Recognition of Detail in Mammography

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ABSTRACT

In radiological practice the term *recognition of detail* is widely used. We examined how the term can be defined and interpreted, and how recognition of detail relates to radiological phantoms such as CDMAM (Contrast Detail Mammography). For tasks in visual perception a processing hierarchy can be assumed: The perception of a structure can occur at different processing levels, such as required in detection, discrimination, identification and recognition, with an ascending order of hierarchical relation. It is not always possible to predict from results at one hierarchy level those at another level. If an observer detects a structure, there is no prediction whether the observer will be able to discriminate the structure from another or whether he or she is even able to interpret the structure. Furthermore, the perceptibility of a detail is influenced by surrounding or overlapping anatomical noise. The presence of noise elevates visual thresholds and may change the overall perceptual behavior with regard to the examined parameter. Thus, perceptibility of structures (*details*) is strongly bound to the type of perceptual task and the image background used. Speaking of *recognition of detail* should not liberally extended to evaluating performance parameters of a technical system. If the term is applied, it needs to be specified how detail is characterized and which perceptual task is used for operationalizing recognition.

Keywords: Perception, recognition of detail, contrast sensitivity, noise, mammography

1. INTRODUCTION

The term *recognition of detail* seems precise, but at closer look appears ambiguous and diffuse. How is detail and how is recognition characterized? In analog mammography, recognition of detail was often understood as mostly synonymous with visual acuity and has been tested by the use of lead bar patterns. The use of more complex phantoms, such as CDMAM (Contrast Detail Mammography), allows the monitoring of resolution in context of different contrast levels providing more substantial information on the recognition of detail.

However, in the worst case, recognition of detail is interpreted as the size of the detector elements or the pixel size, respectively. This does not nearly meet the complexity of the term, since it does not include any perceptual aspect. Recognition of detail is strongly influenced by physiological and psychological parameters. Essentially, hidden in the term are questions from two fields of knowledge: the characterization of the image quality on the retina by the specification of resolution and contrast (detail), and the description of the cognitive processes involved in the perceptual task (recognition).

In an early publication from 1919, Chalmers[1] looks into *recognition of detail* describing the limits of visibility under several conditions. For recognition of detail there are many factors, such as the amount of light received from each element of the detail, the contrast between neighboring parts, the quality of the images from the limits imposed by the diffraction of light and the aperture of the eye, and by the coarseness of the retinal elements. Besides Chalmers mainly physical perspective on recognition of detail there are also semantic aspects to be considered.

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We present a perspective on recognition of detail, driven by basic perceptual knowledge and linked to investigations in the context of mammography. Images used for such investigations are, for example, images for quality control (e.g. from a CDMAM phantom), for perceptual issues (homogeneous, phantom or mammographic images), and for performing radiological tasks (with mammographic images). We focus on the following topics:

- specification of *detail* and *recognition* for perceptual investigations in a mammographic context
- exemplifying the impact of anatomical noise, target items and observer's tasks used for conducting perceptual-science driven studies

Our report cannot provide a comprehensive analysis of the issues involved in the term *recognition of detail* but shall point out its complexity and present aspects helping to design observer studies with high validity for the radiological practice. One motivation for conducting studies is to bridge the gap between theory and practice,[2] e.g. for choosing optimal illuminance conditions in the reading room.[3,4,5] Getting useful and valid results from a study can be compromised by many problems. The following excerpt lists some of the important questions presented by Kosara et al.:[2]

- Is the task appropriate?
- Are all participants able and willing to perform the task?
- Is there a learning effect or are there effects of the participants' expertise?

In general, the results of observer studies answer rather specific questions only; any more general conclusions rely on assumptions that might not be valid.[2] Thus, the selection of the details to be perceived and the specification of the perceptual task the observer is to perform ("recognition") is required in light of the hierarchy in visual processing (detection → discrimination → identification → recognition), and the use of anatomical noise, which consists of anatomical structures and the system's noise,[6] will improve validity of the measurement results.

2. METHODS AND DISCUSSION

This section provides an overview of aspects for specification of *detail* and *recognition*, and summarizes facts and thoughts on the impact of anatomical noise, the type of target items and the observer's tasks used for performing perceptual-science driven studies.

2.1 Hierarchy in observer tasks

The perception of a structure can occur at different processing levels, such as those involved in detection, discrimination, identification and recognition, with an assumed ascending order of hierarchical relation.[7,8] Conclusions drawn from tasks at one level do not necessarily lead to valid results with tasks at a higher level. For example, if an observer detects a structure, there is no prediction whether the observer will be able to discriminate the structure from another or, moreover, whether he or she will be able to interpret what structure it is.

Unfortunately, in medical image analysis, the term *recognition* is often used synonymously for detection as well as for the recognition itself. In the field of mammographic softcopy reading which we consider here, let us take a closer look at the meaning of recognition of a detail. When an observer recognizes a detail, from a perceptual point of view it means that he or she:

- detects the detail,
- discriminates the detail from others in the image,
- identifies the detail out of a given set of structures, and finally,
- is able to interpret or recognize the detail.

Since human pattern recognition is a nonlinear process,[9,10] the results of measuring perceptual performance in e.g. detecting an extracted malformation might not allow predictions on the performance for recognizing this malformation.

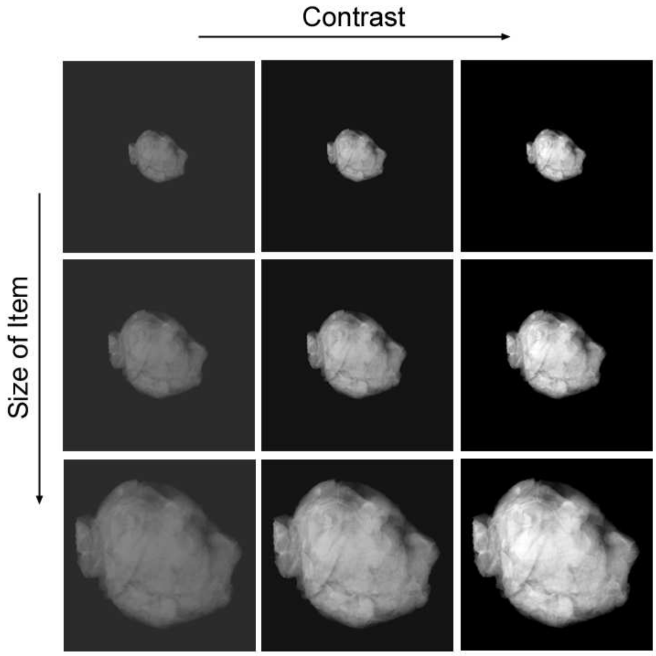

Figure 1. Perceptibility of an extracted breast malformation on a homogeneous background at various sizes and contrasts. Even at large size the structure is hardly to recognize when the contrast is low.

2.2 Detail

According to Stender and Stieve,[11] image details are image features which define the structure of a given object on the radiography. They are assigned to the anatomical substrate by the perception and experience of the radiologist. Deviations from those details lead to a diagnostic rating, with details of breast-specific structures having sizes of 0.2 mm up to 3.0 mm. The threshold for the perceptibility is at about 0.1 mm.

In that statement about the recognition of detail it is noteworthy that the term perceptibility is already bound to a recognition task. This is in agreement with the psychological interpretation of recognition. It is, however, conspicuous that primarily the lower limits for the size of details are stated. This is probably foremost driven by the assumption that the perception of larger structures can be attributed to that of smaller structures. This assumption is often postulated tacitly, but is not correct. Furthermore, the indication of lower limits for the size of detail could be sufficient for high-contrast structures, e.g. calcifications, but low-contrast structures are badly noticed even when they are large. Figure 1 illustrates this by an extracted malformation with varying size and contrast level. Transferred to the reading of a mammogram this means that, for example, a calcification of 200 micrometers is well noticed by the radiologist, whereas a low-contrast mass of 200 micrometers is nearly imperceptible. For the perception of low-contrast malformations, the indication of lower size limits admits no useful statement.

There is, however, no proportional relation between contrast and malformation size. Instead, three bandpass channels, peaking at low, medium and high spatial frequency were identified by Simpson and McFadden.[12] In general, sensitivity is best for medium spatial frequencies.[13]

Another factor for the perceptibility of a structure (detail) is its orientation. The sensitivity of the visual system for lines and gratings differs for vertical, horizontal and oblique orientations.[14] For sinusoidal patterns presented on a homogeneous background, sensitivity is best for horizontal and vertical orientations, and is lowest for oblique orientations.[15] Conversely, when sinusoidal patterns are presented on a complex background, there is a horizontal-disadvantage effect, i.e. sensitivity is maximal for oblique orientations and lowest for horizontal orientation.[16]

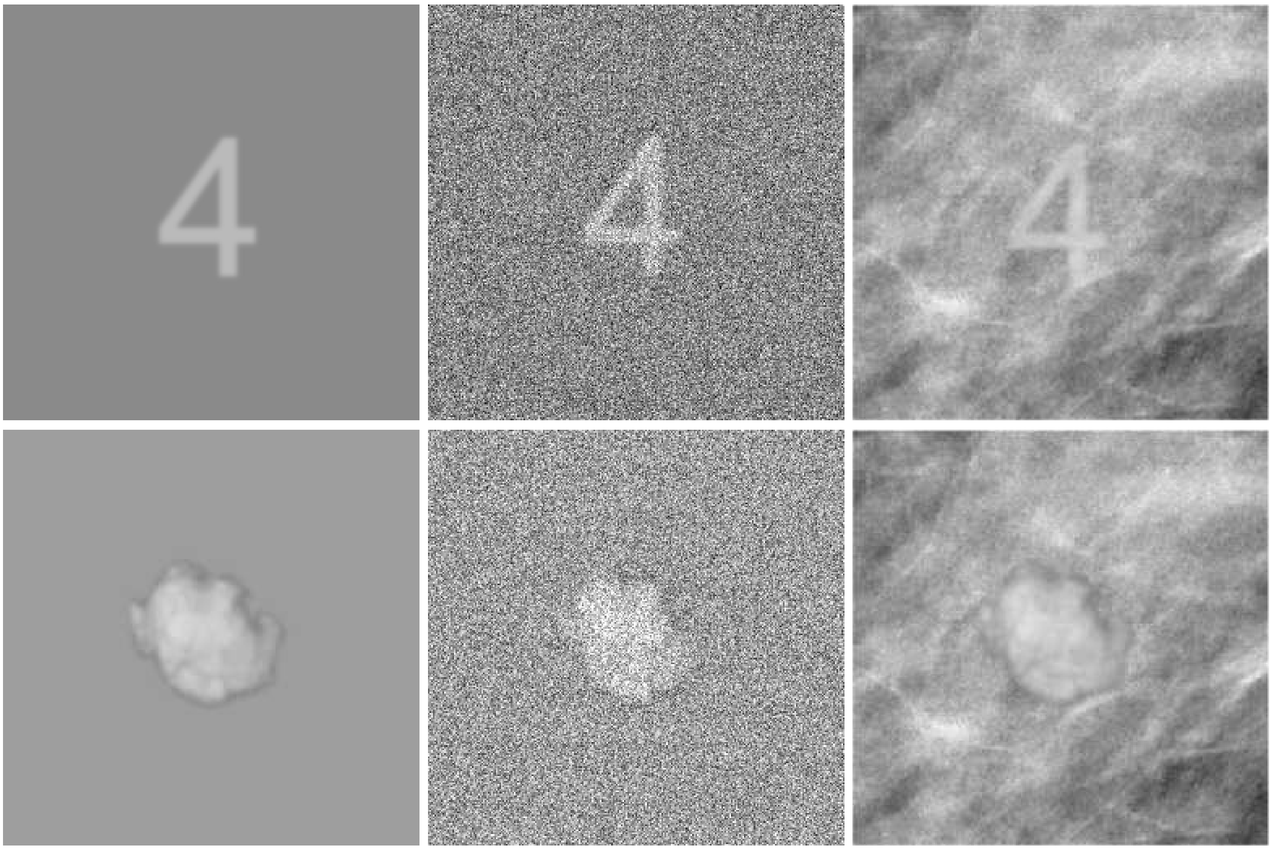

Figure 2. A malformation extracted from a mammogram and a digit on homogeneous blank background (left), with Gaussian noise (middle) and superimposed onto mammographic tissue (right). The more similar the target item is to the background, the more difficult is its detection. If the digit 4 would be presented on a background consisting of an assembly of the digits 1 and 7 the detection of the 4 is expected to be more difficult than on a mammographic image.

2.3 Influence of anatomical noise

A basic, well-studied measure of visual performance is contrast sensitivity for targets on homogeneous, blank backgrounds.[17,18] Contrast sensitivity is also influenced by specific noise, however, such as system noise, anatomical noise and noise added by the visual system of the observer (Fig. 2). There are estimations that the effect of anatomical structure variations is three times as important as the imaging system's noise for microcalcifications, and 30 to 60 times as important for an 8 mm simulated nodule.[19]

The presence of noise elevates visual thresholds and may, moreover, change the overall perceptual behavior. Pelli and Farell[17] showed this for the identification of letters. Letters were presented on a homogeneous background, and contrast thresholds for identifying letters with varying size were determined. Thresholds were measured in both, the presence and absence of noise. With noise present, more contrast was necessary to solve the identification task, but not similarly for all tested letter sizes. The effect of noise on letters smaller than 1 degree of visual angle was significantly stronger than the effect on larger letters.

This observation was confirmed by our study investigating the applicability of contrast sensitivity measurement by the MCS method (Mammographic Contrast Sensitivity).[20,21,22] In this study, sinusoidal patterns (Gabor patterns) were presented with four different orientations on both a homogeneous and a mammographic background. Contrast thresholds of the observers were measured in an orientation-discrimination task. Comparing the results for the homogeneous and the mammographic image background revealed an elevation of visual thresholds as well as changes in the shape of the contrast sensitivity functions.

For anatomical noise there are further difficulties, since the apparent anatomical noise consists of both the imaging system's noise and the anatomical structures of the mapped breast tissue.[6] Thus, anatomical noise has a component that can be considered as noise and another that can be considered as signal. The use of a homogeneous test object without anatomical structures appears inadequate for qualifying the system performance or for optimizing a radiological procedure.[23] Even with white noise the observer's behavior with regard to contrast sensitivity can differ from that in a mammogram. Burgess et al.[19] determined the variation of malformation contrast thresholds for detection as a function of malformation size. The tests were carried out on mammographic images and images with filtered noise of the same power spectra. Burgess et al. found that the results are *opposite* to tests with other types of noise (white noise, radiographic and CT imaging system noise). Hence, drawing conclusions from investigations with non-anatomical images to complex medical constellations may be critical.

The more similar a target item is to the background image or the surrounding structures, the more difficult the observer's task becomes. One reason can be found in the crowding effect,[24,25] which is manifesting itself in adverse effects on the visual performance for a target item because of the presence of surrounding structures. Furthermore, in perception science it is well known that a perceptual task for a set of items is solved faster if there is a "feature present" than a "feature absent" (Treismans feature integration theory).[26,14] For example, the detection of the letter R is more difficult in a set of the letters P and B than in a set of the letters P and Q, because of the small dash present in the letter Q (feature present). The number of shared features is greater for the letters R, P and B. Thus, transferred to the radiological context, an observer's task as that of detecting a malformation (feature absent) on a mammographic image is expected to require more contrast than detecting a sinusoidal pattern or a character (feature present) on the same image.

In a study from Burgess et al.[19] contrast thresholds for malformations with different size presented on several mammographic images were analyzed. The observers had the task of deciding which of two presented images contained the malformation. Thus, the observers seemingly had a two-alternative forced choice detection task on a high level of difficulty because of the background (the mammogram). Detecting a malformation in a mammogram is, however, more than a simple detection task, as e.g. detecting the malformation on a homogeneous image because it involves the processes of discriminating the anatomical structures from each other. Thus, the processing hierarchy of detection → discrimination → identification → recognition is linked to potential interactions between the target item and the background image with its structural characteristics. Naturally, in mammographic images an observer's task as discriminating malformations from one another or identifying a malformation from a given set of malformations is even more difficult than the detection task according to the processing hierarchy described above.

2.4 Consequences for a perception-driven approach to mammography

As a consequence of the conceptual hierarchy in visual processing and the influence of (anatomical) noise, the following suggestions for the selection of target items can be made. If an investigation aims just on the perceptibility of small details with high contrast as in the case of measuring visual acuity, the use of simple-shaped target items such as a the optotype Landolt-C in front of a homogeneous or noisy background may be sufficient. When, however, the perceptibility of objects with differing contrast (and size) is studied, the use of sinusoidal patterns, characters, CDMAM phantoms and simulated or extracted malformations as target items is expected to be instrumental (Fig. 3).

The type of background images should be chosen depending on the significance of (anatomical) noise for the issue to be investigated. Spatial frequency content does influence the radiologists' perception and interpretation of images,[27,28] and the use of real medical images for investigating the observers' performance for tasks in a medical context may lead to results with higher validity.

Which target items and images are used must be specified with regard to the observer's task. It may be advantageous to have results that are mostly independent from the observer's radiological expertise. In a study conducted by Burgess et al. for example, the overall result that the observer's behavior for contrast sensitivity correlated with the malformations' size was the same, but the extent differed significantly for the observers.[19] On the other hand, the presence of real anatomical structures has significant effects on the task outcome. Thus, the use of target items which require no radiological expertise but are presented in mammographic images is suggested to be supportive. The MCS method[20] mentioned above provides such an approach by superimposing

Figure 3. Three types of target items on a part of a mammographic image. From left to right: Gabor pattern, digit, malformation.

sinusoidal patterns on mammograms. Further studies are necessary to show whether the outcomes of determining contrast sensitivity with the MCS method are actually independent of the observer's expertise.

Finally, let us apply the discussed issues of relevance of a conceptual processing hierarchy, the detail characteristics and the presence and absence of noise, respectively, to a practically relevant example: In quality control of mammography CDMAM phantoms[29] are established, which serve the mapping of objects with different size and contrast. A CDMAM phantom consists of an aluminium base with attached gold disks of various thicknesses and diameters. The disks are arranged in a matrix divided into square regions, and the disks' thickness and diameter, respectively, increase logarithmically within the rows and columns.[30] In each square region two disks are placed, one in the center and the other in one of the four corners. The observer has to localize the corner of the second disk. Thus, rating a CDMAM phantom is a simple detection task. The minimum contrast required to detect the disks of a given size is determined. The results are recorded in a contrast-detail diagram in which the locations correspond to the square regions of the phantom.

Drawing conclusions from those results on detection of low contrast structures in a mammogram is tempting, e.g. for the determination of optimal illuminance levels in the reading room. The structures in a mammogram, however, have a far more complex background than the image of a CDMAM phantom with its homogeneous structures. Looking for a target structure in a mammogram is coupled to more complex processes in pattern recognition. Therefore, detecting e.g., a calcification in a mammogram cannot be expected to be predictable from the task of detecting a structure with the same size and comparable contrast in a CDMAM image. Thus, studies investigating the effect of specifics on performance in radiological tasks, such as the detection of calcifications or masses, should not rely on the rating of CDMAM phantom images. Nevertheless, for assessing the performance of a system, for example the contrast resolution, rating a CDMAM phantom provides a solid basis.

3. CONCLUSIONS

Bridging the gap between basic perceptual research and research driven by tasks in radiological practice opens plenty of possibilities for improvements in the development of diagnostic software tools. Visual perception is a complex field of research with high public awareness and many interesting open questions. Especially conclusions about the perception of complex structures in mammographic images can rarely be drawn from research projects which are concerned with the perception of text, digits or simple shapes in front of a homogeneous background.

Although the term *recognition of detail*—which is widely used in radiological colloquial language—is ambiguous it summarizes the complexity of perceptual tasks arising in mammographic softcopy reading. We propose, however, that the term should not be used without specifying and naming the type of details used, the observer's task, and the image noise used in the task.

Besides, in the use of the term tone might bear in mind that it relates to psychological and psychophysical concepts and that the cognitive act of recognition is best considered part of a whole hierarchy in visual processing.

There is, moreover, a wide literature on machine visual pattern recognition. Speaking of recognition of detail should be confined to investigations on visual perception and not liberally extended to evaluating performance parameters of a technical system. Hence, recognition of detail has to be defined according to the observer, i.e. the radiologist or pathologist. It is no physically measurable quantity of an imaging system or method. For an analysis of recognition of detail perceptual aspects have to be included, and it has to be indicated how a detail is characterized and what perception task is associated with recognition.

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