Functional Impairment of Reading in Patients with Dry Eye

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Running Title: Dry eye and reading impairment

Key words: quality of life, reading, functional impairment, dry eye**.**

Word Count: 3,777

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SUBTITLE

Dry eye is associated with slower out-loud and silent reading. The decrement in reading speed directly correlates with the severity of dry eye disease, as measured by the Ocular Surface Disease Index and corneal staining score.

ABSTRACT

Background/Aims: To evaluate the impact of dry eye on reading performance.

Methods: Out-loud and silent reading in patients with clinically significant dry eye (n=41) and controls (n=50) was evaluated using standardized texts. Dry eye measures included tear film break-up time, Schirmer's test, and corneal epithelial staining. Symptoms were assessed by the Ocular Surface Disease Index.

Results: The dry eye group had a greater proportion of women as compared to the control group but did not differ in age, race, education level, or visual acuity ($p \geq 0.05$ for all). Out-loud reading speed averaged 148 words per minute (wpm) in dry eye subjects and 163 wpm in controls ($p=0.006$). Prolonged silent reading speed averaged 199 wpm in dry eye subjects versus 226 wpm in controls ($p=0.03$). In multivariable regression models, out-loud and sustained silent reading speeds were 10 wpm (95% CI= -20 to -1 wpm, $p=0.039$) and 14% (95% CI = -25% to -2%, $p=0.032$) slower, respectively, in dry eye subjects as compared with controls. Greater corneal staining was associated with slower out-loud (-2 wpm/1 unit increase in staining score, 95% CI=-3 to -0.3 wpm) and silent (-2%, 95% CI=-4 to -0.6 wpm) reading speeds ($p<0.02$ for both). Significant interactions were found between OSDI score and word-specific features (longer and less commonly used words) on out-loud reading speed ($p<0.05$ for both).

Conclusions: Dry eye is associated with slower out-loud and silent reading speeds, providing direct evidence regarding the functional impact of dry eye. Reading speed represents a measurable clinical finding that correlates directly with dry eye severity.

INTRODUCTION

Dry eye is a common condition affecting approximately one in three individuals over the age of 50.[1–4] Although ocular discomfort may be the most bothersome symptom, visual complaints are also common. Dry eye has a substantial yet often under-appreciated impact on vision-related quality of life.[5–6] Prior research has shown that dry eye patients report difficulty in various vision-related tasks such as driving, reading, computer work, watching television, and performing work-related activities.[7–11] Arguably the most common visual complaint reported is difficulty with reading, which may affect employment or decrease work productivity.

In a population-based sample of elderly, we previously noted that dry eye symptoms were associated with greater perceived difficulty with reading and also the avoidance of specific reading tasks.[12] Here, we designed a clinical study to quantify reading performance through measuring actual reading speed on both a full-passage and individual word level by using several different previously validated texts.

MATERIALS AND METHODS

The study protocol was approved by the Johns Hopkins University Institutional Review Board in accordance with the Declaration of Helsinki and was Health Insurance Portability and Accountability Act compliant. Study subjects completed the study procedures between July 2009 and January 2012.

Study Subjects

Eligible subjects had to be 50 years or older, literate by self-report, and able to communicate in English. Dry eye subjects were recruited from the Ocular Surface Diseases Clinic at Wilmer Eye Institute and had: (1) clinically significant dry eye defined as Schirmer's test result without anesthesia ≤7 mm at 5 minutes and/or bulbar conjunctival staining with lissamine green ≥1 on the Oxford scale in either eye [13], and (2) an Ocular Surface Disease Index (OSDI) score of 13 or higher. All patients were on topical treatment at the time of enrollment (including artificial tears and/or anti-inflammatories), which was not held prior to testing.

Control subjects were gathered from individuals followed for suspicion of glaucoma at the Glaucoma Clinic of the Wilmer Eye Institute who had (1) never been diagnosed with dry eye, and (2) had an OSDI score of 12 or less. All controls had normal visual fields in both eyes over the central 24 degrees using a size III stimulus and assessed by the Swedish interactive threshold algorithm standard testing program (HFA2, Carl Zeiss Meditec Inc., Dublin CA). Thirty-one (62%) of the control subjects were on intraocular pressure-lowering drops at the time of enrollment, which was not held prior to testing.

Tests Performed

All subjects were examined in a uniform manner using the tests performed on a single day in the following order:

Evaluation of Vision and Covariates

Sociodemographic variables were gathered using standardized forms. Visual acuity was measured binocularly with patients' habitual distance correction using the Early Treatment Diabetic Retinopathy Study vision chart, and summarized as the negative logarithm of the minimum angle of resolution(logMAR).[14,15] All subjects had at least 20/40 or better vision in both eyes.

Contrast sensitivity was measured using the Pelli-Robson chart under binocular conditions and converted to a log scale.[16] The presence of depressive symptoms was assessed using part D of the General Health Questionnaire.[17] Cognitive ability was evaluated using the Mini Mental State Exam (MMSE).[18] After reading tests were administered, pupils were pharmacologically dilated and lens changes were graded as present or absent as described previously.[19]

Evaluation of Reading

Subjects wore their habitual reading correction for the following assessments: (a) out-loud reading speed using the Minnesota low vision reading test (MNRead)[20], (b) out-loud reading speed using a 77-word international reading speed test (IReST)[21], and (c) sustained silent reading speed using a 7,300-word validated passage read silently for 30 minutes or until the passage is finished. Greater detail regarding the administration of these three reading tests is provided elsewhere.[22]

Reading speed was calculated in words per minute (wpm). Maximum reading speed was calculated from MNRead times using nonlinear mixed effects models.[23] IReST passage reading speed was calculated after adjusting for reading errors. Sustained silent reading speed was calculated from the total words read and time required for reading. Details regarding these parameters are provided elsewhere.[22,23]

Evaluation of Word-specific Reading Data

Audiorecordings of the IReST passage were imported into Wave Editor Version 1.5.5 (Audiofile Engineering, Minneapolis, MN) and analyzed by a masked evaluator. The start and end of each individual word was determined using the software spectrogram, and then imported into a separate database to calculate the exact duration to say each word out-loud and the following interval duration (before the start of the next word). Each word was analyzed as a word plus post-word interval unit to capture any potential interactional effect of the word-level feature (i.e. word length, word frequency, and location of word in text). A detailed description of the derivation of these outcomes is described in detail elsewhere.[24]

Dry Eye Evaluations

The Ocular Surface Disease Index (OSDI) questionnaire was administered to all subjects by a masked examiner.[10] Total scores were categorized for severity (normal=0–12, mild=13-22, moderate=23–32, severe=33–100).[25,26] A similar formula was used to compute two OSDI subscores: 1) vision-related subscore corresponding to questions 4-9 assessing the impact of dry eye on visual functioning, and 2) ocular discomfort-related subscore corresponding to questions 1-3 and 10-12 evaluating symptoms relating to irritation or discomfort.[27] Subscale scores ranged from 0 to 50.

Dry eye signs was assessed by one of three masked examiners (EKA, PYR, or CAU) and in the order listed here. Tear film break-up time (TBUT) was measured with 5 microliters of anesthetic-free preservative-free 2% sodium fluorescein using the cobalt blue light of a slit lamp and a Wratten 12 yellow filter 1 minute after instilling the eye drop. Three TBUT measurements were obtained (maximum value of 10 seconds) and averaged for each eye.

Corneal staining was evaluated using the National Eye Institute grading system. Within 2 to 3 minutes after TBUT testing, the extent of punctate epithelial erosions was graded using Wratten 12 filter paper.[28] Total corneal staining grade for each eye ranged from 0–15. Lastly, Schirmer's test was performed without anesthesia in each eye at least 10 minutes after corneal staining assessment, read at 5 minutes, and averaged.[29]

Statistical Methods

Group differences in demographic, health, and visual features were assessed using the Student's t-test for normally-distributed continuous variables, Wilcoxon rank sum testing for non-normally distributed continuous variables, and chi-squared testing for categorical variables. The worse eye values for the TBUT, corneal staining, and Schirmer's test were used for the data analysis. Variables associated with MNRead and IReST reading speeds were evaluated using age-adjusted and multivariable linear regression models adjusting for age, sex, race, education, employment status, cognitive ability, and the presence of depressive symptoms. Sustained silent reading speeds were log-transformed and analyzed in age-adjusted and multivariable linear regression models in order to obtain normally-distributed residuals. The percent change in log sustained silent reading speeds associated with model elements was calculated as $(10^{(\beta)}-1)*100$.

Predictors of the word/post-word interval unit were evaluated using multivariate linear regression models. Covariates were included in multivariate models if they demonstrated a significant impact on word time in age-adjusted models or had been previously shown to impact reading speed.[30] Word features (i.e. word size, word frequency, location in text) were also included in multivariable models. Lastly, GEE multivariate models were used to assess interactions between dry eye severity and word features on word/post-word interval time. This interaction analysis was included to evaluate whether dry eye patients had particular difficulty with certain text features, similar to glaucoma patients.[24] All data were analyzed using STATA statistical software (STATA Release 12.1; STATA Corp., College Station, TX).

RESULTS

Forty-one dry eye patients and 50 controls completed study procedures and were included for analysis. One patient was excluded based on a greater than 2-fold difference between their silent and out-loud reading speeds.

Participant characteristics are summarized in Table 1. There was no difference between the two groups with regards to sociodemographic characteristics, cognitive ability, depressive symptoms, presence of cataracts/posterior capsular opacity, visual acuity, or contrast sensitivity. Women formed a greater proportion of the dry eye subject group as compared to the control group (90% vs. 58%, p=0.001). Subjects with dry eye had significantly greater total (39.5 vs. 4.7, p<0.001), ocular discomfort-related (22.2 vs. 2.8, p<0.001) and vision-related (17.3 vs. 1.8, p<0.001) OSDI scores than controls, in addition to shorter TBUTs (1.9 vs. 3.3 seconds, p=0.01) and greater corneal fluorescein staining (7.4 vs. 5.2, p=0.007). Schirmer's test without anesthesia did not differ between the two groups (p=0.41).

In unadjusted analyses, dry eye subjects demonstrated slower reading speeds than controls for the IReST passage (148 vs. 163 wpm, p=0.006) and sustained silent reading (199 vs. 226 wpm, p=0.03) but did not demonstrate slower maximum reading speeds in the MNRead test (180 vs. 186 wpm, p=0.22)(Table 2). No significant differences were noted in other MNRead parameters including reading acuity and critical print size (p>0.05 for both)(Table 2).

In multivariable models, dry eye was associated with significantly reduced IReST passage reading speed (-10 wpm, 95% CI=-20 to -1 wpm, p=0.04) and sustained silent reading speed (14% slower, 95% CI=-25 to -1%, p=0.03), but not with a slower maximum MNRead speed (Table 3). In separate multivariable models, reduction in the MNRead, IReST, and sustained silent reading speeds correlated with total OSDI scores (p≤0.05 for all). Ocular-discomfort-related and vision-related subscores were associated with slower IReST and sustained silent reading (p≤0.05 for both), but not for the MNRead passage. As compared to those with normal OSDI scores, those with severe scores had significantly slower IReST (-18 wpm, 95%

CI=-31 to -7, p=0.003) and sustained silent reading (26% slower, 95% CI=-38 to -13%, p<0.001).

Additional multivariable models were run to determine the association between ocular surface measures and reading speed (Table 3). Worse-eye TBUT was not significantly associated with reading speed for all three tests. Corneal staining was associated with changes in IReST (-2 wpm/1 unit change in staining score, 95% CI=-3 to -0.3, p=0.015) and sustained silent reading speeds (-2%/1 unit change in staining score, 95% CI=-4 to -0.6, p=0.009), but not with maximum reading speed calculated from the MNRead test (p=0.93). African American race and lower MMSE score were significantly associated with reduced reading speed for at least one reading test.

Multivariate GEE models (using the exchangeable correlation structure) assessing the time required to read individual word/post-word interval durations demonstrated that higher OSDI (+1.1 ms/1 point increase in OSDI; 95%CI = 0.6 to 1.5; p<0.001) and corneal staining scores (+3.0 ms/1 point increase in corneal staining; 95%CI = 0.1 to 5.8; p=0.045), but not TBUT or Schirmer's (p>0.05 for both), were associated with longer word/post-word interval complex durations. Greater word/post-word interval durations were also associated with increased word size, word frequency, and word location (end of line versus any other location) (p<0.05 for all).

Interactions between dry eye severity and text features on word/post-word interval durations were also analyzed in separate multivariate GEE models for each dry eye metric. Each interaction model included the metric of dry eye severity, word feature of interest, interaction term (dry eye metric x word feature), and all relevant non-visual metrics. Significant interactions were noted between greater OSDI score and both word length (p=0.002) and word frequency (p=0.02), but not with any other dry eye measures or features (p>0.05 for all).(Table 4)

DISCUSSION

In this clinic-based patient population, dry eye was associated with reduced reading speeds using a variety of reading tests. This decrement correlated directly with the severity of symptoms as measured with OSDI. Individuals with severe dry eye symptoms (OSDI score>33) had substantial reductions in sustained silent reading (26% decrease in wpm). These findings suggest that dry eye symptoms impair reading performance, and likely interfere with daily activities for which reading is critical.

Previous studies have demonstrated the functional impact of dry eye on various everyday tasks, such as reading.[5-10,31-32] We previously demonstrated self-reported difficulty with reading in an elderly population-based cohort.[12] In that study, dry eye did not significantly affect reading speed, although dry eye subjects reported reading difficulty and avoidance of newspaper reading. This discrepancy can be attributed to the fact that subjects from our prior study were derived from a population-based sample who are likely to have less severe disease, compared to the patients in the current study who were cared for at a tertiary dry eye center. Additionally, in our previous study, reading speed was only measured using short out-loud text passages. Finally, limited objective measures were available to categorize the severity of the dry eye in our prior work.

Only two other studies to our knowledge have evaluated reading speed in dry eye. One study used the Wilkins Rate of Reading test, which consists of simple words without context that are read aloud and takes less than 2 minutes to complete.[33, 34] Dry eye subjects exhibited slower reading speeds (134.9 ± 4.95 wpm) than controls (158.3 ± 8.40 wpm, p=0.046), but were not undergoing treatment at the time of evaluation which may have resulted in a larger difference in reading speed than we observed. Another recent small-scale case-control study reported slower reading rates in dry eye patients as well, but its association with subjective or objective measures of dry eye disease was not studied.[35] Our study improves on the methodology of prior studies by using reading tests that more closely mimic reading scenarios which patients encounter in their day-to-day lives.

An interesting finding in our study was that the impact of dry eye on reading speed differed based on the type of reading test employed. Of the two out-loud reading tests, the magnitude of the associations found between dry eye measures and IReST reading speed was greater as compared to MNRead maximum reading speed. One possible reason for this difference is that dry eye exerts its impact on reading speed through visual disturbances that were not identified in the current study (our groups had similar distance/reading acuity and contrast sensitivities). MNRead reading speeds are modeled as the maximum reading speed observed for the sentences presented at different text sizes, and perhaps larger text size can overcome the visual disturbances associated with dry eye. We found a greater impact of dry eye on sustained silent reading speed. In multivariable models, dry eye was associated with 14% slower sustained silent reading (20 wpm decrement at the mean reading speed, p=0.03), while the reduction with IReST testing was 15 wpm (p=0.04). Our findings therefore support the validity and utility of sustained silent reading speed as an important measure to evaluate patients with dry eye disease.[22] Finally, our interaction analysis showed that dry eye patients do not appear to have particular difficulty with word-specific features, in contrast to what has been demonstrated in the glaucoma population.[24] These results suggest that dry eye disease likely affects reading in a more diffuse manner, as opposed to a distinct process which manifests with particular text features (i.e. peripheral visual constriction in glaucoma patients leading to particular difficulty during line transitions). For example, decreased ocular optical qualities due to dry eye disease (i.e. those captured by dynamic aberrometry) may represent the mechanism of decreased reading speed.[36] Therefore, visual rehabilitation may be more difficult to specifically tailor to the dry eye population as compared to other ocular conditions.

The limitations of our study include the fact that a great majority of the participants were on topical therapy (artificial tears, anti-inflammatories, or intraocular pressure-lowering drops), which was not held prior to enrollment. It is possible that the overall reading disability measured here is understated, given that dry eye patients were getting appropriate therapy that was not held prior to testing. The participants represented a convenience sample; therefore, perhaps less symptomatic dry eye patients were less likely to participate, biasing our findings in a positive direction. Also, patients with best-corrected visual acuity (BCVA) better than 20/40 were included, but may have had other pathology influencing reading speed. However there was no statistical difference in the BCVA between the two groups, and the associations were observed to exist independent of BCVA. Additionally, we included glaucoma suspects as controls and not individuals without any signs of dry eye. We considered the possibility that using this control group could bias our findings towards the null hypothesis if reading speed was affected by eye drop therapy. However, in our sensitivity analyses we found no difference in reading speed on any of the tests between controls using eye drops to those who did not. In addition, controls who attend essentially the same clinic as cases are more likely to be similar on unmeasured factors. Recruitment of entirely normal controls (i.e. spouses or friends accompanying patients to clinic) would likely exclude individuals who are less likely to venture outside the home due to poorer general health, mood, or cognitive ability, thus producing a ‘‘supranormal’’ group of controls. Also our data collection did not include blink frequency, which could affect reading time and dry eye measurements. Our findings pertain to a specific set of office-based environmental testing conditions, and the effect of dry eye on reading may differ under other conditions such as higher or lower humidity or air drafts or different lighting conditions. Future studies may consider using dynamic aberrometry of the tear film in the future, which could be utilized as a standardized surrogate marker and potentially facilitate multicenter clinical trials.[37]

In summary, our findings provide direct evidence for the impact of dry eye on reading performance. Our results show that reading speed could be utilized as a tool to directly measure functional impairment from dry eye.

Table 1. Characteristics of subjects with physician-diagnosed dry eye versus controls participating in reading evaluations.

	Control* **(n=50)**	**Dry Eye** **(n=41)**	***p*** **value**
Demographics			
Mean age, years (SD)	67.4 (8.5)	65.7 (10.3)	0.42
African-American, n (%)	9 (18.0)	3 (7.3)	0.13
Female, n (%)	**29 (58.0)**	**37 (90.2)**	**0.001**
Education, years (SD)	15.6 (2.1)	15.1 (1.9)	0.25
Employed, n (%)	24 (48.0)	16 (39.0)	0.39
Vision			
Better-eye acuity, logMAR, mean (SD)	–0.01 (0.11)	0.02 (0.10)	0.18
Binocular log CS, mean (SD)	1.93 (0.12)	1.88 (0.16)	0.11
Cataract/PCO, either eye, n (%)	4 (8.0)	6 (14.6)	0.31
Health			
MMSE Score, mean (SD)	27.6 (1.5)	26.8 (2.4)	0.06
Depressive symptoms, n (%)	3 (6.0)	6 (14.6)	0.17
Dry Eye Measures (SD)			
Mean OSDI Total score	**4.7 (3.8)**	**39.5 (21.1)**	**<0.001**
Mean OSDI Discomfort subscore	**2.8 (2.8)**	**22.2 (12.2)**	**<0.001**
Mean OSDI Vision subscore	**1.8 (2.1)**	**17.3 (1.9)**	**<0.001**
Mean TBUT in worse eye	**3.3 (3.0)**	**1.9 (2.0)**	**0.01**
Mean corneal staining score in worse eye	**5.2 (3.8)**	**7.4 (3.6)**	**0.007**
Mean Schirmer's test in worse eye	10.2 (9.2)	8.6 (9.2)	0.41

*Control patients included were glaucoma suspects without any history or symptoms of dry eye disease

CS: Contrast sensitivity; **logMAR:** Logarithm of the minimum angle of resolution; **MMSE:** Mini Mental State Exam; **OSDI:** Ocular Surface Disease Index; **PCO:** Posterior capsular opacity (in pseudophakic subjects); **SD:** Standard deviation; **TBUT:** Tear film break up time

Table 2. Comparison of reading parameters in subjects with physician-diagnosed dry eye versus controls: Unadjusted values.

	Control* (n=50)	Dry Eye (n=41)	p value
Out-loud reading, MNRead acuity card (SD)			
Mean maximum reading speed, wpm	186 (21)	180 (25)	0.22
Mean critical print size	0.14 (0.16)	0.21 (0.21)	0.08
Mean reading acuity, logMAR	–0.05 (0.11)	–0.01 (0.15)	0.09
Out loud reading, IReST passage			
Mean reading speed (SD) wpm	**163 (22)**	**148 (27)**	**0.006**
Sustained silent reading passage (SD)			
Median reading speed, wpm	**226 (59)**	**199 (82)**	**0.03**

*Control patients included were glaucoma suspects without any history or symptoms of dry eye disease

IReST: International Reading Speed Text; **MNRead card:** The Minnesota low vision reading test; **SD:** Standard deviation; **wpm:** words per minute

Table 3. Associations between MNRead, IReST, and sustained silent reading speeds with dry eye status, vision, demographic, and health variables in subjects with physician diagnosed dry eye versus controls: Multivariable analyses

Variable	Interval	Outloud (MNRead) Reading Speed Change in wpm (95% CI)	Outloud (IReST) Reading Speed Change in wpm (95% CI)	Sustained Silent Reading Speed % Change (95% CI)
Vision Parameters				
Dry eye (OSDI ≥13)	vs. control	–1 (–11 to 9)	**–10 (–20 to –1)**	**–14% (–25 to -1)**
OSDI Discomfort score	5 units lower	–2 (–4 to 0.1)	**–4 (–3 to –1)**	**–4% (–7 to –2)**
OSDI Vision score	5 units lower	–2 (–4 to 0.2)	**–3 (–5 to –1)**	**–5% (–8 to –2)**
OSDI Total score	5 units lower	**–1 (–2 to –0.002)**	**–2 (–3 to –1)**	**–3% (–4 to –1)**
OSDI Total Score Severity				
Mild(13 to 22)	vs. normal (0 to 12)	9 (–6 to 23)	–2 (–16 to 13)	1% (–19 to 21)
Moderate(23 to 32)		–6 (–20 to 9)	–6 (–21 to 9)	–5% (–23 to 17)
Severe (33 to 100)		–5 (–17 to 7)	**–18 (–31 to –7)**	**–26% (–38 to -13)**
TBUT in worse eye (seconds)	1 unit lower	–2 (–3 to 0.1)	–0.3 (–2 to 1)	0.3% (–2 to 3)
Corneal staining in worse eye	1 unit worse	–0.1 (–1 to 1)	**-2 (-3 to -0.3)**	**–2% (–4 to –0.6)**
Schirmer's in worse eye	1 mm greater	-0.04 (-1 to 0.4)	0.02 (-1 to 1)	-0.3 (-1.0 to 0.5)
Non-Visual Parameters*				
Age	5 years older	–0.2 (–3 to 3)	–0.2 (–2 to 2)	–1% (–5 to 3)
Male	vs. female	7 (–4 to 17)	1 (–10 to 12)	1% (–13 to 18)
Black	vs. non-black	–8 (–22 to 5)	–11 (–25 to 3)	**–28 (–41 to –13)**
Education	4 years less	–5 (–15 to 4)	–2 (–12 to 8)	–10% (–21 to 4)
Employed	vs. not employed	10 (–2 to 21)	9 (–2 to 20)	9% (–7 to 29)
MMSE score	5 points lower	**–13 (–25 to –1)**	**–24 (–37 to –13)**	–14% (–31 to 6)
Depressive symptoms	Present	–2 (–17 to 13)	–5 (–21 to 10)	–17% (–33 to 2)

Bolded values represent statistical significance (p<0.05)

*The values for non-visual parameters taken from a single model including dry eye covariate and all nonvisual variables are shown. All other visual parameter values were derived from a separate multivariable model including the non-visual variables shown.

IReST: International Reading Speed Text; **OSDI:** Ocular Surface Disease Index; **SD:** Standard deviation; **TBUT:** Tear film break-up time; **wpm:** Words per minute

Table 4: Significant Interactions between Dry Eye Severity and Word Features on Word/Post-Word Interval Complex Duration, Multivariable Analysis*

Variable	**Interval**	**OSDI** Word/Post-Word Interval Complex (ms) β (95% CI)	**Tear Break Up Time** Word/Post-Word Interval Complex (ms) β (95% CI)	**Corneal Staining** Word/Post-Word Interval Complex (ms) β (95% CI)	**Schirmer's Test** Word/Post-Word Interval Complex (ms) β (95% CI)
Dry Eye & Word Size					
Dry eye metric*	1 unit increase	0.2 (-0.5 to 0.9)	2 (-4 to 7)	0.1 (-4 to 4)	0.3 (-1.2 to 2)
Word Size	1 letter longer	**23 (19 to 28)**	**29 (24 to 34)**	**24 (18 to 29)**	**28 (23 to 33)**
Dry eye metric • Word Size[†]		**0.2 (0.1 to 0.3)**	-0.6 (-1 to 0.3)	0.7 (-0.1 to 1.4)	-0.1 (-0.3 to 0.2)
Dry Eye & Word Frequency[‡]					
Dry eye metric*	1 unit increase	**2 (1 to 3)**	-2 (-7 to 4)	**5 (0.2 to 10)**	-0.2 (-2 to 2)
Word Frequency	10 fold less common	**44 (41 to 48)**	**46 (43 to 49)**	**45 (40 to 49)**	**46 (43 to 50)**
Dry eye metric • Word Frequency[†]		**0.1 (0.02 to 0.2)**	0.1 (-0.6 to 0.8)	0.3 (-0.3 to 0.9)	0.02 (-0.2 to 0.2)
Dry Eye & Last Word of Line					
Dry eye metric*	1 unit increase	**1 (0.5 to 1.5)**	-1 (-4 to 3)	3 (-0.4 to 5)	-0.3 (-1 to 1)
Last Word of Line	vs. not last word	**30 (7 to 53)**	**44 (18 to 71)**	21 (-9 to 51)	**44 (17 to 70)**
Dry eye metric • Last Word of Line[†]		0.4 (-0.4 to 1)	-2 (-7 to 4)	3 (-1 to 8)	-0.5 (-2 to 1)

Bolded values represent outcomes with p<0.05. Positive values indicate slower reading (longer word/post-word interval complex reading times) for words that were longer, less frequently used, or found at the end of a line of text for the respective dry eye metric. Negative values represent faster reading (shorter word/post-word interval complex reading time).

* Four dry eye metrics used: OSDI (unit= 1 point), Tear Film Breakup Time (unit=1 second), Corneal Staining (unit= 1 point), and Schirmer's Test (unit= 1 millimeter).

[†] The impact of each interaction derived from a separate model including the dry eye metric, the word feature of interest, the interaction term (dry eye metric x word feature), and all relevant non-visual metrics (age, gender, race, education, mini-mental state exam, word size, word frequency).

‡ Represented by negative log of word frequency per million words used in common English language

CI- Confidence interval; **mm-** millimeter

Funding: EY018595, EY022976, and Dr. Akpek has been supported in part by an unrestricted grant provided by Jerome L. Greene Sjögren’s Center, Johns Hopkins University, Baltimore, Maryland.

Competing Interests:

Esen Akpek: Allergan (Irvine, CA); Advisory boards supported by Biogen Idec (Cambridge, MA), Seattle Genetics (Bothell, WA), Novartis (New York, NY) & Shire (Lexington, MA); Unpaid member of Sjogren's Syndrome Foundation.

No other authors have any competing interests/disclosures.

<u>Contributorship Statement:</u>

Priya Mathews: Acquisition/analysis/interpretation of data, drafting the manuscript, final approval of version to be published, and agreeable to be accountable for all aspects of the work

Pradeep Ramulu: Design of the work, acquisition/analysis/interpretation of data, revising the manuscript, final approval of version to be published, and agreeable to be accountable for all aspects of the work

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Canan Utine: Design of the work, acquisition/analysis/interpretation of data, revising the manuscript, final approval of version to be published, and agreeable to be accountable for all aspects of the work

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Esen Akpek: Design of the work, acquisition/analysis/interpretation of data, drafting and revising the manuscript, final approval of version to be published, and agreeable to be accountable for all aspects of the work

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