# 41 Visual Ergonomic Issues of LCD Displays – An Insight into Working Conditions and User Characteristics

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## 1 Introduction

More and more workplaces today depend on the frequent interaction of humans with visual displays. Different from earlier times, in which mostly young and technology-prone users were the major user group of computer work, more and increasingly diverse user groups, e.g. children and older workers, are confronted with electronic work. It is of central importance that electronic displays allow a trouble-free usage and provide a high working productivity. Also, technical developments and improvements necessitate the need to continuously evaluate new technologies with respect to their actual benefit for human performance.

There is quite a long history of studies dealing with the evaluation of visual displays (DILLON 1992; LUCZAK & OEHME 2002). Visual ergonomic studies were concerned with the evaluation of displays and the identification of shortcomings of current display design. The criteria for the suitability of displays for presenting information were users' productivity in terms of speed and accuracy of visual performance as well as the emergence of visual strain (e.g. GOULD et al. 1987a, 1987b; DILLON 1992, 2004; LUCZAK et al. 2003; SCHLICK et al. 2007; SHEEDY & BERGSTROM 2002; ZIEFLE 1998). Over the years a solid visual ergonomic knowledge was gathered with respect to how electronic information should be displayed appropriately. The knowledge regards different sources of influencing factors. A considerable number of studies examined the importance of text factors (e.g. structure, format, and breadth of electronic information) as well as display factors (e.g. contrast, resolution, image quality) on visual performance (e.g. GOULD et al. 1987a,b; OEHME et al. 2001; OETJEN & ZIEFLE 2004, 2007; QIN et al. 2006; SHEEDY et al. 2003; ZIEFLE 2001a,b; ZIEFLE et al. 2003). Also, the impact of visual and cognitive demands imposed by different tasks and prolonged on-screen reading have been examined respecting their consequences for visual performance (e.g.

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GRÖGER et al. 2005; LUCZAK et al. 2003; ZIEFLE et al. 2005; SCHLICK et al. 2007; ZIEFLE 1998). Another prominent research issue referred to the question, which screen type benefits or disadvantages visual performance. The comparison of different display types received special attention lately as screen technology changed. While a few years ago the cathode ray tube (CRT) had been the state-of-the-art technology (LUCZAK et al. 2003; SCHLICK et al. 2007), Liquid Crystal Displays (LCD) replaced the CRTs and represent now the state-of the-art technology. From a visual ergonomic perspective, LCDs have many advantages compared to CRTs. They are lightweight, flicker free and provide higher luminance and contrast levels compared to CRTs. As LCDs have a smaller footprint and weigh less, they can easily be moved on the desk to meet preferred viewing distances onto the display. Also, they can be used for mobile devices. However, LCDs have one major drawback: the displayed information is "perfectly" visible if users work in front of the screen. Whenever this "optimal" position is not present, visibility is distinctly worse. This specific property is called anisotropy. The psychophysical nature of anisotropy is such that photometric measures (contrast and luminance) are not constant over the screen surface, but rather decrease with increasing viewing angle. Anisotropy is given if a display shows a deviation of more than 10% of its luminance subject to the target location or viewing angle (ISO 13406-2 2001). Recent studies show that anisotropy has to be taken seriously. The visual performance when working with LCDs considerably deteriorates when users are looking from 10° to 50° off-axis (GRÖGER et al. 2003; HOLLANDS et al. 2001, 2002; OETJEN & ZIEFLE 2004, 2007; OETJEN et al. 2005; ZIEFLE et al. 2003).

In real life many situations can be referred to in which anisotropy plays an important role. In school contexts it is frequently the case that several pupils are sitting in front of one screen, and naturally extended or off-axis viewing angles are present. In mobile contexts working with notebook computers the probability of extended viewing angles is also high. Other prominent examples are traffic controlling environments or stock exchanges, in which several screens placed in parallel and/or upon one another have to be surveyed by one operator.

Figure 41.1 shows a typical example from a rail control station. In order to avoid train collision, the operator surveys up to six monitors simultaneously and keeps rail tracks and ramifications of different trains and stations under surveillance.

**Fig. 41.1:** An example of an LCD working place within a rail way control (private photos, OETJEN 2008)

## 2 Psychophysical Measuring Rationale of Anisotropy

Whenever anisotropy is experimentally investigated, a specific quantification rationale is necessary, which has to meet several methodological demands. The measuring procedure should allow a reliable expression of anisotropy in terms of single components (luminance levels of bright and dark areas). Also, luminance values should be known for different screen positions and result from a standardized procedure, which allows reliable comparisons between and across screens. As anisotropy occurs on the complete screen surface and is not necessarily symmetrical, the measuring must be small-grained and detailed, including different screen positions and viewing angles. Also, it has to be assured that anisotropy is not limited to selected screens but reflect general characteristics of LCDs. To meet these demands, we developed a measurement set-up that enabled us to quantify changes of photometric measures for different viewing angles and relate these to visual performance (GRÖGER et al. 2003; ZIEFLE et al. 2003; OETJEN & ZIEFLE 2007, 2009).

In order to refer to replicable screen locations, the screen was virtually divided into 63 black and white fields (nine lines, seven rows). The ambient lighting was set to 300 Lx during measurement (ISO13406-2 2001) and testing. The luminance of the background (bright areas) was standardised to 100 cd/m², according to ISO 9241-3 (2000). All 63 screen locations were measured by a photometer (Luminance Meter Type 1101, Bruel & Kjaer®, minimum flare angle of 1/3°).

For the understanding of anisotropy it is crucial to consider that the outcomes in photometry depend on how the measurements are carried out. In the measurement procedure that is normally used by the industry the photometer is placed in front of the screen and displaced gradually from field to field (standard measurement, Fig. 41.2, left). Thus, it always has a right angle to the screen surface. These conditions result in luminance values that are quite homogeneous, but do not reflect the actual extent of the divergence of luminance values over the screen surface. The procedure is highly artificial as users do not displace themselves in front of the screen, but rather turn their head (and view). Viewing angles change remarkably depending on where users are looking at. To simulate this behaviour, the photometer adopted two viewing angles: in the central (0°) position the photometer was turned to all 63 screen locations just as it is the case when users are working with the screens (User view, Fig. 41.2, centre).

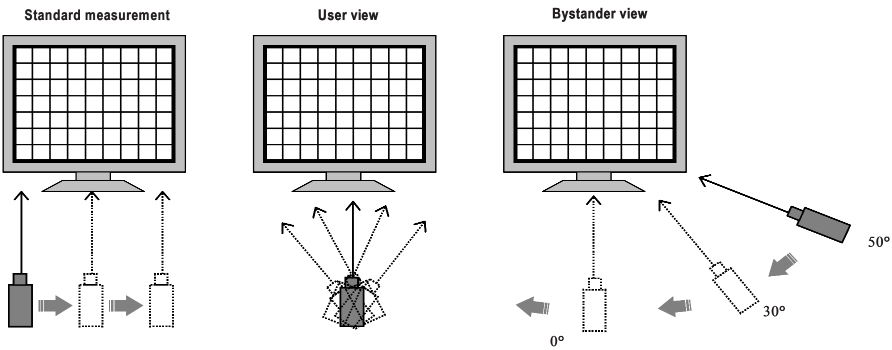


**Fig. 41.2:** Quantifying anisotropy: Left: "standard view"- the photometer is displaced at right angles; center: "user view"- the photometer emulates users' head movements; right: "bystander view"- the photometer is positioned off-axis (ZIEFLE et al. 2003)

For the extended viewing condition, the photometer was placed in the off-axis position (50°) and its view pointed to all 63 fields of the screen surface from the left and right side, respectively (bystander view, Fig. 41.2, right). This measurement rationale was applied to various screen types (CRTs and LCDs), different screen sizes (15" and 17"), brands and fabrication times (1999 to 2005).

Outcomes show that photometric measures change dramatically as a function of viewing angle (Fig. 41.3). The changes were less pronounced for CRTs (Sony S200PS; Elsa Ecomo Office) than for all LCDs. The most prominent anisotropic effects were observed for the two Notebook-LCDs (Dell 8100; IBM Thinkpad). Characteristically, with increasing viewing angles the luminance of the bright areas is less bright (Fig. 41.3, left). The luminance of the dark areas (Fig. 41.3, right) does not vary monotonically with increasing viewing angle. Overall, it has to be concluded that anisotropy is a general characteristic of LCDs.

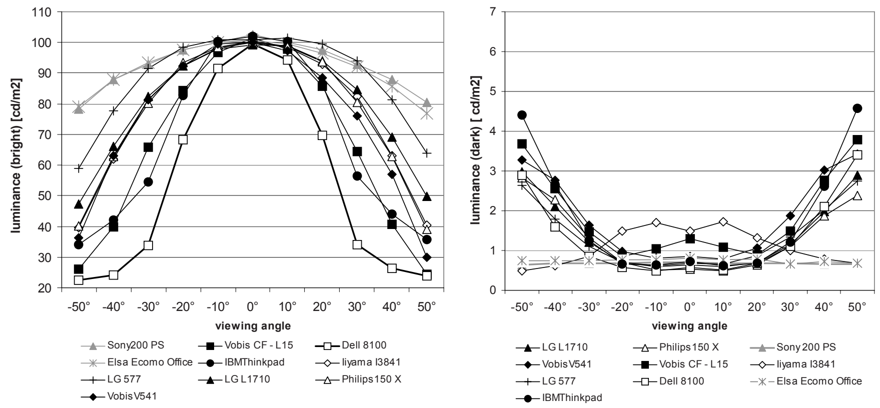


**Fig. 41.3:** Photometric measurements for different screen types. Left: luminance of bright areas (background). Right: luminance of dark areas (objects) (OETJEN & ZIEFLE 2009)

# 3 Anisotropy and Users' Age

In visual ergonomic studies dealing with LCD's anisotropy (e.g. GRÖGER et al. 2003; HOLLANDS et al. 2001, 2002; OETJEN & ZIEFLE 2004; OETJEN et al. 2005; ZIEFLE et al. 2003), mostly young adults have been examined as participants. However, young adults do not represent the whole working force which are using display technologies. Rather, children and teenagers as well as more and more older users do frequently use electronic displays within private and working contexts. Up to now, both major user groups have been mostly disregarded by visual ergonomic studies. As visual functions do significantly change with age (e.g. ELLEMBERG et al. 1999; KLINE & SCIALFA 1997; SALTHOUSE 1982), we need to know to what extent anisotropy affects performance in other age groups in order to maximize work productivity. Therefore, a first study is reported here in which teenagers, younger and older adults were compared with respect to visual performance in anisotropic displays.

## 3.1 Experimental Details, Procedure, and Design

Three independent variables were under study. (1) Screen technology: An LCD display (CF-L 15, 15", 1024 × 768) was compared to a cathode ray tube (CRT; Sony S 200 PS, 17", 100 Hz, 1024 × 768) which served as an experimental control condition. (2) Viewing angle: A 0° central sitting position was compared to a 50° extended sitting position. In the 50° off-axis position half the participants worked from the left and the other half from the right hand side. Five different viewing angles were established by virtually dividing the screen into three equally large sections (Fig. 41.4). For the central sitting position, two different viewing angles (0° and 11.3° on the left and right side of the screen) were extracted. In the 50° sitting position, three viewing angles resulted (41.4°, 50° and 56.4°). Performance was examined for these five viewing angles. (3) Users' age: In order to survey aging effects, three age groups were contrasted: a teenager group (28 participants, M=13.9, SD=3.3), a group of 28 young adults (M=23.9, SD=2.6) and an older age group (14 participants, M=56.4, SD=4.2). All groups consisted of 50% male and 50% female participants. Overall, 70 persons participated, all of them reported to be frequent computer users and accustomed to electronic reading. They had a normal or corrected to normal visual acuity and no history of eye-illnesses. The decimal visual acuity was at least 14/14 (Snellen) and it did not differ significantly between the groups ($M_{10–18}$=14/13, $M_{20–31}$=14/12, and $M_{50–63}$=14/13 Snellen).

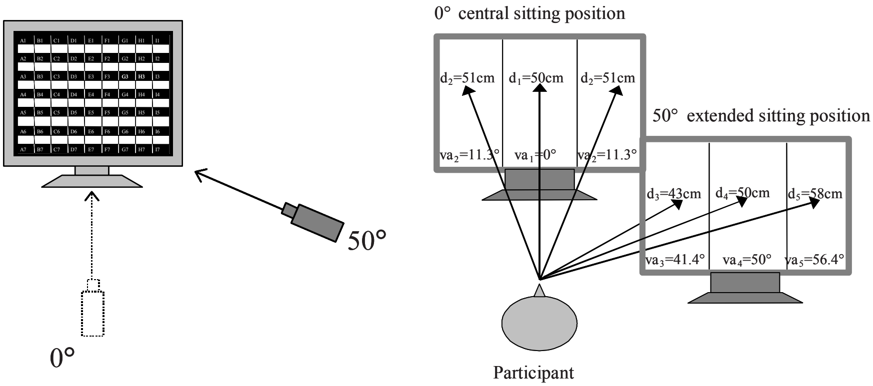


**Fig. 41.4:** Left: The photometer set up with the screen divided into 63 single fields; right: The experimental setting with the two sitting positions. By dividing the screen into three sections, five viewing angles can be distinguished (OETJEN & ZIEFLE 2007)

To measure the effects of these factors and to determine interactions, performance measures were used as dependent variables. (1) Speed (ms): The time participants needed to detect a target was recorded. (2) Errors: The accuracy of participants' reaction was measured.

As anisotropy is assumed to be primarily visual by nature, we used a simple detection task, which has a low cognitive complexity but is visually demanding. A detection task was used to quantify anisotropic effects on visual performance. Quadratic Landolt C's (with the gap oriented upwards, downwards, left and right) were displayed randomly on all 63 screen fields which had been measured within the photometric measuring procedure. Participants had to detect where the gap is and to indicate the chosen answer by pushing the appropriate button on a keyboard. Targets were eight pixels big (2.4 mm), the stroke width was one pixel (0.3 mm) and the gap was two pixels (0.6 mm). Participants had to push the central button of the keyboard and remain on this button until the encoding process was finished (discrimination time). As soon as participants detected the gap's direction, they had to release the central button. Instantly, the target disappeared and the appropriate answer key had to be pushed as quickly as possible.

As experimental design, a 2 (screen type) ×5 (viewing angle) ×3 (age) within/between experimental design was adopted. Screen type and viewing angle were treated as within group variables, user age as a between group variable. Four independent experimental conditions were applied: (1) LCD; sitting position of 0°, (2) LCD, sitting position of 50° off-axis, (3) CRT, sitting position of 0°, and (4) CRT, sitting position of 50° off-axis. In each condition 504 trials had to be completed. The order of conditions was counterbalanced across participants.

## 3.2 Results

Results were analysed by ANOVA-procedures. Levene tests were carried out to control homogeneity of variances, which was given for discrimination speed and accuracy. The significance level was set at 5%.

Overall, participants worked extremely accurately. For the whole group accuracy reached 98.1% (teenagers: 98%, young adults: 99.1%; older adults 96.5%). Neither age, nor screen technology or viewing angle revealed significant differences. With respect to the discrimination speed, significant effects were identified. A significant main effect of the screen type ($F_{(1,67)}$=14.0; $p<0.05$) was found: Over all screen positions, discrimination times were 7.6% longer for the LCD compared to the CRT. Another significant main effect was revealed for viewing angles ($F_{(4,268)}$=82.2; $p<0.05$): Discrimination times rose by 21.9% from the central (0°) to the 56.4° off-axis-conditions. Furthermore, a significant main effect of age ($F_{(2,67)}$=9.4; $p<0.05$) was identified: Young adults showed the fastest discrimination performance, and differed from the teenager group and the group of older adults, which did not show significant differences.

Performance decrements due to extended viewing angles were not equally disadvantageous for all groups (significant 2-way interactions of viewing angle and age; $F_{(8,268)}$=14.5; $p<0.05$): The largest performance decrease between the central and the off-axis viewing condition was present in the older group. Also, the significant 2-way interaction of screen type and viewing angle ($F_{(4,268)}$=9.7; $p<0.05$) shows that anisotropy is decreasing performance with increasing viewing angle more strongly in LCDs compared to CRTs.

The most crucial finding of the study however is the significant three-way interaction among screen type, viewing angle, and age ($F_{(8,268)}$=2.9; $p<0.05$). It shows that LCD's anisotropy does not equally disadvantage all age groups, but rather reveals to be age-related (Fig. 41.5). From Fig. 41.5 it can be seen that discrimination times decreased in all age groups when using an LCD instead of a CRT. Also, performance worsened when extended viewing angles were present. But the impact of anisotropy was most prominent in the older group, showing a tremendous performance decrease with increasing viewing angle.

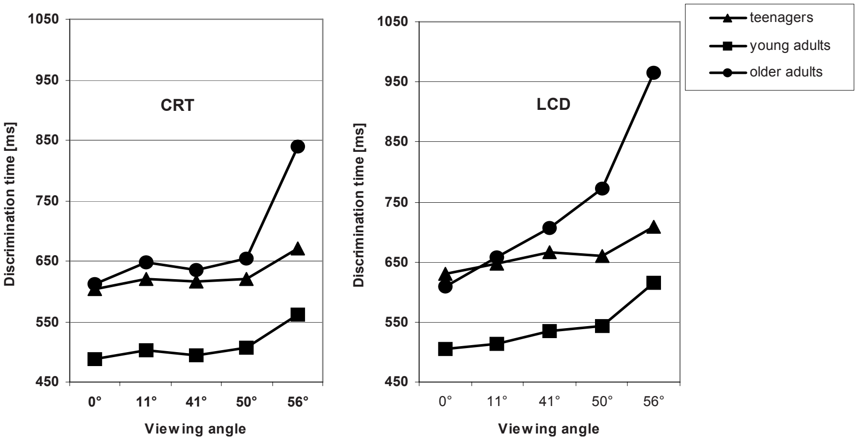


**Fig. 41.5:** 3-way interaction effect between screen type, viewing angle and age groups (OETJEN & ZIEFLE 2007)

# 4 Anisotropy in Notebook Computer Displays

In mobile contexts the probability of extended viewing angles is high especially when taking into account that mobile computers increasingly replace stationary desk top computer systems (KIRSCH 2004). Doubtless, it is definitively an advantage to work mobile and flexible, and we all do so. Though, the visual effects of electronic reading in notebooks should also be considered. The displays in notebooks have a lower threshold voltage than external LCD screens. This opens the possibility to use smaller components and reach an even lower weight. Further, energy consumption can be reduced and the operation time of the batteries can be extended, an important feature of computer notebooks. Lower threshold voltages can be realised as the liquid crystal mixtures in notebook-LCDs are slightly different from the ones used in conventional external LCDs (HECKMEIER et al. 2002). While visibility problems of LCD screens are well known by notebook users, whenever viewing angles are off-axis, up to now no research study was concerned with the visual effects of anisotropy in notebook devices. This was undertaken in the present study (OETJEN & ZIEFLE 2009).

## 4.1 Experimental Details, Procedure and Design

Two independent variables were under study. A first variable was the screen type (and the extent of anisotropy, respectively): (1) CRT; Elsa Ecomo Office; (2) LCD: CF-L 15 and (3) Notebook-LCD (Dell 8100). The second independent variable was the viewing angle: A central sitting position (0°) was contrasted to a 50°

off-axis position. Based on the two sitting positions five different viewing angles were extracted – following the same procedure as in the first study (Fig. 41.4). 30 young adults, 12 males and 18 females, volunteered (20–33 years; M=23.8). All had a normal or corrected to normal visual acuity (14/12 Snellen). Participants reported to be frequent computer users, and 57% of the participants were used to work with a CRT, the others used either an LCD or both screen types.

Dependent variables were the speed of visual performance (discrimination times in ms) and accuracy (errors). As experimental task, the same discrimination task as in the first study was used. Targets were quadratic Landolt C's with a gap at the top, the bottom, the right or the left. The target size was 1.5 mm in all screen types, the size of the gap 0.38 mm. Background luminance was set at 100 cd/m² in the centre of the screens; the targets had a luminance of 0.85 cd/m².

The study was based on a 3 (screen type) × 2 (sitting position)–experimental design with repeated measurement on both factors. Overall, six conditions resulted: (1) CRT with a sitting position of 0° (2) CRT with a sitting position of 50°, (3) LCD with a sitting position of 0°, (4) LCD with a sitting position of 50°, (5) Notebook-LCD with a sitting position of 0° and (6) Notebook-LCD with a sitting position of 50°. The order of conditions was balanced via a Latin Square. In each condition, 504 trials had to be completed.

## 4.2 Results

Discrimination times and accuracy were analysed by ANOVA procedures (repeated measurements). Assuring homogeneity of variance, Levene tests were carried out (it was given for both performance components). The significance level was set at p=0.05 (and adjusted in the case of multiple testing).

The screen type significantly affected discrimination performance in both discrimination speed ($F_{(2,58)}$=10.4; p=0.00) and accuracy ($F_{(2,58)}$=19.1; p=0.00). Thus, participants needed considerably more time to detect targets on the Notebook-LCD and had a lower accuracy than on the CRT and the external LCD. This is illustrated in Fig. 41.6.

Also, a significant main effect of viewing angle was found, for the speed of visual discrimination ($F_{(4,116)}$=59.7; p=0.00) as well as for the discrimination accuracy ($F_{(4,116)}$=28.2; p= 0.00). According to post-hoc-tests all single comparisons between the five viewing angles were significant.

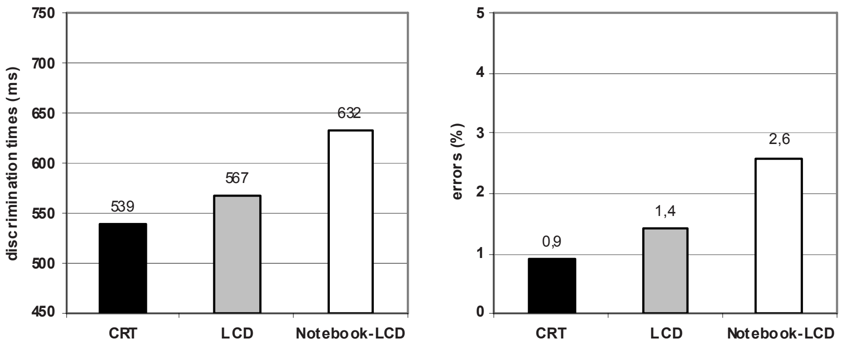


**Fig. 41.6:** Effects of screen types on discrimination speed (left) and accuracy (right) (OETJEN & ZIEFLE 2009)

The significant interacting effect between screen type and viewing angle is the most crucial finding (discrimination speed: $F_{(8,232)}$=16.5; p=0.00; discriminaion accuracy: $F_{(8,131)}$=17.9; p=0.00): Discrimination performance is distinctly worsening the more off-axis viewing angles were in the LCD conditions, especially in the notebook LCD (Fig. 41.7). Using a 50° sitting position increases the discrimination times far more when participants work with the Notebook-LCD than when an external LCD or a CRT is used.

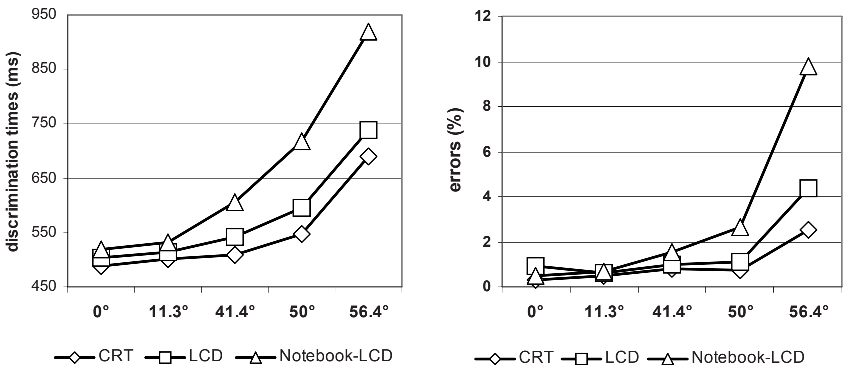


**Fig. 41.7:** Interaction effect of screen type and viewing angle on discrimination speed (left) and accuracy (right) (OETJEN & ZIEFLE 2009)

## 5 Discussion and Conclusion

The present chapter was concerned with the ergonomic evaluation of visual performance in electronic displaying of information, taking LCD's anisotropy in different screens into account. Though LCDs have many advantages, one of their major shortcoming is that luminance measures are not homogenous over the screen surface, but vary distinctly as a function of the viewing angle. In addition, users' age was under study, referring to the increasing user diversity which is present in the current work force. Most of the relevant research mainly used young adults as participants in visual ergonomic studies. Therefore, it was of considerable impact to learn which benefits but also barriers might be present in other user groups when using electronic displays. In accordance with recent studies (e.g. GRÖGER et al. 2003; HOLLANDS et al. 2002; OETJEN & ZIEFLE 2004; ZIEFLE et al. 2003), the present study corroborated anisotropy as a serious factor in LCD screens, especially in time-critical task settings. Physical measurements revealed the strongest fluctuation of luminance parameters for Notebook-LCDs, followed by external LCDs. The CRT technology was not affected by anisotropy.

When evaluating the aging impact, two prominent findings come into fore. One is that the effect of aging has to be taken seriously for computer work. As expected, young adults showed the highest performance level. The teenagers' group showed a considerable decrease in performance (23%). The performance decrement was still higher in the older group (33%). It should be noted here that outcomes might be a solid underestimation of the real situation, as the older group was comparatively young and not bothered by age-related visual illnesses. The second finding to be considered for human-centred work-place designs is that all age groups were negatively affected by anisotropy. Thus, having a "young" visual system does not defend screen users from anisotropy-based performance decrements. From an ergonomic point of view however it is especially meaningful that the older group turned out to be affected strongest by anisotropy. This should be taken into account in work settings for older adults.

When focussing on the screen types and levels of anisotropy, it can be concluded that Notebook-LCD performed worst. Over all screen positions, the mean performance difference was 6% when CRT and external LCD were compared, and it increased to 18% between CRT and Notebook-LCD. The strong susceptibility to off-axis viewing can be demonstrated, when only the off-axis conditions are contrasted. In the 56.4°-condition the speed of visual discrimination decreased by 33% in the Notebook-LCD compared to the CRT. Though, it has to be considered that the major advantage of Notebook computers is the possibility to work in mobile settings, and this advantage is not taken into account in this research. Also, it should be mentioned that for privacy reasons anisotropy effects might be welcome. With respect to their visual display quality, however, Notebook computers do not lead to the best visual performance possible.

Concluding this research, recommendations for screen types should be related to the task context they are to be used for and tailored to the specific user group which is using these displays. When taking visual ergonomic issues in discrimination tasks into account, considerable performance decrements have to be expected when LCDs are used, time-critical tasks have to be completed, the whole display surface is used to display the stimuli and/or extended viewing angles are present.

## 6 References

Dillon A (1992) Reading from paper versus screens: a critical review of the empirical literature. Ergonomics, 35: 1297–1326.

Dillon A (2004). Designing usable electronic text. CRC Press, Boca Raton, FL.

Ellemberg D, Lewis TL, Liu CH, Maurer D (1999) Development of spatial and temporal vision during childhood. Vision Research, 39: 2325–2333.

Gould J, Alfaro L, Barnes V, Finn R, Grischkowsky N, Minuto A (1987a) Reading is slower from CRT displays than from paper: Attempts to isolate a single-variable explanation. Human Factors, 29(3): 269–299.

Gould J, Alfaro L, Finn R, Haupt B, Minuto A (1987b) Reading from CRT displays can be as fast as reading from paper. Human Factors, 29(5): 497–517.

Gröger T, Ziefle M, Sommer D (2003) Anisotropic characteristics of LCD-TFTs and their impact on visual performance. In Harris D, Duffy V, Smith M, Stephanidis C (Eds.) Human-Centred Computing: Cognitive, Social and Ergonomic Aspects. LEA, Mahwah, NJ, 33–37.

Gröger T, Oetjen S, Ziefle M (2005) Using a more complex task to compare anisotropic effects of LCD and CRT screens. Proceedings of the HCI International 2005. Vol. 1: Engineering Psychology, Health and Computer System Design, Mira Digital.

Heckmeier M, Lüssem G, Tarumi K, Becker W (2002) Flüssigkristalle für Aktivmatrix-Flachbildschirme [Liquid crystal displays for active matrix flat screens]. Bunsen Magazin, 4(5): 106–116.

Hollands JG, Cassidy HA, McFadden S, Boothby R (2001) LCD versus CRT Displays: Visual Search for Colored Symbols. Proceedings of the Human Factors and Ergonomics Society 45th Annual Meeting. Human Factors Society, Santa Monica, CA, 1353–1357.

Hollands JG, Parker HA, McFadden S, Boothby R (2002) LCD versus CRT Displays: A Comparison of Visual Search Performance for Colored Symbols. Human Factors, 22(2): 210–221.

Kirsch C (2004) Laptops als Ersatz für Desktop-PCs. Überall im Büro [Notebooks as a replacement for desktop PCs. The office is everywhere] iX, 12: 40–45.

Kline DW, Scialfa CT (1997) Sensory and Perceptual Functioning: Basic Research and Human Factors Implications. In: Fisk A, Rogers W (Eds.) Handbook of Human Factors and the Older Adult. Academic, San Diego, CA, 27–54.

Luczak H, Oehme O (2002) Visual Displays – developments of the past, the present and the future. In: Luczak H, Çakir A, Çakir G (Eds.) Proceedings of the 6th International Conference on Work with Display Units. Ergonomic, Berlin, 2–5.

Luczak H, Roetting M, Oehme O (2003) Visual Displays. In Jacko J A, Sears A (Eds.) The Human Computer Interaction Handbook – Fundamentals, Evolving Technologies and Emerging Applications. LEA, Mahwah, NJ, 187–205.

Luczak H, Park M, Balazs B, Wiedenmaier S, Schmidt L (2003) Task Performance with a Wearable Augmented Reality Interface for Welding. Proceedings of the 10th International Conference on Human-Computer Interaction 2003, 98–102.

Oehme O, Wiedenmaier S, Schmidt L, Luczak H (2001) Empirical Studies on an Augmented Reality User Interface for a Head Based Virtual Retinal Display. Proceedings of the 9th International Conference on Human-Computer Interaction 2001. LEA, Mahwah, NJ, 1026–1030.

Oetjen S, Ziefle M (2004) Effects of Anisotropy on Visual Performance Regarding Different Font Sizes. In: Khalid H, Helander M, Yeo A (Eds.) Work with Computing Systems 2004. Damai Sciences, Kuala Lumpur, 442–447.

Oetjen S, Ziefle M, Gröger T (2005) Work with visually suboptimal displays- in what ways is the visual performance influenced when CRT and TFT displays are compared? Proceedings of the HCI International 2005. Vol. 4: Theories, Models and Processes in Human Computer Interaction. Mira Digital Publisher.

Oetjen S, Ziefle M (2007) The Effects of LCD's Anisotropy on the Visual Performance of Users of Different Ages. Human Factors, 49(4): 619–627.

Oetjen S (2008) Der Einfluss blickwinkelabhängiger Leuchtdichteunterschiede auf die Bildschirmarbeit. Dr. Kovac, Hamburg.

Oetjen S, Ziefle M (2009) A visual ergonomic evaluation of different screen technologies. Applied Ergonomics, 40: 69–81.

Qin S, Zhong X, Heynderick I, Teunissen C, Lian YG, Xia J, Yin H (2006) Perceptually relevant characterization of LCD viewing angle. SID 2006 Symposium, 4–9 June 2006, San Francisco, CA.

Salthouse TA (1982) Adult Cognition. An Experimental Psychology of Human Aging. Springer, Berlin.

Schlick C, Ziefle M, Park M, Luczak H (2007) Visual displays. In: Jacko J, Sears A (Eds.) The Human Computer Interaction Handbook: Fundamentals, Evolving technologies and Emerging Applications, 2nd edition. LEA, Mahwah, NJ, 201–228.

Sheedy J, Bergstrom N (2002) Performance and comfort on near-eye computer displays. Optometry and Vision Science, 79(5): 306–312.

Sheedy J, Subbaram M, Hayes J (2003) Filters on computer displays. Effects on legibility, performance and comfort. Behaviour and Information Technology, 22(6): 427–433.

Ziefle M, Oehme O, Luczak H (2005) Information Presentation and Visual Performance in Head-Mounted Displays with Augmented Reality. Zeitschrift für Arbeitswissenschaft, 59(3): 331–334.

Ziefle M, Gröger T, Sommer D (2003) Visual Costs of the Inhomogeneity of Luminance and Contrast by Viewing LCD-TFT Screens Off-Axis. International Journal of Occupational Safety and Ergonomics, 9(4): 515–525.

Ziefle M (2001a) CRT screens or TFT displays? A detailed Analysis of TFT screens for reading Efficiency. In: Smith M, Salvendy G, Harris D, Koubek R (Eds.) Usability Evaluation and Interface Design: Cognitive Engineering, Intelligent Agents and Virtual Reality. LEA, Mahwah, NJ, 549–553.

Ziefle M (2001b) Aging, visual performance and eyestrain in different screen technologies. Proceedings of the 45th Human Factors and Ergonomic Society Annual Meeting. Human Factors Society, Santa Monica, CA, 262–267.

Ziefle M (1998) Effects of display resolution on visual performance. Human Factors, 40(4): 554–568.

## Standards

ISO (2001) ISO 13406-2: Ergonomic requirements for work with visual displays based on flat panels (Part2) ISO, Geneva.

ISO (2000) ISO 9241-3: Ergonomic requirements for work with visual display terminals (Part 3) ISO, Geneva.