Contrast Sensitivity in Mammographic Softcopy Reading

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ABSTRACT

In mammographic softcopy reading, assessment of contrast resolution is mainly performed with phantoms, including detection tasks with a homogeneous image background. For tasks in visual perception a processing hierarchy is assumed, where detection tasks represent the base level. The results of investigations based on detection tasks might not allow predictions on the sensitivity for recognizing low-contrast patterns in a situation with complex images. We introduce the MCS method (Mammographic Contrast Sensitivity) for determining the contrast sensitivity function (CSF) in mammograms. Gabor patterns and digits are used as visual targets. The observers have to cope with an orientation discrimination task for the Gabor patterns and an identification task for the digits. The contrast thresholds are measured by a psychophysical staircase procedure at six spatial frequencies up to 16 cycles per degree. A study with eight observers was performed to show the applicability of the MCS method. The results of the observer study with several mammographic cases show that the approach is applicable independent of the chosen images. The results for Gabor pattern targets were different from those with digits, both in overall sensitivity and in the shape of the contrast sensitivity function. Sensitivity to pattern recognition is thus not reliably predicted from the Gabor CSF, and a more complex target like a digit or a character should be preferred. The measurement of a contrast sensitivity function does not take more than 4 minutes. The results can be used to appraise the effects of viewing conditions with an aim of drawing conclusions for mammographic softcopy reading.

Keywords: Contrast sensitivity, perception, mammography

1. INTRODUCTION

Mammographic images are characterized by a large variability of anatomic and pathologic structures, and reading mammographic images is a challenge. The perception of complex patterns and the recognition of low-contrast patterns depend on the processing of luminance differences, i.e. of contrast, by the human eye and brain.

1.1 Definitions of contrast

Depending on the complexity of the observer's perceptual task and the image, several definitions of *contrast* are suitable. For binary patterns two contrast definitions are commonly used, the Weber contrast C_{Weber} and the Michelson contrast $C_{Michelson}$:[1]

$$C_{Weber} = \frac{L_1 - L_2}{L_2}, C_{Weber} \in [-1, \infty] \tag{1}$$

$$C_{Michelson} = \frac{L_1 - L_2}{L_1 + L_2}, C_{Michelson} \in [0, 1] \tag{2}$$

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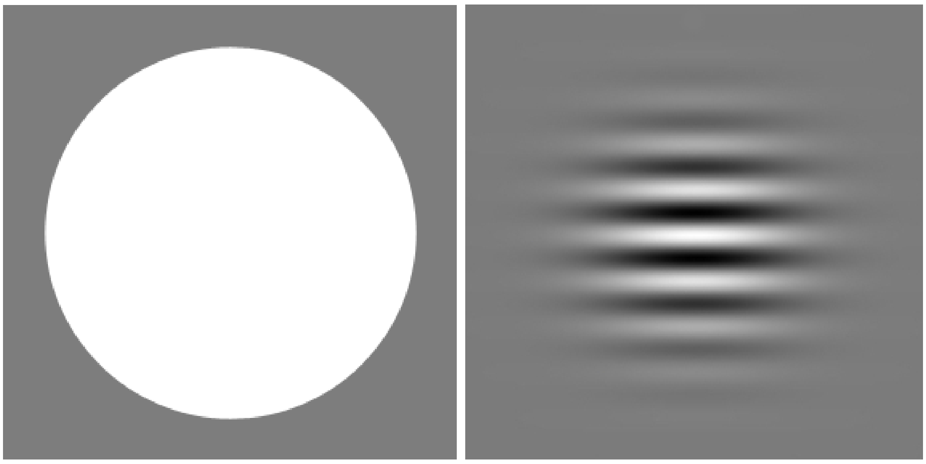

Figure 1. Typical patterns for the application of the Weber contrast C_{Weber} (left) or the Michelson contrast $C_{Michelson}$ (right).

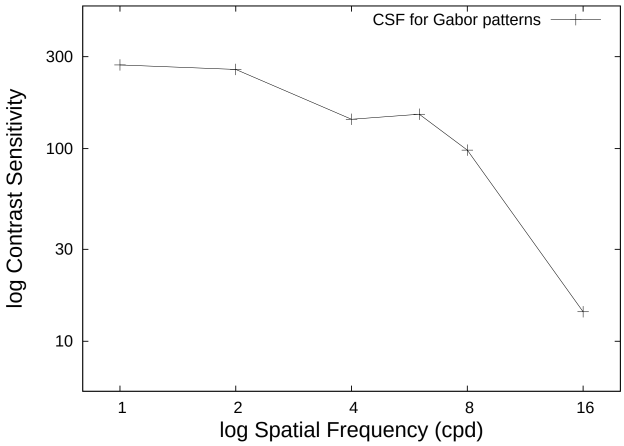

Figure 2. Example for a contrast sensitivity function (CSF) of an observer, determined with an orientation discrimination task for Gabor patterns on a homogeneous background (modified from Apelt et al.[5])

where L_1 determines the maximum luminance or the luminance of the object to be viewed. L_2 determines the minimum luminance or the luminance of the background. For simple shapes on a homogeneous background the Weber contrast is used. The Michelson contrast is preferred for lattice-like or sinusoidal objects. Examples for typical patterns on which the contrast definitions are applied, are shown in Figure 1. For the presentation of investigation results on contrast perception the specific contrast definition should be given, since the range of values differs.

The contrast threshold marks the contrast necessary for the "visibility" of a given object for a specified task of the observer, e.g. for identifying a character. Contrast sensitivity is defined as the inverse of the contrast threshold. Usually, the contrast sensitivity is described for a set of spatial frequencies, resulting in a contrast sensitivity function (CSF; Fig. 2).[2] The perception of a coarse structure (low spatial frequency) cannot be predicted from the perception of fine-grain structure (high spatial frequency). Most of the CSFs variation is captured by three factors, or bandpass channels, peaking at low, medium and high spatial frequency.[3] In general, the perception of low and high spatial frequency requires more contrast than the perception of spatial frequency at the mid range.[4]

1.2 Assessment of contrast measures in a medical context

The assessment of contrast transmission of technical systems is amongst other things covered by the rating of phantom images. For appraisal of the contrast perception of human observers there are various approaches in the scopes of observer studies and the use of human observer models.[6,7,8] The used image material includes uniform images, phantom images, simulated and medical images. The corresponding observer's task comprises several levels of difficulty ranging from detection to recognition of structures.

Anatomical noise in a mammographic image influences the perception of structures because of the structure's features in the image and the features of the surrounding anatomical structures. In general, the surroundings have an adverse effect on the pattern recognition of the "target" structure. In basic perceptual research this is known as the crowding effect.[9,10,11] For example the recognition performance for a target character is impaired by the size and distance of flanking characters. In the context of medical images an interference of perception of a target structure and its surrounding was reported by Samei et al.[12] for the detection of subtle lesions in X-ray images of the thorax. Thus, the use of real medical images instead of homogeneous images for investigating the observer's performance for tasks in a medical context may lead to results with higher validity. Moreover, spatial frequency content does influence the radiologist's perception and interpretation of images.[13,14,15]

Besides, previous psychophysical studies have shown that human detection performance does not predict pattern recognition performance,[8] which has led to the model of a visual processing hierarchy of detection → discrimination → identification → recognition,[1,8] where it is not always possible to predict results at one hierarchy level from those at a different level.

In mammography the mapping of luminance differences is routinely investigated by test patterns, such as the CDMAM phantom,[16] or by lesions simulated or extracted from mammograms,[17] both resulting in a description of the individual contrast resolution in appropriate contrast detail diagrams. The CDMAM phantom permits a standardized assessment of the imaging properties of a system, but disregards the anatomical structure of mammograms. The detection or discrimination of lesions in different contrast levels on a mammogram takes anatomical noise into account, but the results of such an investigation strongly depend on the radiological expertise of the observers.

Since an arbitrary pattern can be linearly decomposed into a set of sinusoidal-profile Gabor patterns, the sensitivity to these patterns on a homogeneous image background has been of particular interest[2,18] and is measured as a function of target spatial frequency in the contrast sensitivity function. Gabor patterns are the standard test patterns for investigating the contrast sensitivity in psychophysical research which provides an objective, standardized measurement. However, human pattern recognition is a nonlinear process,[19,20] and the results of standard CSF measurement might not allow predictions on the sensitivity for recognizing low-contrast patterns in an applied situation as in the diagnostics of mammograms. We have developed the MCS method (MCS: Mammographic Contrast Sensitivity) that aims to combine the advantages of both the CDMAM approach and the approach using simulated or extracted lesions in a mammogram, by presenting Gabor patterns in mammographic images. Because the observers are given a non-radiological task of discriminating Gabor patterns it can be expected that there is no necessity of radiological knowledge for them. Therefore, more stability in the results can be achieved compared to investigations in which lesions are used as targets.

We conducted a study investigating the applicability of the MCS method. Three aspects were investigated:

- Do the level *and* shape of contrast sensitivity functions vary depending on the complexity of the used image background? Are the variations similar for the observers (interobserver)?
- Are the level and shape of contrast sensitivity functions similar for mammograms having different tissue characteristics?
- Do the level and shape of contrast sensitivity functions differ depending on the used target item and observer's task?

First results of the study have been described in Apelt et al.,[5,21] but there are new and extended findings to be presented.

2. METHODS

For investigating the effects of the image background, the target item and the observer's task on contrast sensitivity, an observer study was conducted. Eight non-radiologist observers aged between 25 and 65 years participated in the study. Since general preferences for channels of spatial frequencies were determined[3] and since the observer's tasks do not require radiological expertise, achievement of valid results can be expected for the non-radiological observers.

Three hypotheses are tested in the study:[5]

- A CSF determined with a homogeneous background is dissimilar from a CSF with a complex image background.
- The shape of the CSF is similar for mammograms having different tissue characteristics.
- The CSF has an overall higher level for a discrimination task with Gabor patterns compared to the CSF for an identification task with digits.

In the following subsection the MCS method[5,21] is explained. Afterwards, further details on the realization of the tests for the listed hypotheses are described.

2.1 The MCS method in general

On a mammographic image, Gabor patterns—Gaussian filtered sinewave-modulated "stripes"—are presented as targets for determination of the individual contrast sensitivity. The patterns are superimposed onto the mammographic image. Spatial frequency, contrast and orientation are varied. The six spatial frequencies applied, ranged from 1 up to 16 cycles per degree (cpd; number of "stripes" per degree visual angle). Orientations swap for horizontal, vertical, and left and right oblique. A fixation circle on the image marks the target location (see Fig 3). The Gabor patterns are presented on an area of 2.5 × 2.5 degree of visual angle and for a duration of 720 ms.

The observers task is to focus on the area defined by the fixation circle and to detect the orientation of the presented pattern (orientation discrimination task). Individual contrast thresholds are measured by use of the UWUD procedure,[22] an adaptive psychophysical staircase procedure[23] differing from usual nAFC-tasks (nAFC: n Alternative Forced Choice) by the additional option of answering *nothing seen*. The measurement of a contrast threshold starts with a significantly above-threshold contrast. After a stimulus presentation the observer states the perceived orientation. Dependent on the correctness of the observer's answer the contrast is increased or decreased according to the adaptive staircase procedure. Target contrast is specified in the Michelson measure, and contrast steps are specified in the log domain so the contrast is modified by a (decreasing) factor after each presentation.

Stimuli were presented on two standard mammography grayscale monitors (Siemens DSB 2103-D-5MP, 2048 × 2560 pixel). Room illumination at the observer's position was 10 lx to obtain typical viewing conditions.[24,25] The observers viewed the monitors from a distance of 57 cm. The displayed mammogram, the position of the target and the window level settings were kept constant during the course of a measurement.

The images were presented in a manner that matched the practice in softcopy reading. Two corresponding images of a case were presented. MLO (medio lateral oblique) projection images were chosen instead of CC (cranio caudal) projection images, due to their wider range of visible anatomical structures and gray values.

2.2 Contrast sensitivity depending on complexity of the image background

The homogeneous image was created by segmentation of the mammographic image with a gray value threshold (Fig. 4). Thus, the comparison of contrast sensitivity functions for a homogeneous background and a mammographic image is performed with the same area ratio. The luminance of the background was identical with the mean luminance of the normalized mammographic image, which was 32.4 cd/m^2 (at the gray value of 2048 out of the range of 0-4095).

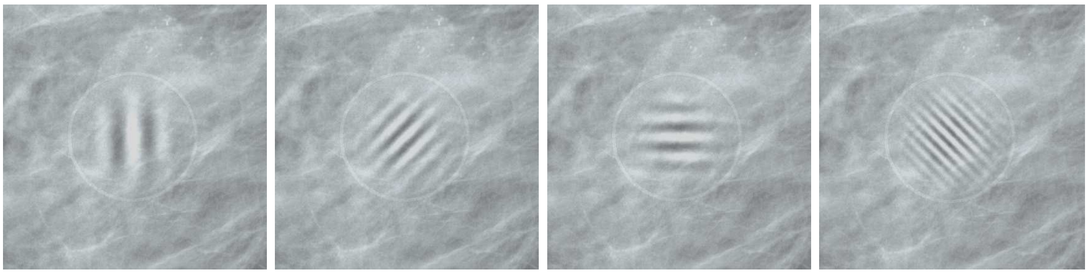

Figure 3. Part of a presented image with examples for Gabor patterns, surrounded by a fixation circle. (modified from Apelt et al.[5,21])

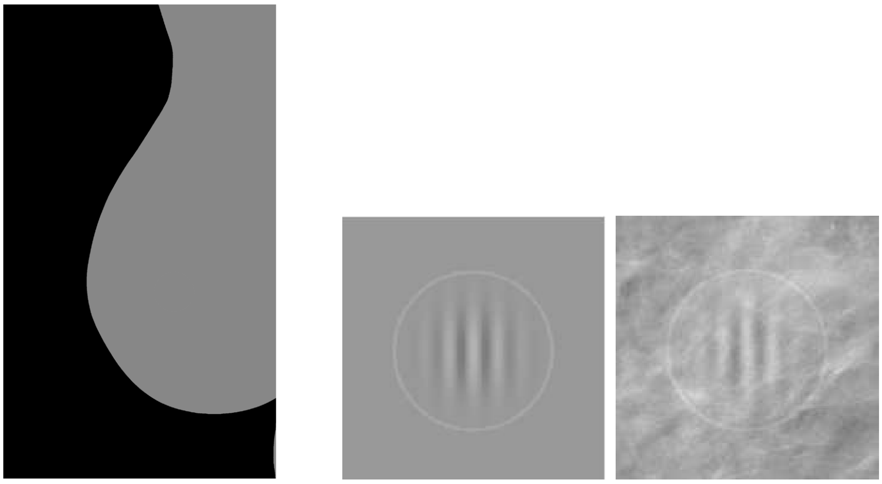

Figure 4. Left: Processed mammogram with homogeneous background of the same mean luminance as the breast tissue of the mammographic image. Right: Parts of the presented images with Gabor pattern examples for comparison of contrast sensitivity in dependence of the complexity of the image background (homogeneous background vs. mammographic image).[5,21]

2.3 Contrast sensitivity depending on tissue characteristics

Four common types of mammographic tissues were selected for this part of the study (Fig. 5): diffuse, radiolucent, strongly structured and dense tissue. Radiolucent tissue appears more homogeneous than the other tested tissues, and a slightly higher level of the contrast sensitivity functions can be expected.

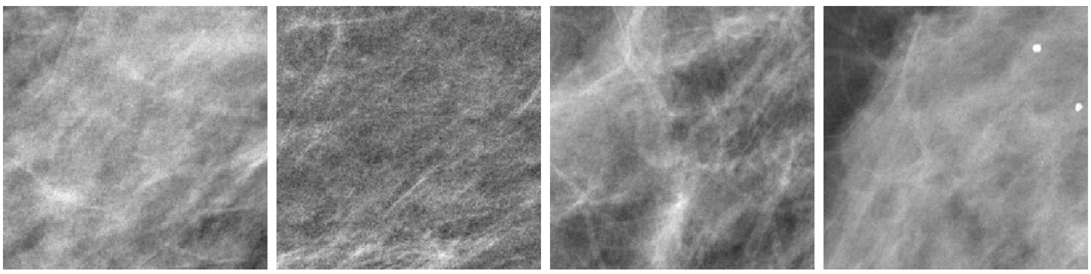

Figure 5. Parts of the mammographic images with different types of tissues, from left to right: diffuse, radiolucent, strongly structured and dense tissue. On these parts the Gabor patterns were presented.[5,21]

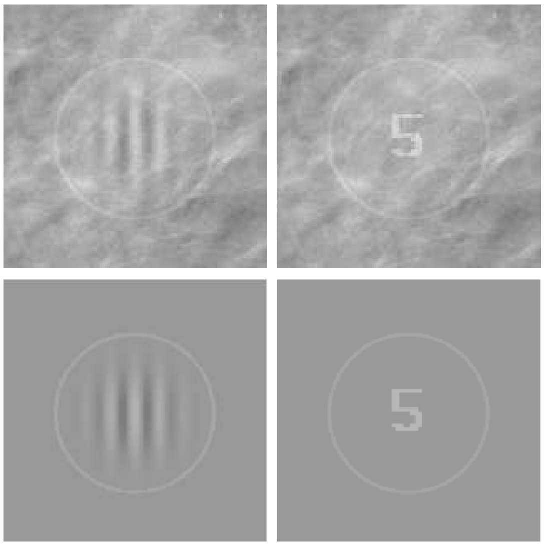

Figure 6. Parts of the presented images with examples for the target items, used for comparison of contrast sensitivity in dependence of the complexity of the target item (Gabor patterns vs. digits) and observer's task (discrimination vs. identification) in the context of mammographic images and homogeneous backgrounds.[5,21]

2.4 Contrast sensitivity depending on difficulty of the target item and observer's task

The effect of the target item's type and with it the observer's task on contrast sensitivity is investigated by comparing the CSFs for Gabor pattern and characters, the digits 0...9 (Fig. 6 (first row)). The observers were thus given both a task of discrimination and one of identification, with Gabor patterns for the orientation discrimination task and digits for the identification task. In this way two levels of the processing hierarchy are checked. The task of identifying a stimulus is perceptually more difficult than that of discrimination.

The size of the digits varied at six levels between 0.08 $\times$ 0.12 cm and 1.67 $\times$ 2.31 cm, analogous to the variations of the spatial frequencies of the Gabor patterns. Both types of target items, Gabor patterns as well as digits, are presented on the same area of 2.5 $\times$ 2.5 degree of visual angle.

An additional test on a homogeneous background was performed for both types of target items to determine whether the effect of the different items and observer's tasks are similar in a context without anatomical noise (Fig. 6 (second row)).

3. RESULTS

The main results of the study are shown in Fig. 7 – 10. The outcomes are presented as individual contrast sensitivity functions (Fig. 7), and contrast sensitivity functions generated from the pooled data of the eight observers (Fig. 8, 9, 10), respectively. The error bars denote the range of variation in the measured contrast thresholds and therefore the contrast sensitivities.

3.1 CSF in comparison of homogeneous background and mammographic image

For all observers the contrast sensitivity is significantly higher on a homogeneous background than on a tissue background with its anatomical noise. However, not only the overall level but also the shape of the CSF varied between the homogeneous and the tissue case. These variations were different between the observers. The precise shape of the CSF on tissue thus seems not predictable from the CSF on homogeneous background. Figure 7 shows the CSF acquired on a homogeneous background in relation to the CSF acquired on a mammographic image for four of the eight observers.

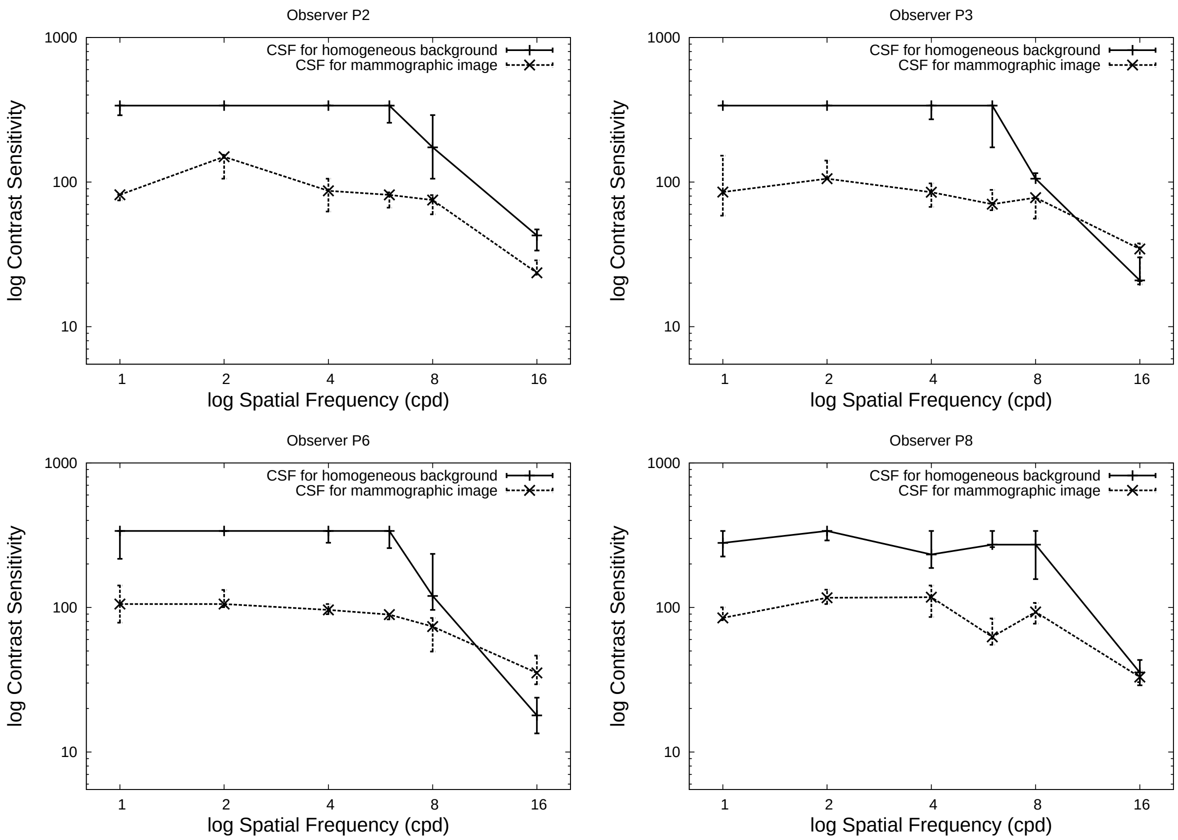

Figure 7. Comparison of contrast sensitivity functions (CSF) acquired with Gabor pattern stimuli on a homogeneous background and a mammographic image, respectively. Results for observers P2, P3, P6 and P8. The difference between the CSF on both types of images is similar for P3 and P6. For the other observers there are stronger individual differences in the shape of both CSFs.

3.2 CSF for different mammographic images

The level and shape of the CSF curve on mammograms with different tissue characteristics are quite similar (Fig. 8). It is striking that the CSF is slightly higher on radiolucent tissue, which appears more homogeneous than the other tested tissues. For strongly structured tissue the CSF level is a little bit lower, i.e. more contrast is required for orientation discrimination of Gabor patterns on the strongly structured tissue. Among the slight differences in the level of the CSFs the shape of the CSFs is nearly identical. There are no considerable "preferences" for one of the tested spatial frequencies. Merely a discomfort for dealing with the discrimination task, performed on the strongly structured tissue, was reported by all observers. We assume that an analysis of the CSF for a tissue background will only slightly depend on the selected mammographic image.

An additional test was performed for a practical relevant application of the MCS method: investigating the influence of masking with an oval display shutter on contrast sensitivity. Apelt et al.[25] have shown that masking has no significant effect on the contrast sensitivity in the central visual field. In the additional test the observers had to solve the discrimination task for Gabor patterns on the four types of tissues. For all tissues the contrast sensitivity in the masking condition was not improved (Fig. 9), i.e. independent from the selected mammographic image the investigation of the influence of masking led to the same results.

3.3 CSF for Gabor pattern discrimination versus digit identification

The plots in Fig. 10 summarize the results for comparison of contrast sensitivity for orientation discrimination of Gabor patterns with identification of digits. Contrast sensitivity values are higher for the discrimination

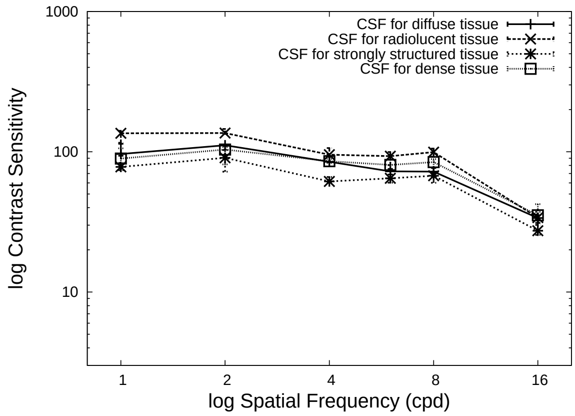

Figure 8. Comparison of contrast sensitivity functions (CSF) acquired with Gabor pattern stimuli on four types of breast tissue. Results pooled for all observers P1–P8.

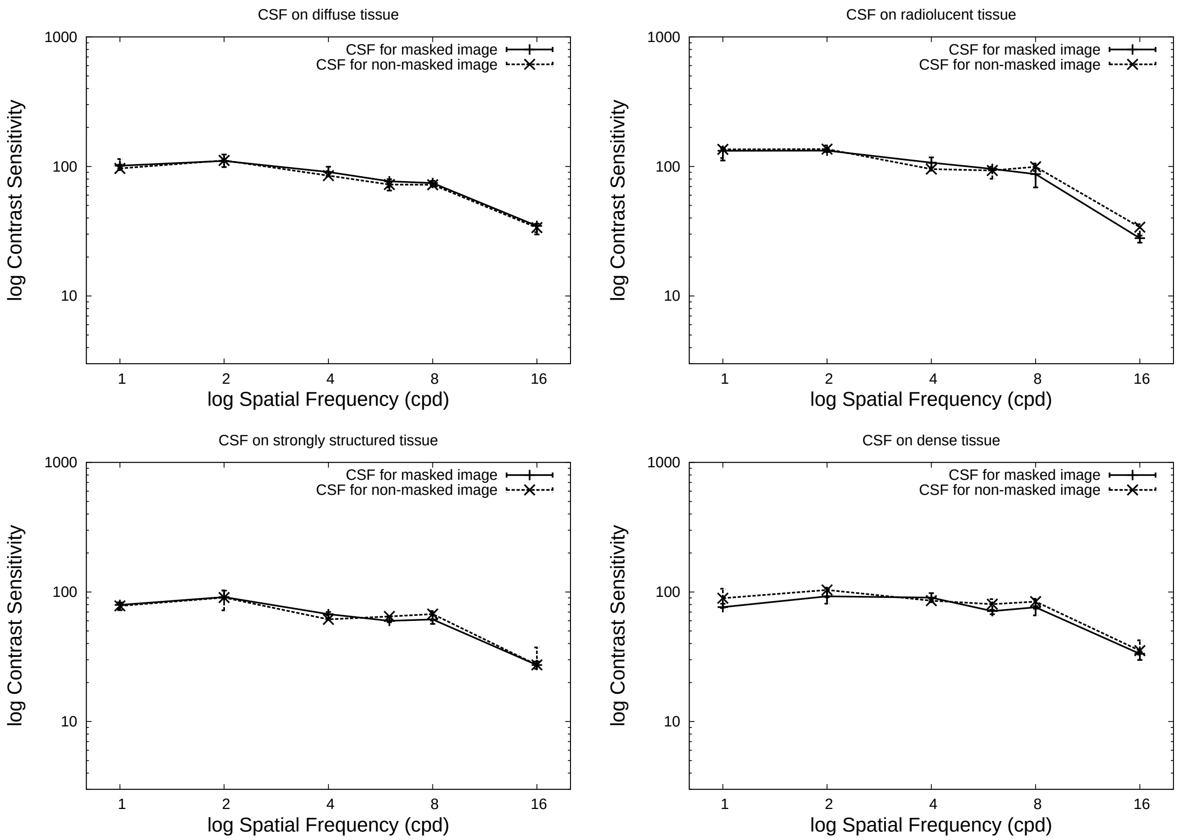

Figure 9. Comparison of contrast sensitivity functions (CSF) acquired with Gabor pattern stimuli for a non-masked and a masked image. Results for measurements performed on the tissues, described in Fig. 5.

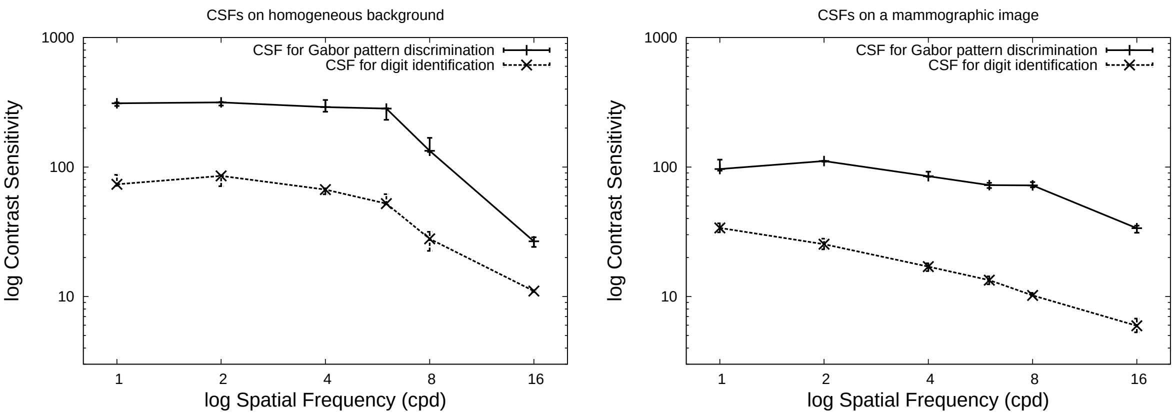

Figure 10. Comparison of contrast sensitivity functions (CSF) acquired with Gabor pattern and digit stimuli, respectively. Results pooled for all observers P1–P8.

than for the identification task and are characterized by a different behavior for the tested spatial frequencies. This is evident for both a homogeneous and a tissue background. The result confirms previous results[8] and the hypothesis that contrast sensitivity has an overall higher level for the discrimination task compared to the identification task.

Furthermore, there is a basic difference in the relation of the CSFs for discrimination and identification on a homogeneous background (Fig. 10 (left)) compared to the relation of the CSFs on a mammographic image (Fig. 10 (right)). Whereas on a homogeneous background the CSFs of the discrimination and identification task run together for higher spatial frequencies, the CSFs on a mammographic image diverge from each other. This fits with our interpretation that higher cognitive processes are required for the identification of characters.

4. CONCLUSIONS

The presented approach provides a method for determining the contrast sensitivity by use of a Gabor pattern on a mammographic background. The influence of anatomical noise on visual processing is thus taken into account and the method can be used with mammograms having different tissue characteristics. However, within an investigation we suggest to use the MCS method with just one type of tissue, since radiolucent or strongly structured tissue may slightly affect the level of the determined contrast sensitivity functions.

Results for Gabor pattern targets were markedly different from those with digits, both in overall sensitivity and in the shape of the contrast sensitivity function. Sensitivity to pattern recognition is thus not reliably predicted from the standard Gabor CSF. Since the detection of malignant alterations in mammogram amounts to a task of pattern recognition, a more complex target like a digit or a letter might yield more valid results. The type of target item used for the MCS method can be easily replaced. The parameters of the adaptive psychophysical staircase procedure have to be changed according to the number of alternatives[22,23] resulting in adjusted step widths.

Determining a contrast sensitivity function with the MCS method does not take more than 4 minutes. The expenditure of time for measuring the contrast thresholds is comparable to determining a contrast-detail diagram with a CDMAM phantom.

The MCS method can be performed for different conditions, as e.g. varying illuminance conditions,[25] and the resulting contrast sensitivity functions can give information on the effects of the investigated conditions on individual contrast sensitivity. Thus, an objective method for examining the effects of specifics of the image presentation process is provided.

Studying the CSF in a mammographic context opens new possibilities for a psychophysical analysis of the diagnostic situation including the effects of individual preferences, ambient lighting conditions in the reading room,[25] visualization methods and the design of diagnostic application software, e.g. with respect to the luminance distribution in the field of view. Such optimizing of the setting for pattern recognition may enhance the diagnostic reliability in detecting breast cancer.

Radiological observers are accustomed to interpretation of images with low contrast objects and conditions in reading rooms. Thus, a further study on the applicability of the MCS method—performed with radiological observers—will be necessary to ensure the independence of the results from the individual radiological expertise. Moreover, there should be investigations performed with more difficult observer's tasks, such as detecting given breast lesions in a mammogram, to verify the comparability with the results acquired with the MCS method.

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