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Visual Perception: How Better Imaging Can Make Things Worse

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Visual search is critical to daily life and to socially important tasks — from cancer screening to airport security. New research shows how a technological advancement can interact with the human visual system to improve search for one type of target while making matters worse for another. Part of the problem is that we are surprisingly bad at knowing where we have looked.

What do you see when you look at Figure 1? Do you look at the whole picture? Surely, the colloquial answer is 'yes'. Do you see the cat? Here, the answer may well be 'no'. At least, that is the answer most people give when first asked. You might have some trouble finding the cat even now, after having been asked. No, that patch of orange above the green shelf on the right is not a cat in a tree. Look just behind the bright red leaf in the center of this image and you should find the cat's face. If you are reading this on your cell phone, the resolution might be inadequate but if the image is of decent size, the cat will become obvious. Even though you 'looked' at the 'whole' image, you did not 'see' the cat, despite the fact that the cat is clearly 'retrospectively visible' (in the jargon of medical image perception). Once your attention is correctly deployed, that cat is easily seen.

If this demonstration worked for you, it may qualify as a mildly amusing failure of perception. This amusement lies behind the success of entertainments like 'Where's Waldo?' or 'I Spy' images. The failure is less amusing if the image is a mammogram and the targets of search are signs of breast cancer. The chance that an expert radiologist will miss a retrospectively visible indication of cancer is higher than we would like[1]. One effort to improve performance has been the development of digital breast tomosynthesis (DBT). Instead of a single two-dimensional image of the breast, DBT generates a three-dimensional stack of virtual slices through the breast. This improves performance[2], though the increase in the volume of images costs time[3]. A similar pattern of results has been seen in lung cancer screening with the move from two-dimensional chest X-rays to three-dimensional computerized tomography (CT) scans. In this issue of *Current Biology*, Lago *et al.*[4] show that the move from two dimensions to three dimensions is not a guarantee of improved detection. To oversimplify somewhat, breast cancer screening can be thought of as a search for relatively big, low contrast masses and relatively small, high contrast calcifications. In experiments with simulated breast imagery, Lago *et al.*[4] found that detection of big targets was improved in the three-dimensional stack, but detection of small targets actually got worse. This is interesting because their modeling work shows that performance should have been better in the three-dimensional stack if the humans were using the information optimally.

What is the problem? At any one moment, your eyes are fixated on a single location. Obviously, you are seeing more than that single spot, but your ability to resolve and process stimuli away from the point of fixation declines with distance from fixation. It declines differently for different stimuli or even different aspects of the same stimuli. Thus, if you look at this 'X', you can see that there is what appears to be writing to the left and right

of the X, but you can read only the letters in a narrow range around fixation. Lago *et al.*[4] tracked the eye movements and fixations of their observers and offer a biologically plausible model that shows that those observers did not look at enough of the three-dimensional image to reliably find small targets. Importantly, when asked, observers overestimated how much of the three-dimensional volume of imagery they had examined. When forced to spend more time searching, observers managed to find more of the little targets. It might seem unsurprising that more time would help, but that is not always the case. When we forced observers to spend more time looking for threats in luggage X-rays, they did not get better[5]. This may reflect the difference between overlooking a little detail and misinterpreting an ambiguous 'threat'.

You can learn a lot about failures of visual search by looking at the searcher's eye movements. Missed targets are not just a matter of failing to look in the right place. Kundel *et al.*[6] developed a tripartite categorization of errors in radiology. The errors described above would be 'search' errors — those where the eyes never get close enough to the target. You can, however, look at the target and still not find it. Kundel *et al.*[6] defined a 'recognition error' as one where the eyes fixated the target for up to half a second. We did not track your eyes as you looked for the cat, but there is a very good chance that you fixated on the red leaf right next to the cat simply because it was a salient object[7]. This would mean that you looked more or less directly at the cat without recognizing it as the target. These errors are important to inattentional blindness phenomena, where very striking anomalies like out-of-place gorillas[8,9] are not seen. (If you are not familiar with 'inattentional blindness' or even if you are, check out Dan Simon's Monkey Business Illusion https://www.youtube.com/watch?v=IGQmdoK_ZfY). Finally, there are stimuli that are simply ambiguous. When radiologists fixate a mass repeatedly but still fail to report it, that would be a 'decision error'.

Interestingly, the hardest cases may be the easiest miss errors to prevent. Better imaging technology and better AI algorithms can make the ambiguous less ambiguous, reducing decision errors. It is much harder to provide a technological fix for search and recognition errors. As noted above, people are not good at monitoring their own eye movements. But they are not clueless. You make three or four fixations every second. If you looked at the cat picture for three seconds and were asked to mark the 10–12 spots that you fixated, you would not guess randomly. But your answers about where you fixated would be no better

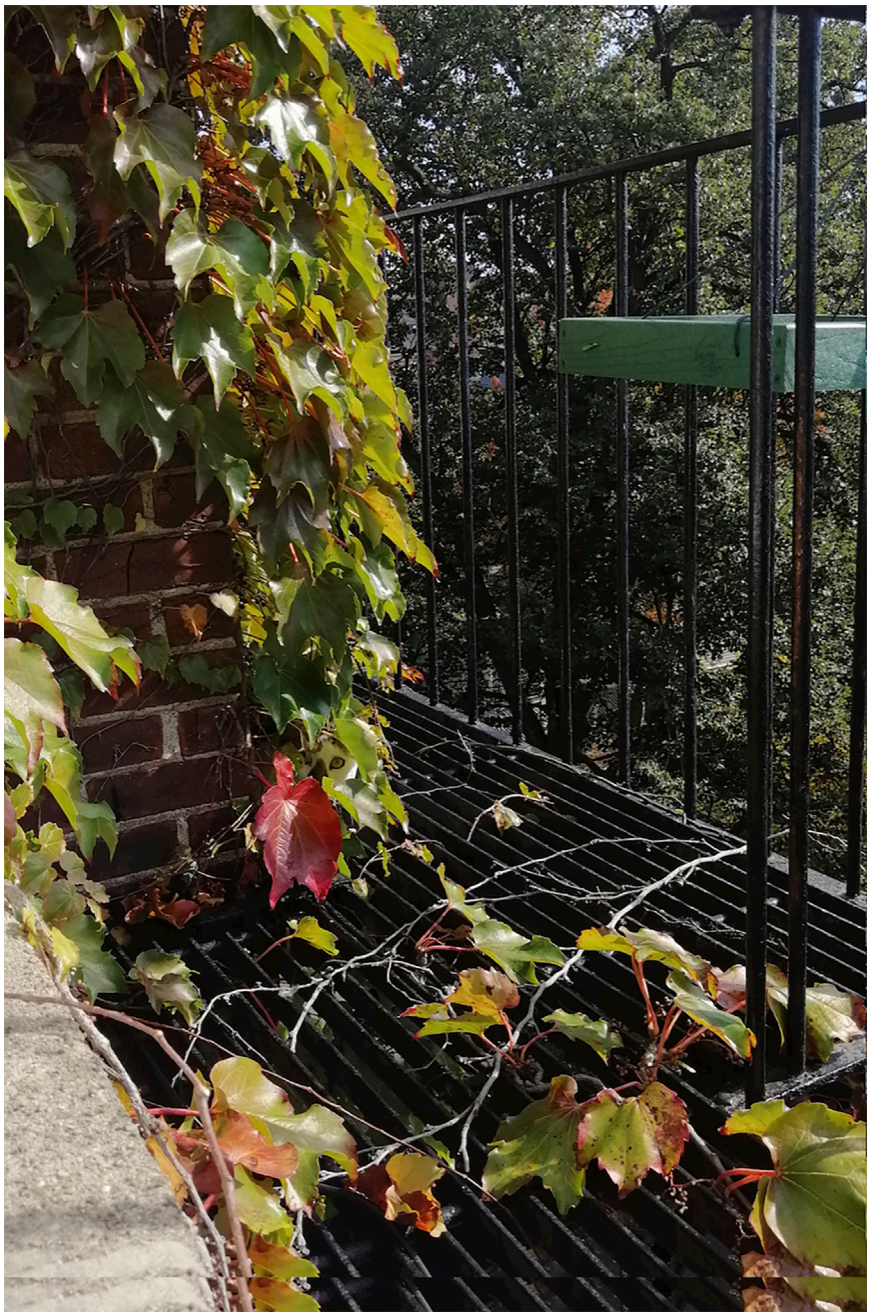

Figure 1. Find the cat.
Assuming that you are viewing this image at sufficient resolution, there is a clearly identifiable cat here. If you have trouble finding it, the main text will help you. Once it is pointed out, the cat will be 'retrospectively visible' like many cancers in the radiology suite or many threats in airport luggage. The new paper by Lago *et al.*[4] illustrates how technology can interact with human capabilities to make some targets easier to find and others, harder. (Photo credit: Wanyi Lyu.)

than your guesses about where a friend would fixate when looking at the same image[10].

If you are fixated at a particular point, there will be a region, known as the useful field of view (UFOV[11]) or functional visual field (FVF[12]), around that spot within which you will process stimuli. As we have mentioned, fundamental visual limitations mean that the FVF for, say, little calcifications, cannot extend too far from fixation, but even within that range, you probably do not process everything. Limits on your attentional capacity mean that you might fixate on that red leaf and not process the adjacent cat face to the point of recognition, and you have very limited access to the record of your own deployments of attention.

Findings like those of Lago *et al.*[4] make it clear that, as long as humans are involved in tasks like cancer screening, technology needs to be designed with an eye on the limitations of the human search engine.

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Population Genetics: How Many Variable Genes Affect Variable Traits?

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How many genes control a given trait? And are genes with defined knockout phenotypes affecting a given trait the same genes that also underlie population-wide variation in that trait? A new study in *Drosophila melanogaster* has some surprising answers.

In introductory genetics classes, students are taught the distinction between phenotypes determined by individuals' genotypes at one or two major gene loci, as in Mendel's crosses, and polygenic traits, such as human height, where the explanatory principles of quantitative genetics apply. Here, while varying Mendelian genes underly the trait variation seen — which is often approximately normally-distributed — the effects of individual genes are too subtle to be identified directly, and variable environments also cause some of the phenotypic variation. Quantitative genetics characterizes polygenic traits in terms of their 'heritability', the proportion of the variance due to genetic differences[1], the 'narrow sense' version of which (h^2) predicts the response of a population to selection[2]. This concept has been the cornerstone of the remarkable success of plant and animal breeding in improving agricultural productivity[2]. A new study by Wenyu Zhang, R. Guy Reeves and Diethard Tautz[3] in this issue of *Current Biology* reveals much about the genetic variation underlying heritability, and suggests that Fisher's[1] hypothetical 'infinitesimal' model, where there are very many variable genes, each contributing a very small effect, may be close to reality for some traits.

The successful application of quantitative genetics in selective breeding does not require knowledge of the identities and effects of the variable genes that create the genetic variance. However, in other contexts,