

# Return of the mental image: are there really pictures in the brain?

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**In the past decade there has been renewed interest in the study of mental imagery. Emboldened by new findings from neuroscience, many people have revived the idea that mental imagery involves a special format of thought, one that is pictorial in nature. But the evidence and the arguments that exposed deep conceptual and empirical problems in the picture theory over the past 300 years have not gone away. I argue that the new evidence from neural imaging and clinical neuropsychology does little to justify this recidivism because it does not address the format of mental images. I also discuss some reasons why the picture theory is so resistant to counterarguments and suggest ways in which non-pictorial theories might account for the apparent spatial nature of images.**

It seems obvious that we think in either sentences or in pictures. Of these two formats the pictorial has received the most attention in recent years. Famous thinkers are frequently quoted as saying that their ideas did not come to them logically but appeared to them in mental pictures. What exactly this means is far from clear, especially because a little analysis shows that neither language nor pictures are sufficient to represent the content of thought and that most thought is not available to conscious inspection.

## The format of thought

I have argued [1,2] that the difference between pictorial and other forms of reasoning rests primarily in what different thoughts are *about*, rather than the *form* that they take, and that contemporary discussions of mental imagery often confound questions of form with questions of content. There is clearly a difference between thinking about how something looks and thinking about what it means. Because thinking about how something looks feels very different from thinking about its non-visual properties, it is plausible that it might involve a different format. Yet if there is something special about the format in which we think when we have the experience of 'seeing with the mind's eye', nobody has satisfactorily articulated what it is, despite some 300 years of discussion (going back at least to Locke and Berkeley) and 30 years of active experimental research.

## The picture theory of mental images

Despite the problem of stating clearly what it means for imagistic thought to be pictorial, claims that mental images have a special picture-like (or depictive) format have persisted. One of the few explicit statements concerning what this means ([3], p. 5), defines a depictive representation as '...a type of picture, which specifies the locations and values of configurations of points in a space. ... [in which] each part of an object is represented by a pattern of points, and the spatial relation among these patterns... correspond to the spatial relations among the parts themselves.' For obvious reasons I refer to such theories as 'picture theories'.

Over the past three decades a large number of experimental studies have claimed to support the picture theory. Among the most widely cited is the finding that it takes longer to scan one's attention over a greater imagined distance [4] (Box 1). Other experiments claim that it takes longer to 'see' visual details in a 'small' image, and that the resolution of the 'mind's eye' drops off with eccentricity and exhibits the 'oblique effect' (it is harder to discriminate gratings aligned obliquely), in roughly the way these phenomena are reported in vision. A large number of studies have also examined whether entertaining an image impairs or enhances performance on certain visual, visuomotor, recall, or adaptation tasks. In each case researchers concluded that the results support the assumption that images are pictorial entities that are examined by the visual system (see the extensive reviews in [1–3]).

One of the problems with this research is that nearly all experimental findings cited in support of the picture theory can be more naturally explained by the hypothesis that when asked to imagine something, people ask themselves what it would be like to see it, and they then simulate as many aspects of this staged event as they can and as seem relevant. I refer to this explanation as the 'null hypothesis', because it makes no assumptions about format – it appeals only to the tacit knowledge that people have about how things tend to happen in the world, together with certain basic psychophysical skills. (The few experimental findings that do not fit the null hypothesis, such as the classical 'mental rotation' findings, do not provide support for the picture theory for other reasons. For example, images do not appear to be 'rotated' holistically and rigidly the way pictures might be [5]).

The fundamental problem with appeals to the format of images in explaining observed properties of imagistic

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### Box 1. Mental scanning

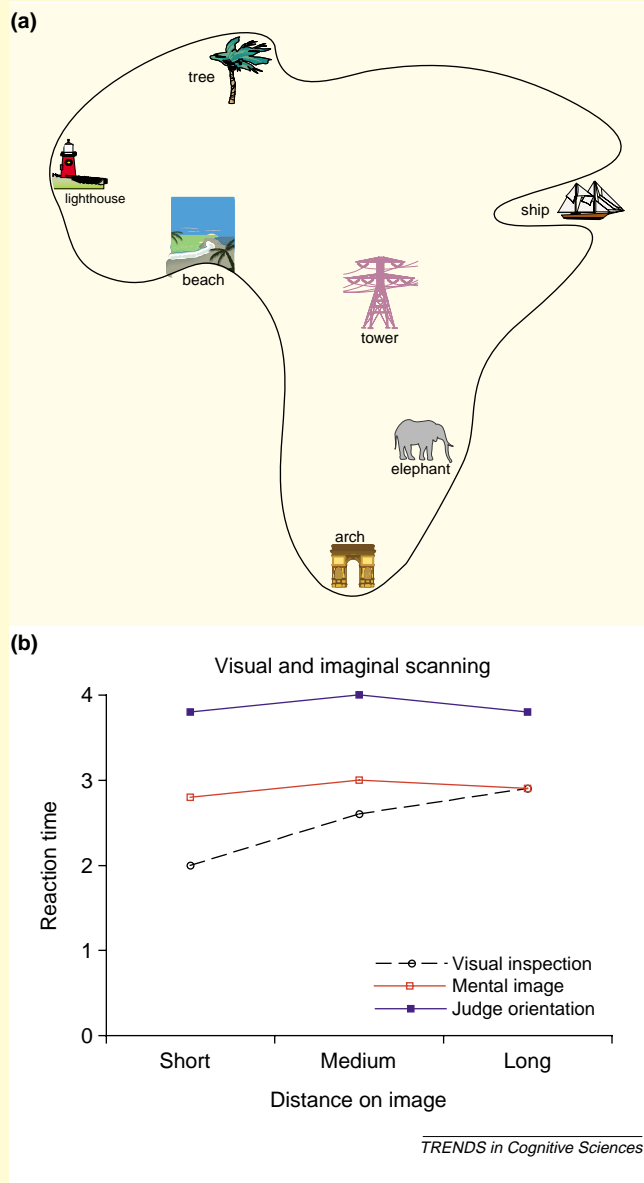


Fig. 1. (see text)

In many experiments [28], observers learned a map, such as the one shown in Fig. 1a. They were then asked to imagine the map, fix their attention on a given landmark, and indicate when they could 'see' a second named landmark in their image. A linear relation was observed between reaction time and distance between the two landmarks (Fig. 1b).

In our experiments observers studied a map that had lights at each of the landmarks ([29] and L.J. Bannon, Ph.D. dissertation, University of Western Ontario, 1981). The lights could be turned off by operating a switch, which resulted in another light immediately coming on at another landmark. Observers were asked to imagine this map, fix their attention on a given landmark, and then to imagine that the light switch was operated and the light came on at a second named landmark. They indicated when they could 'see' the second illuminated landmark. In another experiment observers made judgments about the *orientation* of the first landmark from the second named one.

Reaction time and distance were reliably correlated only in the visual case. There was no effect of distance on the time it took to switch attention between landmarks in the two imagery cases. We concluded that mental scanning is cognitively penetrable and therefore not attributable to image format.

reasoning is this: because it is *your* image you can make it have very nearly any property, or exhibit any behavior you wish (Box 2). Consequently, nothing is gained by assuming that images are pictorial in form because the form does not constrain the possible empirical phenomena. (It's true that you sometimes get different outcomes depending on whether or not the task is to solve a problem by visualizing. But human cognition is generally sensitive to exactly how a problem is framed, so context-dependency by itself has no implications for the format of images.)

### Are there 'functional' pictures in the brain?

Picture theorists often explicitly deny the claim that there are literally pictures in the brain. Yet appealing to a pictorial format to explain experimental phenomena invariably *requires* such a literal picture. For example, to explain why it takes longer to mentally scan a greater imagined distance, the image format would have to underwrite the equation:  $time = distance/speed$ . What has sometimes been called a 'functional space' (such as a matrix data structure) will not do because such a space, being a fiction, can have any properties we like. That we find certain properties more 'natural' in such a data structure (e.g. to scan between two points in a matrix we must pass through 'intermediate' empty cells) simply shows that the theorist tacitly assumes the matrix to be a simulation of real space, because otherwise nothing compels us to visit the cells in any particular order. (This would not be true of a real analogue proposal in which space and time were mapped onto some isomorphic system of brain properties. Such an option has never been seriously proposed as it would have to satisfy not only geometrical constraints, such as Euclidean and metrical axioms, Pythagoras' theorem, etc., but also physical laws governing motion, whenever such laws were found to hold of the behavior of our images.)

It is much more plausible that scanning and other mental imagery phenomena have nothing to do with the format of a mental image, but rather with how people understand the task: imagining something arguably *means* considering what it would look like if you saw it. No format-based theory can explain why the mental scanning effect disappears if subjects take the task to be that of imagining a process that does not take longer for larger distances (Box 1).

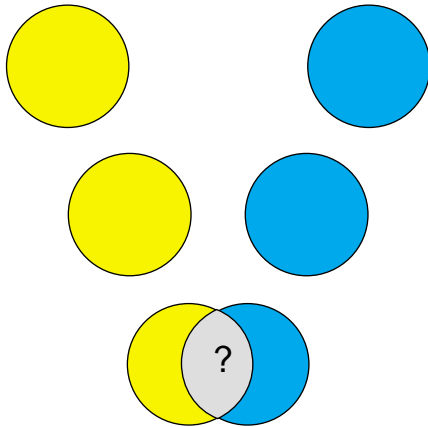
### Has neuroscience resolved the imagery debate?

Recently there have been claims that neuroscience evidence supports what would otherwise have been a grotesque proposal; that to have a mental image is to project two-dimensional moving pictures onto the surface of your visual cortex. This idea has been fostered by the following findings from neuroscience:

- (1) When a visual pattern is presented to the eye, a homeomorphic (continuously deformed) mapping of retinal activity occurs in visual cortex [6].
- (2) Although it remains controversial [7–10], it has also been reported that there is increased activity in retinotopically-organized areas of visual cortex during mental imagery.

From these findings (as well as evidence from clinical

### Box 2. Mixing colors in your mind



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Think of the circles in Fig. 1 as colored filters or light beams and imagine that they are moved closer together until they overlap. What color do you see in your 'mind's eye' at the overlapping part? Why do you see *that* color rather than some other? Can you voluntarily make the overlap be some other color?

What if people give different answers when they are asked outright what color would appear: would that tell us that when using imagery the format causes the result to come out as it does? There is a fundamental difference between empirical phenomena that reveal properties of mind and ones that reveal what a subject knows or remembers (Ref. [30], Chapter 5).

The chances are that the color you 'saw' in your mind is different from the one you would have seen in reality, because few people are aware of the difference between additive and subtractive color mixing. If these were filters (carefully balanced for brightness and saturation), they would allow no light through so the overlap would be black; however, if they were (carefully balanced) light sources the colored lights would mix to form white light, and if they were pigments they would mix to form a green pigment.

neuropsychology) some people have concluded that images are displayed in visual cortex during mental imagery, much as visual information from the eye is thought to be displayed there on the way to being interpreted. This suggests that cortical images occur in both vision and imagery, the difference being that the former is caused by light on the retina while the latter is caused by top-down projections from higher cognitive systems. In the face of this sort of 'hard' biological evidence, some people have concluded that the long standing 'imagery debate' was over and resolved in favor of the picture theory [3].

As Mark Twain once said about mistaken rumors of his death, reports of the success of the picture theory 'are greatly exaggerated.' The finding that some parts of the visual system are active during mental imagery is interesting and perhaps important to an eventual understanding of this puzzling phenomenon, but it tells us nothing about the *form* of the representation because imagery and vision might involve the very same form of representation without it being pictorial in either case (indeed the case against pictorial representations in vision is as strong as it is for

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### Box 3. Drawing and seeing what is in a mental image

**NOTE:** Do these examples before reading the explanation in the text.

**Example 1:** Imagine a parallelogram such as the one in Fig. 1:

Now imagine an identical parallelogram directly below it. Connect each vertex of the top figure to the corresponding vertex of the bottom figure. Close your eyes and see what it looks like. As you look at it, does anything happen? Now draw the figure and look at it.

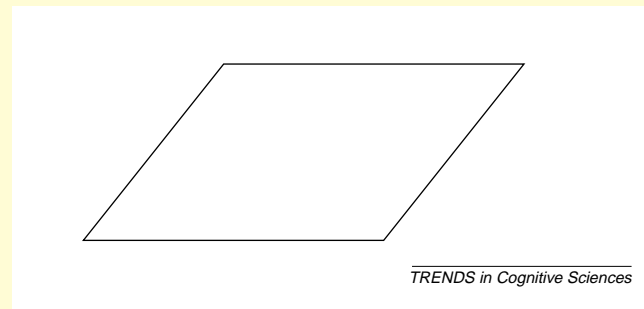


Fig. 1.

**Example 2:** Imagine a solid cube about one foot on each side (as in Fig. II):

Imagine placing one corner (A) on a table and holding the diagonally opposite corner (B) with your finger, so that the axis from the table to your finger is vertical. By examining only your mental image (and not looking at the above figure), point to (and count) the corners not in contact with either the table or your finger. (Example from Ref. [31])

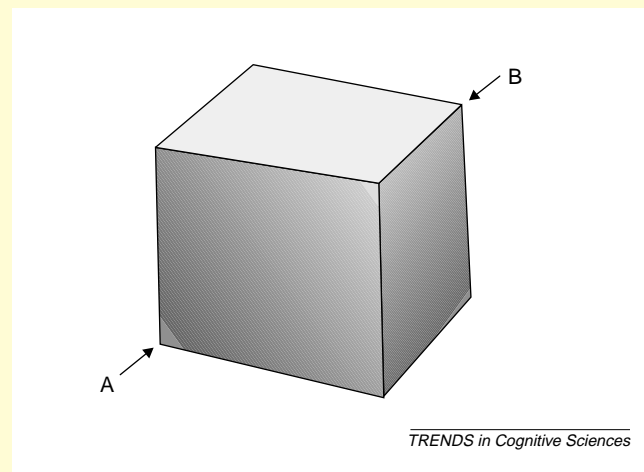


Fig. II.

imagery [1,11]). Moreover, the argument from the similarity of vision and imagery ignores very significant differences between retinal/cortical images and mental images.

#### *Representational scope and size in cortical and mental images*

The pattern of activation in primary visual cortex is a projection of activity on the retina, and therefore is similarly restricted in its field of view and is constrained to representing space in retinal coordinates. By contrast, mental images are in allocentric coordinates [12] and are panoramic in scope, reportedly even extending behind the head [13]. Consequently, the finding that a retinotopically-mapped area of the cortex is activated during mental

#### Box 4. Can images be visually reinterpreted?

Slezak [32,33] asked subjects to memorize one of the images in Fig. 1. He then asked them to rotate each picture 90 degrees clockwise and report what they saw. None of his subjects reported seeing the very clear interpretations that can easily be seen if you rotate the pictures themselves. But even more telling, subjects *could* get the second interpretation if they were allowed to first sketch the image from memory and then to rotate the sketch. Thus it appears that they recalled enough of the figure to allow reinterpretation, but were unable to do it in their mind alone.

There has been an argument in the literature about whether mental images can be visually reinterpreted. One of the most detailed analyses [34] concluded that images could be reinterpreted in some ways, yet the data showed that reinterpreting mental images was very different from reinterpreting real displays. Unlike vision, image reinterpretation tends to rely on fragmentary clues and yields a range of interpretations, rather than a few clear ones such as obtained from bistable images like the Necker cube (which do not switch in mental images).



Fig. 1. (see text; left image reproduced from Ref. [33] with permission from Greenwood Publishing. Center image reproduced from Ref. [32] with permission from the publisher.)

imagery in no way supports the assumption that such a pattern of activity *corresponds to the mental images that we experience*, and that have been studied experimentally. Moreover, when topographically organized regions of cortex map visual space *they only map two-dimensional retinotopic space*. Yet mental images are not only experienced as three-dimensional, but such basic experimental phenomena as mental scanning and mental rotation occur equally in depth or in the plane, so any format explanation would have to apply to three-dimensions.

Picture theorists take comfort from the fact that different mental image sizes have a cortical counterpart: larger mental images appear to be associated with more activity in the anterior parts of the medial occipital region [14]. But a correspondence between image size and brain *locus* does not help to explain why it takes longer to scan greater distances or why it takes less time to report details from larger mental images. Picture-theory explanations appeal to metrical properties of image representations: shorter reaction times arise because details in bigger pictures are easier to discern, not because the pictures are located in a different place.

#### Information access from cortical and mental images

Another striking difference between cortical and mental images is in how they are accessed and interpreted. If you construct a mental image from a description, the result does not have the signature properties of visual perception. Work through the examples in Box 3 before reading on. In Example 1 you constructed an image of a Necker cube, but in your

image you do not automatically see it as a three-dimensional object, nor does it spontaneously reverse. In Example 2 you most likely got the answer wrong: typically when people rotate the cube it tends to transform into an octagon with four vertices lying in a horizontal plane.

Accessing information from a mental image is very different from accessing information from a visual scene. Imagine any 9 letters written in a  $3 \times 3$  table. Read the letters in various orders. It is very difficult to read information off an image in an arbitrary order, the way you can off a real display. Such differences are often explained by assuming that the image fades rapidly, yet the image does not appear to fade as rapidly for all reading orders, or with the much more complex displays used in mental scanning or mental rotation experiments. An even more revealing way that mental images are not like retinal (or cortical) images is that they are not subject to Emmert's law. If you have an image on your retina (e.g. an after-image), and you look at some surface, the apparent size of the image varies with the distance of the surface: the further away it is the larger the apparent size of the image. This is not true of a mental image.

If the cortical display provides input in both vision and imagery, both should connect with the motor system in the same way. Yet they do not [15]. Reaching for an imagined object does not exhibit the signature properties that characterize reaching for a perceived object, and many visuomotor phenomena, such as ocular smooth pursuit, do not occur with imagined motion (indeed it is even doubtful that you can imagine smooth motion as a continuous change in location [16]).

But the central fact is that images on the retina/cortex have yet to be interpreted, while mental images *are* the interpretation; not only are they not in need of interpretation, there is good reason to believe that they *cannot* be reinterpreted *visually*. Of course one can figure out what some pattern might look like if we rotated it or combined it with other patterns, but we can only do so when the combinations are easy to infer from a description of the shapes, not when they involve a clearly visual (re)perception, such as the examples in Box 4.

#### Clinical support for the cortical display theory

Clinical neuropsychology findings are sometimes cited in support of the cortical display theory. But if mental imagery and vision used the same cortical display, it is hard to see why vision and imagery capacities are dissociated: there are many reports of normal imagery in people who have cortically blindness, achromatopsia, visual agnosia, and hemispatial neglect; and there are also many reports of normal vision in people with little or no mental imagery [17]. Indeed, virtually all the experimental phenomena involving mental imagery have been reported in blind people.

Several clinical findings thought to support the picture theory also have plausible alternative explanations. For example the finding that a patient who developed tunnel vision after unilateral occipital lobectomy also developed 'tunnel imagery' [18] might well be due to the fact that the patient had nearly a year of experience with her tunnel vision before being tested – sufficient time to be able to

report *what things looked like* to her, which is a very plausible interpretation of what she was asked to report on the imagery test. The finding that patients who exhibited hemispatial visual neglect also exhibited a corresponding neglect of their mental images [19], has now been followed by many cases showing the independence of imaginal and visual neglect [20]. Moreover the originally finding also has a plausible alternative explanation, suggested below.

### How are images 'spatial'?

*Tell me where is fancy bred, Or in the world or in the head? [The Merchant of Venice]*

A plausible property that is unique to mental imagery is its *spatial* character. Objects in an image seem to *be* in some spatial relation relative to one another, so that some objects are to the right of, or above, other objects. Of course, to *represent* locations you don't need a format that *has* locations. Yet we do exhibit some location-dependent effects in imagery, such as stimulus–response compatibility (we are slower to respond with a left response to things on the right side of the image [21]), which suggests that images can be spatial in some stronger sense than implied by the use of a symbolic spatial code. Although there is some validity to this suggestion, I believe the image format is the wrong place to be looking for the required spatial properties. The place to look for these spatial properties is in the real space around us which we exploit when we 'superimpose' images on the perceived real space.

It is easy to see how a *visually* perceived scene can be exploited to provide spatial properties for a superimposed mental image. All you need in order literally to scan your attention from place to place in what appears to be your image (Box 1) is to think such thoughts as, 'the lighthouse is located *here*, the ship is located *here*,...' and so on, where the demonstrative terms pick out elements in the actual visual scene. Once you have associated objects of thought with individual elements in a scene (using a binding mechanism such as the FINST visual index, described in [22]), the rest of the phenomena are provided by vision. For example, you can scan your attention from element to element over real space, and if you bound three imagined objects ( $x, y, z$ ) to perceived objects that happen to be collinear in the scene, you can actually *see* that  $y$  is between  $x$  and  $z$ , and moreover distances  $d$  will always obey the inequality  $d(x, z) \geq d(x, y) + d(y, z)$ , so that your image will inherit metrical spatial properties from the world, as long as you can perceive them in the scene.

But what about the images you have when your eyes are closed? Exactly the same applies except you rely on spatial locations perceived (largely unconsciously) through other modalities – proprioception, audition, and so forth. We are extremely good at orienting in space without sight, even to objects behind us [13,23], and we automatically update our frame of reference when we move [24]. If we orient to several landmarks in space, then we can associate objects of thought with these landmarks, just as we do in vision. And just as in vision, we can derive spatial properties of images from this capacity when we project images into perceived allocentric space. *None of this requires that we*

*assume a spatial display in the head; the one in the world will do!*

This way of looking at the spatiality of images might explain why blind people exhibit most of the phenomena of mental imagery and why superimposing images on a scene can lead to visuomotor adaptation [25]. It could also explain why visual neglect is sometimes accompanied by imaginal neglect, as there is reason to believe that neglect involves a failure to orient attention in real space [26]. It is also consistent with recent theorizing that emphasizes the role played in cognition by the environment in which the organism is situated, and our possible motor interaction with this environment [22,27].

### Is there something missing in this way of viewing imagery?

I have argued that far from supporting the picture theory, the results of imagery experiments tell us nothing about the format of images. So why do we persist on searching for pictures in the mind/brain? Perhaps it is because something is missing from this 'null hypothesis'. If representations underlying imagery are no different in form from those underlying other kinds of thought, then why does imaging *feel like* we are looking at something; and why do our mental images *resemble* what we are imagining?

The question why something looks the way it does might not have a scientific answer because it concerns the relation between brain processes and conscious experience – nothing less than the intractable mind–body problem. It is also intimately connected with what it means to have an experience that 'looks like' something. Is it an empirical or a conceptual fact that your image of your cat does not look like a teacup? Is it logically possible that it could, given that it is *your* image? Wittgenstein is credited with the following story that puts this question in perspective. Two philosophers meet in the hall and one says to the other, 'Why do you suppose people always thought that the sun went around the earth, rather than that the earth was rotating?' The second philosopher replies, 'Obviously because it looks like the sun goes around the earth.' To which the first philosopher replies, 'But what would it look like if it looked like the earth was rotating?' There is much we don't know about what it means for something to 'look like' what we describe in words.

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### References

- 1 Pylyshyn, Z.W. *Seeing and Visualizing: It's not What you Think*, MIT Press/Bradford Books (in press)
- 2 Pylyshyn, Z.W. (2003) Mental imagery: in search of a theory. *Behav. Brain Sci.* 25, 157–237
- 3 Kosslyn, S.M. (1994) *Image and Brain: The Resolution of the Imagery Debate*, MIT Press
- 4 Denis, M. and Kosslyn, S.M. (1999) Scanning visual mental images: a window on the mind. *Cahiers Psychol. Cogn.* 18, 409–465
- 5 Pylyshyn, Z.W. (1979) The rate of 'mental rotation' of images: a test of a holistic analogue hypothesis. *Mem. Cogn.* 7, 19–28
- 6 Tootell, R.B. *et al.* (1982) Deoxyglucose analysis of retinotopic organization in primate striate cortex. *Science* 218, 902–904
- 7 Roland, P.E. and Gulyas, B. (1995) Visual memory, visual imagery, and

- visual recognition of large field patterns by the human brain: Functional anatomy by positron emission tomography. *Cereb. Cortex* 5, 79–93
- 8 Roland, P.E. and Gulyas, B. (1994) Visual imagery and visual representation. *Trends Neurosci.* 17, 281–287
  - 9 Roland, P.E. and Gulyas, B. (1994) Visual representations of scenes and objects: retinotopical or non-retinotopical? *Trends Neurosci.* 17, 294–297
  - 10 Mellet, E. *et al.* (1998) Reopening the mental imagery debate: lessons from functional anatomy. *Neuroimage* 8, 129–139
  - 11 O'Regan, J.K. (1992) Solving the 'real' mysteries of visual perception: the world as an outside memory. *Can. J. Psychol.* 46, 461–488
  - 12 Ingle, D.J. (2002) Problems with a 'cortical screen' for visual imagery. *Behav. Brain Sci.* 29, 195–196
  - 13 Attneave, F. and Farrar, P. (1977) The visual world behind the head. *Am. J. Psychol.* 90, 549–563
  - 14 Kosslyn, S.M. *et al.* (1995) Topographical representations of mental images in primary visual cortex. *Nature* 378, 496–498
  - 15 Milner, A.D. and Goodale, M.A. (1995) *The Visual Brain in Action*, Oxford University Press
  - 16 Pylyshyn, Z.W. and Cohen, J. (1999) Imagined extrapolation of uniform motion is not continuous. *Invest. Ophthalmol. Vis. Sci.* 40, S808
  - 17 Bartolomeo, P. (2002) The relationship between visual perception and visual mental imagery: a reappraisal of the neuropsychological evidence. *Cortex* 38, 357–378
  - 18 Farah, M.J. *et al.* (1992) Visual angle of the mind's eye before and after unilateral occipital lobectomy. *J. Exp. Psychol. Hum. Percept. Perform.* 18, 241–246
  - 19 Bisiach, E. and Luzzatti, C. (1978) Unilateral neglect of representational space. *Cortex* 14, 129–133
  - 20 Beschin, N. *et al.* (2000) Perceiving left and imagining right: dissociation in neglect. *Cortex* 36, 401–414
  - 21 Tlauka, M. and McKenna, F.P. (1998) Mental imagery yields stimulus–response compatibility. *Acta Psychol.* 98, 67–79
  - 22 Pylyshyn, Z.W. (2000) Situating vision in the world. *Trends Cogn. Sci.* 4, 197–207
  - 23 Attneave, F. and Pierce, C.R. (1978) Accuracy of extrapolating a pointer into perceived and imagined space. *Am. J. Psychol.* 91, 371–387
  - 24 Rieser, J.J. *et al.* (1986) Sensitivity to perspective structure while walking without vision. *Perception* 15, 173–188
  - 25 Finke, R.A. (1979) The functional equivalence of mental images and errors of movement. *Cogn. Psychol.* 11, 235–264
  - 26 Bartolomeo, P. and Chokron, S. (2002) Orienting of attention in left unilateral neglect. *Neurosci. Biobehav. Rev.* 26, 217–234
  - 27 O'Regan, J.K. and Noë, A. (2002) A sensorimotor account of vision and visual consciousness. *Behav. Brain Sci.* 24, 939–1031
  - 28 Denis, M. and Kosslyn, S.M. (1999) Scanning visual mental images: a window on the mind. *Cahiers Psychol. Cogn.* 18, 409–465
  - 29 Pylyshyn, Z.W. (1981) The imagery debate: analogue media versus tacit knowledge. *Psychological Review* 88, 16–45
  - 30 Pylyshyn, Z.W. (1984) *Computation and Cognition: Toward a Foundation for Cognitive Science*, MIT Press
  - 31 Hinton, G.E. (1987) The horizontal–vertical delusion. *Perception* 16, 677–680
  - 32 Slezak, P. (1991) Can images be rotated and inspected? A test of the pictorial medium theory. *Proc. 13th Annu. Meet. Cogn. Sci. Soc.*, pp. 55–60, Erlbaum
  - 33 Slezak, P. (1995) The 'philosophical' case against visual imagery. In *Perspectives on Cognitive Science: Theories, Experiments and Foundations* (Slezak, P. *et al.*, eds), pp. 237–271, Ablex Publishing
  - 34 Peterson, M.A. *et al.* (1992) Mental images can be ambiguous: reconstructions and reference-frame reversals. *Mem. Cogn.* 20, 107–123

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