurstone Adults Mental Abilities Test [70] he scored markedly lower on the subtest Object Rotation which requires mental rotation of concrete line

drawings (T-score = 38), than on the subtest Figure Rotation which requires mental rotation of abstract figures (T-score = 47).

Colour discrimination, colour sorting and colour naming

The patient correctly read pseudoisochromatic plates [74]. On a test of colour discrimination which requires comparison between pairs of colour patches which are either identical or differ slightly in hue [30] his score corresponded to the mean score of the control group (see Table 1).

Colour sorting was assessed by means of the Goldstein Scheerer colour sorting test [48]. K.Qu. was given one sample each of red (No. 7), violet (No. 14), blue (No. 44), green (No. 24), yellow (No. 28), brown (No. 36) and grey (No. 58) wools and was asked to sort the remainder of the wools to these samples. He proceeded by comparing each wool to each of the samples one after the other until he was satisfied with a match. In this way he correctly sorted the majority of wools, but came into difficulties when wools of corresponding hue differed largely on brightness or, respectively, saturation. Thus he sorted bright shades of green (No. 18) and turquoise (No. 16) to yellow, and refused to associate very dark (Nos 26, 27 and 48) or very light (Nos 2, 19 and 39) shades of green, blue, and violet to any of the samples. He also refused to match white (No. 61) and black (Nr. 61) with grey or any other of the samples.

Naming of colours and pointing to named colours was examined repeatedly. In August 1990 he could not give the correct name of any of six colours, but pointed to all of them correctly when the name was spoken to him. In October 1990 he named four out of 10 colours, and comprehension was not assessed. In May 1991 he named five out of 10 colours and comprehended the names of seven out of 10, and in November 1991 he named three out of nine and correctly pointed to eight out of nine. Thus, comprehension of colour names was better than naming, but defective. Naming errors consisted mainly in incorrect colour names, but sometimes also in descriptions like "it is a very bright colour, not intensive" for grey. Naming of black was assessed in two of the examinations and was correct once and incorrect the other time, naming of white was assessed only once and was correct. Occasionally, when comprehension was examined, the patient's comments pointed to a lack of a concept of the colour. For example, when asked to point to orange, he said: "What is orange at all? Is it between red and blue? The name is familiar to me, but there are two colours."

By contrast, he produced colour names without errors or hesitation in response to questions for symbolic connotations of colours, as, for example, what are the colours of innocence, hope, love, jealousy and evil, or, how do you call a Monday when you don't go to work (in German a "blue Monday").

Knowledge about colours

Questions concerning the relationship between colours gave rise to long reflections and severe errors. Thus, when asked whether green is more similar to yellow or to red, he answered "there is light green and dark green - you can't say which one is nearer to red, it is a combination", and when the examiner insisted on wanting to know whether the difference was larger to yellow or to red, he conceded that the difference to red might be somewhat smaller. When asked whether he knew violet, he asserted that it is a combination colour, but when asked from what colour it is combined, he said "red and green". When asked what colour derives from the combination of black and white, he first responded with rose, then

corrected: "no . . . a combination of black and white . . . I know that this exists, but I don't know the name." He did, however, respond without errors to questions as to which of a pair of colours (e.g. yellow and violet, orange and red, rose and blue) is generally darker.

VISUAL IMAGERY AND KNOWLEDGE ABOUT THE VISUAL APPEARANCE OF OBJECTS

Evidence pertaining to the relationships between visual imagery and visual knowledge will be reported separately for colours and shapes of objects, shapes of letters, topological relationships, and faces. Dissociations between visual and non-visual knowledge will be dealt with after knowledge about the shape of objects.

Colour of objects

Responses to questions about the colour of objects were frequently wrong. Thus, K.Qu. said that the sky is "reddish", an elephant "reddish-brown", a carrot "yellowish". When giving correct responses, he sometimes volunteered to have found them by verbal association as, for blood, "it is red as blood".* When colouring line drawings of objects he frequently selected grossly aberrant colours, and in addition to choosing the wrong colour he misnamed it. Thus, he would paint the sign of the Vienna Underground Railway, which is actually blue, brown and comment that it is green. Correct naming of the appropriate colour by verbal association did not help him for colouring, and he painted grass brown while saying that it must be green, because there is a song that goes "green is the grass".

The relationship between imagery and knowledge about the colours of objects was assessed systematically as part of a test which has previously been administered to normal controls and groups of patients with posterior cerebral artery lesion [30]. It is based on the paradigm of low- and high-imagery sentences [21]. There are 75 sentences with two possible predicates, one of which is factually wrong. As validated in a pilot study, verification of 25 of the sentences does not call for imagery, while verification of the other sentences does. Twenty-five high-imagery sentences make statements about shapes of objects, and 25 about colours of objects. For example, a low-imagery sentence is: "The squirrel gives birth to living youngsters/lays egg", a high-imagery sentence concerning shape: "The eyes of a squirrel are slit/round", and a high-imagery sentence concerning colour: "Most squirrels are reddish brown/yellowish brown". The high-imagery sentences are complemented by visual shape and colour questions, in which the referents of shape- and colour-imagery sentences are depicted in two versions corresponding to the two predicates of the sentence. Whereas verification of high-imagery sentences calls for both visual knowledge and image generation, verification of the pictorial versions probes visual knowledge by perceptual access and hence does not afford image generation.

K.Qu. was first presented the 75 sentences. Low-imagery, shape-imagery and colour-imagery sentences were presented in random order. The examiner read aloud each sentence with both possible predicates and K.Qu. was asked to select the correct one. Then he was shown the 25 visual shape questions. Each visual shape question consists of two line

*The use of verbal associations for retrieving the colours of objects was not infallible. Thus, in the above example, he designated the sky as "reddish" although there is doubtlessly a strong verbal association between "sky" and "blue". It may be of relevance that this error occurred when K. Qu. had a line-drawing of a landscape before him and could look at the sky through the window. Possibly, these visual clues discouraged him from using a strategy of verbal association for finding the name of the correct colour [5].

drawings of the same object which differ in the detail asked for by the corresponding high-imagery sentence (see Ref. [30] for examples). K.Qu. was asked to select the correct picture of the object and to indicate the crucial difference between the two drawings. If the difference was not designated correctly, it was demonstrated and K.Qu. was asked whether a consideration of the demonstrated difference would alter his choice. Finally, the 25 visual colour questions were presented. Each one consists of two identical drawings which are coloured differently according to the two versions of the corresponding high-imagery sentence. The results of the whole test are shown in Table 1 together with those of a control group.

K.Qu.'s score on verification of colour-imagery sentences was at chance level, that on the visual version was better but below the range of normal controls. On the visual version, he selected the correct colour for 18 out of 25 objects. He rightly named five out of 18 objects for which he had selected the correct colour and three out of seven for which he had chosen the incorrect one, and he produced the correct name of 11/18 correctly selected and of four out of seven incorrectly selected colours (Fisher's Exact Test, all $P > 0.3$). Thus, neither the capacity to name the object nor the capacity to name the colour influenced his success on selecting the correctly coloured object.

The wrong colours of the visual colour questions were generally much less deviating than the colours which the patient used when colouring himself. Therefore, errors on this test would not necessarily indicate that he was unable to decide between his own errors and the true colours of objects. He was given uncoloured versions of the drawings used in the test and 10 coloured pencils, and was asked to indicate the colours of the objects by a few strokes. He coloured correctly eight out of the 25 items. Then, a new version of the dual-choice test was prepared by combining the correctly coloured picture with a picture painted in the colour selected by the patient. Items which had been coloured correctly were paired with another far deviating colour. He chose the correct version in 17 out of 25 instances. When allowance is made for the different chance probabilities (one out of 10 for colouring, and one out of two for selection in dual-choice), the recognition of correct colours was not at all more accurate than free colouring.

Shapes of objects

Figures 2–6 show examples of K.Qu.'s drawing of objects on verbal request. When drawing, he spontaneously complained of the absence of mental images of the object. For example, when trying to design a Volkswagen (Fig. 2) he said; "I cannot imagine it. I don't have a picture", or, when attempting to draw a banana (Fig. 6): "I have to reflect what a banana is. It is a fruit that grows on a tree. It is imported. But I have to reflect how it looks like, I don't have it in my head how it looks." Evaluation of his ability to recognize pictures of the same objects was made somewhat problematic by his word-finding difficulties, but his naming responses did not point to misidentification, and sometimes he correctly named an object which he could not at all draw from memory. For example, a picture of a banana was recognized as being a "southern fruit". A picture of a Volkswagen was called a "vehicle" on the day of his first attempt to draw it (Fig. 2, top). It was recognized as being the one he had been asked to draw, and was consistently named "Volkswagen" on later occasions, when his drawings still failed to give any evidence of the characteristic shape of this type of automobile (Fig. 2, bottom).

Descriptions of objects from memory were similarly defective. For example, when asked to describe peas, he said: "I am reflecting how they look like. Their colour is . . . light brown,

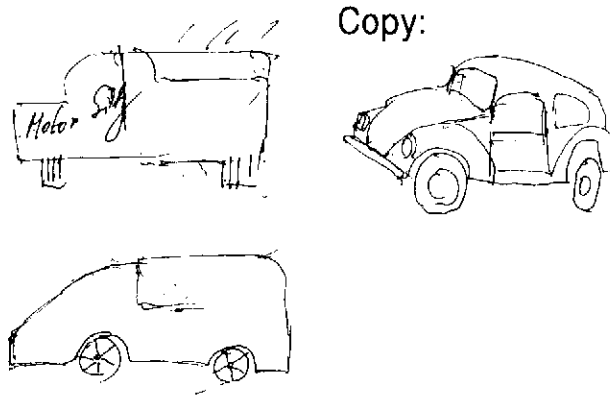


Fig. 2. *Left*: Two trials to draw a Volkswagen "beetle" from memory. The inscriptions in the first drawing were made spontaneously. They indicate the engine ("Motor") and the seat ("Sitz"). *Right*: Copy of a drawing of a Volkswagen.

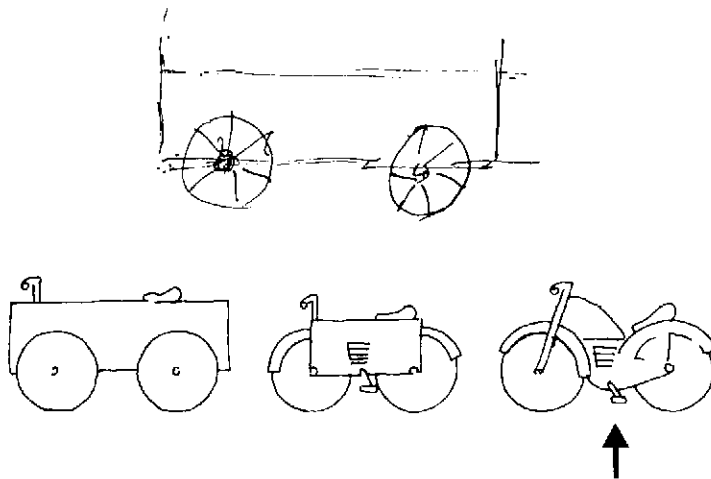


Fig. 3. *Top*: K.Qu.'s attempt to draw a motorcycle from memory. *Bottom*: On multiple choice K.Qu. rejected a version of the motorcycle similar to his own drawing and selected the correct version.

and their size approximately like this (demonstrates size of a nut)." Asked to describe their shape he responded: "I have to think, so that I can have a look on them, can imagine them, the peas . . . how do they look like? Well, they are probably round but I don't have it in my head how they look like, I don't have them before me. I know them, however. They even grow in our garden. My daughter raises them as she has a special liking for biological food."

K.Qu. correctly verified 18 high-imagery sentences concerning shapes and chose the correct pictorial version for 17. Both results are below the range of controls. On the pictorial versions, he correctly indicated the detail that was crucial for comparison on 23 items (mean of controls 22.9) and did not change his – incidentally correct – decisions for the remainder when the crucial differences were demonstrated. He could name eight of the 17 items for which he had decided correctly, and five of the eight for which his choice was incorrect.

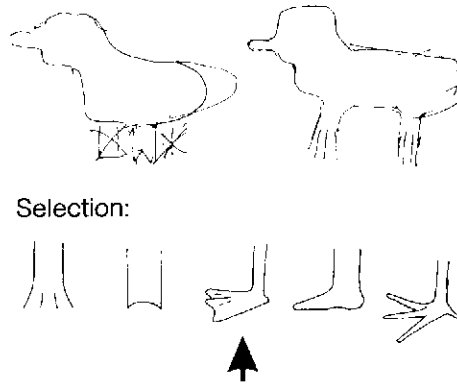


Fig. 4. *Top*: Two attempts to draw a duck from memory. *Bottom*: On a multiple choice of duck feet which included versions similar to his own attempts, K.Qu. selected the correct version.

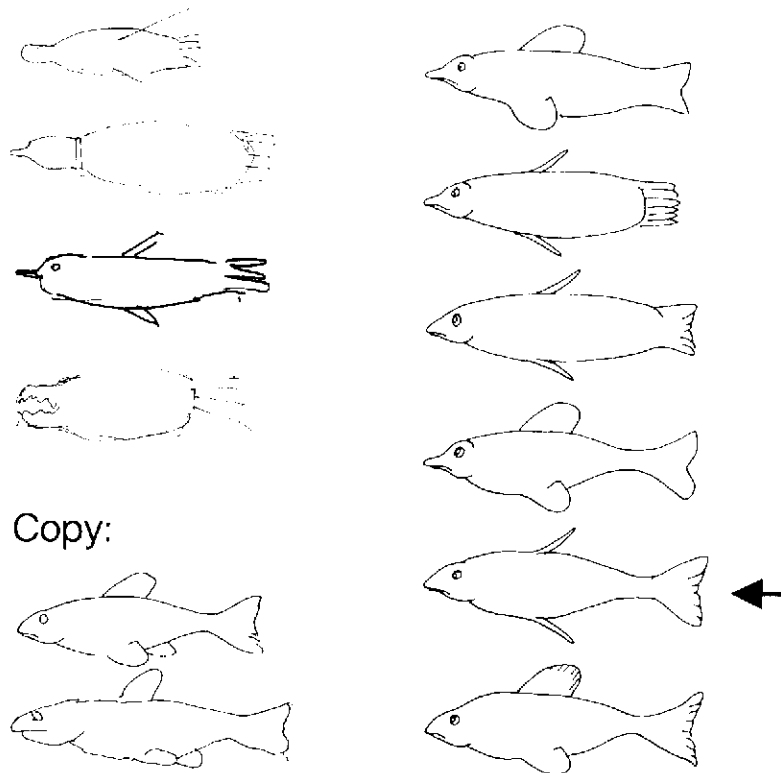


Fig. 5. *Top left*: Four attempts to draw a fish from memory. *Bottom left*: Model and copy of a fish. *Right*: On multiple choice K.Qu. rejected a version similar to one of his own drawings (second from top) but preferred a drawing with incorrect fins to the correct one. He explicitly stated that he did so because of the fins.

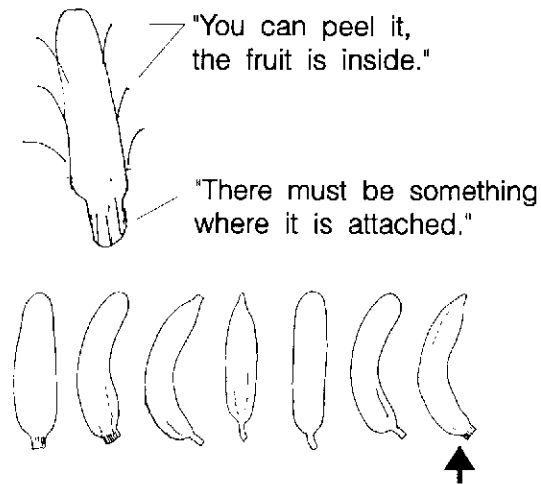


Fig. 6. *Top*: Drawing of a banana and K. Qu.'s comments made during drawing. *Bottom*: On multiple choice K. Qu. selected a banana with a correct general shape but explicitly preferred a thick stem to the correct one which is represented on the third version from left.

The absence of a selective deficit on verification of high-imagery sentences as compared to verification of pictures does not necessarily prove that the patient's mental images of objects were equivalent to his visual knowledge, as the wrong versions of the test were far less deviating than were spontaneous drawings done by the patient. However, in this case it was not feasible to systematically examine free drawing of the same objects, since designing of most of them is beyond the capacity of unskilled persons. Instead, images of objects he had attempted to draw from memory were redrawn with the same errors and paired with a correct and other wrong versions (see Figs 2–4). He consistently choose the correct version. When the number of variations was increased, and more subtle errors were introduced (see Figs 5–6), he committed errors, but still refused to accept the version corresponding to his own drawing. There was thus a dissociation between his inability to evoke mental images of objects, as assessed by drawing, and his better knowledge about the shape of the same objects, as assessed by identification and verification of pictures, although knowledge was defective too, as manifested by his inferior score on verification of the pictorial shape questions.

Non-visual properties of objects

K. Qu.'s comments during drawing frequently conveyed considerable knowledge about non-visual properties of the objects he was unable to imagine. When drawing the motorcycle shown in Fig. 3 he told that nowadays most motorcycles have four-stroke engines whereas previously two-stroke engines were more frequent, and that today most motorcycles are produced in Japan. During his failed attempt to draw anything resembling a Volkswagen he related that it had been constructed at the beginning of the Third Reich by a native Austrian (Ferdinand Porsche), and that the engine was cooled by air instead of water. He was however, not sure whether the engine was in the rear or in front. He frequently tried to exploit his knowledge about functional properties of objects for reconstructing their shape, as when drawing a stem to the banana because "there must be something where it is attached." (See

Fig. 6). A similar dissociation between knowledge about visual and non-visual properties of objects was observed when K.Qu. was asked to verbally describe objects. For example, the request to describe a giraffe led to the following dialogue between the patient and the author:

K.Qu.: "A giraffe is an animal. I have first to imagine what that is, a giraffe. . . . I know it is an animal, but I don't have in my head what it looks like. I cannot describe it to you, that is queer." G.G.: "Do you know where the giraffe lives?" K.Qu.: "Here only in the . . . (it seems that he does not find the word "zoo") where it is bred, but regularly in Africa." G.G.: "Do you know how it nourishes itself?" K.Qu.: "It does not eat meat, it is herbivorous." G.G.: "There is something very characteristic about its appearance. Do you remember that?" K.Qu.: "No, precisely not, otherwise I knew what it is, a giraffe. . . . is it the one with the long thing, is that the giraffe?" G.G.: "Yes" K.Qu.: "Oh, I am stupid, now I know it. With the long, how do you call it?" G.G.: "Neck" K.Qu.: "The neck, yes. Now I have it, the giraffe!"

Preserved knowledge about non-visual properties of objects was documented by his score on verification of low-imagery sentences which was virtually identical to the mean of the control group.

Shapes of letters

K.Qu. was asked to count the number of corners of imagined capital letters named to him [14, 29]. He gave correct responses for 10 out of 12 letters which is less than 1 S.D. below the mean, and within the range, of 60 normal controls [29]. When asked to write down the letters on which he had erred, he confounded one of them. His incorrect response would have been correct for the written letter. He could read normally only five out of the same 12 letters and found the correct name for further two letters with his strategy of rehearsing the alphabet until the letter was matched. As it appears, imagery of named letters was better than naming of perceived letters.

Topological relationships

As already mentioned, K.Qu. could draw from memory a correct layout of his room on the ward and accurately insert towns into an empty map of Austria. Without having a map before him, he could without error describe the relative positions of town (e.g. "Klagenfurt is on the left and below Graz", or, "relative to Vienna, Eisenstadt is less southern, but more eastern than Graz") and compare distances between two pairs of towns. When asked whether during that task he had mentally seen the map, he responded: "Of course I have. I must imagine that on the map."

Faces

K.Qu. asserted that the vividness of his mental images of faces had not changed since his accident. He could answer questions as to which of two nurses looked younger, had longer hair, or a slimmer face, and he could tell whether they had their lips usually ajar, so that the teeth could be seen, or closed. He would describe the face of the Austrian president Kurt Waldheim as having a long nose and a thin mouth, and correctly decided that the president's mouth was wider than that of the chancellor.

DISCUSSION

Imagery was affected differently for different classes of visual entities, and there were also differences in the relationships between imagery and perceptual access to visual knowledge.

There was no evidence of either impaired imagery or impaired recognition of faces and topological relationships. For letters, imagery correlated with writing rather than reading and was, consequently, superior to reading. Reading requires perceptual access to stored knowledge about letter shapes. Pointing to named letters, which also affords a recognition of perceived letters, was better preserved and approximately as good as writing. The difference between recognition and imagery of letters would be judged differently according to whether reading or pointing to named letters is deemed adequate for assessing recognition, but in neither case was imagery worse than recognition. Possibly, K.Qu.'s success in pointing to named letters was even based on imagery. Names of letters could have evoked mental images of their shape via mental writing [31, 43], and recognition could have been achieved by comparison between the imagined and the perceived shape.

Imagery was impaired for both colours and forms of objects. In both cases, errors in picture verification indicated that the knowledge base from which mental images should have been derived was defective, but for shapes, there was evidence that the knowledge deficit was less severe than the imagery deficit. On the other hand, loss of knowledge about object colours was embedded in a more widespread impairment of colour processing. The discussion will deal first with imagery and knowledge of object colour, and then with object forms, and will finally return to the issue of the image generation deficit.

Colour

Brain damage can affect colour processing at four different stages [17, 71]: central dyschromatopsia manifests itself by an inability to discriminate colours. Colour agnosia is defined by an inability to sort and categorize colours according to their hue. Colour agnosia is presumed to result from a loss of colour concepts, and is to be differentiated from the inability to name colours, designated as colour anomia, as well as from a loss of knowledge about the characteristic colours of objects which would most appropriately be termed object colour amnesia. Out of these four possible central disturbances of colour processing, only dyschromatopsia appeared to be absent in K.Qu.

There was colour agnosia. Although K.Qu. succeeded in sorting the majority of skeins of the colour sorting test, the procedure he used and the errors he made betrayed a loss of colour concepts. He sorted colours by perceptual similarity rather than by conceptual identity. Therefore, he had to compare each skein to each of the samples for finding out the perceptual distances, and he committed errors when differences in brightness elevated the perceptual distance between a skein and the appropriate sample above the threshold for accepting them as similar, or made it larger than the perceptual distance to a sample of a categorically different hue. A loss of colour concepts was also documented by his inability to answer questions concerning categorical relationships between colours or distances in colour space.

K.Qu. misnamed colours and committed errors when asked to point to named colours. His colour anomia cannot plausibly be referred to an aphasic disturbance of producing or comprehending colour names, since he could name colours perfectly when asked for their symbolic connotations. It could be doubted whether in his case colour anomia was more than a sequel of colour agnosia. There are several cases of colour anomia without colour agnosia ([27, 28] case 1, 5 case RV. [20, 38, 60], case 2) but the reverse dissociation, intact colour naming in the presence of impaired colour sorting, has not yet been reported [17]. Logically, it would seem plausible that an inability to sort colours into basic categories would abolish the possibility to assign them names which correspond to these categories.

Finally, K.Qu. suffered a loss of knowledge about object colours and committed severe

errors not only when asked to say the characteristic colour of objects, but also when colouring line-drawings or deciding between correctly and wrongly coloured pictures.

When corrected for different chance probabilities, K. Qu.'s colouring of line drawings was not at all worse than his accuracy in distinguishing between correctly and wrongly coloured pictures. By contrast, the number of correct decisions dropped to chance when object colours were asked for by verbal questions. The verbal questions had been validated for being "high-imagery", that is, they demanded the evocation of a mental image of the coloured object. Presumably, the same mental image would also be necessary for choosing the appropriately coloured pen to fill line drawings. It thus seems improbable that the poor score on verbal colour questions could be referred to an image generation deficit. More likely, it resulted from an additional sensitivity of the verbal questions to colour agnosia and colour anomia. They demanded comprehension of colour names, and several of them referred to relationships between colours (e.g. "Is the green of fir trees closer to yellow or to blue"). Their meaning must have been difficult to comprehend for K.Qu. whose knowledge about categorical relationships between colours was severely disturbed.

Shapes of objects

There was no difference between verification of high imagery sentences concerning object forms and verification of corresponding pictures on a test whose wrong pictorial versions were close enough to veridicality to be easily recognizable as representing the object they were derived from Ref. [30]. Since the questions were couched in a dual choice format, K.Qu.'s errors did not necessarily indicate that his wrong beliefs about object forms were identical to those proposed by the test. His own drawings and verbal description lacked features crucial for recognizing the object and sometimes betrayed a complete breakdown of knowledge about characteristic object forms. Nonetheless, he was able to identify pictures of the same objects and he reliably rejected his own designs when confronted with designs which were correct or at least closer to veridicality. There was thus a discrepancy between his knowledge about the shapes of objects as manifested by recognition, and his ability to imagine these objects as assessed by drawing or verbal description. This discrepancy does fulfil criteria for being recognized as an image generation deficit.

The nature of the image generation deficit

If K.Qu.'s image generation deficit was caused by damage to an image generation process which creates mental images out of visual knowledge, this would imply that there is at least one component of the image generation process which is necessary for creating images of the forms of objects, but neither for imagining their colour, nor for imagining forms of letters and faces, nor for imagining topological relationships. Although in principle possible, such a coincidence does not appear as being very likely. As predicted by the alternative hypothesis of a visual knowledge deficit underlying impaired image generation, K.Qu.'s recognition of visual attributes of objects was not normal. It does seem worth-while to consider this hypothesis in more detail.

It has been suggested that knowledge about object forms is represented at two levels [17]. "Entry level" representations of the visual appearance of objects permit rapid identification of most instances of a given kind of object [36]. They may correspond to prototypical images [36, 67] or to object-centred descriptions of invariant structural properties [15, 52]. In any case, for ecological advantage, these representations should be suited for being activated by the minimum of information necessary for identification. One should be able to recognize a

bear without looking closely at its ears. In addition to rapid identification at the entry level, visual percepts can be analysed for their spatial features, surface properties, and details. The results of these analyses are stored in a knowledge base which specifies visual attributes of objects. Its content may overlap with that of the entry level representation (e.g. both might specify that a bear has a long trunk with comparatively short legs) but it contains knowledge beyond the needs for object identification. Development of knowledge about visual attributes of objects may depend on cultural influences and owe more to education in drawing and painting than to naïve perception.

A dissociation between impaired imagery and preserved recognition would be possible if visual imagery of objects corresponds to an activation of knowledge about their visual attributes, and if entry level representation would permit recognition of object but not their imagery. Loss of imagery with preserved recognition of objects would follow loss of knowledge about visual attributes of objects. This hypothesis would be plausible if entry level representations were conceived of as being part of dedicated perceptual devices which function rapidly and mandatorily but whose contents are not accessible to conscious introspection or alteration [26].

The distinction between entry level representations and knowledge about visual attributes may be absent for other domains of visual apprehension, and image generation may employ different mechanisms for different classes of visual entities. Possibly, the hypothesis that image generation deficits stem from a selective loss of knowledge about visual attributes has to be specified differently for different classes of visual entities, as visual knowledge serves different purposes and is organized in different fashions for different domains of visual apprehension. Analysis of impaired visual imagery may provide valuable insights into the organization of knowledge about the visual appearance of the world.

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