Impact of Luminance Distribution in the visual Field on foveal Contrast Sensitivity in the Context of mammographic Softcopy Reading

Dörte Apelt[a], Richard Rascher-Friesenhausen[b], Jan Klein[b], Hans Strasburger[c], Bernhard Preim[d] and Heinz-Otto Peitgen[b]

[a]MeVis BreastCare Solutions GmbH & Co. KG, Universitätsallee 29, 28359 Bremen, Germany;
[b]Fraunhofer MEVIS, Universitätsallee 29, 28359 Bremen, Germany;
[c]Dept. of Med. Psychology and Med. Sociology, University of Göttingen, Waldweg 37, 37073 Göttingen, Germany;
[d]Otto-von-Guericke University, Universitätsplatz 2, 39106 Magdeburg, Germany

ABSTRACT

For quality control in mammographic softcopy reading (SCR) a number of recommendations exists. Among them is a room illuminance of 10 lx. Moreover, the use of masks on the image seems to be advantageous, due to a reduction of scattered light in the focus of view. Room illuminance affects the global luminance adaptation and the maximal monitor contrast; masking decreases the luminance in the central and near-peripheral region. We investigated the effects of masking and illuminance on foveal contrast sensitivity. A study with eight observers was conducted in the context of mammographic softcopy reading. Using Gabor patterns with varying spatial frequencies, orientations and contrast levels as stimuli and an orientation discrimination task, the intraobserver contrast sensitivity was determined for foveal vision. Tested illuminances for a non-masked image were 10, 30, 50 and 90 lx, and for a masked image 10 lx. Major findings are: (1) Masking does not lead to improved contrast sensitivity. Instead, all observers reported a strong fatigue effect during the presentation of the masked image. (2) Among the illuminances tested, only half of the observers showed the best contrast sensitivity at 10 lx. For the other observers best results were achieved at illuminance levels of 50 or 90 lx, respectively. The results can be used to appraise the effects of viewing conditions with the aim of drawing conclusions for mammographic SCR, and to initiate further studies.

Keywords: Contrast sensitivity, perception, illuminance, mammography

1. INTRODUCTION

Mammographic images are characterized by a wide diversity of low-contrast structures, and interpreting those images is a veritable challenge. The perception of complex patterns is linked to the perception of luminance differences and, as a consequence, to the contrast sensitivity of the human eye.

The contrast sensitivity in the focus of view depends, amongst others, on the illuminance of the environment, i.e. the reading room, the image, and the application user interface. Conventionally ambient lighting in reading rooms has been kept at a minimum.[1,2] The ability to discern low-contrast objects decreases with increasing ambient light,[3] due to the fact that displayed gray values are superimposed with glare such that the ratio of minimum to maximum luminance in a displayed pattern is reduced. Thus, an observer loses contrast at higher ambient light levels.

In the European guidelines for quality assurance in mammography screening, a room illuminance near the monitor of < 10 lx is recommended.[4] However, low illuminance levels cause inadequate viewing conditions, since they affect light adaptation.[5] Under typical conditions in diagnostic reading rooms the luminance level of the displayed image is higher than the luminance level of the reading room. Eye movements between the parts of the

Send correspondence to Dörte Apelt: E-mail: doerte.apelt@gmx.de, phone: +49 421 22495 0; www.mevis.de

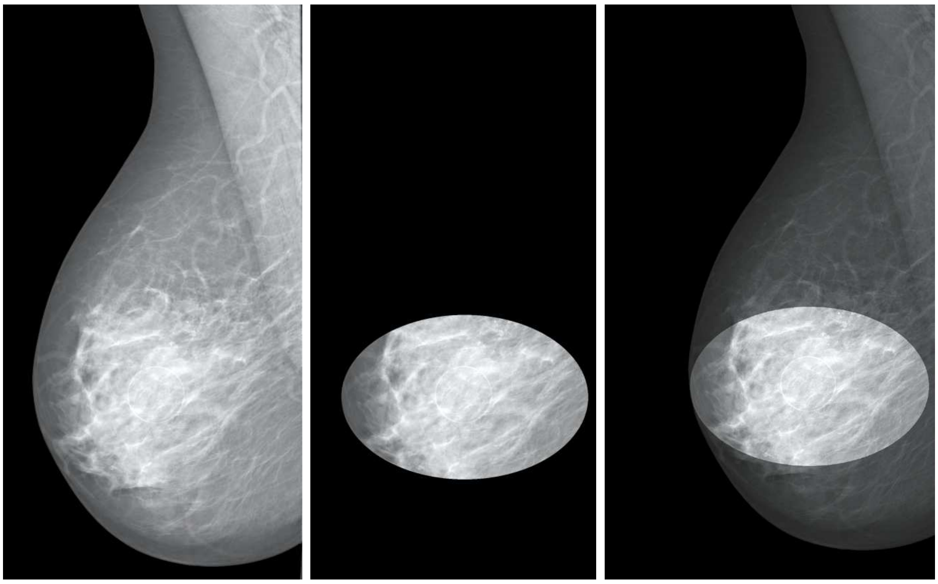

Figure 1. One of the presented images from left to right without a mask, with a mask and with a semitransparent mask (used in an additional test; image from Apelt et al.[7]). The mask has a size of 9 × 6 cm; its shape is motivated by the shape of the binocular field of view.

image and its environment lead to a permanent change of light and dark adaptation and pupil size,[1,2] possibly resulting in increased visual fatigue and reduced diagnostic performance.

Chawla et al.[2] suggest that for typical luminance settings of current LCDs the ambient light illumination may be raised without compromising the controlled contrast rendition. Future LCDs with lower diffuse reflectivity and higher inherent luminance ratios may provide further improvement of ergonomic viewing conditions in the reading room.

Recent studies indeed reported an improved observer performance at medium ambient light levels. The detection probability for objects with subtle bar patterns presented on a uniform background increases when the illuminance level of the ambient lighting matches the luminance level to which the eyes adapt while viewing an image.[2] For a detection task on a uniform background Pollard et al.[1] identified an optimum illuminance of approximately 50–80 lx for mammographic softcopy reading. Even for reading images of the wrist, where a room illuminance of 100 lx is recommended, the diagnostic performance was better for matched illuminance and luminance values, respectively: For the investigated illuminances of 7, 25, 40, 100 and 480 lx the performance was best at 25 and 40 lx.[6]

The results of Pollard et al.[1] have been ascertained in the context of mammographic softcopy reading. The observers were presented a detection task for different shapes displayed on a circle with uniform background and embedded into a mammogram. In the present study we asked whether the results of Pollard et al. would hold up for more difficult tasks as for orientation discrimation of sinusoidal patterns or the identification of characters, directly superimposed to a mammogram.

We conducted an observer study to investigate the effect of illuminance levels in the environment on the contrast sensitivity in the central part of the visual field. Two aspects were investigated: (1) Does the use of a mask (display shutter) around the image part of interest (see Fig. 1 midway) have a positive effect on the contrast sensitivity? (2) Is the contrast sensitivity best at an illuminance level of 10 lx that is commonly used in reading rooms,[3,4] or does it increase with higher illuminance?

The most apparent difference between the two questions lies in the area of the affected field of view. The luminance in the central and semiperipheral areas is reduced by the use of a mask, while the illuminance in the reading room affects the overall monitor field. Increasing the room illuminance affects the level of the global luminance adaptation and the maximal perceivable monitor contrast. Although the resolvable luminance

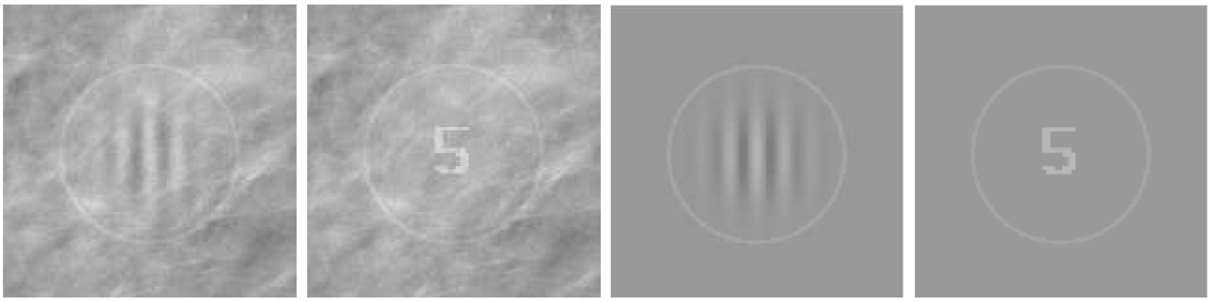

Figure 2. Parts of the presented images with examples for the used target items, Gabor patterns and digits.[7,9]

is largely independent of the adaptation luminance,[8] the illuminance has an indirect effect on the contrast sensitivity, because the perceivable monitor contrast decreases with increasing room illuminance.[3]

2. METHODS

For investigating the effect of the illuminance on the foveal contrast sensitivity, the MCS method (MCS: Mammographic Contrast Sensitivity)[7,9,10] was used. Eight non-radiologist observers aged between 25 and 65 years participated in the study.

2.1 The MCS Method

The MCS method uses Gabor patterns superimposed onto a mammographic image background for determination of the individual contrast sensitivity.[7] Gabor patterns are Gaussian filtered sinewave-modulated "stripes". The use of Gabor patterns is motivated by the fact that spatial frequency content does influence the radiologist's perception and interpretation of images,[11,12,13,14] and by that Gabor patterns are today's standard stimulus for assessing human contrast sensitivity.

The patterns are presented for a duration of 720 ms at several spatial frequencies, contrasts and in four orientations (horizontal, vertical, and left and right oblique). The location of each pattern is marked by a fixation circle (see Fig. 2). The task of the observer is to focus on the given area and to detect the orientation of the target item. This is an orientation discrimination task with four alternatives.

The individual contrast thresholds are measured by use of an adaptive psychophysical staircase procedure,[15] starting with a significantly above threshold contrast. After each presentation of a Gabor pattern, the observer has to state the perceived orientation. Dependent on the observer's answer the contrast of the Gabor pattern to be displayed next is increased or decreased by an adaptive step width. Six spatial frequencies between 1 and 16 cycles per degree (cpd; number of "stripes" per degree visual angle) are applied for the measurement of the contrast thresholds and the following determination of the contrast sensitivity function (CSF), where contrast sensitivity is defined as the inverse threshold value.

In a variant of the MCS method the Gabor patterns are replaced by characters (digits 0...9) to be identified. In general, the observer's task of identifying a stimulus is perceptually more difficult than that of discrimination according to a hierarchy in visual processing, where detection represents the base level (detection → discrimination → identification → recognition).[16,1710] Analogous to the variations in the spatial frequencies of the Gabor patterns, the size of the digits varies at six levels between 0.08 × 0.12 cm and 1.67 × 2.31 cm. Both types of target items, Gabor patterns as well as digits, are presented on an area of 2.5 × 2.5 degree of visual angle.

The used mammograms have a normalized range of gray values. In our study the mean luminance of the image background was 32.4 cd/m^2 (at the gray value of 2048 out of the range of 0–4095).

2.2 Experiment Constellation

The study consists of five parts with the following experimental conditions. In the basic condition an illuminance of 10 lx was applied. The second condition is with the same illuminance but with a masked image used. Three more conditions were tested with the non-masked image at illuminance levels of 30, 50 and 90 lx, respectively. Two 5K (2048 × 2560 pixel) grayscale monitors (Siemens DSB 2103-D-5MP), commonly used for mammographic softcopy reading, were used for the stimulus presentation. The observers viewed the monitors from a distance of 57 cm. Two hypotheses were tested in the study:

- The CSF is better for a masked image than for a non-masked image.
- The CSF is best at an illuminance of 10 lx.

Whether masking improves the contrast sensitivity was investigated with the original MCS method, i.e. by presenting Gabor patterns on a mammographic image, and with three modifications of the MCS method: with Gabor patterns on a homogeneous background, with digits on a homogeneous background and with digits on a mammogram. This way, both the influence of anatomical noise and the difficulty of the observer's task—orientation discrimination versus digit identification—are considered. The effect of the illuminance level was investigated for Gabor patterns on a mammographic image as well as for Gabor patterns and digits on a homogeneous background.

The lighting solution for a reading room shall avoid glare and asymmetrically lighting of the observer's visual field of view. Furthermore, the room illumination shall be adapted to the surfaces in the reading room.[2] We decided for a portable lighting solution, including two illuminators with fluorescent lamps (Philips TL-D 36W/54-765) for workplaces. The illuminators were upgraded with a dimmable electronic ballast and an electronic potentiometer for varying the illuminance. The portability of the lighting solution allows a stable, reproducible setup of the study environment.

Both illuminators were used for indirect and smooth lighting of the wall behind the radiologist's workspace. They were placed behind the two standard mammography grayscale monitors and in front of a typical white wallpaper, see Fig. 3. In this constellation the reflections on the monitors are reduced, too. Furthermore, the observers of the study were instructed to wear a black cape so that potential reflections of bright clothes on the monitors are prevented. The illuminance was controlled with a digital lux meter, MavoLux 5032C (GOSSEN). The illuminance was measured with the lux meter close to the eye in order to determine the quantity of light arriving at the observer's eyes.

3. RESULTS

The main results of the study are shown in Fig. 4, 5 and 6. Each plot in Fig. 4 and 5 shows two contrast sensitivity functions, generated from the pooled data of the eight observers and including error bars which denote the range of variation in the measured contrast thresholds and therefore the contrast sensitivities.

Fig. 4 (left) shows the contrast sensitivity functions for Gabor patterns on a homogeneous background; on the right are the results for Gabor patterns on mammograms. Obviously, masking has no significant effect on the contrast sensitivity in the central field of view, independent from the presence of anatomical noise. The results of presenting digits on a homogeneous and mammographic image background, respectively, show the same behavior (Fig. 5). So, even for the more difficult perceptual task of identification, masking does not help to improve the perception of contrast. The hypothesis that masking leads to an improved contrast sensitivity was not confirmed.

Instead, all observers reported strong fatigue effects and the occurrence of after-images in the shape of the mask, following the presentation of the masked image. One observer repeated one part of the study, the determination of the contrast sensitivity for Gabor patterns on a mammogram, with a semi-transparent mask (see Fig. 1 right): instead of a full darkening around the area of interest, the surroundings have a just decreased luminance. So there are less luminance differences between the area of interest and its surroundings. In this constellation the contrast sensitivity was again not improved, but at least the fatigue effect was reduced.

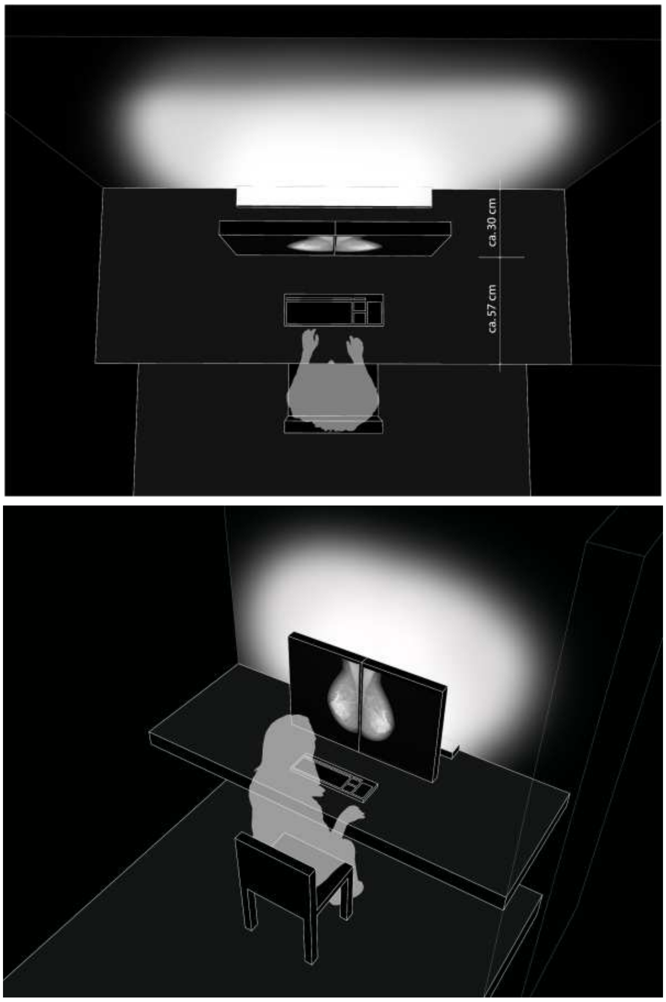

Figure 3. Experiment constellation, view from above and bird's eye view (by courtesy of Haike Apelt and Marco Arts)

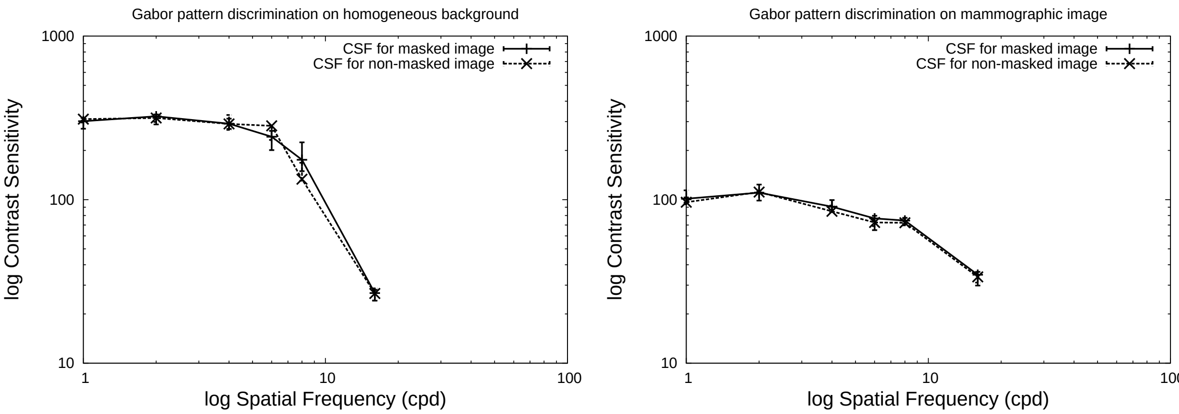

Figure 4. Comparison of contrast sensitivity functions (CSF) acquired with Gabor pattern stimuli for a non-masked image to a masked image (data pooled for the eight observers). The contrast sensitivity in the foveal field of view is not improved by the application of a mask for both homogeneous background and mammographic images. (modified from Apelt et al.[7])

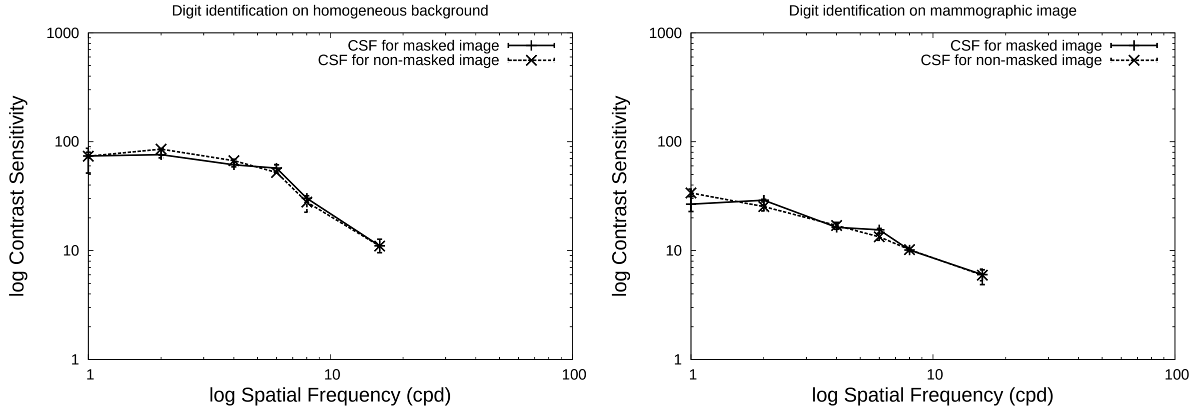

Figure 5. Comparison of contrast sensitivity functions (CSF) acquired with digits as stimuli for a non-masked image to a masked image (data pooled for the eight observers). The behavior is the same as for Gabor patterns, i.e. the contrast sensitivity in the foveal field of view is not improved by the application of a mask. (modified from Apelt et al.[7])

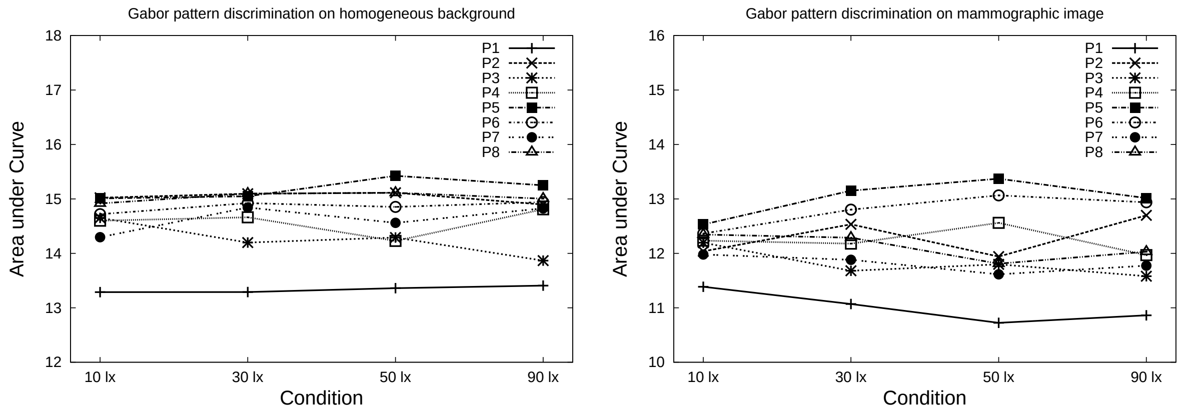

Figure 6. AUC values for the contrast sensitivity functions for all observers P1 – P8 and for the illuminance conditions 10 lx – 90 lx, acquired with Gabor patterns.

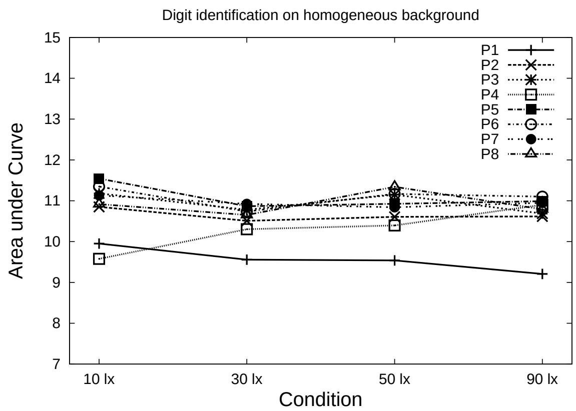

Figure 7. AUC values for the contrast sensitivity functions for all observers P1 – P8, for the illuminance conditions 10 lx – 90 lx, acquired with digits.

The results for the contrast sensitivity under different illuminance conditions are shown in Fig. 6. The change of the overall contrast sensitivity (i.e. the contrast sensitivity for all tested spatial frequencies) with the illuminance level is illustrated by integral values (AUC, area under curve). One AUC value summarizes one contrast sensitivity function. The higher the AUC value, the better the contrast sensitivity. Lines, connecting the AUC values for the different illuminance conditions, describe the increase and decrease, respectively, of the contrast sensitivity. The four illuminance conditions 10, 30, 50 and 90 lx are marked on the x-axis.

There are strong interactions between the observers and illuminance conditions, i.e. there are interindividual differences between the observers with respect to which luminance condition gives the best response, and no general statement on an illuminance level to prefer in the radiological practice can be made. The observers further show different preferences for an illuminance level depending on the complexity of the image (homogeneous background versus mammographic image, Fig. 6), as well as depending on the complexity of the perceptual task (discrimination versus identification, Fig. 7 in comparison with Fig. 6 left).

On a mammographic image, for four observers the CSF is best at an illuminance of 10 lx—this confirms the results and recommendations of Chakrabarti et al.[3] and van Engen et al.[4] For three observers, however, the CSF is best at 50 lx, and one observer shows the best results for an illuminance of 90 lx (Fig. 6 right).

On a homogeneous background, only for one observer the CSF is best at an illuminance of 10 lx (P3). Four observers show just small differences in the CSF at the different illuminance levels (P1, P2, P6, and P8). One observer was best at illuminances of 50 lx and 90 lx (P5). For two observers (P4 and P7) the contrast sensitivity was best at 30 and 90 lx (Fig. 6 left).

In an additional test on a homogeneous background, with digits as stimuli instead of Gabor patterns, three observers are best at 10 lx (P1, P5, and P6), three other observers show just small variations at the different illuminance levels (P2, P3, and P7), and two observers are best at 50 lx and 90 lx, respectively (P4 and P8). So for some observers the illuminance preference varies not only with the complexity of the image background but also with the complexity of the perceptual task. With these results, a confirmation of the hypothesis that the CSF is best at an illuminance of 10 lx, is not possible.

4. CONCLUSIONS

The study's aim was to investigate whether masks as image presentation tool affect the foveal contrast sensitivity. Moreover, we verified the results of Pollard et al.[1] in our modified context, i.e. with a discrimination task for Gabor patterns and an identification task for digits, both directly superimposed onto breast tissues in mammograms.

The use of masks leads to a change in the luminance distribution in the visual field: In the focus there is the brightest part, the area of interest in the mammogram. The luminance is lowest in the semiperipheral part. As desired, this leads to a reduction of scattered light. However, a lateral boost on the neuronal level is inherent in this constellation because of the intense luminance difference between the area of interest and the adjacent areas, leading as it seems to fatigue effects. The fatigue effect dominates the potential positive effects of the reduced scattered light. Thus, contrast sensitivity is not improved by the application of a mask. This is the case for a number of constellations, i.e. this behavior is independent of the type of the target item used (Gabor patterns versus digits) and of the image background (homogeneous background versus mammographic image). The findings of Pollard et al.[1,18] and Chawla et al.[2] support our observation of fatigue effects.

However, although the results of our study show no increase of the foveal contrast sensitivity for a masked mammogram, it cannot be reasoned that masking has a negative influence on detecting lesions in mammograms. The fatigue effects were reduced when a semitransparent mask was used, so semitransparent masks may have positive effects on visual search and attention. There should be further investigations on the effect of masking, regarding both contrast sensitivity and processes of visual search.[7]

The investigation of the contrast sensitivity at varying illuminance levels shows interesting interindividual differences: for half of the observers contrast sensitivity on a mammographic image was best at 10 lx. For the other observers a higher illuminance was supportive. Additional tests with both Gabor patterns and digits on a homogeneous background show strong interactions for the observers, the type of the observer's task (discrimination, identification) and the image used (homogeneous background versus mammographic image). There is no clear preference of certain illuminance levels for all observers and constraints.

Besides, Goo et al.[19] found that low illuminance does not significantly affect the primary reading of chest images if the observers are allowed to adjust the window-level values of the images to their individual preferences. Further studies on the effect of illuminance levels will be necessary to get findings on the illuminance level to be preferred in realistic mammographic softcopy reading. Moreover, the effect of illuminances > 90 lx should be considered. The investigations should also be performed with higher levels of observer tasks, such as detecting breast lesions in a mammogram, to verify the comparability with the results acquired with the MCS method.

Studying the contrast sensitivity in dependence of the illuminance and for different degrees of difficulty in image material and observer's tasks opens new perspectives on psychophysically motivated preferences for the illuminance in reading rooms. Moreover, the findings can be used for the design of visualization methods and user interfaces of software applications for softcopy reading. Thus, the results may support the diagnostic certainty in reporting breast cancer.

REFERENCES

[1] Pollard, B., Chawla, A., Delong, D., Hashimoto, N., and Samei, E., "Object detectability at increased ambient lighting conditions," *Med Phys* **35**(6), 2204–2213 (2008).

[2] Chawla, A. and Samei, E., "Ambient illumination revisited: A new adaptation-based approach for optimizing medical imaging reading environments," *Med Phys* **34**(1), 81–90 (2007).

[3] Chakrabarti, K., Kaczmarek, R., Thomas, J., and Romanyukha, A., "Effect of room illuminance on monitor black level luminance and monitor calibration," *J Digit Imaging* **16**(4), 350–355 (2003).

[4] van Engen, R. and et.al., [*Addendum on digital mammography - to chapter 3 of the european guidelines for quality assurance in mammography screening*], EUREF Nijmegen (2003).

[5] Hood, D. and Finkelstein, M., "Sensitivity to light," in [*Handbook of perception and human performance*], K.R. Boff, L. K. and Thomas, J., eds., 5–1 – 5–66, J. Wiley, New York (1986).

[6] McEntee, M., Brennan, P., Evanoff, M., Phillips, P., O Connor, W., and Manning, D., "Optimum ambient lighting conditions for the viewing of softcopy radiological images," in [*Medical Imaging: Image Perception, Observer Performance, and Technology Assessment*], Jiang, Y. and Eckstein, M. P., eds., *Proc SPIE* **6146**, 61460W–1 – 61460W–9 (2006).

[7] Apelt, D. and Peitgen, H.-O., "Contrast sensitivity in mammographic softcopy reading – determination with psychophysical procedures," in [*IWDM 2008: Proceedings of the 9th International Workshop on Digital Mammography*], 756–763, Springer-Verlag, Berlin, Heidelberg (2008).

[8] Bartleson, C. and Breneman, E., "Brightness perception in complex fields," *J Opt Soc Am A* **57**, 953–957 (1967).

[9] Apelt, D. and Peitgen, H.-O., "Determination of contrast sensitivity for mammographic softcopy reading," in [*Bildverarbeitung für die Medizin*], *Informatik Aktuell*, 458–462, Springer (2008).

[10] Apelt, D., Strasburger, H., Rascher-Friesenhausen, R., Klein, J., Preim, B., and Peitgen, H.-O., "Contrast sensitivity in mammographic softcopy reading," in [*Medical Imaging: Image Perception, Observer Performance, and Technology Assessment*], *Proc SPIE* **7263** (2009).

[11] Krupinski, E., "The future of image perception in radiology: synergy between humans and computers," *Acad Radiol* **10**, 1–3 (2003).

[12] Mello-Thoms, C., "Perception of breast cancer: eye-position analysis of mammogram interpretation," *Acad Radiol* **10**, 4–12 (2003).

[13] Mello-Thoms, C. and Chapman, B., "A preliminary report on the role of spatial frequency analysis in the perception of breast cancers missed at mammography screening," *Acad Radiol* **11**, 894–908 (2004).

[14] Campbell, F. and Robson, J., "Application of fourier analysis to the visibility of gratings," *J Physiol* **197**, 551–556 (1968).

[15] Kaernbach, C., "Adaptive threshold estimation with unforced-choice tasks," *Percept Psychophys* **63**(8), 1377–1388 (2001).

[16] Strasburger, H., [*Indirect vision (in German)*], Hogrefe Göttingen (2003).

[17] Strasburger, H. and Rentschler, I., "Contrast-dependent dissociation of visual recognition and detection fields," *Eur J Neurosci* **8**, 1787–1791 (1996).

[18] Pollard, B., Chawla, A., Hashimoto, N., and Samei, E., "Breast mass detection under increased ambient lighting," in [*IWDM 2008: Proceedings of the 9th International Workshop on Digital Mammography*], 243–248, Springer-Verlag, Berlin, Heidelberg (2008).

[19] Goo, J., Choi, J.-Y., Im, J.-G., Lee, H., Chung, M., Han, D., Park, S., Kim, J., and Nam, S.-H., "Effect of monitor luminance and ambient light on observer performance in soft-copy reading of digital chest radiographs," *Eur J Radiol* **58**, 471–479 (2006).

[20] Toomey, R., Curran, K., D'Helft, C., Joyce, M., Stowe, J., Ryan, J., McEntee, M., Manning, D., and Brennan, P., "Visual adaption: softcopy image contribution to the observer's field of view," in [*Medical Imaging: Image Perception, Observer Performance, and Technology Assessment*], Berkman, S. and Manning, D., eds., *Proc SPIE* **6917**, 69170O – 69170O–6 (2008).

[21] Ishihara, S., Shimamoto, K., Ikedac, M., Katoa, K., Moria, Y., Ishiguchia, T., and Ishigakia, T., "CRT diagnosis of pulmonary disease: influence of monitor brightness and room illuminance on observer performance," *Comput Med Imaging Graph* **26**, 181–185 (2002).