Are we properly using our brains in seismic interpretation?

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Behind the workstation screen is an extraordinary array of technology to which, quite correctly, we devote considerable attention. But we devote far less to the extraordinary technology in front of the screen—the human brain. Our business performance relies fundamentally on human interpretation of increasingly complex images, yet image interpretation by the human visual processing system is an incredibly complex—and imperfect—task. Seismic interpretation relies on the human view of sophisticated and complex images; we need to improve our human interpretation as much as we seek to improve the images themselves. Knowledge of the way the human visual system works can enhance the way we use our best technology (see also Donnelly, Welland, Cave and Menneer, in press). The results of recent experiments by the authors, designed to address some of the specific issues of seismic data display and interpretation, provide the basis for effectively applying this knowledge.

Upwards of two-thirds of the brain is devoted to processing visual information, using at least 30 different visual processing areas, connected by at least 80 reciprocal pathways. There is no "screen" inside our heads: vision is a process, a combination of bottom-up mechanisms which, literally, construct elements of an image to which we apply top-down processing (knowledge, expectations and so on) to make an interpretation. The complexity of this process leads to its being, while remarkable, less than perfect—which is why optical illusions work.

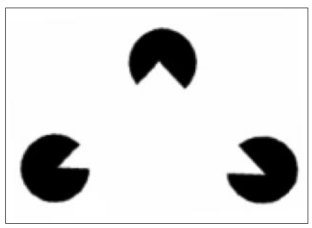

Figure 1. *Kanisza triangles revealing image construction through amodal completion.*

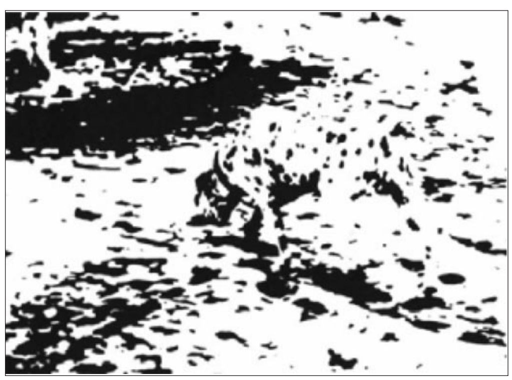

Figure 2. *Bottom-up and top-down processes at work.*

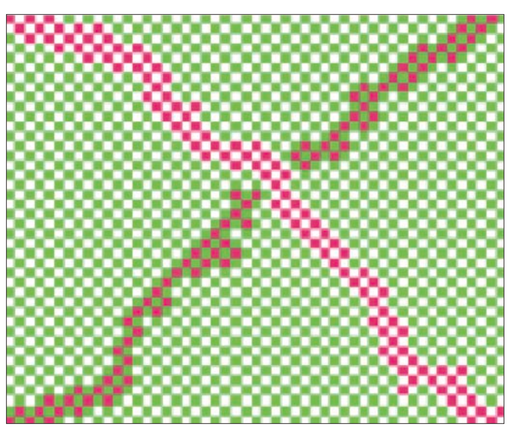

Figure 3. *The influence of context on perceived color.*

Bottom-up representation creates nonexistent forms (we even begin to construct, to see, edges of the nonexistent triangle in Figure 1). In Figure 2, we generate a top-down Dalmatian interpretation, together with complete body parts. There is no real dog in the image: our suggestion has put a form to what is only an assemblage of black and white areas. Importantly, we cannot unlearn this interpretation once we have made it. When we are directed to look for channels in our seismic data, will we not find channels (which are no more real than the dog)?

This is not an article on optical illusions, but such illusions show clearly the vast range of issues associated with the way in which the human brain interprets images, issues which are of fundamental importance to the display of subsurface data and the working practices we should develop for proper interpretation.

The key issue which we shall focus on here is that of color. Our visual perception of color is full of pitfalls; for example, there is only one red and one green in Figure 3, but we perceive different reds and greens depending on context.

A crucially important characteristic of our color perception is that it is nonlinear. We assume that our recognition on the computer screen of a small change in blue means the same thing as a small change in, say, yellow. We categorize the colors of the physical spectrum into distinct groupings. Figure 4 shows the familiar physical rainbow spectrum, with wavelength varying linearly. We, however, do not see a linear change, but color categories and our ability to distinguish changes in wavelength varies in a highly nonlinear way across the spectrum. The graph shows the change in wavelength necessary for it to be discernible (a measure of our ability to distinguish different colors)—we are particularly bad at perceiving differences within the blues and the reds (common colors on a geophysical image!). This has nothing to do with variations in individuals—color blindness and so on—it is an experimentally demonstrated characteristic of the visual processing system of every one of us. A very slight change in yellows is very obvious to our brains, but large changes in blues and reds are overlooked.

If we are to display an image of digital data so that equal changes in data values are shown as equally discernible color changes, then clearly using a physical color space as the basis for image coding cannot work—and can introduce bias. Either we need to train interpreters in the details of the human visual processing system or we need to straighten out the line in Figure 4—to modify the color scale into units of equal identity. In common with others, we suggest that the latter as the more practical approach. However, previous attempts to flatten the line in Figure 4 (e.g., the Munsell Colour Space and CIELAB space) have been based on the human perception of colors presented in isolation, and as such are

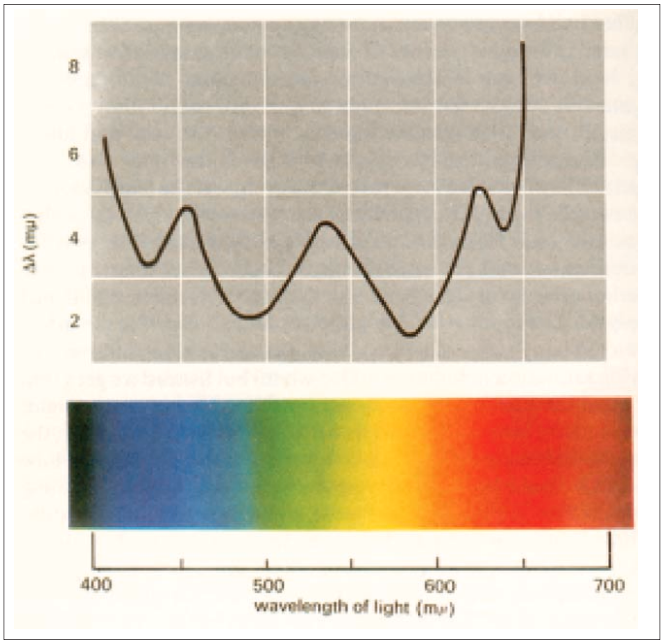

Figure 4. The nonlinear perception of wavelength change (Gregory 1966). Reprinted with the permission of Clark University Press.

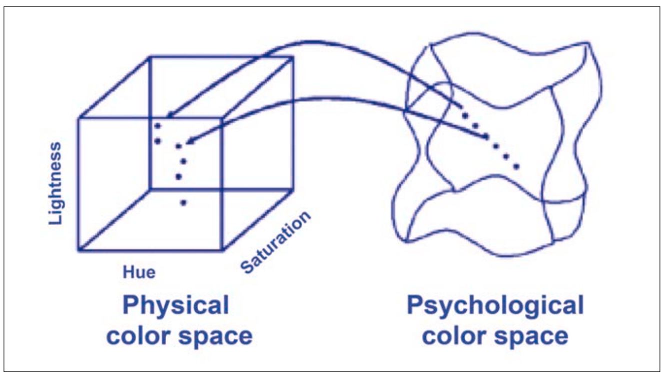

Figure 5. Translation of points in psychological color space to their equivalents in physical space.

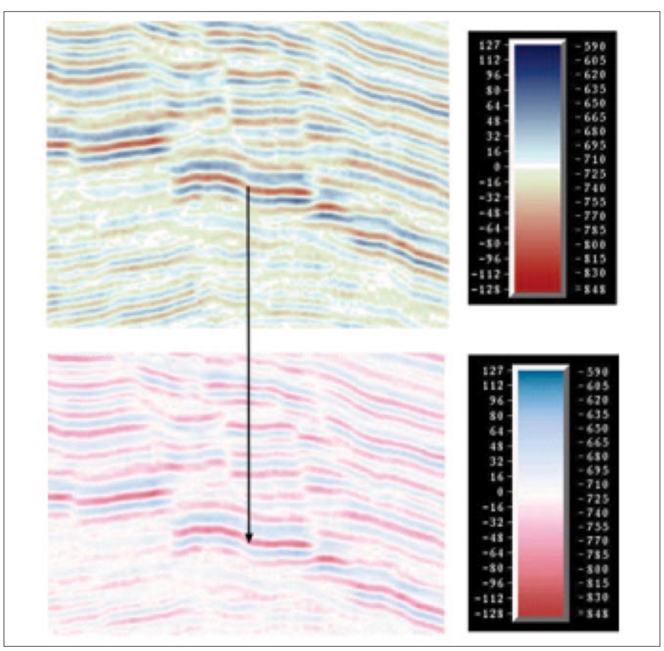

Figure 6. A comparison of data displayed using a conventional color bar (upper) and one derived from psychological color space (lower). Data courtesy of Ikon Science.

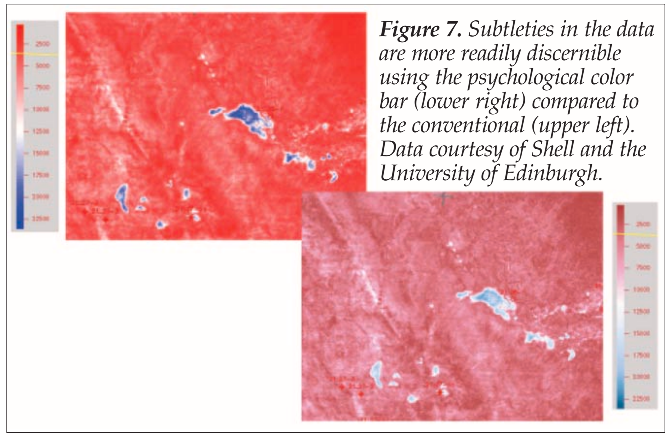

Figure 7. Subtleties in the data are more readily discernible using the psychological color bar (lower right) compared to the conventional (upper left). Data courtesy of Shell and the University of Edinburgh.

of limited value in geophysical image interpretation, where colors are surrounded by colors. In contrast, our approach is to generate new color spaces from experiments designed to mimic contextual and spatial factors likely to be found in geophysical images.

The experimental data of color comparisons and ease of discrimination are used to build, through multidimensional scaling, a context-sensitive "psychological" color space equivalent to the physical hue-lightness-saturation space. Because of the nonlinear nature of human color perception, the psychological space can be thought of as a deformed version of the physical space (Figure 5). As suggested in the figure, a linear sequence of points in the psychological space can be translated back into their equivalents in physical space which provide the means to construct a color bar which honors the principles of equal discrimination by the human observer.

The nonlinearity of Figure 4 has now been eliminated; the problems of perceiving changes within, particularly, the red and blue ends of the spectrum have been addressed by "stretching" those segments of the color bar. This is illustrated in Figure 6, where the upper illustration is of data using a conventional (physical) color space, the lower using the psychological space. While the important effects of using a correctly calibrated monitor cannot be reproduced here, it is nevertheless clear that, while the relative amplitudes of the highlighted blue/red/blue events appear essentially equal in the upper display, the lower illustration best captures their true relative amplitudes.

The way in which using the psychological color space to code data displays permits the interpreter to discern subtle variations in the data (which can be masked by using physical color space) is further illustrated in Figure 7.

The issues which need to be addressed extend beyond the relatively simple ones of enhancing calibration of perception of data, and past the proper use of color to improve detection and interpretation. Today's geophysical world is essentially an infinite one in terms of the technologies of data analysis and display; we have developed these technologies in the belief that the human brain has an equally infinite capacity to respond appropriately—but it does not. We need to understand how the brain responds to an image, how it searches across complex images and detects features of interest, how the way in which the image is displayed introduces bias into that search, and move toward the design of the display technology that ensures that the interpreter's performance is optimized for any particular task.

We have conducted basic image search experiments which dramatically illustrate the importance of understanding how the interpreter works. Increasingly complex images which begin to mimic the real challenges of inter-

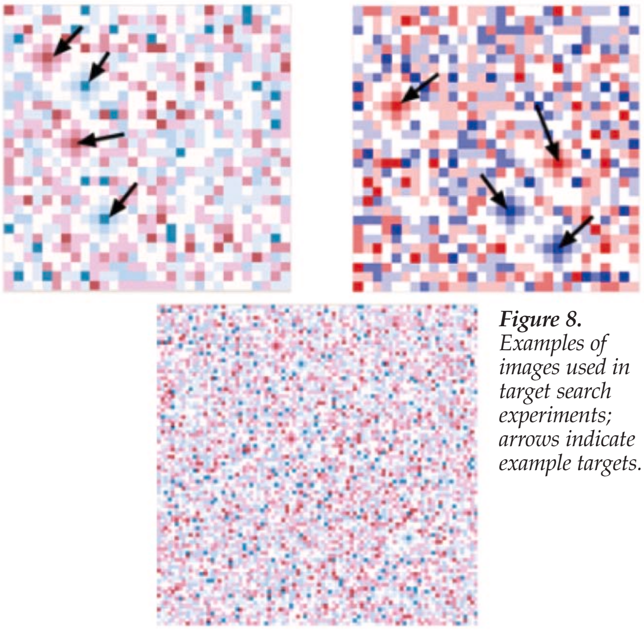

Figure 8. Examples of images used in target search experiments; arrows indicate example targets.

preting geophysical images were used in these experiments. The principles are simple: the subject has to identify a total of four "targets" in an image (see also Spence and Efendov, 2001) and reaction times and spatial and color sequence of target identification are measured. The targets are, in this case, cross-shaped clusters of "pixels," two in each color used in the display. Examples of a simple image in psychological and physical color space are shown in the upper two illustrations in Figure 8, with the targets shown by the arrows. The lower illustration is of a typical larger and more complex image shown to the subjects.

The experiments were conducted with a variety of color schemes, including gray scale. Analysis of the results demonstrates clearly the profound influence of display on search effectiveness, even under conditions which only begin to approach the complexity of a geophysical image. For example, in red-white-blue color schemes, the dominant mode of search is completely different for images coded using psychological versus conventional color bars; the dominant search method is by target color in the former, and spatial location (where the target is) in the latter. In conventionally coded images, color is essentially irrelevant; only in psychologically coded images is search conducted by—and therefore controllable by—color. The details and the range of experimental results are beyond the scope of this short article, but they illustrate clearly the value of addressing quantitatively the human process of image interpretation. We conclude by answering the question in our title—no, we are not properly using our brains in seismic interpretation.

It is possible to reduce interpreter bias and to enhance efficient target detection by reconsidering how images are coded. In a world where bottom-up processes and top-down knowledge influence perception, an understanding of vision science can improve best practice in interpretation. The implications for interpretation, working practices, and training are clear. The method that we have developed for constructing the psychological color space is new and has broad applications; we are actively seeking collaborative opportunities to test and develop these concepts. We would very much appreciate hearing from you with your comments and ideas.

Suggested reading. *Colorimetry* (CIE Publication No. 15, 3rd Edition, 2004). "Breast screening, chicken sexing and the search for oil: challenges for visual cognition" by Donnelly et al. (Special publication of the Geological Society, in press). *Eye and Brain* by Gregory (Weidenfeld and Nicholson, 1966). "Subjective contours" by Kanizsa (*Scientific American*, 1976). *The Munsell Book of Colour* by Munsell (Munsell Color Company, 1929). "Target detection in scientific visualisation" by Spence and Efendov (*Journal of Experimental Psychology: Applied*, 2001). TLE

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