1040-5488/02/7903-0158/0 VOL. 79, NO. 3, PP. 158–169
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

The Proximity-Fixation-Disparity Curve and the Preferred Viewing Distance at a Visual Display as an Indicator of Near Vision Fatigue

WOLFGANG JASCHINSKI, Dr-Ing

Institut für Arbeitsphysiologie, Dortmund, Germany

ABSTRACT: *Purpose.* This laboratory study investigates the relation between measures of fixation disparity (FD) (and other optometric measures) and near vision fatigue at a computer workstation. *Methods.* Young adult subjects with normal binocular vision performed three blocks of a visual task of 30 min each. In Block A, the viewing distance was 100 cm, as a reference without near vision. In Block B, the viewing distance of 50 cm induced a defined near vision load. In Block C, subjects were free to choose a comfortable viewing distance. This preferred viewing distance was used as an indicator of near vision fatigue because subjects adopting longer viewing distances in Block C had more near vision fatigue at 50 cm in Block B. *Results.* Subjects with preferred viewing distances longer than average (63 cm) had steeper slopes of FD as a function of viewing distance (100–30 cm), as shown by discriminant analyses. *Conclusions.* Thus, this steep proximity-FD curve indicates a weak disparity vergence system that may cause near vision fatigue. This may explain why some young adults prefer longer viewing distances at the computer workstation. (Optom Vis Sci 2002; 79:158–169)

Key Words: fixation disparity, asthenopia, near vision, ergonomics

Visual fatigue is more likely to occur in subjects with certain characteristics of their vergence system. As a summary of previous research, Table 1 describes optometric measures that allow one to discriminate between individuals with more or less visual fatigue.[1-14] These include a small "zone of clear single binocular vision" in graphical analysis, an exo fixation disparity (FD) or associated phoria at near, a steeper slope of FD curves, or a low tonic vergence, i.e., distant dark vergence.FD refers to the error of the disparity vergence system, i.e., to the angular deviation (in minutes of arc) from exact bifoveal fixation. FD generally becomes more exo when a target is moved closer to the eyes in the range of 100 to 20 cm, with reliable individual differences in subjects with normal binocular vision.[15, 16] This change in FD with viewing distance (i.e., the slope of the "proximity-FD curve") is correlated with the change of FD with prism load ("prism-FD curve") since in both cases the vergence angle of the stimulus is varied.[15] However, the accommodative stimulus is different in these two conditions: while it is constant (e.g., equivalent to a 40 cm viewing distance) when the conventional prism-FD curve is measured, it varies as in natural vision when the viewing distance is changed. Thus, because of accommodative vergence the prism-FD curve is steeper than the proximity-FD curve.[15]

Ergonomic research of computer workstations has shown that, in many subjects, a viewing distance to the screen of about 50 cm leads to stronger visual fatigue than longer viewing distances, even in prepresbyopic subjects.[12, 17, 18] Subjects tend to prefer reliable individual viewing distances in the range of about 50 to 100 cm.[19, 20]

Given that an inappropriate FD can lead to visual fatigue (Table 1), tests of FD as a function of screen position may be useful for an ergonomic workplace design: one may avoid a viewing distance (or screen height[21]) that induces a large FD. Evidence for this concept was found in a laboratory study in which young adult subjects had to start a near-work session at an initial viewing distance of 40 cm, but later were free to choose any comfortable viewing distance: subjects with a steeper proximity-FD curve moved more quickly away from the screen, presumably in order to avoid visual fatigue due to the exo FD at a shorter viewing distance,[14] similarly to the way that presbyopic subjects tend to use longer viewing distance because of their limited accommodation.

It is the aim of the present study to further investigate the hypothesis of whether subjects with a steep proximity-FD curve may have more near vision fatigue and may benefit from using a longer viewing distance at computer screens. Our previous research,[14] as well as some studies in Table 1, had a limited scope, since visual fatigue was investigated in relation to only one or a few optometric measures. However, a comparative approach is necessary to find out which optometric measure might be the best diagnostic tool for near vision fatigue.[1–3] Therefore, the present experiment also included the following optometric measures used in previous research of visual fatigue (Table 1). For example, the FD and the FD curves were measured with different methods. Accurate, but time consuming, computer-controlled methods[15, 16] were complemented by traditional, as well as new, simple tests that may be useful for screening.[22] The associated phoria, i.e., the prism power that compensates a FD, was tested with the Mallett-unit because this measure was related to visual fatigue in previous research.[6, 8] Furthermore, some accommodative functions were measured, which are relevant for the oculomotor near response and possibly for visual fatigue.

A more extended procedure was used for evaluating near vision fatigue. Subjects performed a laboratory visual task at a computer workstation. After having experienced viewing distances of 100 cm and 50 cm for 30 min, respectively, they were free to choose their preferred viewing distance. The present experimental procedure is based on the concept and terminology of stress, strain, and fatigue that was developed in ergonomics[23] for research of any kind of work: (1) stress is the aspect of the task that induces bodily or mental tension, (2) strain refers to the physiological reaction induced by the stress, and (3) fatigue is the sensation experienced by the subject as a result of a strain exceeding some limit. Specifically, visual fatigue means "any subjective visual symptom of distress resulting from the use of one's eyes"[24, 25] and is conventionally estimated with questionnaires. The terms stress, strain, and fatigue are often used synonymously; however, in order to avoid confusion about causes and effects it is helpful to differentiate between task descriptions, physiological effects, and subjective symptoms.

METHODS

Sample of Subjects

Near vision fatigue can result from hyperopia, vertical phoria, or presbyopia. Since such factors should be compensated with appropriate glasses, they were not in the scope of the present research; thus, subjects with these visual deficiencies were not included. For these reasons, possible participants were screened in the first session to meet the following criteria. Visual acuity at 5 m should be high; it was tested with Landolt rings in the Polatest (Zeiss, Oberkochen, Germany). Thirty-eight subjects reached 20/32, and one subject 20/25 reached in each eye; one subject had 20/25 in the right eye and 20/25 in the left eye. Subjects were not included if a 20/32 spectacle glass of +0.50 D did not blur distant vision in each eye (since this indicates hyperopia), or if the Hakentest of the Polatest indicated a vertical phoria. All reached the smallest disparity of 30 s arc of the Polatest stereotest at 5 m and at 40 cm (both for crossed and uncrossed disparity). They did not wear glasses because these may prevent measurements of accommodation with an autorefractometer. Subjects were not screened depending on FD or whether they tended to have visual symptoms in near vision. Thus, a sample of 40 subjects with normal binocular vision was formed. The mean (±SD) age was 24 ± 3.5 years (range: 19–33).

Experimental Sessions

The present study was part of a larger investigation comprising four sessions on separate days with the same subjects. Table 2 gives an overview of the tests (or tasks) made in each session in the given order. Data of Sessions 1 and 4 confirmed the validity and reliability of new methods for measuring FD,[22] while results of Sessions 2 and 4 described effects of tonic vergence and accommodation on FD.[16] The present paper refers to the relation between near vision fatigue during the visual task in Session 3 and optometric measures of Sessions 1, 2, and 4. The time between Session 1 and Session 4

TABLE 1.
Summary of optometric measures that were related to visual fatigue in clinical and experimental studies.

Measures	Reference[a]
Parameters of graphical analysis (Sheard's amount, vergence opposite heterophoria, vergence ranges, negative and positive blur, heterophoria)	Sheedy and Saladin[1]
	Sheedy and Saladin[2] (summarized in Sheedy and Saladin[3])
Fixation disparity or associated phoria	Yekta et al.[4]
	Pickwell et al.[5]
	Jenkins et al.[6]
	Yekta et al.[7]
	Pickwell et al.[8]
Slope of the prism fixation disparity curve	Sheedy and Saladin[1]
	Sheedy and Saladin[2] (summarized in Sheedy and Saladin[3])
	Hung et al.[9]
Tonic vergence (dark vergence)	Heuer et al.[10]
	Tyrrell and Leibowitz[11]
	Jaschinski-Kruza[12]
	Best et al.[13]
	Jaschinski[14]

[a] Refer to article reference list for bibliographic information.

TABLE 2.
Overview of the sessions.[a]

Series of Sessions	Tests (or Tasks) Performed in Each Session
Session 1	FD[b] (Nonius Offset Card, Mallett-unit), associated phoria (Mallett-unit), prism-FD curve (Disparometer), dissociated phoria, and graphical analysis
Session 2	Dark vergence and dark focus, nonius bias, and accommodation
Session 3	Visual task at a computer workstation
	Block A: viewing distance 100 cm
	Block B: viewing distance 50 cm
	Block C: viewing distance chosen by subject
Session 4	Dark vergence and dark focus, FD (computer test) and accommodation, FD (Nonius Offset Card, Mallett-unit)

[a] Session 1, 2, and 4 included optometric tests that were made in the given order; in Session 3 subjects performed a visual task at a computer workstation. Block A, B, and C were made at different viewing distances, as indicated.
[b] FD, fixation disparity.

differed among subjects with a mean (±SD) of 85 ± 62 days, with irregular intersession intervals. Thus, the data include a certain quasi-random day-to-day variability that is usual in optometric testing. The results of those measures that were taken twice (for evaluating test-retest reliability) were averaged to have the best description of the individual optometric state.

The tests in Session 1 were performed by the author, while Sessions 2, 3, and 4 were conducted by a second experimenter; she was unaware of the optometric results measured in Session 1. The subjects were informed about results only after the end of the last session. Further details of the procedure are described in Jaschinski.[22]

Optometric Measurements

FD and associated phoria were measured with tests that all used dichoptical nonius lines: the right and left eye perceived the upper and lower line, respectively. This method measures the motor component, while any possible sensory component (i.e., change in retinal correspondence) cannot be detected.[26]

The Mallett-unit and the Disparometer were used at 40 cm.[27–31] For measuring FD at the Mallett-unit, subjects estimated the amount of the perceived horizontal offset of the physically aligned nonius lines (as a percentage of the width of the lines). Near associated phoria, i.e., the prism power required to negate the perceived misalignment of the dichoptical nonius lines, was determined with the Mallett-unit. With the Disparometer, the FD curve was measured as a function of prism load, first without and then with prism load of −3, +3, −6, +6 prism dioptres (Δ). The slope of the prism-FD curve was calculated by linear regression using the original readings of the Disparometer. When prisms were used at the Mallett-unit or the Disparometer, possible effects of vergence adaptation[29] were minimized by the following precautions: (1) prisms were not applied longer than 15 s, (2) for measuring the prism FD-curve, the amount of prism was increased stepwise, alternating the base-in and base-out direction, with intermediate binocular vision of about 30 s without prism load, (3) the explanation of the tests to the subjects and rearranging the experimental setup always introduced rest pauses of a few minutes between the single tests of Table 2.

For measuring proximity-FD curves, the following tests were made at 100, 60, 40, and 30 cm (with constant stimulus dimensions in terms of visual angle). For the computer test (Fig. 1A), a purpose-made cathode ray tube display was used.[15] The horizontal nonius offset was varied using an adaptive psychometric procedure with 99 trials of the nonius lines (100 ms) at 2.5 s intervals while the fusion stimulus was continuously present. FD was calculated from the "right" and "left" responses of the subject, as described in Jaschinski.[14] The Nonius Offset Card (Fig. 1B, right) is a simple screening test including two rows of nonius tests.[22] The offset of nonius lines was −6, −4, −2, 0, +2 min arc in the upper row and −5, −3, −1, +1, +3 min arc in the lower row. The amount of the offset was labeled by the small letters. Subjects indicated the nonius

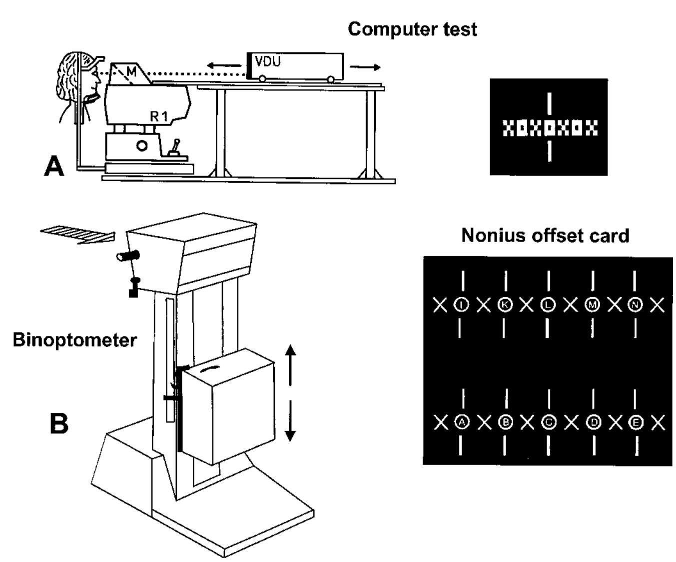

FIGURE 1.
Two methods for measuring fixation disparity at viewing distances of 100, 60, 40, and 30 cm with central fusion stimuli (the fusion characters X and O were 27.5 min arc high, respectively) and nonius lines presented dichoptically by placing polarizing filter foils onto the nonius lines. (A) In the computer test, the stimuli were generated on a visual display unit; accommodation was measured with the free-view autorefractometer R1. (B) The Nonius Offset Card was used in two versions: either the cards were presented in front of the subject's eyes (free-view), or placed into the Binoptometer. This screening device includes a curved mirror to vary the viewing distance (100–30 cm) by shifting the test vertically over a range of only 13 cm (while subjects viewed horizontally).

lines that appeared to coincide, first for the upper and then for the lower row and these two results were averaged. The cards were illuminated with a desk lamp and presented, one after the other, in front of the subjects' eyes; thus, this test is referred to as free-view Nonius Offset Card (German Patent No. 195 19 413). The same test was also produced on a transparent foil of 24 × 36 mm and was placed into a vision screening test device (Binoptometer 1, Oculus, Wetzlar, Germany). This device (Fig. 1B) includes a curved mirror designed so that the target within the apparatus can be moved at various simulated viewing distances with appropriate stimuli for vergence and accommodation.[32] The stimulus dimensions in these tests (Figs. 1A and 1B) are in a range where the length and vertical separation of the nonius lines have little effect on the measured FD.[33]

Open-loop vergence, i.e., the "resting" state of vergence without vergence stimulus, can be described by two measures. First, when both vergence and accommodative stimuli are excluded, the eyes assume a position referred to as tonic vergence.[34, 35] This was measured with a procedure[15, 36] similar to the computer test of FD. However, a pair of small (8 min arc diameter) dichoptical points of light were presented at a 1 m viewing distance in a series of short flashes of 100 ms duration at 2.5 s intervals; no fusion stimulus was given. Since this test was made in otherwise completely dark surroundings, this measure was called dark vergence. In these conditions, accommodation is not stimulated,[37] which was confirmed by the nonsignificant correlation ($r = 0.20$) between dark vergence and dark focus (see below). Second, the clinical measure of open-loop vergence is the dissociated phoria. A kind of Maddox dissociated phoria was determined at 5 m by adjusting a prism compensator to align the images in the two eyes while one eye was covered by a Maddox rod and the fellow eye viewed the Zeigertest of the Polatest: a circular bright disc of 2.5 deg diameter (on black background) with a central fixation target (a black ring of 19 min arc outer diameter). As shown in previous studies,[38–41] dissociated phoria differs from dark vergence because it includes contributions of accommodation. However, both measures are well correlated: they have a large proportion (18–67%) of common variance that may reflect tonic vergence.[40] Near dissociated phoria was tested as described for distant dissociated phoria but at a 40 cm viewing distance.

For a graphical analysis,[42] the following tests were made at the Zeigertest of the Polatest (described above) in the given order: the blur-, break-, and recovery-points at 5 m, first for base-in and then for base-out prisms; the blur-points for binocular, minus lenses and plus lenses at 40 cm; the blur-, break-, and recovery-points at 40 cm, first for base-in and then for base-out prisms; the near points of accommodation (average of right and left eye). Two adjustments at the phoropter were averaged.

Accommodation of the dominant eye was measured with a Canon R1 autorefractor[43, 44] during the computer tests of FD at each viewing distance and during the test of dark vergence, which gives the amount of open-loop accommodation, referred to as dark focus.[45]

Work at a Visual Display Unit, Measures of Visual Fatigue

Session 3 was made to investigate near vision fatigue at a laboratory computer workstation. Subjects performed three blocks of a visual task (Block A, B, and C) of 30 min each, during which the viewing distance from the eye to the screen was measured every second with a video system.[14] During intermediate pauses of 30 min, the subjects left the laboratory and stayed in a common room; reading was not allowed for oculomotor relaxation. Before and after each block, items of a questionnaire were sequentially presented on the screen. Six items referred to symptoms of visual fatigue (I have difficulties in seeing; I have a strange feeling around the eyes; my eyes feel tired; I feel numb; I feel dizzy looking at the screen; I have a headache). The sum of responses to these items was used as an index of the extent of visual symptoms. Two further items referred to the extent to which subjects judged the screen as too near or too far away. The latter pair of items was included to avoid suggestive questions. Subjects responded on a ten point scale: a zero indicated that a symptom did not occur, or that the screen was not judged as too near or too far away.

Blocks A and B were designed to vary the amount of stress due to near vision. In Block A, a constant viewing distance of about 100 cm was used, which is approximately the average tonic or resting position of accommodation and vergence.[34, 35, 45] In Block B, the viewing distance was constant at about 50 cm, which has been reported to induce near vision fatigue[12, 17, 18] and is within the range used at computer workstations. Previous research[12, 19, 20] has shown that near vision fatigue reported by subjects tends to be greater if they had earlier performed the same task at a long viewing distance; this appears to make them more sensitive to the adverse condition of near vision. Therefore, to evaluate interindividual differences in near vision fatigue, all subjects were tested in Block B at 50 cm after they had the same prior experience in Block A at the 100 cm reference viewing distance. This procedure differs from a conventional design with a balanced order of conditions across the sample that would be appropriate for investigating group mean effects of the viewing distances (50 cm vs. 100 cm), but this was not the aim of the present study.

In Block A (100 cm) and Block B (50 cm), the screen was placed at an appropriate position on the table according to the upright body posture of the subject. Whenever the subject assumed a viewing distance that deviated by more than 5 cm from the nominal viewing distance, an automatic acoustic signal instructed the subject to return to the correct viewing distance. The height of text characters was 3 and 6 mm at 50 and 100 cm, respectively, which is 21 min arc in terms of visual angle and agrees with ergonomic guidelines.[46] Such characters can just be discriminated at about three-times longer viewing distances (with normal acuity).

Block C was made to see whether a viewing distance that the subjects prefer as most comfortable is a measure of near vision fatigue. This method appears to be of practical relevance because, in a field study, subjects who had reported more near vision fatigue and had judged a near screen strongly as too near subsequently preferred a longer viewing distance when they were free to choose a comfortable screen position.[19] The procedure in the present study was as follows. When Block C started, the screen was placed at a viewing distance of 50 cm. The subjects were instructed that they might keep this distance, but that they were free to move closer to the screen (so that the characters would appear larger) or lean back (or move the chair backwards) to use longer viewing distances should this be more comfortable. These two possibilities were explicitly mentioned to the subjects in order not to give suggestive instructions. In Block C, the character height was 3 mm

TABLE 3.
Description of 27 optometric measures with means, standard deviations, minima and maxima, and factor score coefficients, if a single factor was extracted from the original variables.

	Mean	SD	Min.	Max.	Coefficient
(a) Score of fixation disparity at 40 cm[a]					
Mallett-unit	−2.27	2.31	−9.66	1.61	0.18275
Disparometer, original readings	1.05	3.78	−12.00	6.00	0.18473
Nonius Offset Card, free-view	−1.17	0.89	−2.80	1.45	0.21050
Nonius Offset Card, Binoptometer	−1.15	1.01	−4.80	0.95	0.21513
Computer test, 99 trials	−2.23	3.17	−10.11	5.07	0.19674
Computer test, first 33 trials only	−1.95	2.80	−9.40	5.33	0.21418
(b) Score of graphical analysis[a]					
Base-in blur limit, 5 m (Δ)	6.67	1.69	2.50	10.00	0.14066
Base-out blur limit, 5 m (Δ)	13.66	6.27	4.00	28.00	0.21593
Minus lens blur limit, near (D)	−3.04	1.37	−6.37	−0.25	−0.20356
Plus lens blur limit, near (D)	1.98	0.46	0.88	2.75	0.22071
Base-in blur limit, near (Δ)	14.18	5.11	6.00	26.00	0.20464
Base-out blur limit, near (Δ)	22.58	7.20	3.50	31.00	0.24222
Accommodation nearpoint (D)	9.64	2.06	5.00	15.38	0.15504
(c) Associated phoria at 40 cm (Δ)					
Mallett-unit[a]	−0.83	1.61	−6.00	3.00	—
(d) Open-loop vergence at distance					
Dark vergence (meter angle)[a]	0.70	0.54	−0.19	2.35	—
Distant dissociated phoria (Δ)[a]	1.48	2.78	−6.00	8.00	—
(e) Slope of proximity-FD curve (min arc/m^{-1})					
Nonius Offset Card, free-view[a]	−0.36	0.25	−0.86	0.26	—
Nonius Offset Card, Binoptometer[a]	−0.49	0.27	−1.18	−0.12	—
Computer test, 99 trials[a]	−1.51	1.25	−5.36	0.57	—
Computer test, first 33 trials only[a]	−1.30	1.06	−3.64	0.70	—
(f) Slope of prism-FD curve (min arc/Δ)					
Disparometer[a]	−0.73	0.42	−2.33	−0.27	—
(g) Vergence and near dissociated phoria measures (Δ)					
Sheard's amount[a]	8.75	9.16	−12.00	16.00	—
Vergence opposite from phoria[a]	16.00	6.38	3.50	27.50	—
Near dissociated phoria[a]	0.40	5.18	−16.00	13.00	—
(h) Measures of accommodation					
Dark focus (D)[a]	0.68	0.32	−0.28	1.34	—
Accommodation at 40 cm (D)[a]	2.22	0.24	1.81	2.74	—
Slope of accommodative response function (binocular)[a]	0.99	0.11	0.74	1.20	—

[a] Indicates the 16 variables included into the discriminant analyses (Table 6).

because it was expected that subjects without near vision fatigue kept the distance of 50 cm and because in this case the character height was appropriate to the viewing distance. However, if subjects might have near vision fatigue they were expected to change their posture to adopt a longer viewing distance, at the cost of rather small text characters. A duration of the blocks of 30 min was chosen because in a similar previous study[14] subjects on average arrived at their final preferred viewing distance within about this period.

The task was presented on a cathode ray tube (Sony CPD-15SF1, 15" Trinitron™ tube) with dark characters on a bright background of 50 cd/m^2. The screen contained an array of random text characters with 10 text lines and 20 characters per line. The "words" were 3 to 10 characters long and were separated by blanks. The characters in the text were chosen so that the one character to the left and to the right of a blank were identical in 50% of the blanks. The subject's task was to identify each pair of words, which have the same character located at the two sides of a blank. Hits were recorded by pressing one button of a computer mouse. The number of blanks varied between 22 and 38 per page. After scanning one page, the subjects displayed the next page by pressing the second button of the computer mouse. The usual operation of a computer mouse on the table-top would require a rather fixed sitting posture and, as a consequence, a fixed viewing distance to the fixed screen, which was not intended in Block C. Therefore, subjects held the mouse with two hands and pressed the buttons with the two thumbs; thus they were able to rest their arms on their thighs and, in this way, they were able to move away from the table while doing the task.

To exclude possible effects of vertical gaze inclination,[21, 47–50] the screen height was adjusted for each subject to have a nearly horizontal gaze direction. The mean downward gaze angle from eye position to the center of the screen was −5.0° (range of 0° to −12.5°) as measured with the video system. This did not deviate much from the horizontal gaze direction in the optometric measurements.

Statistical Analyses

The BMDP Statistical Software[51] was used for correlations, analyses of variance with repeated measures (with Greenhouse-Geisser adjusted error probabilities), rank sign tests, factor analyses with varimax rotation, and stepwise discriminant analyses.

RESULTS

Before the main results (on the relation between near vision fatigue and optometric measures) are presented in Part 3 of this section, two preceding steps of analyses have to be presented. In Part 1, the full number of 27 optometric measures is reduced to a smaller set of most informative variables. Part 2 describes indicators of visual fatigue that is specifically induced by the proximity of the screen.

Part 1: Reduction of the Number of Optometric Measures

In Part 3, it will be analyzed which optometric variables allow one to discriminate between subgroups of high and low near vision fatigue. If analysis is made with many optometric variables, some significant results will appear just by chance. To reduce this risk, the full number of 27 optometric measures in Table 3 was reduced to 16 by combining those measures that describe a similar optometric function and, by means of factor analyses, could be represented by a single score. This statistical procedure was made for the optometric variables in Table 3a and b as follows.

The FD data at 40 cm are summarized in Table 3a; for details see Jaschinski.[22] The results of these six measures were significantly correlated (range of $r = 0.45–0.86$; median 0.59; $p < 0.001$). The factor analysis revealed a single factor: the six original variables (in terms of z scores to account for differences in means and standard deviations) were multiplied by the factor score coeffients (last column of Table 3) and averaged to calculate a FD score, i.e., a weighted mean value. A zero score represents the group mean FD.

The seven variables of the graphical analysis (Table 3b) had 21 intercorrelations in the range of 0.20 to 0.70 (median 0.38), of which 18 were significant ($p < 0.05$). A factor analysis indicated a single factor. A large factor score, i.e., large amounts in these correlated variables, may represent a large area of the "zone of clear single binocular vision," which is a measure of the quality of binocular vision.[42]

The following optometric variables were not combined by factor analyses for different reasons. Dark vergence and distant disso-

TABLE 4.
Description of the ratings of visual symptoms in the questionnaire, before and after Block A, B, and C of the visual task (with different viewing distances).

	Mean	Median	Quartile Q_1	Quartile Q_3	Range
Pretask					
Block A, 100 cm	3.45	2.0	0.0	4.0	0–22
Block B, 50 cm	4.05	2.0	0.0	5.75	0–21
Block C, free	4.80	4.0	1.25	7.0	0–22
Post-task					
Block A, 100 cm	9.10	7.0	3.0	12.75	0–32
Block B, 50 cm	9.32	7.5	3.0	13.00	0–23
Block C, free	9.43	9.0	3.0	13.65	0–30

TABLE 5.
Correlations between six indicators of visual fatigue.[a]

	Post-task Extent of Visual Symptoms at Different Viewing Distances			Visual Symptoms at 50 cm (compared with 100 cm)	"50 cm Too Near"	Two Factors of Visual Fatigue
	Block A, 100 cm	Block B, 50 cm	Block C, Free			
Post-task extent of visual symptoms						
Block A, 100 cm						(I) Task-related
Block B, 50 cm	0.65					
Block C, free	0.81	0.69				
Visual symptoms at 50 cm (compared with 100 cm)	−0.53	0.29	−0.26			(II) Near vision
"50 cm too near"	0.14	0.44	0.21	0.31		
Preferred viewing distance	−0.26	−0.11	−0.26	0.19	0.42	

[a] If $r > 0.26$, correlations are significant with $p < 0.05$ (one-tailed, because the hypothesis is a positive correlation between the indicators). The right column indicates the two factors of visual fatigue: task-related (I) and induced by near vision (II).

ciated phoria, the two measures of open-loop vergence in Table 3d, were significantly correlated ($r = 0.57$; $p < 0.005$); however, because these two measures differ with respect to accommodation[36–38] (see Methods) they were not combined. The four measures of the slope of the proximity FD-curve did not form a common factor following factor analysis (Table 3e). The slope of the prism-FD curve (Table 3f), near dissociated phoria, Sheard's amount (the compensating fusional vergence relative to twice the near dissociated phoria), and vergence opposite from near dissociated phoria (Table 3g) were used in previous studies.[1–3] The three measures of accommodation describe different physiological aspects of accommodation (Table 3h).

As a result of these analyses in Part 1, the number of 27 optometric measures was reduced to the 2 scores in Table 3a and b and the 14 measures of Table 3c-h. These 16 optometric variables are indicated in Table 3.

Part 2: Indicators of Near Vision Fatigue

Visual fatigue at a computer screen may result from several aspects of the task, e.g., eye movements, visual detection and discrimination, mental workload, or a short viewing distance that may stress convergence and/or accommodation. Because the present study investigates effects of the proximity of the screen, the following analyses describe the different indicators of visual fatigue and identify which of these can be attributed specifically to the effect of near vision. In summary, these were the ratings of visual symptoms at 50 cm (as compared with 100 cm), the judgment of the screen at 50 cm as too near, and the preferred viewing distance in Block C of Session 3.

The ratings of visual symptoms (Table 4) were tested pairwise with rank sign tests for possible mean differences. However, Block A (100 cm viewing distance) did not differ significantly from Block B (50 cm), neither in terms of post-task ratings ($p = 0.37$), nor in terms of the increase in ratings from before to after the task ($p = 0.17$). Thus, neither the course of time from Block A to Block B, nor the two viewing distances of 100 cm and 50 cm had an effect, i.e., averaged across subjects, the symptoms reported did not depend on viewing distance (but see the correlations reported below). Thus, in the present study, these mean ratings of visual symptoms appear not to reflect near vision fatigue; rather, they may be attributed to other components of the visual task (mentioned above). However, to eliminate such factors and to find an individual indicator of symptoms induced by near vision, it may be useful to evaluate the extent to which the symptoms at 50 cm exceeded those at 100 cm within each subject (Table 5).

After Block B, three subjects judged the screen at 50 cm as too far away and 32 subjects as too near, to a greater or lesser extent: the median score of the latter rating was 2.0 with quartiles Q_1 and Q_3 of 1.0 and 4.75, respectively. This judgment of the screen as too near may be an indicator of fatigue associated with near vision.

In Block C, subjects started at 50 cm, but then were free to choose a comfortable viewing distance. Fig. 2a shows the mean viewing distance for each 5-min interval. The viewing distance increased significantly with time ($F_{5,195} = 8.41$; $p = 0.0003$). However, this increase was limited to the start of the block, since no significant time effect was observed from the third interval on ($F_{3,117} = 1.58$; $p = 0.2092$). The correlations among the individual viewing distances of intervals 3, 4, 5, and 6 were highly significant (all $r > 0.93$). Thus, during the first ten minutes, subjects found their most comfortable viewing distance, which they kept for the rest of the block. This preferred viewing distance, i.e., the mean of intervals 3 to 6, had a distribution shown in Fig. 2b, with a mean (±SD) of 63 ± 13 cm (range 43–99 cm).

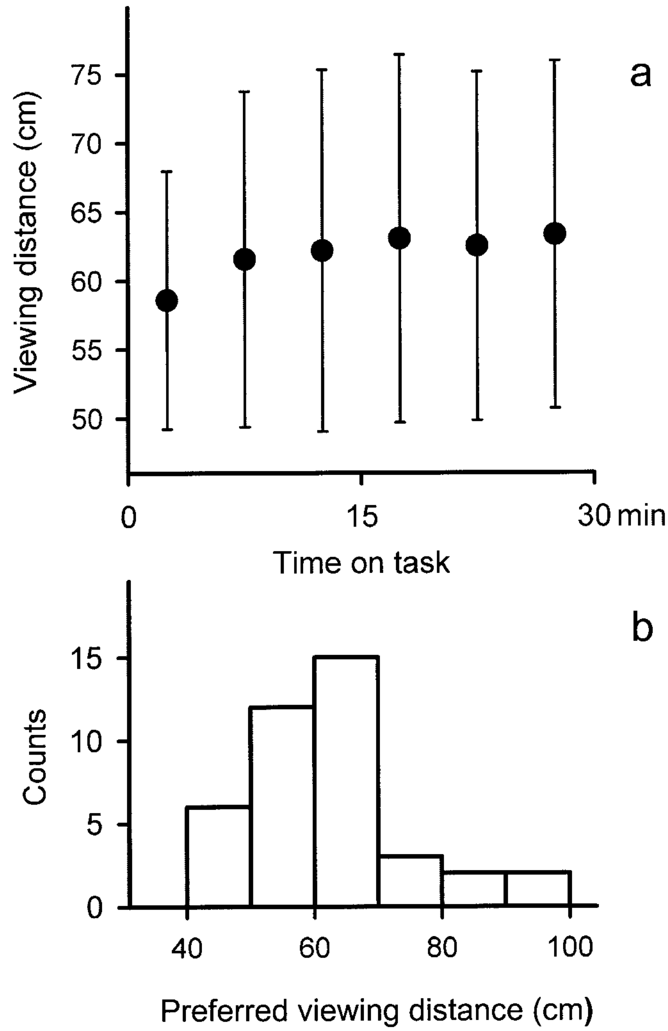

FIGURE 2.
Viewing distance in Block C. (a) Mean (±SD) viewing distance as a function of time, when the 40 subjects were free to choose a comfortable viewing distance. Since the mean viewing distance was constant during the last 20 min, the individual mean of this period was taken as the preferred viewing distance of each subject. (b) Distribution of preferred viewing distance, i.e., number of subjects with preferred viewing distances as indicated on the x-axis.

The following analyses were made to determine which indicator is specific for visual fatigue due to near vision. Table 5 shows the correlations between the six possible indicators. The visual symptoms reported in the questionnaire after the blocks had significant intercorrelations ($r = 0.65$, 0.81, and 0.69, $p < 0.0005$). Those subjects who judged the screen to be too near at 50 cm (Block B) preferred longer viewing distances in Block C ($r = 0.42$; $p < 0.005$), had a larger difference (Block B vs. Block A) in post-task symptoms between 50 and 100 cm ($r = 0.31$; $p < 0.05$), and reported stronger visual symptoms after the task at 50 cm (r =

0.44; $p < 0.005$). The latter two correlations do not contradict the result reported in Table 4 that, averaged across the group, the ratings of symptoms were not significantly different after the blocks at 100 and 50 cm. A mean value is always a result from the majority of subjects, while a correlation can be significant and meaningful on the basis of a smaller part of the sample; e.g., the above correlation of $r = 0.44$ relies on a subgroup of about eight subjects, corresponding to $r^2 = 0.19$ or 19% of the sample size of 40.

A factor analysis with the six variables in Table 5 was made to test which subsets of these variables describe possibly different and independent aspects of visual fatigue, i.e., variables with high positive intercorrelations are combined in a factor that represents all relevant information of these variables. As shown in Table 5, the factor analysis identified two separate factors (I and II). Factor II included the visual symptoms at 50 cm (compared with 100 cm) and the ratings of the screen at 50 cm as too near; thus, the subjects with a high score on factor II appeared to have more visual fatigue because of near vision in Block B at 50 cm. Furthermore, they tended to choose a longer viewing distance in Block C, presumably to avoid near vision fatigue. In these conditions, a long preferred viewing distance can be interpreted as an indicator of near vision fatigue (which the subjects had experienced earlier in Block B at 50 cm). Therefore, the variables of factor II apparently reflect near vision fatigue. The separate factor I, however, comprises the ratings of visual symptoms after the three blocks; the average of these ratings was the same at the different viewing distances (Table 4). Thus, factor I does not depend on near vision, but rather may describe the fatigue induced by performing the visual task, which involves saccadic eye movements, visual detection and discrimination, and mental workload. This latter task-related fatigue is not in the scope of the present study on near vision.

Part 3: Relation between Optometric Measures and Near Vision Fatigue

On the basis of the results reported in Part 1 and 2, the present Part 3 describes discriminant analyses in order to find out which optometric variable(s) may be related to near vision fatigue induced by the proximity of the screen. For each of the three indicators of near vision fatigue identified in Part 2 (Table 5, factor II), separate discriminant analyses were made with the 16 optometric measures deduced in Part 1 (indicated in Table 3) as follows.

In the first step of discriminant analyses, it was determined which optometric variable, by itself, was significantly different between two groups that were formed on the basis of the median of each indicator of visual fatigue. Table 6 summarizes those optometric measures with $F > 3.0$, i.e., which were at least nearly significant ($p < 0.09$). As shown in Table 6a, the group with symptoms at 50 cm (compared with 100 cm) stronger than the median had a significantly more negative slope of the proximity-FD curve measured with the computer test (99 trials; $F = 7.41$; $p = 0.0103$) and with the free-view Nonius Offset Card ($F = 6.92$; $p = 0.0129$). The aim of the following stepwise analysis is to test whether, after the variance of the best discriminating variable of the previous steps was extracted, further variables can be found that contribute to the discrimination. In all three discriminant analyses in Table 6a-c, this stepwise procedure did not yield a significant

TABLE 6.
Indicators of near vision fatigue.[a]

Indicator of Near Vision Fatigue	Optometric Measure	F Value	p Level, Two-Tailed	Criterion Level	Hits, False Alarms (%)	p′ Level, One-Tailed, p′ = 16*p/2
(a) Visual symptoms at 50 cm (compared with 100 cm)	Slope of proximity-FD curve (computer test, n = 99)	7.41	0.0103	-1.49 min arc/m^{-1}	50 24	0.0824
	Slope of proximity-FD curve (Nonius Offset Card, free view)	6.92	0.0129	—	—	—
(b) "50 cm too near"	Score of FD at 40 cm (z-score)	5.35	0.0276	0.03	58 29	0.2208
	Associated phoria (Mallett-unit)	4.45	0.0431	—	—	—
	Slope of proximity-FD curve (Nonius Offset Card, Binoptometer)	3.48	0.0717	—	—	—
(c) Preferred viewing distance	Slope of proximity-FD curve (Nonius Offset Card, Binoptometer)	11.39	0.0017	-0.49 min arc/m^{-1}	60 20	0.0136
	Score of FD at 40 cm (z score)	4.60	0.0385	—	—	—

[a] For each indicator of near vision fatigue (a–c), the first step of discriminant analysis gave optometric measures that discriminated between subgroups of high and low fatigue (with $F > 3.0$ and corresponding two-tailed p levels). After stepwise discriminant analyses, only the one optometric measure with the largest F value remained significant, for which are given the criterion level, the hit and false alarm rates, and the one-tailed Bonferroni-corrected $p' = 16*p/2$ (see text).

[b] FD, fixation disparity.

improvement; thus, discrimination relied only on the one variable with the highest F value in the first step. Discriminant analysis provides a criterion level that was −1.49 min arc/m^{-1} for the slope of the proximity-FD curve of the computer test. Thus, all subjects with a slope more negative than this were classified as having strong visual symptoms at 50 cm (compared with 100 cm), as expected from their proximity-FD curve. From the 18 subjects with symptoms stronger than the median, 9 had slope values more negative than the criterion; thus, the rate of correctly classified subjects, or the "hit-rate," was 9/18 or 50%. In the group of 17 subjects with symptoms smaller than the median, 4 subjects had slopes more negative than the criterion, and thus, the "false alarm rate" was 4/17 or 24%.

The discriminant analyses of the other indicators of near vision fatigue are given in Table 6b and c and can be summarized as follows. If two groups were formed according to the median judgment of the screen at 50 cm as too near, the score of FD at 40 cm was the best discriminating variable (F = 5.35; p = 0.0276). Two groups with preferred viewing distances longer and shorter than the median were best separated by the slope of the proximity-FD curve, measured with the Nonius Offset Card in the Binoptometer (F = 11.39; p = 0.0017).

Because the stepwise procedure revealed only a single variable, these discriminant analyses indicate which optometric variable, by itself, is significantly different in groups of high or low near vision fatigue. This procedure is equivalent to separate t-tests for each optometric variable. Including many optometric variables has the advantage that the relative power of variables can be compared; however, the risk of randomly significant results increases. This can be taken into account by calculating Bonferroni corrections: the raw error probabilities (p, two-tailed) resulting from the discriminant analyses are multiplied by the number of variables, i.e., 16. Since we test directional hypotheses, we can use one-tailed tests. The resulting one-tailed Bonferroni-corrected p' = 16 *p/2 (last column of Table 6) was significant for the preferred viewing distance (p' = 0.0136, Table 6c), nearly significant for the visual symptoms at 50 cm compared with 100 cm (p' = 0.0824, Table 6a), and insignificant for the judgment of 50 cm as too near (p' = 0.2208, Table 6b). However, for the three indicators of near vision fatigue (Table 6a-c), the seven optometric measures with F > 3.0 all refer to a more exo condition at near vision, described either by slopes of proximity-FD curves, by the score of FD, or by the associated phoria (both at 40 cm). It is unlikely that this occurred by chance.

The significant result of Table 6c is illustrated in Fig. 3. The group with preferred viewing distances longer than average had a distribution of the slope of the proximity-FD curve (Nonius Offset Card, Binoptometer) that was shifted to more negative values, i.e., to steeper FD curves. These two groups were best separated by the criterion level of −0.49 min arc/m^{-1} and had proximity-FD curves shown in Fig. 4.

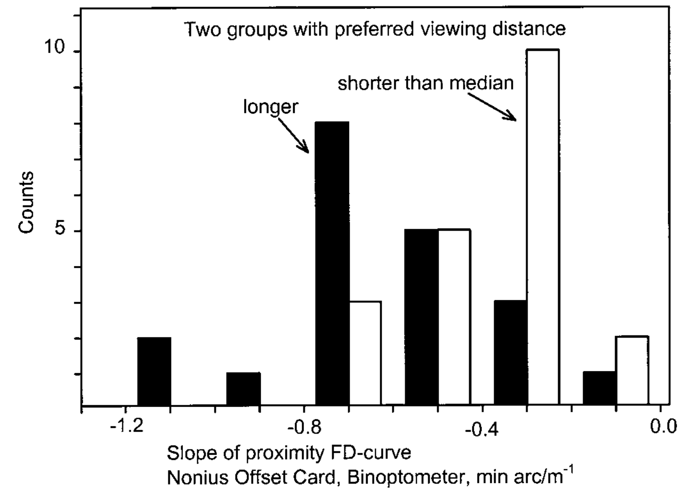

FIGURE 3.
Two groups (each with n = 20) with preferred viewing distance longer and shorter than the median (63 cm) had significantly different distributions of the slope of the proximity-fixation-disparity curve (min arc/m^{-1}), measured with the Nonius Offset Card in the Binoptometer.

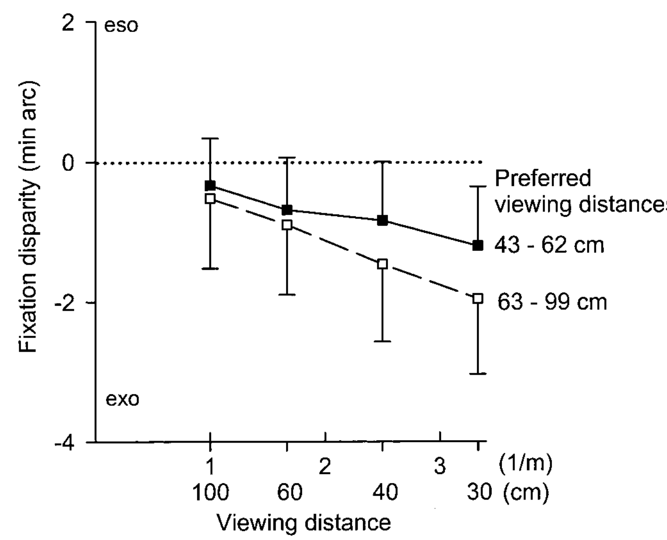

FIGURE 4.
Proximity-fixation-disparity curves (measured with the Nonius Offset Card in the Binoptometer) for the two groups (each with n = 20) with ranges of the preferred viewing distance longer and shorter than the median (63 cm). Error bars indicate standard deviations.

DISCUSSION

In the present study, the same visual task was performed at different viewing distances, thus the specific effect of near vision at 50 cm could be investigated in relation to the same task at 100 cm, which was about the ocular resting position. As found in previous studies,[10, 14, 19] the preference of long viewing distances appears to be a strategy of computer screen users to avoid near vision fatigue. Thus, in the present study, near vision fatigue was indicated by the judgment of the screen at 50 cm as too near, the preference of a longer viewing distance, and the extent to which visual symptoms at 50 cm exceeded those at 100 cm. The two latter indicators were related to the slope of proximity-FD curves, measured with the Nonius Offset Card in the Binoptometer and with the computer test (p = 0.0136 and p = 0.0824 after a statistical Bonferroni-correction, respectively). For the ergonomics of computer workstations, the present results and those of a previous study[14] suggest that most subjects with a more negative slope of the proximity-FD curve preferred longer viewing distances.

A steeper slope means a more exo FD at near vision. Accordingly, exo FD (or the related associated phoria) at 40 cm indicated visual symptoms in the studies of Sheedy and Saladin[1–3] and of Pickwell and coworkers.[4–8] These results suggest that near vision fatigue can arise in young adults with FD, even at a 50 cm viewing distance, which is long compared to their mean (±SD) accommodative near point of 10.8 ± 2.5 cm.

In a previous[17] visual task at 50 cm viewing distance, subjects with a near dark focus (and also a better accommodative response at 50 cm) reported less visual symptoms than subjects with a distant dark focus (but nevertheless found 50 cm to be too short). However, such effects were neither found in Jaschinski[14] nor in the present study. Thus, visual fatigue appears not to come from the accommodation system (in prepresbyopic subjects with normal vision), but rather from the disparity vergence system, as described above. However, transient accommodative changes following near work are discussed in relation to the development of myopia.[52]

Although the different vergence measures may reflect different physiological mechanisms, they depend on each other and are correlated. While dark vergence is the state without accommodative and fusional stimuli, dissociated phoria depends on dark vergence and accommodation.[34–38] FD depends on the elements of the control mechanisms of disparity vergence and accommodation,[53] including dark vergence[54] and vergence gain. This gain determines the slope of FD curves,[55] which describe the relation between FD and associated phoria. Because of these intercorrelations, it is no surprise that in research that deals with a subjective phenomenon such as visual fatigue, the result of a series of studies are not always unequivocal, especially since methods and criteria for estimating visual fatigue and the visual tasks vary, and the samples of subjects also differ with respect to their optometric status. However, from studies that used discriminant analyses to take into account the intercorrelations between optometric measures, it can be concluded that measures of FD belong to the optometric variables that are best related to visual fatigue. The reason may be that tests of FD include many physiological mechanisms that are involved in performing a visual task, i.e., tonic vergence, fusion, and accommodation. In tests of the proximity-FD curve, accommodative stimuli correspond to those in natural vision at the workplace.

In the present conditions and sample of subjects, discriminant analyses did not result in a set of optometric tests; rather, only a single variable, the slope of the proximity-FD curve, was the best discriminating variable. Other optometric variables did not contribute significantly, presumably since discriminant analysis takes into account the intercorrelations between optometric variables, i.e., further variables did not provide additional information that was not included in the slope of the proximity-FD curve. Thus, this measure may complete tests used in research and practice.

The present study and most studies in Table 1 identified optometric functions the parameters of which are more or less stable within individuals but vary among subjects without being clinically significant. Even so, these measures can be important for vision screening at workplaces. More severe disorders of accommodation and vergence,[29] or sensory components of heterophoria,[56–59] may play a role for visual fatigue in these individuals. However, any rare vision disorder will not give statistically significant results in a random sample of subjects.

Despite significant differences in the optometric status between groups of low and high visual fatigue, the conclusions on the basis of groups need not be true for each individual. For the prediction of the preferred viewing distance from the slope of the proximity-FD curve (Table 6c), the percentage of subjects correctly classified (the hit rate) was 60%, while the false alarm rate was 20%. Pickwell et al.[8] found similar rates for the associated phoria as an indicator of visual symptoms in young adults. Thus, it is a common experience in the area of binocular vision testing to find individuals with weak disparity vergence who do not report severe symptoms or, more critically, other subjects with visual symptoms that are not related to FD or associated phoria, but may be to other optometric anomalies. These latter cases certainly require further diagnoses. Furthermore, visual fatigue is a subjective phenomenon that is difficult to quantify.

For subjects with unexplained symptoms of visual fatigue at the computer workstation, the method in the present study may help to determine whether the proximity of the screen may be causing the problems. The subject may perform a visual task at a computer screen in the office or at home, first at a longer viewing distance, then at a shorter one. Finally, the subject may try the preferred viewing distance in free adjustment. After this procedure, the subject will probably have discovered whether proximity is the origin of visual symptoms. This try-out of different viewing distances appears to be a useful method for measuring near vision fatigue and can be helpful for an individual design of computer workstations, as shown in ergonomic field studies.[19, 20] While 30 min were needed for most subjects to reach their final preferred viewing distance in Jaschinski,[14] the subjects in the present study needed only 10 min, presumably since they had prior experience with their visual fatigue at the viewing distances of 100 cm and 50 cm.

In summary, nonpresbyopic subjects with normal vision differed in near vision fatigue at a 50 cm viewing distance. Those with higher fatigue, indicated by a longer preferred viewing distance, tended to have a steeper proximity-FD curve, measured with a simple new screening procedure. Thus, the role of FD as a relevant diagnostic optometric measure was confirmed and extended to conditions of convergence at the computer workstation.

ACKNOWLEDGMENTS

Received March 19, 2001; revision received June 28, 2001; final revision received October 17, 2001.

REFERENCES

1. Sheedy JE, Saladin JJ. Phoria, vergence, and fixation disparity in oculomotor problems. Am J Optom Physiol Opt 1977;54:474–8.
2. Sheedy JE, Saladin JJ. Association of symptoms with measures of oculomotor deficiencies. Am J Optom Physiol Opt 1978;55:670–6.
3. Sheedy JE, Saladin JJ. Validity of diagnostic criteria and case analysis in binocular vision disorders. In: Schor CM, Ciuffreda KJ, eds. Vergence Eye Movements: Basic and Clinical Aspects. Boston: Butterworth, 1983:517–40.
4. Yekta AA, Jenkins T, Pickwell D. The clinical assessment of binocular vision before and after a working day. Ophthalmic Physiol Opt 1987; 7:349–52.
5. Pickwell LD, Yekta AA, Jenkins TC. Effect of reading in low illumi-

nation on fixation disparity. Am J Optom Physiol Opt 1987;64: 513–8.
6. Jenkins TC, Pickwell LD, Yekta AA. Criteria for decompensation in binocular vision. Ophthalmic Physiol Opt 1989;9:121–5.
7. Yekta AA, Pickwell LD, Jenkins TC. Binocular vision, age and symptoms. Ophthalmic Physiol Opt 1989;9:115–20.
8. Pickwell LD, Kaye NA, Jenkins TC. Distance and near readings of associated heterophoria taken on 500 patients. Ophthalmic Physiol Opt 1991;11:291–6.
9. Hung GK, Ciuffreda KJ, Semmlow JL. Static vergence and accommodation: population norms and orthoptics effects. Doc Ophthalmol 1986;62:165–79.
10. Heuer H, Hollendiek G, Kroger H, Romer T. Rest position of the eyes and its effect on viewing distance and visual fatigue in computer display work. Z Exp Angew Psychol 1989;36:538–66.
11. Tyrrell RA, Leibowitz HW. The relation of vergence effort to reports of visual fatigue following prolonged near work. Hum Factors 1990; 32:341–57.
12. Jaschinski-Kruza W. Eyestrain in VDU users: viewing distance and the resting position of ocular muscles. Hum Factors 1991;33:69–83.
13. Best PS, Littleton MH, Gramopadhye AK, Tyrrell RA. Relations between individual differences in oculomotor resting states and visual inspection performance. Ergonomics 1996;39:35–40.
14. Jaschinski W. Fixation disparity at different viewing distances and the preferred viewing distance in a laboratory near-vision task. Ophthalmic Physiol Opt 1998;18:30–9.
15. Jaschinski W. Fixation disparity and accommodation as a function of viewing distance and prism load. Ophthalmic Physiol Opt 1997;17: 324–39.
16. Jaschinski W. Fixation disparity and accommodation for stimuli closer and more distant than oculomotor tonic positions. Vision Res 2001;41:923–33.
17. Jaschinski-Kruza W. Visual strain during VDU work: the effect of viewing distance and dark focus. Ergonomics 1988;31:1449–65.
18. Bergqvist UO, Knave BG. Eye discomfort and work with visual display terminals. Scand J Work Environ Health 1994;20:27–33.
19. Jaschinski W, Heuer H, Kylian H. Preferred position of visual displays relative to the eyes: a field study of visual strain and individual differences. Ergonomics 1998;41:1034–49.
20. Jaschinski W, Heuer H, Kylian H. A procedure to determine the individually comfortable position of visual displays relative to the eyes. Ergonomics 1999;42:535–49.
21. Jaschinski W, Koitcheva V, Heuer H. Fixation disparity, accommodation, dark vergence and dark focus during inclined gaze. Ophthalmic Physiol Opt 1998;18:351–9.
22. Jaschinski W. Methods for measuring the proximity-fixation-disparity curve. Ophthalmic Physiol Opt 2001;21:368–75.
23. Rohmert W. Ergonomics and manufacturing industry. Ergonomics 1985;28:1115–34.
24. National Research Council (U.S.). Video Displays Work, and Vision. Washington, DC: National Academy Press, 1983.
25. Watten RG. Reinvention of visual fatigue: accumulation of scientific knowledge or neglect of scientific history? Ophthalmic Physiol Opt 1994;14:428–32.
26. Jaschinski W, Bröde P, Griefahn B. Fixation disparity and nonius bias. Vision Res 1999;39:669–77.
27. Mallett RJF. The investigation of heterophoria at near and a new fixation disparity technique. Optician 1964;148:547–51.
28. Sheedy JE. Actual measurement of fixation disparity and its use in diagnosis and treatment. J Am Optom Assoc 1980;51:1079–84.
29. Scheiman M, Wick B. Clinical Management of Binocular Vision: Heterophoric, Accommodative, and Eye Movement Disorders. Philadelphia: J.B. Lippincott Co., 1994.
30. Evans BJW. Pickwell's Binocular Vision Anomalies: Investigation and Treatment. 3rd. Ed. Oxford: Butterworth-Heinemann, 1997.
31. Pickwell LD, Gilchrist JM, Hesler J. Comparison of associated heterophoria measurements using the Mallett test for near vision and the Sheedy Disparometer. Ophthalmic Physiol Opt 1988;8:19–25.
32. Reiner J. [A new vision test instrument]. Zentralbl Arbeitsmed Arbeitsschutz Prophyl Ergonomie 1980;30:110–3.
33. Ukwade MT. Effects of nonius line and fusion lock parameters on fixation disparity. Optom Vis Sci 2000;77:309–20.
34. Rosenfield M. Tonic vergence and vergence adaptation. Optom Vis Sci 1997;74:303–28.
35. Owens DA, Leibowitz HW. Perceptual and motor consequences of tonic vergence. In: Schor CM, Ciuffreda KJ, eds. Vergence Eye Movements: Basic and Clinical Aspects. Boston: Butterworth, 1983:25–74.
36. Jaschinski-Kruza W. Effects of stimulus distance on measurements of dark convergence. Ophthalmic Physiol Opt 1990;10:243–51.
37. Owens DA, Leibowitz HW. The fixation point as a stimulus for accommodation. Vision Res 1975;15:1161–3.
38. O'Shea WF, Ciuffreda KJ, Fisher SK, Tannen B, Super P. Relation between distance heterophoria and tonic vergence. Am J Optom Physiol Opt 1988;65:787–93.
39. Wolf KS, Bedell HE, Pedersen SB. Relations between accommodation and vergence in darkness. Optom Vis Sci 1990;67:89–93.
40. Owens DA, Tyrrell RA. Lateral phoria at distance: contributions of accommodation. Invest Ophthalmol Vis Sci 1992;33:2733–43.
41. Jiang BC, Woessner WM. Dark focus and dark vergence: an experimental verification of the configuration of the dual-interactive feedback model. Ophthalmic Physiol Opt 1996;16:342–7.
42. Hofstetter HW. Graphical analysis. In: Schor CM, Ciuffreda KJ, eds. Vergence Eye Movements: Basic and Clinical Aspects. Boston: Butterworth, 1983:439–64.
43. Matsumura I, Maruyama S, Ishikawa Y, Hirano R, Kobayashi K, Kohayakawa S. The design of an open view autorefractor. In: Breinin GM, Siegel IM, eds. Advances in Diagnostic Visual Optics. Proceedings of the Second International Symposium, Tuscon, Arizona, October 2:3–25, Berlin: Springer-Verlag, 1982;1983:36–42.
44. McBrien NA, Millodot M. Clinical evaluation of the Canon Autoref R-1. Am J Optom Physiol Opt 1985;62:786–92.
45. Owens DA. Near work accommodative tonus and myopia. In: Grosvenor TP, Flom MC, eds. Refractive Anomalies: Research and Clinical Applications. Boston: Butterworth-Heinemann, 1991:318–44.
46. International Standards Organization. ISO 9:241–3:1992. Ergonomic requirements for office work with visual display terminals (VDTs)—Part 3: Visual display requirements. Geneva, Switzerland: International Standards Organization, 1992.
47. Heuer H, Owens DA. Vertical gaze direction and the resting posture of the eyes. Perception 1989;18:363–77.
48. Lie I, Fostervold KI. VDT-work with different gaze inclinations. In: Grieco A, Molteni G, Occhipinti E, Piccoli B, eds. Work with Display Units 94. Proceedings of the 4th International Scientific Conference on Work with Display Units, October 2–5, 1994, Milan, Italy. Amsterdam: North Holland, 1995:137–42.
49. Lie I, Fostervold KI, Aarås A, Larsen S. Gaze inclination and health in VDU-operators. In: Seppälä P, Luopajärvi T, Nygård C-H, Mattila M, eds. From Experience to Innovation, IEA '97. Proceedings of the 13th Triennial Congress of the International Ergonomics Association. Helsinki, Finland: Finnish Institute of Occupational Health, 1997:50–2.
50. Heuer H. Visual work with different gaze inclinations. In: Luczak H, Çakir A, Çakir G, eds. Work with Display Units 92. Proceedings of WWDU 92: Third International Scientific Conference on Work with Display Units, September 1–4, 1992, Milan, Italy. Amsterdam: North Holland, 1993:115–20.

51. Dixon WJ. BMDP Statistical Software Manual. Berkeley, CA: University of California Press, 1992.
52. Gilmartin B. Autonomic correlates of near-vision in emmetropia and myopia. In: Rosenfield M, Gilmartin B, eds. Myopia and Nearwork. Oxford: Butterworth-Heinemann, 1998:117–46.
53. Hung GK. Quantitative analysis of associated and disassociated phorias: linear and nonlinear static models. IEEE Trans Biomed Eng 1992;39:135–45.
54. Jaschinski-Kruza W. Dark vergence in relation to fixation disparity at different luminance and blur levels. Vision Res 1994;34:1197–204.
55. Schor CM. Fixation disparity and vergence adaptation. In: Schor CM, Ciuffreda KJ, eds. Vergence Eye Movements: Basic and Clinical Aspects. Boston: Butterworth, 1983:465–516.
56. Schor C. Binocular sensory disorders. In: Regan D, ed. Binocular Vision. Boca Raton: CRC Press, 1991:179–223.
57. Wick B. Stability of retinal correspondence in normal binocular vision. Optom Vis Sci 1991;68:146–58.
58. Lie I, Opheim A. Long-term acceptance of prisms by heterophorics. J Am Optom Assoc 1985;56:272–8.
59. Lie I, Opheim A. Long-term stability of prism correction of heterophorics and heterotropics; a 5 year follow-up. I. Heterophorics. J Am Optom Assoc 1990;61:491–8.

Wolfgang Jaschinski
Institut für Arbeitsphysiologie
Ardeystrasse 67
D-44139 Dortmund
Germany
jaschinski@arb-phys.uni-dortmund.de