§I.C.3. Mental Rotation.

Ian Hacking has recently suggested that what in practice (and, he thinks, quite properly) leads scientists to be confident about the real existence of certain of their theoretical entities is the ability to manipulate these entities and use them for some purpose {1}. Explanatory power does not seem to be enough to guarantee existence; after all, many things which are now discredited - planetary epicycles, luminiferous aether, phlogiston, caloric, the Galenic humours, etc. - provided considerable explanatory and even predictive resources in their day. The knowledge that such things are no longer accepted by science may lead to scepticism about the theoretical entities of today, and doubtless in some cases it is justified, but need we accept that all such postulated entities {2*} must forever remain on the same ontological footing? If we could bottle caloric and pour it in to heat our bath, surely we would have to accept it as real. Hacking concerns himself largely with the example of electrons, whose real existence could be (and quite often was) quite reasonably doubted in the early years of this century, but cannot, he thinks, be reasonably doubted now that we have got so good at doing things with them. The examples which Hacking gives are of the uses of electrons within scientific experiments designed to detect something else (such as quarks, or violations of parity conservation). He claims to have become converted to a belief in scientific realism, and specifically in the reality of electrons and positrons, in the course of a discussion with a physicist about an attempt to find free quarks through a modern version of the classic Millikan oil drop experiment. In this experiment a tiny superconducting niobium ball was suspended in a magnetic field, and the very small electrostatic charge on it was varied in the hope of observing a charge state which was not zero or some multiple of e (the electronic charge), but plus or minus one third of e (the charge hypothetically borne by the elusive quark). Hacking wondered how the charge on the floating niobium ball was to be altered:

> "Well, at that stage," said my friend "we spray it with positrons to increase the charge or with electrons to decrease the charge." From that day forth I've been a scientific realist. **So far as I'm concerned, if you can spray them they are real.** {3}.

Perhaps an even more eloquent demonstration of the existence of electrons is the existence and proper functioning of my television set, and millions more like it. Electrons are sprayed at the insides of TV screens, to make the phosphor coating glow into a picture, every day and all across the world.

Mental images (and other mental entities) have not achieved, and perhaps can never legitimately achieve, the same ontological status as is ascribed to electrons by most physical scientists and realist philosophers. The usages of electrons, after all, are publicly observable - anyone can watch television, and can even, in principle, observe the execution of a physics experiment - whereas any useful employment which we might make of images would seem fated to remain forever inside our own heads, concealed from public view. We can only do things with our **own** images. Psychologists cannot manipulate people's images directly, at best they can induce their subjects to manipulate them in some way. However, popular and personal belief in the reality of imagery may indeed owe something to the manipulability and usefulness of the images of our own experience. Many of us know quite well that we make use of our imagery in our thinking and mental problem solving - we are just at a loss to prove to others that we actually **did** work things out that way. This lack is not without its significance, for the intellectual **zeitgeist** of most of the earlier part of this century has been so iconophobic that not only Behaviorist psychologists, but philosophers as divergent as Sartre {4} and Wittgenstein {5} have denied that imagery can have any cognitive value at all (and for very similar reasons). Sartre puts the point succinctly enough; in contrast to perception:

> The image teaches nothing: it is organized exactly like the objects which do produce knowledge, but it is complete at the very moment of its appearance. If I amuse myself by turning over in my mind the image of a cube, if I pretend that I see its different sides, I shall be no further ahead at the close of the process than I was at the beginning: I have learned nothing. (...) No matter how long I look at an image I shall never find anything in it but what I put there. {6*}.

No doubt it is true that whatever we find in our mental imagery must have been in some sense 'in' us before the image was formed. However, it does not follow that nothing can be learned from images. As Taylor {7} points out, new knowledge is not only to be gained from new sensory experiences but can also be acquired through acts of "calculation" or "synthesis" upon knowledge we already have. The fact that any mathematical or logical result is in a sense already 'contained in' its premises does not mean that the arrival at some result does not constitute the gaining of new knowledge - or perhaps we should say, since human calculative abilities are somewhat unreliable, new beliefs. Although imagination is no doubt even less reliable than mathematical calculation, we can also, surely, "synthesize" our mental images to produce new, useful and often correct beliefs. Taylor gives the example of imagining how someone whom we know would look with glasses on, or of imagining how some piece of furniture would look in our room {8}.

What is perhaps an even more persuasive example of how we can gain information from our imagery was provided by the psychologist Roger Shepard in 1966 (when the scientific respectability of imagery was still very much in the balance):

> if I am now asked about the number of windows in my house, I find that I must **picture** the house, as viewed from different sides or within different rooms, and then count the windows presented in these various mental images. No amount of purely verbal machinations would seem to suffice. {9}.

Shepard's account of his mental processes here sounds convincing enough to me (i.e. I would do it that way too), and very likely to you also, but it can hardly be called scientific evidence. Even compared to the discredited introspective protocols as gathered by Titchener and Külpe and their students, these observations are unsystematic and anecdotal. Shepard, who, after all, grew up in the Behaviorist era {10*}, is, of course, well aware of this. He knows that the using and manipulation of mental entities cannot be directly and publicly demonstrated {11}. However, as we know from the previous section, very persuasive, if not totally compelling, **indirect** experimental demonstrations of the mental employment of imagery can be made. Paivio, Bower, Bugelski etc. do not actually **see** their subjects using images as **aides mémoires**, but the presumption that they are doing so seems pretty well founded. Even so, the images are not used in a very active way in these experiments. They are just gathered up, in some cases seemingly involuntarily or even unconsciously, they are not really **manipulated**. Nor, indeed, can 'new information' be said to be extracted from them. Shepard's distinction is to have provided (five years after the above quoted remarks) the first and still one of the most elegant really convincing experimental demonstrations that people can and do manipulate images in order to find things out {12*}. This work has become probably the best known and celebrated of all modern imagery research.

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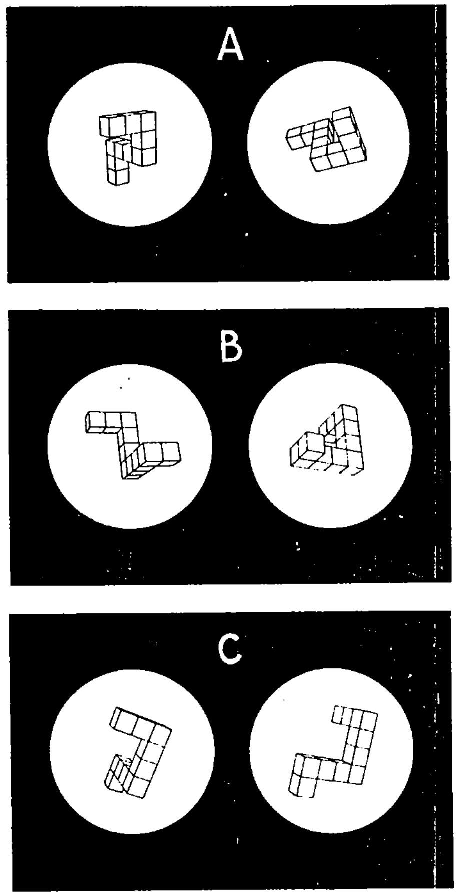
Shepard relates that the idea for his famous experiments on 'mental rotation' first came to him in a



Illustrative pairs of perspective views, including a pair differing by an 80 degree rotation in the picture plane (A), a pair differing by an 80 degree rotation in depth (B), and a pair differing by a reflection as well as a rotation (C).

Figure I.C.3_1
(Reproduced from Shepard & Cooper [1982].)

hypnopompic image {13*} of "three dimensional structures majestically turning in space" which he experienced whilst waking up one morning in November 1968 {14}. In fact he claims that many of his best scientific ideas have occured to him in this hypnopompic form {15}. In this instance he wrote down his idea a couple of days later in the form of a brief memorandum, which he circulated amongst some of his students at Stanford {16}, and the experimental approach suggested therein was eventually followed up in collaboration with one of them, Jacqueline Metzler {17}. These experiments employed line drawings of simple three-dimensional objects, in fact computer generated pictures of assemblages of cubes, such as are shown in figure I.C.7_1. The pictures were presented to the subjects in pairs - either showing identical objects in two different orientations (as in I.C.7_1 A and B) or two different objects which were in fact enantiomorphs, 'mirror images' of one another (as in I.C.7_1 C). The task given to the experimental subjects was to determine whether the two objects shown in each pair of pictures were congruent with one another or were in fact 'mirror images'. Shepard's assumption, as is clear from his memorandum and his account of his original inspiration, was that in order to ascertain whether two such pictures were in fact of congruent objects in different orientations the subject would form a mental image corresponding to one of the pictures, and then rotate this image in his mind until it came into register with the other one. He took it that such rotation would take place at a constant rate, in which case the time taken to confirm two objects as congruent should increase in a linear fashion with the angular difference in their depicted orientations. It would take longer to rotate the image through a larger angle. This prediction was very well borne out by the experiment, and it would seem also that the subjects' introspections generally agreed with Shepard's: they believed they had done the task by rotating an image. A further interesting point is that rotations in depth seemed to be made just as quickly - if anything a little more quickly - as rotations in the picture plane. Shepard & Metzler thus take themselves to have demonstrated a "mental rotation in three-dimensional space". With this sort of object (and with some variation between subjects) the rotation seemed to take place at an angular velocity of "roughly 60° per second" {18}.

If Shepard's interpretation of these results is accepted then this experiment becomes about as compelling a demonstration of the reality of mental imagery as one could hope for. After all, "if you can rotate them they are real" is surely at least as good a slogan as "if you can spray them they are real". Unfortunately, however, to the sceptical eye this interpretation is less than entirely compelling. In fact it can reasonably be doubted whether doing the experimental task really involves imagery at all; after all, both pictures to be compared are perceptually present throughout. Indeed, Just & Carpenter {19} have shown that a subject's eyes constantly move from one picture to the other whilst performing the task (an observation already made, more casually, by Metzler & Shepard {20}), and, on the basis of a detailed analysis of these eye movements, have put forward an interpretation of the effect which does not involve images or steady rotation at all {21*}. However, further experiments, mainly carried out by another of Shepard's students, Lynn Cooper, do not seem to be open to this sort of objection. Cooper's experiments do not involve comparing two perceptually present, physical pictures, but comparing a remembered object with a present one, and sometimes with a quite consciously formed and deliberately rotated image. Perhaps these experiments do not quite attain the striking elegance of the Shepard & Metzler work. However, they do seem fairly unequivocally to involve imagery in the full sense {22*}. The fact that this imagery also seems to undergo analogue mental rotation of a very similar sort must surely lend credence to the image interpretation of the earlier work.

Cooper's work depends on the hypothesis that having an appropriate mental image of something will allow us to recognise that thing, or discriminate it from other similar things, significantly more quickly than we could if we did not have the image ready in mind. Naïvely put, it would seem as if the image might serve like a template which could be overlain on an actually known pattern, quickly telling us whether or not they matched. In fact, template matching accounts of perceptual recognition have long been decisively rejected by psychologists {23}. However, it does not follow from this that having a mental image is not intimately bound up with our readiness for pattern recognition, and indeed, Shepard has repeatedly expressed the view that they are so {24*}. That specifically visual readinesses for recognition of particular patterns do occur was demonstrated in some well known experiments by Michael Posner and his colleagues {25}. In this work the subject's task was to press an appropriate button to indicate whether two visually presented letters of the alphabet were the same or not. They were supposed to classify them as the same regardless of case (i.e. either A and a, or A and A would be classified as 'same' pairs). What was found, however, was that 'same' responses were considerably faster when the letters were both in the same case (and thus formed visually identical patterns) than when they differed in case. It would seem that in the first instance a direct visual match is possible, whereas in the second instance the letters must be recognized and named before it can be realised that they are examples of the same letter. This experiment works not only when the two letters are presented simultaneously, but also when they are presented in succession with a brief interval in between. Apparently some sort of 'visual code' for the first letter is retained in memory for a while, and, while present, facilitates recognition of another, similar pattern {26*}. It would be fairly natural to identify this 'visual code' with a mental image. However, this identification is far from inevitable, for clearly an image is more than such a state of readiness; we can do many things with images besides matching them with our percepts. As Cooper & Shepard put it:

> Presumably, to have a mental image, then, is to activate an internal representation that - in addition to preparing one for an external stimulus - can be used as a basis for further information processing even if the relevant stimulus is never actually presented. {27}.

What their experiments set out to show is that such states of readiness can be manipulated - in fact rotated - and that deliberately formed rotating images can function just like Posner's 'visual codes'. This would seem to make the case for connecting imagery and perceptual readiness, and for treating images as functionally real psychological entities, very strong.

The first of Cooper & Shepard's experiments {28} used letters of the alphabet, like Posner, and also numerals. However, here the task was to distinguish between the normal letter or number and its 'mirror image' (only asymmetrical letters and numerals were used), and the test letters were presented rotated into various orientations. The hypothesis was that the subjects must first form, from memory, an image of the letter in its familiar upright position, and then rotate this until it can be directly compared with the tilted stimulus letter. As this would lead us to expect, the times taken to make the comparisons increased as the angles through which the test letters had been rotated, reaching a maximum when the test letter was presented upside-down, calling for a mental rotation of a full 180°. However, if the subjects were cued beforehand with both the identity of the test letter and with the orientation in which it would appear (shown by an arrow tilted an equivalent amount from the vertical), then all the reaction times decreased. Indeed, if the subjects had received both identity and orientation information by a full second before the test letter appeared then the reaction times became very quick (almost as fast as when the subjects were shown the normal letter in the appropriate rotated orientation shortly before the test letter - which presumably allows direct visual comparison without rotation, as in Posner's work {29*}), and the dependence on angle disappeared. This is easily explicable in terms of the mental rotation of an image. Presumably the subject can begin to rotate his image of the letter into the needed orientation as soon as he sees the arrow indicating at what angle the test letter will be tilted. A full second gives ample time to have the image in position and ready for matching as soon as the test letter appears. Shorter times give him time to rotate his image part of the way beforehand, but not all of it. Some rotation is still needed after the test letter appears, and how much more still depends on the actual angle of tilt.

Although the results of this experiment (and the subjects' introspective reports) were very much in accord with the notion that mental images were being formed and rotated, there was one fly in the ointment. The most striking aspect of the Shepard & Metzler {30} results was the highly linear relation between angle and time, which seemed to indicate rotation at a steady speed. Angle and

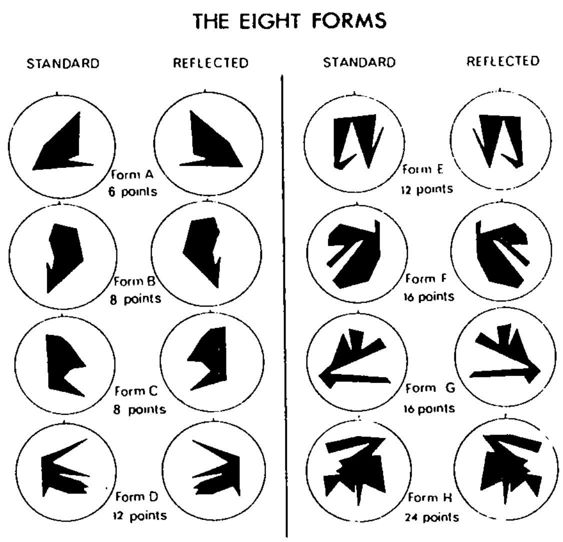


Figure I.C.3_2
(Reproduced from Shepard & Cooper [1982].)

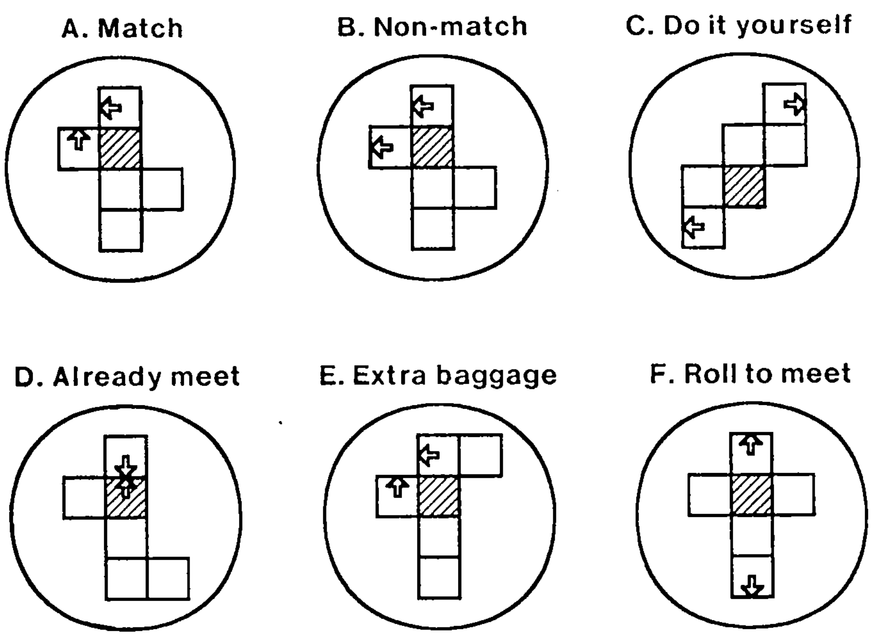


Figure I.C.3_3
(Reproduced from Shepard & Cooper [1982].)

time were still positively correlated in Cooper & Shepard's experiment, but the relation departed noticeably from linearity. They suggest that this might have something to do with the great familiarity of the alphanumeric stimuli used, especially when in an upright or close to upright position {31}. This explanation may seem somewhat **ad hoc**, but it looks as if it was correct. Cooper later performed an essentially similar experiment, but using irregular polygons (see figure I.C.7_2) instead of letters and numbers {32}. Although the subjects were well familiarized with these polygons (in arbitrary 'standard' orientations) and with the task of distinguishing them from their mirror reflections before the experiment began, obviously their familiarity could never have approached that of the alphanumeric stimuli used in the earlier work. In the experiment proper the polygons (or their 'mirror images') were simply presented in an orientation different from that originally learned, and again the subjects had to indicate whether they were the standard or reflected forms. This time the correlation of time with angle of rotation was again highly linear.

In the same paper Cooper {33} also reports a variant of this experiment in which the subjects were first shown an outline of the polygon to be presented and an arrow indicating by how much it (or its 'reflection') would be rotated. Their instructions were to rotate an image of this polygon into the designated orientation, and then to indicate that they were ready for the test figure. In this