Optimizing Reading Tests for Dry Eye Disease

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Purpose: The aim of this study was to evaluate the visual function information obtained from multiple reading tests in a dry eye population.

Methods: In this case–control, single-center clinical research center–based study, 15 subjects with dry eye (mean age 65 years) and 10 normal subjects (mean age 40 years) were included. The Standardized Mini-Mental Examination was given to assure that subjects had normal cognitive function. Reading tests were both sentence based (Radner reading acuity test, reading contrast sensitivity test at a fixed print size, and menu-reading test) and paragraph based (Wilkins test and International Reading Speed Texts [IReST]). Wilkins and IReST tests were slightly modified to increase difficulty and visual stress. The main outcome measures were cognitive function, fatigue, dry eye symptoms, reading acuity, reading rate, and blink rate.

Results: Results showed significantly lower rates in all reading tests in subjects with dry eye than in normal subjects; in the age-matched subgroup, only the menu and contrast sensitivity tests lost significance. Fatigue was significantly related to the IReST test, both at normal and critical print sizes. Reflex tearing was monitored and shown to significantly decrease the reading rate. IReST scores were considered the baseline, and the percent change from one test to IReST was also used to differentiate dry eye and normal subjects. The blink rate, symptoms, and demographics were not significantly correlated with reading tests.

Conclusions: Reading is a relevant end point that differentiates dry eye and normal subjects. This study evaluated a variety of reading tests for relevance as a measurable assessment of visual function in dry eye disease.

Key Words: visual function, dry eye, reading rate, IReST reading test, Wilkins reading test, Radner reading acuity test, fatigue and dry eye, visual function and dry eye

(P)atients with dry eye disease frequently complain of reading difficulties that can have an adverse effect on quality of life."1–4 Visual disturbances such as blurred vision and keratitis are known to affect visual function5,6 and may be contributing factors that affect reading performance in subjects with dry eye. In addition, symptoms of ocular irritation, fatigue, and cognitive function may also limit the reading rate.

Although affected by the lexicographic properties of the text, such as the type size, reading fluency is quite robust in normal subjects for text above the critical print size (CPS).7 The smallest print size at which a subject can successfully read a line of text is referred to as the reading acuity. The reading acuity limit is closely related to minimal contrast perception.8,9

Many reading tests have been developed over the years. Some of these tests are specifically designed to induce visual stress through lexical formatting, such as the Wilkins test.10 Others have focused on standardization of the cognitive and syntactical content in a paragraph form as a more natural context for assessing reading such as the IReST test.11

The aim of this study was to perform a comparative evaluation of several categories of reading tests in a dry eye population and a control group. Visually stressful tests, such as the Wilkins test, and a paragraph reading test at critical print size (CPS), as well as the Radner et al12 and contrast sensitivity tests that explore limitations of optical resolution were evaluated. These tests will be optimized for clinical trial purposes to assess clinical relevance in the context of dry eye.

METHODS

All procedures in this single, research center–based, case–control study were performed as part of standard clinical care and complied with the tenets of the Declaration of Helsinki regarding human research. Informed consent was obtained. No treatment for dry eye was tested in this study.

Subjects

All subjects were non–contact lens wearers of at least 18 years of age, and all had at least a high school level of education. A total of 10 normal subjects (age, mean ± SD: 39.5 ± 12.6 years) and 15 subjects with dry eye (age, mean ± SD: 64.5 ± 11.7 years) were included. Eight subjects had a history of dry eye disease for more than 11 years, and 6 subjects had a history of dry eye from 6 to 10 years.

Because age was significantly different between these groups (P < 0.0001), a subgroup of age-matched subjects was also analyzed: 5 normal subjects (age, mean ± SD: 50.6 ± 5.9 years) and 7 subjects with dry eye (age, mean ± SD: 53.4 ± 3.6 years).
Subjects with dry eye were required to have used eye drops for dry eye symptoms within the previous 6 months and to have successfully completed a randomized clinical trial of new treatments for dry eye within the past 12 months. Inclusion required a baseline tear film break-up time value $\leq 5$ seconds in at least 1 eye, a total corneal fluorescein staining score $\geq 2$, and a Schirmer score $< 10$ mm. Subjects with confounding comorbidities were excluded based on clinical assessment. Finally, subjects were required to have answered affirmatively to reading-related problems on previously completed dry eye quality of life.

**Reading Tests**

All reading tests were presented at a standardized distance of 40 cm with incident light on the test page maintained at 100 cd/m$^2$. All tests were read aloud with the subject instructed to read continuously as rapidly as possible without errors and without correcting for errors. Errors were recorded and subtracted from the subjects’ reading rate scores. Sentence-based tests (presented OD/OS) were used to measure the reading acuity based on the CPS (Radner) and contrast sensitivity. The contrast sensitivity test consisted of a series of 11 sentences (14-point, Calibri font) presented at successively lower contrast levels.$^{13}$ The last line read was the outcome variable.

Paragraph-based reading tests (presented OU) were selected to measure the reading rate and errors under both visually stressful (Wilkins test, subjects asked to read the entire block of text) and nonstressful conditions (IReST). In addition, subjects were asked to read a paragraph at the CPS as determined by the Radner test. Subjects were also asked to read a menu consisting of 15 lines of text (70 words) in 12-point Times New Roman font.

**Signs and Symptoms**

Symptoms of ocular irritation were assessed OU on a 0-to-5 point scale (0 being none and 5 being the most severe) using the keywords: burning, dryness, grittiness, stinging, blurring, and overall discomfort. Global ocular discomfort (OD/OS) was also given one comprehensive grade from 1 to 4.

The Standardized Mini-Mental State Examination$^{14}$ was used to assess basic cognitive function of all subjects. Fatigue state was evaluated using the Stanford Sleepiness Scale,$^{15}$ the Fatigue Severity Scale,$^{16}$ and Karolinska$^{17}$ sleepiness scales.

Subjects were video recorded while they read the assessments, and the blink rate was manually counted from these videos. Because reflex tearing is a well-known response of stress to the visual system, after each reading test, subjects were queried whether they felt the presence or absence of reflex tearing during each reading test.

**Statistical Methods**

Sample means were calculated for reading rates in words per minute (wpm) for each test. Pearson correlations were calculated between symptoms, between each test, and between quantitative measurements and each test. Two-sample $t$ test comparisons were performed between various group means, with $P < 0.05$ defining significance.

**RESULTS**

All subjects achieved a score of 25 or better on the Standardized Mini-Mental State Examination, indicating normal cognition.

**Comparisons Between Dry Eye and Normal Groups**

Reading speed in wpm (Table 1) was significantly lower for all 4 reading tests ($P < 0.01$) for the full dry eye group relative to the control group. Raw data for each test are shown in Figure 1.

The reading rate remained significantly different in the age-matched subgroups for all tests ($P < 0.03$) except the menu-reading test ($P = 0.28$) (Table 1).

Mean contrast sensitivity for the full dry eye group was 5.9 lines read (SD = 0.3) based on the averaged eye and 6.4 (SD = 0.3) based on the best eye. Mean contrast sensitivity for the full normal group was 7.4 lines read (SD = 0.4) for the averaged eye and 8.0 (SD = 0.4) for the best eye. Both measures were significantly different between the populations ($P < 0.01$).

Mean contrast sensitivity for the age-matched dry eye group was 6.1 lines read (SD = 0.6) based on the averaged eye and 6.4 (SD = 0.5) based on the best eye for dry eye. Corresponding values for the age-matched normal group was 7.4 (SD = 0.7) for the averaged eye and 7.6 (SD = 0.6)

| TABLE 1. Reading Rate (wpm) and Blink Rate (Blinks/Minute) for All Reading Tests (W/SD) |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Reading Test | Normal (N = 10) | Dry Eye (N = 15) | Age-Matched Normal (N = 5) | Age-Matched Dry Eye (N = 5) |
|              | Reading Rate | Blink Rate | Reading Rate | Blink Rate | Reading Rate | Blink Rate | Reading Rate | Blink Rate |
| IReST        | 210.5 (12.9) | 6.0 (4.2)   | 155.9 (28.6) | 10.1 (8.3)  | 208.1 (17.2) | 5.3 (4.7)  | 167.0 (22.3) | 11.8 (7.1)   |
| CPS          | 207.0 (24.5) | 4.6 (5.4)   | 122.7 (40.6) | 9.4 (8.1)   | 199.7 (15.7) | 3.8 (6.1)  | 129.7 (38.2) | 12.6 (9.1)   |
| Menu         | 131.2 (19.6) | 6.2 (4.7)   | 102.2 (21.5) | 11.7 (11.4) | 122.3 (24.5) | 7.1 (6.4)  | 107.7 (20.5) | 14.6 (11.9)  |
| Wilkins      | 161.1 (21.6) | 5.1 (4.8)   | 128.0 (21.2) | 7.8 (6.5)   | 160.4 (27.7) | 4.2 (2.5)  | 128.1 (14.3) | 8.1 (2.1)    |

Significant intergroup comparisons are in bold.
for the best eye. Neither measure was significantly different ($P > 0.1$).

The mean blink rate for either the full dry eye group or the age-matched subgroup was not significantly different ($P > 0.09$) from the corresponding control group during any of the reading tests (Table 1).

Only 1 of 9 subjects (11%) within the control group experienced reflex tearing, which occurred during 2 reading tests. Within the dry eye group, 12/15 subjects (80%) reported reflex tearing on at least 1 test. Table 2 summarizes reflex tearing incidence for each test.

Within the dry eye group, the presence of reflex tearing resulted in a significant reduction in the reading rate in the Wilkins test: 118 wpm (SD = 14.9) for subjects with reflex tearing versus 139 wpm (SD = 22.7) for subjects who did not have reflex tearing ($P = 0.02$).

**Correlations (Within Group Comparison)**

No significant correlation was found between any of the reading tests and either age or duration of the dry eye history or with ocular symptoms (data not shown).

Results for the 2-point Pearson correlation analysis between all reading tests are summarized in Table 3. Statistically significant correlations were found for the control group between all but the menu-reading test and the critical print paragraph test. For the dry eye group, the IReST to the menu test, and the Wilkins test to both IReST and menu-reading tests were all highly correlated, but no correlations with the CPS reading test were significant.

The Radner test (based on the CPS) and contrast sensitivity test (based on the last line read) showed statistically significant correlations comparing the best eye of each group with $r = -0.901$ ($P < 0.001$) for the control group and $r = -0.554$ ($P = 0.0321$) for the dry eye group. Comparisons based on the average eye were also significant with $r = -0.815$ ($P < 0.01$) for the control group and $r = -0.763$ ($P < 0.001$) for the dry eye group.

Fatigue, as measured by the Stanford scale, was negatively and significantly correlated for the dry eye group with the CPS paragraph-reading test ($r = -0.619$, $P = 0.0139$) and the IReST test ($r = -0.53$, $P = 0.0421$), although not the Wilkins ($r = -0.403$, $P = 0.136$) or menu-reading test.
(r = −0.334). Neither the contrast sensitivity test nor the Radner test showed a significant correlation with fatigue.

Change in the Baseline Reading Rate

Comparisons of each test with the IReST test were then considered. This test served as a paradigm of paragraph-based reading not designed to induce visual stress, and as such was considered the subject’s “baseline” reading rate. The percent change in the reading rate relative to the baseline IReST mean reading rate in wpm and the statistical significance of these differences were calculated. Relative to IReST results, the reading rates significantly decreased on all other tests (from −17% to −37%), with the exception of the CPS in normal subjects. The results of these comparisons are shown in Table 4.

**DISCUSSION**

This study aimed to identify the reading tests that would be most useful for the assessment of changes caused by dry eye signs and symptoms. Some of these tests were modified slightly for our purposes, by adding the stress of increased duration, in the case of the Wilkins test, or the stress of the CPS, in the case of IReST. A reading contrast sensitivity test at a fixed print size and a menu-reading test were also developed and evaluated.

Although subjects with dry eye typically present with elevated blink rates compared with normal subjects,18 in this study, blink rates during reading did not provide a basis for differentiating performance in dry eye and normal subjects. Within groups, the blink rate did seem to be relatively lower for both groups for the stressful tests (Wilkins and CPS), but the difference was not significant.

Reflex tearing was shown to significantly decrease the reading rate in subjects who experienced it; and thus, this factor must be accounted for when evaluating subjects in reading. Fatigue also correlated with the reading rate, and could thus be a confounding factor that should be minimized or at least measured. Ocular symptoms in the dry eye population did not correlate with reading tests. It is possible that an evaluation of signs would have been preferred over symptoms, and these additional assessments will be explored further in future studies.

The use of a non-stress-inducing reading test, such as the IReST test, provided meaningful information on baseline reading performance under ideal conditions. Calculation of the change from IReST was another option explored that showed discrimination between the 2 groups. A suitable protocol may therefore be to use a standardized paragraph-reading test such as IReST for screening purposes together with a stress-inducing test such as the Wilkins test, as well as the percent change from one to the other. This challenge functions similarly to an environmental challenge in its ability to heighten differences and magnitudes of the change to observable clinical relevance.

The results of these tests confirm the common quality of life complaint that the reading rate and quality were diminished by dry eye, although the exact mechanism of this loss seems complex. Reading assessments might in the future be coupled with objective measurements of optical aberrations caused by central corneal staining and/or tear film irregularities6 to identify what exactly is causing the breakdown in visual function in dry eye. These outcomes might be valuable end points in clinical trials, for the development of novel therapies, and also for patient diagnostics. This proof-of-concept study demonstrates the interesting relationship between reading and ocular surface disease, and the findings warrant further exploration in a larger adequately powered study.

**REFERENCES**