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Psychophysical Aspects in Medical Imaging

by

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Psychophysikalische Aspekte der medizinischen Bildgebung

Synopsis: The relation between image generation and perception, visual perception, video displays and the perception by the human eye have to be considered in the context of digital imaging systems. Ongoing research should therefore pay more attention to the psychophysical aspects of image perception and interpretation. The goal of optimising the performance of digital imaging systems can only be reached if the important final steps in the diagnostic process – visual perception and signal detection – are taken into account. Both have important characteristics as well as limitations, and are still far from being fully understood.

1. Introduction:

The transition of hospitals and radiology departments into an era of informatization seems to be unavoidable in the near future. This requires the availability of digital data sets and images. Digital systems for projection radiography will replace conventional x-ray equipment and digital detectors will take the place of conventional screen-film combinations. The most important physical parameters which characterise digital receptors are matrix size, detective quantum efficiency (DQE), and modulation transfer function (MTF). Apart from technical image quality the overall quality of radiology services depends on the diagnostic performance of the radiologist. Therefore the relation between image generation and perception, visual perception, video displays and the perception by the human eye have to be considered in the context of digital imaging systems (PROKOP et al. 1995). The evaluation of image quality is still a typical observer task and thus a subjective matter. Therefore, ongoing research should pay more attention to the psychophysical aspects of image perception and interpretation.

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2. Literature on psychophysical aspects at medical imaging:

In order to assess the current research status a MEDLINE literature research was carried out which covered relevant articles published from 1983 to 1997. The keywords used were combined in a way that MEDLINE was able to produce at least simple list results. A total of 416 articles was listed by the research system. However, the number of recent publications on psychophysical aspects of medical imaging appeared to be quite low (tables 1, 2).

Table 1: MEDLINE SEARCH (1983 - 1998).

Number of Articles	Search Topic
0	VIDEO DISPLAY TERMINALS and COGNITVE PERCEPTION
167	VIDEO DISPLAY TERMINALS
3	VIDEO DISPLAY TERMINALS and WORKING CONDITIONS
10	VIDEO DISPLAY TERMINALS and EFFECTS ON HEALTH
2	VISUAL DISPLAY and HUMAN EYE
38	RADIOLOGY and VISUAL PERCEPTION
86	RADIOLOGY and OBSERVER PERFORMANCE
4	RADIOLOGY and IMAGE PERCEPTION
2	MEDICINE and IMAGE PERCEPTION
0	MEDICINE and VIDEO TERMINALS AND VISUAL DETECTABILITY
12	MEDICINE and OBSERVER PERFORMANCE (Dataset 9)
1	MEDICINE and VIDEO TERMINALS
0	MEDICINE and PSYCHOPHYSICS and IMAGE PERCEPTION
0	RADIOLOGY and PSYCHOPHYSICS and IMAGE PERCEPTION
0	RADIOLOGY and PSYCHOPHYSICS and IMAGE DISPLAY
74	MEDICINE and SPATIAL RESOLUTION and RADIOLOGY
0	SPATIAL RESOLUTION and IMAGE PERCEPTION
5	MEDICINE and SPATIAL RESOLUTION and DETECTABILITY
12	RADIOLOGY and SPATIAL RESOLUTION and DETECTABILITY
Total: 416	

The research topic VIDEO DISPLAY TERMINALS lead to only 3 relevant articles. Six relevant articles were dealing with RADIOLOGY and VISUAL PERCEPTION and seven with RADIOLOGY and OBSERVER PERFORMANCE. The task MEDICINE and OBSERVER PERFORMANCE lead to 4 articles, while the tasks VIDEO DISPLAY TERMINALS and EFFECTS ON HEALTH, VISUAL DISPLAY and HUMAN EYE, RADIOLOGY and IMAGE PERCEPTION and MEDICINE and SPATIAL RESOLUTION and DETECTABILITY showed no relevant results.

Table 2: Summary of relevant dealing with psychophysical aspects of medical imaging.

Number of Articles	Search Topic
3/60	VIDEO DISPLAY TERMINALS
0/2	VIDEO DISPLAY TERMINALS and EFFECTS ON HEALTH
0/1	VISUAL DISPLAY and HUMAN EYE
6/18	RADIOLOGY and VISUAL PERCEPTION
7/40	RADIOLOGY and OBSERVER PERFORMANCE
0/1	RADIOLOGY and IMAGE PERCEPTION
1/1	MEDICINE and IMAGE PERCEPTION
4/9	MEDICINE and OBSERVER PERFORMANCE
2/49	MEDICINE and SPATIAL RESOLUTION and RADIOLOGY
0/4	MEDICINE and SPATIAL RESOLUTION and DETECTABILITY
0/6	RADIOLOGY and SPATIAL RESOLUTION and DETECTABILITY

3. Developments in psychophysical aspects:

The radiologist's visual perception is a bottleneck in the diagnostic process. Despite some advances in the investigation of human visual perception, receiver operating characteristics (ROC) in medical imaging, image information content, and decision theory, the diagnostic chain still appears remarkably unbalanced. During the past decades significant improvements in x-ray technology have been made, and a variety of new imaging modalities such as computed topography, MR imaging, sonography, and positron imaging tomography (PET) have been developed. However, the final link in the imaging chain – the light box itself – is still on a primitive technological level which remained essentially unchanged for almost 100 years. A typical radiology department makes great investments in imaging systems to produce high quality images, but virtually no attention is paid to the last and critical stage, where the radiologist reads and interprets the images, and renders a diagnosis. Generally more than 99,9 % of the capital budget is spent only to upgrade the quality of existing services and less than 0,1 % is used for improvements in film reading (INBAR 1997).

Moreover, the know how in film reading using light boxes has not yet been transferred to digital imaging systems. The standards for image quality are still based on conventional screen/film combinations, exposed under optimal conditions (DHAENENS 1998). There are no generally accepted technical definitions nor measurement procedures of digital images to describe the quality of digital images. Therefore, at present, our aim should be to transfer our technical psychophysical knowledge accumulated with light box technology to digital viewing systems.

The conventional light box consits of a fix intensity light source behind a plastic diffuser. It does not cope well with films of varying optical density. Glare emanating from the light box washes out up to 50 - 90 % of the gray levels recorded on the film, resulting in al loss of clinical information. Glare also causes significant visual fatigue which degrades radiologists' productivity.

It is well known that 50 - 500 nits (1 nit = 1 candela/m^2) are optimal for the human visual acuity. Light levels below this value do not adequately stimulate the retina cone photoreceptors, which are responsible for high resolution detection. Any illumination excess scatters within the eye and reduces contrast resolution. Typically, light box illumination, after passing through a film, is well below the optimal level. The denser the film, the less light is available for the eye. Therefore, an effective lightbox should have a stronger backlighting with the ability to adapt the light level to film density. Lighting of the film reading room should be dimmed to enhance detail visibility. However, too little ambient light causes pupils to expand which leads to a deterioration of visual acuity. Better lightbox systems are able to dim room lights and to expose the human eye to a certain level of blue light which causes the pupils to contract. Computer monitors for diagnostic purposes offer about 400 cd/m^2 in a screen field of 10 cm x 10 cm with a spatial resolution of 1280 x 1024 pixels. A full monitor screen produces about 250 cd/m^2.

There is good evidence in the literature that lesion delectability degrades when the region of interest is surrounded by other complex structures. When focusing on a particular area of the image, masking of clinically unimportant parts could help to prevent cognitive distraction, and to allow the reader to concentrate on the important structures.

4. Research aims for digital medical imaging:

Digital imaging technology in an emergency setting as well in a common radiological environment is a demanding task, in technical, logistical and psychophysical terms. Rapid acquisition of high quality images, image storage, and rapid transfer of image data and radiological reports are important tasks of modern picture archiving and communication (PACS) and radiology information systems (RIS). During the past few years, a number of PACS systems have been installed throughout Europe. However, little experience exists regarding the psychophysical aspects of the image interpretation in a digital environment. Therefore, it seems to be usefull to evaluate one of the following topics:

- An extensive questioning of radiologists and non-radiologists should be carried out to determine the strengths and weakness of digital image systems in daily practice, and to assess the general acceptance for their further development. Furthermore, more ROC-studies should be performed in order to compare digital and conventional imaging systems.
- A practical evaluation of ergonomical aspects of hardware and software design, reader performance and time slots for reading of digital images, as well as an evaluation of environment light conditions for monitor diagnosing is still missing.
- Implications for software design and integration of computer systems into medical working places are still poorly investigated. Results derived from such investigations could be used for new recommendations.

- Despite of the considerable number of digital imaging systems installed there is still no standard phantom for monitor testing available. It is well known that high resolution monitors loose quality of performance after a couple of years.
- Digital imaging environments still do not support any feedback mechanism for controlling exposure dose of digital radiographs. Once an image is made it will be delivered to the digital network without any information on exposure parameters.
- The evaluation of digital viewing stations should lead to consider glare of the human eye, light intensity, chromaticity, ambient light control, scatter suppression, adaptive ilmination and touch screen solutions for faster and economic image handling.

A better understanding of human visual responses should lead to appropriate requirements for the physical environment of the film reading area, including luminosity of monitor screens or viewing boxes, ambient light levels, and varying viewing distances for detecting image features of different sizes and contrast. Coming closer to the end of the 20^{th} century a growing pressure from government agencies towards an improvement of technical and diagnostic performance in medical imaging can be observed which results in a number of demanding guidelines and regulations in the United States and in Europe. The DIN (Germany Industry Standards Institute) regulations, issued in response to the German Governments request, set strict standards for film viewing devices. They explicitly required masking and variable luminance of 500-10 000 NIT adaptive to film density in order to deliver 100 NIT (German DIN 1994). Ambient light must be less than 50 LUX. In late 1995, the German Physicians Chamber issued guidelines that not only to meet the DIN film viewing device standards, but explicitly instruct its members how to carry out demanded film reading. The Guidelines require masking, luminance adaptation to film density for viewing at 100 NIT, and ambient illumination at levels lower than 100 LUX (Leitlinien der Bundesärtzekammer 1995). For the first time in its history the European Community issued specific guidelines for film reading considering specific phsychophysically viewing parameters (EUR 16260 EN 1996). These guidelines will explicitly demand masking, film dependent light intensity for viewing at 100 NIT, specific colour and low ambient light (EUR 16261 EN 1996).

Similar guidelines should be established for digital medical imaging. It took a long time to elaborate guidelines for conventional film technique viewing conditions. However, as the trend throughout the world is to impose higher quality standards in health care and considering the rapid development of digital imaging, we cannot wait for another couple of years to establish guidelines for digital medical imaging techniques. Currently available equipment hardly meets the psychophysical requirements for optimal pattern recognition by the reader. New monitors offer ambient light sensors which are usually mounted on the left side under the monitor. Therefore, these available monitors are not able to adapt properly to the level of ambient light in the reading room and the brightness has to be set on unusual levels.

5. Image quality and perception in digital medical imaging:

A good understanding of the principles of digital imaging technologies is an important prerequisite for evaluating image quality. We need a new way of thinking in non conventional terms. Statistical confirmation methods and the use of radiological perception models instead of technical parameters should be applied within this scope. It is well known that there are at least 35 parameters and conditions which influence the quality of a radiograph. The imaging process itself consists of three major parts:

1. The formation of a radiation image due to partial absorption of the x-ray beam where it passes the body.
2. The transfer in the detector and the visualisation process, including image processing towards and image display.
3. The visualisation or display process should match the broad range of information with the display on film or on the monitor, and should also match the display with capacity of the human eye and the brain. The visualisation process determines how an image can be seen and how much of the original information is kept.

This pass is a crucial one to the image quality because the grey level range of the film is narrow and the sensitometric curve is non-linear. The human eye has a weak response in contrast discrimination in dark regions. Because of the fact that half of the information is not directly visible in conventional or unprocessed films, digital systems are often using window-levelling methods. Therefore it is necessary that intelligent image processing displays match the whole procedure to the human perception, considering our experience with light boxes. This requires new standards for image interpretation, and the abandonance of our conception of a conventional digital image.

Physical models work with resolution, contrast and noise and their inherent relationships (MTF, S/N, Wiener spectra). These parameters can more or less easily be measured for every imaging system, and are directly linked to the image quality. The weak point of most phantoms is that they are not well suited for simulating the real imaging and perception process. Currently available phantoms for digital systems are designed exclusively for the use with physical models. They are pure contrast-detail-absorption phantoms, and have little in common with the imaging properties of human tissue. The process of visualisation can also not be assessed with this type of phantoms. Therefore, the main mistake made in comparing analog and digital systems is that only resolution is compared.

The advantage of human perception models for the assessment of image quality would be that they use human tissue like objects, and observers under realistic clinical conditions. These perception models should be applicable to different observers and modalities and should be related to ROC and contrast-detail analysis. They should take into account the imaging properties of different tissues, the latitude of the detector, radiation dose, and the complex process of visualisation. The ultimate goal of optimising the performance of digital imaging systems can only be reached if the important final steps in the diagnostic process – visual perception and signal detection – are taken into account. Both have important characteristics and limitations, and are still far from being fully understood (HILL 1986).

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Artikel/Article: Psychophysical Aspects in Medical Imaging. 331-337