ORIGINAL ARTICLE

Let's Use Cognitive Science to Create Collaborative Workstations

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Abstract

When informed by an understanding of cognitive science, radiologists' workstations could become collaborative to improve radiologists' performance and job satisfaction. The authors review relevant literature and present several promising areas of research, including image toggling, eye tracking, cognitive computing, intelligently restricted messaging, work habit tracking, and innovative input devices. The authors call for more research in "perceptual design," a promising field that can complement advances in computer-aided detection.

Key Words: Perceptual design, collaborative workstations, reading stations, cognition

J Am Coll Radiol 2016;■:■-■.

Radiologists are drowning in images and health information. Suppose a radiologist views 50 CT, MRI, and/or PET examinations in a day. Each of those examinations might generate 1,000 images (or 2,000 with one prior examination for comparison). That adds up to roughly 100,000 images per day. In addition, while reading, a radiologist must take into account the patient's electronic medical record and the exploding scientific literature. Our human limitations are such that only a subset of those images can get real scrutiny, and only a fraction of the medical record and literature can be weighed. The stress of an insurmountable job is contributing to radiology burnout [1]. It is time for technology that can help radiologists thrive in an era of information overload.

Computer-aided detection and diagnosis could certainly help. Today, computers in radiology can help detect breast lesions and lung nodules; analyze breast, liver, and brain contrast enhancement patterns; assess vascular stenoses; detect cardiac wall motion abnormalities; and more. Furthermore, research suggests that computers may accurately differentiate normal from abnormal chest radiographic findings [2]. Perhaps soon, computers will triage images within an examination, or entire examinations, to determine which require physician evaluation.

Although we hope for further advances in computer-aided detection, our purpose here is to discuss a complementary route to enhancing the lives of radiologists. We have labeled this approach "perceptual design." The goal of perceptual design is to use a scientific understanding of human perception and cognition to guide how images and information are presented to and analyzed by radiologists. This approach can provide low-cost innovations that take better advantage of our human strengths and compensate for our weaknesses.

In what follows, we sketch several examples of perceptual design, starting with ideas that have some research to back them up and ending with more speculative possibilities. In each case, we discuss how design informed by our understanding of human perception, cognition, bias, focus, and emotion can result in better job performance and satisfaction.

TOGGLING BETWEEN IMAGES

Until the past two decades, doctors compared medical images by positioning them side by side because those images were physical pieces of film. The advent of PACS and computerized workstations made alternatives possible. For instance, using computerized image display, it became possible to present a sequence of still images (eg, slices in a chest CT study) as a movie [3]. Paging through anatomically ordered cross-sectional medical images ("stack mode") has now been commonly adopted,

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The authors have no conflicts of interest related to the material discussed in this article.

1546-1440/15/$36.00 ■ http://dx.doi.org/10.1016/j.jacr.2015.11.023

largely replacing the side-by-side comparison of cross-sectional images as was required by film.

Although stack-mode reading has become common for cross-sectional imaging, when it comes to comparing images from two different examinations or two series in the same examination, the most common clinical practice is still side-by-side comparison, as required in the old film-based paradigm. Perceptual science suggests that comparison of medical images by toggling or flickering between comparable images in the same screen location may result in better human performance. Instead of viewing images side by side, the comparable images from new and prior examinations are arranged in an interleaved stack, and the reader moves between the current and older examinations in time rather than in space. Such a technique was used to find Pluto [4] and is used today for a wide range of imaging applications, including comparing retinal photographs and gel electrophoreses [5-8].

Unlike astronomy, in mammography, last year's and this year's images cannot be perfectly aligned. Nevertheless, when nonexperts compare photographs [9] or radiologists compare mammograms [10], observers are significantly faster at finding a change when images are toggled than when they are viewed side by side. This can probably be attributed to a reduction in the number of large saccadic eye movements that are needed in the toggle condition. In side-by-side viewing, any interesting feature in one image must be checked in the other image in a physically different location. In the toggle condition, that interesting feature can be examined without moving the eyes and without the possibility that the large eye movement might not land in exactly the right spot. The data on toggling while reading mammograms also suggest an improvement in radiologist accuracy that needs further evaluation [10]. Even if it only produced time savings, toggling images for purposes of comparison could be an example of a simple, low-cost perceptual design-based intervention that produces real benefit. As automated registration of image position and magnification improve, the benefits of toggling could be further enhanced. For example, with image volumes such as produced by CT, MRI, and PET, 3-D registration can play a role in creating more perfectly matching comparison images.

PERCEPTUAL DESIGN TO ADDRESS THE PREVALENCE PROBLEM IN SCREENING

In situations such as breast cancer screening, radiologists are looking for rare targets (a fraction of 1% of a screening population) [11]. Unfortunately, humans are not built to search successfully for low-probability items. Since World War II, research has shown that observers suffer from a "vigilance decrement" [12-14] when monitoring a display for a signal such as a "blip" on a radar screen. When viewing a stack of images, observers are also more likely to miss a target item if it is rare than if it is more common [15]. The same cancers can be missed when encountered in the course of regular, low-prevalence screening but found when encountered in an enriched, high-prevalence stack of cases [16]. This is not a simple decline in accuracy [17]. It is not that low prevalence makes radiologists sloppy. Rather, knowledge of the likelihood of finding a lesion affects a radiologist's performance. At low prevalence, false negative errors go up, and false positives go down. At high prevalence, false positives go up, and false negatives go down [18]. This is the mark of a criterion shift and is a general problem, showing up, for example, when cytologists screen for cervical cancer on Pap smear slides [19] or when transportation security officers look for threats in carry-on luggage [20].

Low prevalence presents a special challenge for diagnostic tasks such as breast cancer screening. A clinician who reads only a modest number of mammographic cases (eg, in a general radiology practice) will not see many positive results in the course of a year. This probably reduces both sensitivity and specificity [21]. Various solutions have been suggested, for example, adding cases with known pathology into the workflow [16]. It is probably not practical to add enough cases to shift criterion as much as might be desired because of the increase in caseload that would be required [18]. However, the added cases would, at least, expose readers to more positive examples. The use of "test sets," whereby radiologists read dozens of cases as a form of continuing medical education, can serve a similar purpose of "tuning up" a reader's internal template of what cancer looks like [21]. Test sets, when implemented, tend to be read once a year. In the realm of perceptual design, an even better approach might be to have a much briefer task, performed before a screening session, in which the radiologist quickly evaluates a relatively small number of images, receiving instant feedback. With a bit of effort, this might be turned into a game wherein individuals would compete with themselves and one another to help turn this perceptual tune-up into an appealing part of the daily or weekly routine.