

denominal status circularly. Our first set of denominal items were existing verbs that had been independently categorized as denominal and judged as regular by linguists; because some skeptics had dismissed the judgments, we tested them to verify that naïve subjects preferred the regular forms. The second set presented nouns to participants, followed by a novel denominal verb usage. As this was an experimental manipulation that defined denominal status a priori, rather than a correlational study, the absence of ratings of denominal status does not create a logical circle.

Ramscar's findings differ from ours because his instructions stacked the deck against finding an effect of morphology. Sensitivity to morphology was measured by asking participants whether a target verb was similar to a single example: a novel usage of *fly* meaning 'to greet customers while wearing a fly costume'. This complex metalinguistic judgment – whether the target verb is crucially similar to the one in this odd scenario – is an insensitive measure of people's perception of whether a verb is based on a noun, as can be seen in anomalous data such as participants indicating little perceived relationship between 'to brake' and *brakes*.

Conversely, the measure of semantic similarity was confounded with headedness: subjects were asked whether the activity described by the target word 'reminded' them of the base word and to 'consider all the possible things [they] associated with [the] use of the word.' If two words share a root, one will certainly remind people of the other, and trigger associations with the other. This is distinct from whether the two words share semantic features, the mechanism invoked in connectionist accounts.

The pair *shod*–*shoed* does not contrast headless and headed verbs. Both are headless: dictionaries define *to shoo* as 'to say *shoo*.' In any case, *shod* is a dubious example of people irregularizing headless verbs. It is an archaic form (the fossil of a defunct phonological rule) that today is used most often as

a participial adjective. Many people are unaware that it is the preterite of *to shoe*, as can be seen in errors such as *to shod* [13]. That Ramscar had to reach for this as his counter-example shows that the overwhelming tendency is for headless verbs to get regular past-tense forms.

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#### Letters

## Mental imagery: against the nihilistic hypothesis

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We begin with a summary of central elements of our depictive theory, which will allow the reader to decide whether it is 'grotesque' (to use Pylyshyn's term [1]). The theory hinges on the facts that: (i) the occipital lobe contains numerous topographically mapped areas that support depictive representations; and (ii) most cortical areas used in visual perception are also used in imagery [2], including early visual cortex [3–5]. In perception, the occipital topographic areas provide input to two major

visual pathways. One, running down the inferior temporal lobe, is involved in object recognition. Visual memories are stored in this pathway, but in a non-topographic form [6]. The other, running up to the posterior parietal lobe, is involved in specifying locations and orientations in space. According to our theory, a mental image of a shape is created when a visual memory is activated top-down, inducing a pattern of activation in the topographically mapped areas; backward connections from higher-level to lower-level visual areas are well-documented [7]. Similarly, images of spatial relations are created when a spatial

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memory is activated, inducing a pattern of activation in the posterior parietal lobes. Once created, patterns in images can be processed much like the corresponding patterns of activation induced during perception.

From this perspective, we have the following responses to Pylyshyn's [1] critique.

### The format of thought

*Critique:* If a special format is used when we experience 'seeing with the mind's eye', it is not clear what it is. Pictorial and other forms of reasoning rest primarily on what thoughts are about, not their form.

*Response:* The contrast between a depictive and descriptive format has been developed in detail (e.g. Ref. [8]). Briefly, the key ideas of a depictive format are: (i) each portion of the representation corresponds to a representation of a portion of the object, such that (ii) the distances (defined within the metric of the representational space) among the representations preserve the corresponding distances among the represented portions of the object. (Pylyshyn misleadingly refers to such theories as 'pictorial'; although pictures are one form of depiction, they have additional properties that no depictive theorist has ever attributed to mental images.) Topographically mapped brain areas function to depict shapes, and most fMRI studies of visual imagery report activation of these areas [9]; by contrast, these areas are not activated during verbal tasks or auditory imagery. Moreover, if these topographical areas are disrupted or damaged, visual imagery is impaired [5]. Furthermore, the pattern of activation in these areas depends on the spatial properties of what is visualized ([4]; for reviews see [10,11]). Note that this representation literally uses space to represent space; it is not simply functionally depictive.

### Imagery and perception

*Critique 1:* Imagery and vision might involve the same format without its being depictive in either case. The evidence against depictive representations in vision is as strong as it is for imagery.

*Response:* Numerous topographically organized areas exist in the human occipital lobe, and these areas function to represent depictively during visual perception. Hence, (i) geometric properties of stimuli are systematically mapped into local patterns of activation in these areas [12,13]; (ii) stimulation of nearby occipital cortical sites produces phosphenes or scotomas localized at nearby locations in the visual field [14,15].

*Critique 2:* Cortical images are 2-D, retinocentric, and represent only the visual space in front of us. Mental images can be 3-D, are allocentric, and can represent space that is not visible (e.g. behind us).

*Response:* The depictive representation is only one aspect of perception or imagery. Images of spatial relations in the parietal lobe are linked to images of shape, specifying three-dimensional properties. The issue is whether a depictive representation exists, not whether it is embedded in a larger system that includes other properties (which it must be).

*Critique 3:* Imagery and perception can be dissociated.

*Response:* Imagery activates approximately two-thirds of

the same areas as perception; when non-shared areas are damaged, one function is impaired and the other spared.

*Critique 4:* Images are not like pictures that can easily be reinterpreted.

*Response:* Unlike pictures, images are limited because they fade quickly and are created with an internal organization, and therefore rely on limited working-memory capacity – but this is irrelevant for the format issue. Moreover, we note that Pylyshyn mischaracterizes the actual state of affairs: imaged patterns can in fact be reinterpreted in most situations. For example, after memorizing line drawings of objects, one can later visualize them and report whether T, Y, or arrow line junctions were present in the drawing. These basic features are not likely to have been part of a description or 'interpretation' originally encoded [16].

### Tacit knowledge

*Critique 1:* Evidence for the depictive theory can be 'better explained' by the hypothesis that people simulate what they would see; we need not assume any format. This view is called the null hypothesis.

*Response:* Pylyshyn has backed off his prior position that language-like symbolic representations underlie all forms of thought, and now simply argues that we cannot know what sort of representation is used in imagery (not that no representation is used). Thus, what Pylyshyn characterizes as the 'null hypothesis' is misnamed. It is really a *nihilistic* hypothesis, because it leads to no testable predictions. Second, if the results in fact simply reflect high-level knowledge of space, then one should not find that patterns of activation in topographically organized areas reflect properties of the image (which they do). Third, Pylyshyn claims that the blind are able to image like the sighted. However, Arditi *et al.* [17] showed that congenitally blind individuals do not appreciate a fundamental visual characteristic: foreshortening. Although they can accurately point to the left and right sides of objects when close to them, they do not vary their 'visual angle' as they move away from the object – unlike individuals who can form visual images (as opposed only to images of spatial relations). The blind have images of spatial relations, but not object-based visual images. They can perform scanning using parietal mechanisms – but do not appreciate truly visual properties, such as foreshortening.

*Critique 2:* The spatial effects evident in imagery findings arise because 'people superimpose or project images onto the perceived world'. Specifically, spatial indexing can explain the findings.

*Response:* It isn't clear what spatial indexing actually is given the level of theorizing offered by Pylyshyn. There is good evidence that even the spatial representations in the parietal lobe are topographically organized, suggesting that they support depictive representations [18].

### Empty predictions?

*Critique 1:* Scanning is not always used in 'inspecting' an image.

*Response:* Nor should it be. Just as 'pop out' can occur in perception, it can occur in imagery (see Ref. [8], pp. 339–341).

We used scanning in earlier research as a way to show that when people do scan, they take longer to traverse greater distances – as expected if a depictive representation were processed. To our knowledge, no depictive researcher has ever claimed that scanning is *always* used to inspect images.

*Critique 2:* Assuming that images have a depictive format does not constrain the possible empirical phenomena.

*Response:* The issue is whether the properties that are intrinsic to depictions can be altered at will. Whereas one can describe an object without noting its orientation, one *must* include orientation in a depiction – even if orientation is a non-defining, incidental property. So too with size – a depiction (but not a description) *must* specify a visual angle, even if it serves no purpose in individuating the object. Theories that posit a depictive format make clear predictions that hinge on the geometric properties of the representation (such as the existence of the oblique effect in imagery – poorer acuity for diagonal sets of lines than vertical or horizontal).

*Critique 3:* Colors cannot be mixed in imagery; Emmert's law doesn't hold; and one cannot smoothly shift one's eyes to track a moving image.

*Response:* Imagery relies primarily on top-down perceptual processes, and thus depictive imagery representations need not affect low-level, bottom-up, processes such as those underlying color mixing, Emmert's law and smooth pursuit.

### Conclusion

The closing parts of Pylyshyn's article offer a clear choice. One can attempt to work out a scientific theory, which guides empirical research and leads to new discoveries (as the depictive theory of visual images has), or one can argue that such efforts are a dead end and speculate that imagery is an ineffable phenomenon that cannot be illuminated by scientific research. We leave the choice up to the reader.

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### Letters Response

## Explaining mental imagery: now you see it, now you don't

Reply to Kosslyn *et al.*

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Kosslyn, Ganis and Thompson [1] take issue with several statements in my article [2], including my claim that imagery and vision are dissociable, that images are not *visually* reinterpreted, and that the pattern of cortical activity does not spatially (homeomorphically) map properties such as the size of imagined objects. Yet these claims are well documented, as the reader can verify by consulting [3]

and cited references. More important than these disputes is the misleading way, exemplified in the reply itself, that picture theorists appeal to a 'depictive' display in explaining mental imagery phenomena.

### Explaining imagery

To explain experimental findings (such as the image scanning and size effects), picture theories assume that underlying the experienced image is a topographical pattern

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