Impact of Adaptation Time on Contrast Sensitivity

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ABSTRACT

For softcopy-reading of mammograms, a room illuminance of 10 lx is recommended in standard procedures. Room illuminance affects both the maximal monitor contrast and the global luminance adaptation of the visual system. A radiologist observer has to adapt to low luminance levels, when entering the reading room. Since the observer's sensitivity to low-contrast patterns depends on adaptation state and processes, it would be expected that the contrast sensitivity is lower at the beginning of a reading session. We investigated the effect of an initial time of dark adaptation on the contrast sensitivity. A study with eight observers was conducted in the context of mammographic softcopy-reading. Using Gabor patterns with varying spatial frequency, orientation, and contrast level as stimuli in an orientation discrimination task, the intra-observer contrast sensitivity was determined for foveal vision. Before performing the discrimination task, the observers adapted for two minutes to an average illuminance of 450 lx. Thereafter, contrast thresholds were repeatedly measured at 10 lx room illuminance over a course of 15 minutes. The results show no significant variations in contrast sensitivity during the 15 minutes period. Thus, it can be concluded that taking an initial adaptation time does not affect the perception of low-contrast objects in mammographic images presented in the typical softcopy-reading environment. Therefore, the reading performance would not be negatively influenced when the observer started immediately with reading of mammograms. The results can be used to optimize the workflow in the radiology reading room.

Keywords: Visual perception, contrast sensitivity, adaptation time, illuminance

1. INTRODUCTION

The perception of complex patterns in mammograms is linked to the contrast sensitivity of the visual system, i.e. to the sensitivity to contrast at a given spatial frequency. The contrast of an image determines, which structures can be distinguished by an observer, and the observer's sensitivity to contrast is an important basis for the further processing of the visual input. There are a lot of factors influencing the individual perception of mammographic structures and its contrasts, such as ambient lighting, mean luminance, spatial frequency, masking and crowding effects, and adaptation.[1] In the following, we focus on the influence of luminance and contrast adaptation on contrast sensitivity in the context of mammographic softcopy-reading.

The dynamic range of photoreceptors and neurons is limited, but since the visual system works highly adaptive, contrast information in the huge range of luminance values from 10^{-6} cd/m^2 up to 10^8 cd/m^2 can be processed.[2] Photoreceptors in the retina and neurons in the visual system adapt to the recent input parameters,[3, 4] not only to luminance, but also to contrast, orientation, spatial frequency, and other stimulus parameters. In this context, we concentrate on adaptation to the overall luminance level (retinal illumination). Neuronal responses are increased when the average luminance level is weak, with the aim to improve the signal-to-noise ratio. When the luminance level is high, neuronal responses are decreased to prevent saturation.[4]

Adaptation to luminance includes three levels, namely, the pupil reaction, the photochemic reaction of the retinal receptors, and several neuronal processes. Whereas the pupil reaction is fast, it contributes only slightly to the adaptation process, because its operating range is limited to about a decade of luminance values. The

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adaptation to luminance proper is performed in the retinal photoreceptors and neurons. Adaptation to contrast, i.e to the range of intensities around the mean luminance, occurs in the retinal circuit and on higher stages of the visual system.[5]

The processes of luminance and contrast adaptation are independent from each other,[6] and an observer can see stimuli with different mean luminance but same contrast. The contrast sensitivity of the visual system depends comparatively little on the luminance to which it is adapted.[7,8] Nevertheless, contrast sensitivity does depend on adaptation processes. The state and progress of adaptation affect the sensibility of the retinal photoreceptors and the extent of inhibition and gain on neuronal levels. Adaptation to luminance and contrast may cause a measurable reduction in contrast sensitivity.[1,2,9,10]

In mammographic softcopy-reading there are two general events for luminance and contrast adaptation:

- when the observer performs eye-movements, since there are areas with different local luminance and contrast in the mammogram and in the reading room,
- when the observer enters the reading room with its comparably low illuminance level.

When looking at an image or scene with its different luminances, the observer adapts globally. The optimal sensitivity is reached in regions, where the local luminance matches the adaptation luminance. In brighter and darker regions the contrast sensitivity is suboptimal.[1] Besides global adaptation, local adaptation takes place in the extent of the surround of receptive fields.[3] Due to eye movements, the input luminance and contrast may change within small time intervals, and several areas of the retina may have different adaptation states. However, these changes have only a reduced impact on the sensitivity, since there are quickly operating components in gain control that compensate for local changes of luminance and contrast in the visual field.[6]

Illuminance levels in mammographic reading rooms are typically equal to or greater than 10 lx.[11] When entering the reading room the radiologist observer mostly has to adapt to lower luminance levels (dark adaptation). Adaptation effects occur at a wide range of time scales, in fractions of a second up to minutes, and more prolonged adaptation results in stronger effects. Dark adaptation takes much longer than light adaptation: Whereas full dark adaptation is reached only after about 30-40 minutes, light adaptation is attained in a time range from 50 ms up to some minutes. However, full dark adaptation is not necessary for softcopy-reading. The observer, unless looking at the monitor, is exposed to adapting conditions in the mesopic or low photopic range. When looking at the monitor – which is in the focus of view during most of the time of softcopy-reading – less or no dark adaptation is necessary, because of high luminances which are displayed in several regions of the image. Thus, we can assume that adaptation to the luminances in the reading room is mainly performed in the periphery of the visual field.

Luminance adaptation of photoreceptors is fast when starting to view an image under changed luminance conditions. The radiologic observer is also fast in mammogram reading, however, and finishes reading a mammographic case within minutes or even fractions of a minute. We assume that it takes several minutes until the contrast sensitivity is at its optimum after the observer entered the reading room. The primary aim of our work was thus to investigate, whether the processes of adaptation to the lower illuminance levels in the radiologic reading room have a measurable effect on the observer's foveal contrast sensitivity. Since the observer immediately begins to read mammograms in the radiological practice, the detection of a significant effect of adaptation time would justify an initial adaptation time before starting with the softcopy-reading.*

There is already a good understanding of neuronal and cortical responses to adaptation processes. However, results from physiological processes, which are, for example, investigated in single-cell-studies, do not easily translate to perceptual performance of an observer.[16] Conducting a psychophysical observer study is important to detect potential effects of adaptation time onto the observer's contrast sensitivity.

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*There are several investigations, which recommend increasing the illuminance in the mammographic reading room.[12–15] But even with increased room illuminance the observer will encounter situations, where adaptation to lower luminance is necessary. Thus, investigating and understanding the effect of adaptation time remains relevant for the practice of mammographic softcopy-reading.

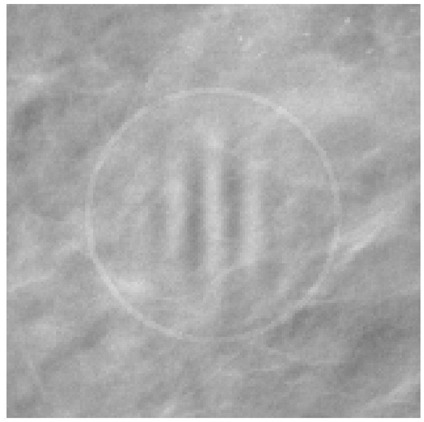

Figure 1. Example of a Gabor pattern stimulus presented on a part of a mammographic image.[17]

2. METHODS

We conducted an observer study to investigate the effect of adaptation time on contrast sensitivity in the central part of the visual field. Eight non-radiologist observers aged 25 to 65 years participated in the study. Through the use of the MCS method (MCS: Mammographic Contrast Sensitivity)[17] the observers' individual contrast sensitivity was determined for a given set of spatial frequencies.

The following aspects seem important for measuring contrast sensitivity in the context of mammographic softcopy-reading:

- Contrast sensitivity is affected by the size or dominant spatial frequency of the stimulus and is maximal for stimuli of intermediate size or intermediate spatial frequency, respectively.[3,17] Therefore, contrast sensitivity should be determined for a set of spatial frequencies, to cover a range of potential sizes of patterns from pathologic objects in a mammogram.
- Due to masking processes, the presence of the anatomical background has a significant effect on the perceptable contrast.[3,17–22] The contrast sensitivity shall be measured directly in a mammogram.
- The measurements need to be taken in a realistic experimental constellation, representing a room typically used for mammographic softcopy-reading. The illumination of the field of view shall be done the same as in the radiologic practice.

The MCS method employs either Gabor patterns or characters as stimuli superimposed to a mammogram to determine contrast sensitivity. The stimuli are presented within a fixation circle, with variable contrast, and for a duration of 720 ms. Gabor patterns are presented at variable spatial frequency and in four different orientations (Fig. 1). The observer's task is to focus on the given area and to report the target's orientation. As character stimuli the digits from 0 to 9 are presented with variable size, and there the observer's task is to identify the digit. With regard to the complexity of the observer's task, digit identification is more difficult than Gabor pattern orientation discrimination. The identification of digits can be assumed to reflect the perceptual tasks in a reading situation more directly.[17]

Contrast thresholds are measured by an adaptive psychophysical staircase procedure[23] resulting in a contrast sensitivity function, in which contrast sensitivity is the inverse threshold value. Six spatial frequencies between 1 and 16 cycles per degree (cpd; the number of "stripes" per degree of visual angle) are used.

Measuring a contrast threshold takes approximately 30 to 50 seconds. A faster measurement would map the time course of adaptation more precisely. Nevertheless, we expected the time frame of threshold measurements in the MCS method to be suitable for reflecting the reading speed and progress in mammographic softcopy-reading.

The measurements were taken with two 5K (2048 × 2560 pixel) grayscale monitors (Siemens DSB 2103-D-5MP), commonly used for mammographic softcopy-reading. The observers viewed the monitors from a distance

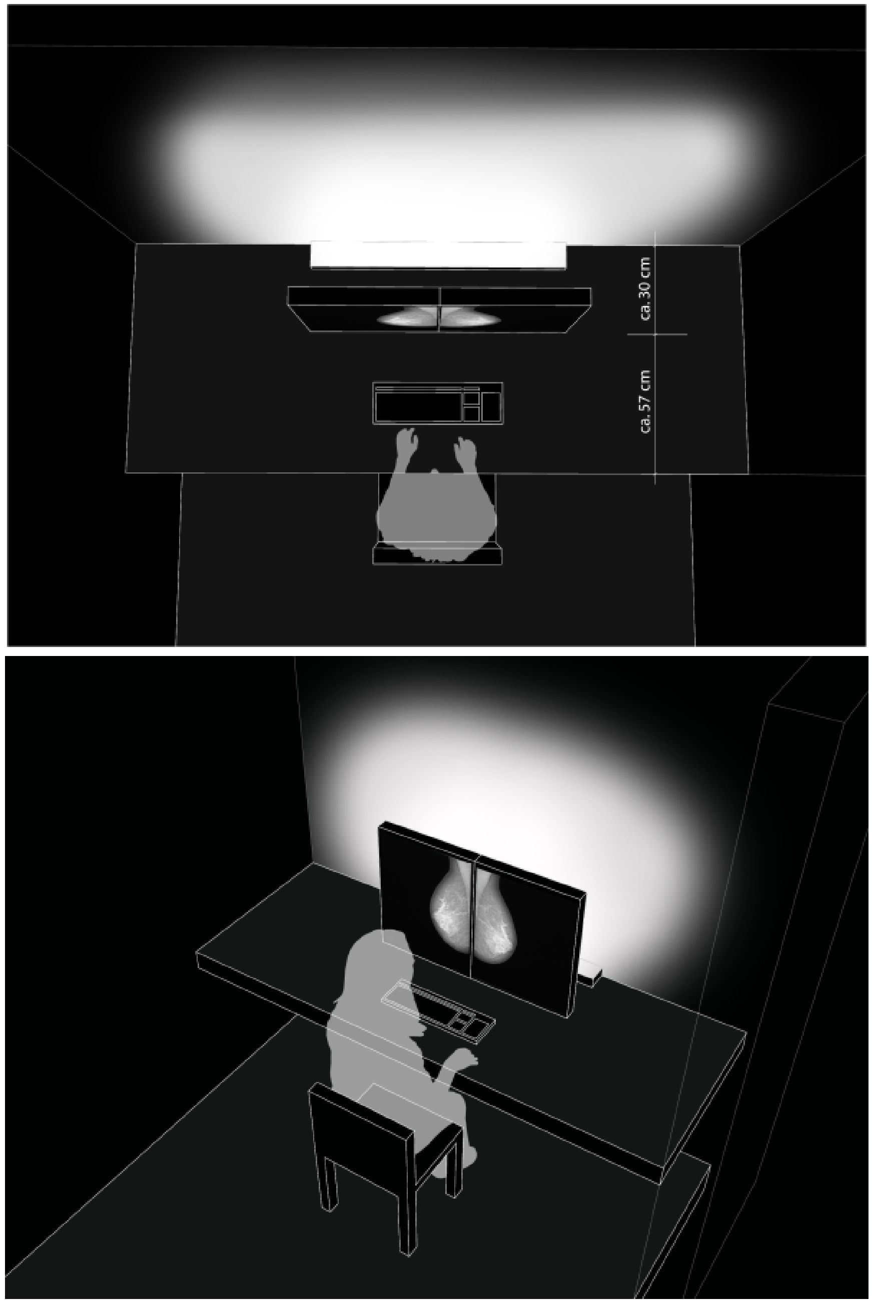

Figure 2. Experimental constellation in a view from above and in a bird's eye view.[15] The effect of a reduced illuminance in the surround of the monitors on the perception of contrast was investigated.

of 57 cm. Since the lighting in the reading room must not induce glare or asymmetric effects on the observer's visual field, we used a portable lighting solution: An illuminator with a fluorescent lamp (Philips TL-D 36W/54-765) was placed behind the monitors for an indirect and smooth lighting of the wall behind the radiologist's workspace. Illuminance was monitored using a digital lux meter (MavoLux 5032C, GOSSEN). The experimental setup is schematically shown in Fig. 2; it can be reproduced easily.[15]

The contrast sensitivity was determined on both, a mammogram and a homogeneous background. The latter was carried out for an additional comparison of the observer's behavior on mammographic and homogeneous images. The mammograms had a normalized range of gray values. All images were displayed with a mean luminance of 32.4 cd/m^2 (at the gray value of 2048 out of the range of 0–4095).

Before starting the measurements, the observers adapted for two minutes to a mean luminance of 80 cd/m^2, which was corresponding to an illuminance of 450 lx. As soon as the room illuminance was reduced to 10 lx, the contrast thresholds were measured repeatedly for 15 minutes. Focussing on an area of the mammogram, the observers had to adapt to a mean luminance of 32.4 cd/m^2 in the central visual field, and to a mean luminance of less than 5 cd/m^2 in the periphery of the visual field. In the time course of the measurements three to five complete contrast sensitivity functions were determined for each observer. The measurements were repeated three times on different days.

3. RESULTS AND DISCUSSION

The results of the observers for Gabor pattern orientation discrimination on a mammogram are shown in Fig. 3. For each measurement period (three up to five periods in 15 minutes) the contrast sensitivity determined for the tested set of spatial frequencies is presented. Period 1 represents the measured sensitivities in the first period after reduction of room illuminance to 10 lx.

For this period, we expected a reduced contrast sensitivity, since the adaptation process might not be finished. However, the plots show no reduction of contrast sensitivity, compared to the results in the later periods. Only for Observer 3 a lower sensitivity is found for a spatial frequency of 1 cpd in the first period. This frequency was tested first and the reduced sensitivity may be attributed to the adaptation process. Nevertheless, already for the next tested frequency (2 cpd), the sensitivity does not differ significantly from the results in the later periods.

A statistical analysis confirms the observation that the adaptation progress does not measurably affect the contrast sensitivity in the first minutes of image viewing: There is no significant difference between the contrast sensitivity functions at the given periods during adaptation (p-value of 0.072, ANOVA). This result pattern was found for all eight observers. For the additional tests, namely the Gabor pattern orientation discrimination on a homogeneous image, and the digit identification on a mammogram and a homogeneous image, also no significant effects of adaptation time were found. In Table 1 the results of the statistical analysis are presented.

The hypothesis – that the adaptation progress has a significant effect on the contrast sensitivity determined in the context of mammographic softcopy-reading – can thus be rejected. Presumably, the process of luminance adaptation to a lower luminance level that is still within the photopic range is sufficiently fast such that it reaches a stable level already within fractions of a minute.

Table 1. Results of an ANOVA performed on the integrals (area under curve; AUC) of the contrast sensitivity functions. No significant differences were found between the contrast sensitivity functions determined at proceeding stages of adaptation.

Observer's task	**p-value**
Gabor pattern orientation discrimination on homogeneous image	0.579
Gabor pattern orientation discrimination on mammogram	0.072
Digit identification on homogeneous image	0.766
Digit identification on mammogram	0.139

4. CONCLUSION

When starting with the reading of mammograms in softcopy-reading, an observer usually has to adapt to the low luminance levels in the reading room. This adaptation process includes both, luminance and contrast adaptation. The MCS method was used for investigating the influence of the adaptation time on individual contrast sensitivity.

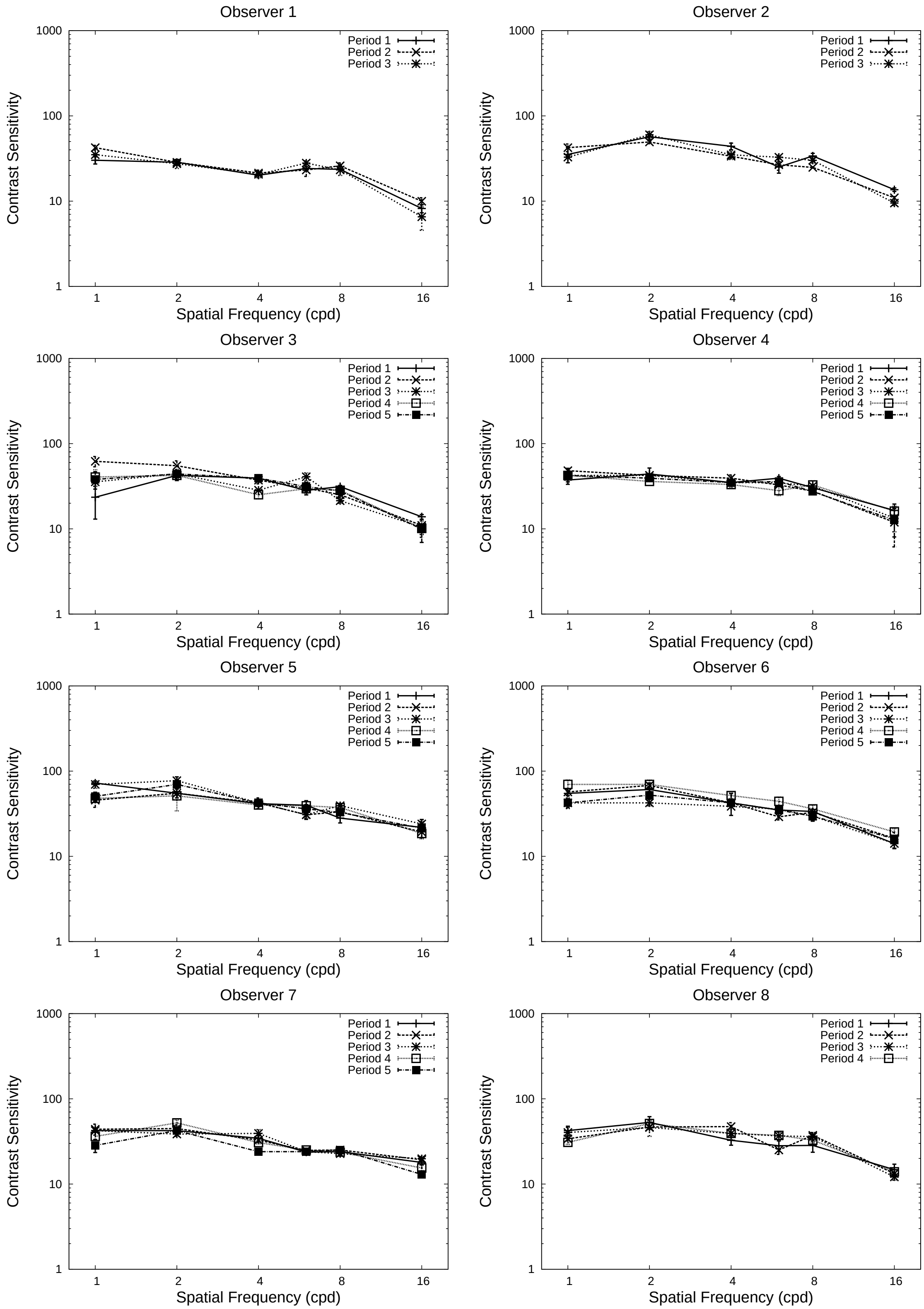

Figure 3. Comparison of contrast sensitivity functions acquired with Gabor pattern stimuli for different periods during a time course of 15 minutes after reduction of room illuminance to 10 lx. The contrast sensitivity in the foveal field of view has not improved in this time.

The results of the presented psychophysical study show that the foveal contrast sensitivity does not significantly increase with initial time for adaptation. Consequently, we can assume that the perception of mammographic low-contrast objects and therefore the reading performance is not negatively influenced if the observer does not take out time for initial dark adaptation.

However, since radiologists may read up to 100 cases per hour, further investigations should be carried out with shorter measurements, in order to cover smaller periods. This can be done by taking fewer measurements, e.g. by testing only a single spatial frequency per adaptation sequence (period). Furthermore, the overall time for a measurement can be reduced from the 15 minutes used in our study to a few minutes, because the adaptation progress within the photopic range is quite fast. The results may help to improve the processes in softcopy-reading and, therefore, may help improving the reliability in reporting breast cancer.

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