



(51) International Patent Classification:
G06F 3/01 (2006.01)

(21) International Application Number:
PCT/GB2017/052656

(22) International Filing Date:
11 September 2017 (11.09.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1615382.7 09 September 2016 (09.09.2016) GB

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(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

(54) Title: A READING SYSTEM, TEXT DISPLAY METHOD AND APPARATUS

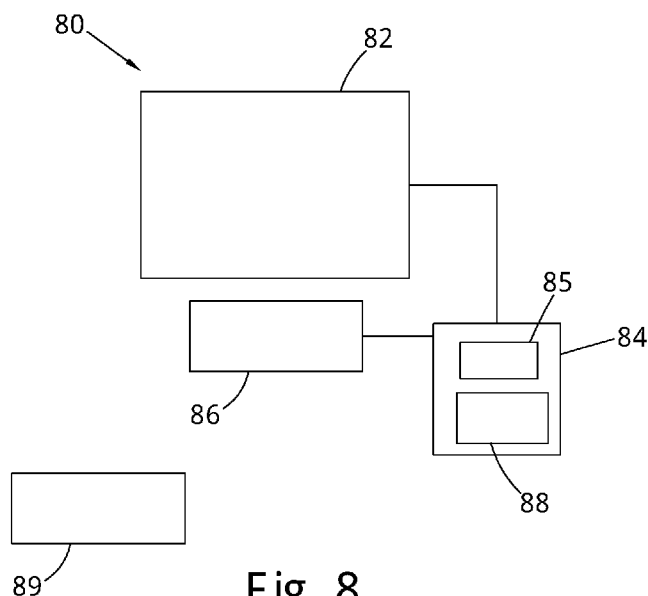


Fig. 8

(57) Abstract: A reading system comprises an apparatus comprising a screen and a processor configured to display a sequence of text to a reader in a reading process; and at least one processing resource configured to obtain reading data representative of at least one property of the text and/or the reading process, and to process the reading data to identify changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader.

Published:

- *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

A reading system, text display method and apparatus

Field

- 5 The present invention relates to a text display method and apparatus. The present invention also relates to a reading system for obtaining and processing reading data, and a method of using the reading system.

Background

- 10 Reading on-screen electronic text may be one of the most widespread and significant human-machine interactions. A proliferation of miniature direct-view display screens, for example in devices such as smart watches, has renewed interest in alternative methods of text presentation to a traditional page-at-a-time display. Proposed text presentation methods may address how to present text so as to facilitate effective reading when there is insufficient space on the screen for a full paragraph.

- 15 Furthermore, the low vision community may seek a wider selection of text presentation formats to optimise use of their residual vision.

- 20 One proposed text presentation method is rapid serial visual presentation (RSVP) in which single words are displayed in quick succession at fixed location on the screen. The use of RSVP may reduce a need for eye movements while reading. Variations and refinements on the RSVP technique have been introduced, for example in an RSVP app called Spritz.

- 25 An intrinsic feature of the RSVP technique may be that parafoveal processing is suppressed. Parafoveal processing refers to the way that readers use their off-central (parafoveal) vision to access information. It has been demonstrated that lack of parafoveal processing may adversely affect comprehension during RSVP reading.

- 30 In RSVP, one word is displayed at a time in sequence. A reader may be unable to regress to a previously-viewed word. Prevention of regressions may adversely affect comprehension during RSVP reading.

- 35 A further proposed text presentation method is continuously scrolling text. In continuously scrolling text, a line of text may move smoothly across a screen from right to left. Continuously scrolling text may display sentences rather than single words. Continuously scrolling text may maintain a benefit of parafoveal preview used in normal reading. Parafoveal preview may be particularly useful for readers with central vision loss.

However, continuously scrolling text may require smooth pursuit eye movements that are not required in normal (non-scrolling) reading. Continuously scrolling text may increase fixation and/or pursuit times when compared with static text. When scrolled too quickly, words may become blurred and become difficult to read.

5 Summary

10 In a first aspect of the invention, there is provided a text display method comprising scrolling a line of text across a screen, the scrolling comprising: at least one pause in which the line of text does not move; and at least one text movement in which the line of text moves; wherein at least one parameter of the scrolling is determined based on measured eye movement data from at least one test subject, such that the scrolling mimics eye movement of the at least one test subject.

Text may be scrolled across the screen in a single visible line.

15 The line of text may move between text positions. A text position may be a position of the line of text on the screen. The line of text may move between a series of text positions. The line of text may move in a series of text movements.

20 The determining of the at least one parameter of the scrolling may comprise selecting and/or controlling at least one parameter of the scrolling.

25 Using measured eye movement data may provide a natural and/or intuitive text display since the scrolling method is based on natural eye movements. A text display method based on measured eye movement data may be more intelligible to at least some readers than a text display that is not based on measured eye movement data.

30 The text display method may provide a faster reading speed than some other scrolling display methods, for example continuous scrolling. The reader's eyes may not have to make smooth pursuit movements. The text display method may provide a faster reading speed than some other display methods, for example display methods that do not use scrolling. A faster speed may result from the scrolled text moving on the screen, which may reduce the amount of eye movement required from a user reading the text. The text display method may be appropriate for use on small screens, for example screens of smart phones or smart watches.

35 By displaying a line of text, a reader may use parafoveal vision to preview parts of the text, which may increase comprehension when compared to methods in which parafoveal preview is not available. Displaying the line of text instead of a single word may have benefit for readers with central vision loss.

The text movement may move the line of text horizontally and/or vertically. The text movement may move the line of text from right to left. The text movement may move the text from left to right. The text movement may move the text vertically upwards. The text movement may move the text vertically downwards.

- 5 The at least one parameter of the scrolling may comprise a duration or text position of at least one pause. The duration or text position of the at least one pause may be based on a duration or text position of a corresponding fixation in the eye movement data and/or on a word frequency and/or on a word length.

- 10 Values for at least one parameter of the scrolling may be determined by at least one feature of the text to be displayed. For example, at least one parameter of the scrolling may be determined by at least one text length, sentence length, word length, word frequency, word familiarity. Values for least one parameter of the scrolling may be determined according to a type of scrolling (for example, whether it is intended to mimic eye movements closely or smooth over it, or whether it is intended to mimic a population or an individual). Values for at least one parameter of the scrolling may be determined according to a type of text (for example, whether the text comprises single sentences or a paragraph, or is complex or simple). Values for at least one parameter of the scrolling may be determined according to a language used. Values for at least one parameter of the scrolling may be determined according to a condition of a reader to whom the text is displayed, for example whether the reader is normally sighted, has vision loss, is dyslexic or has a neurodegenerative disease. Values for at least one parameter of the scrolling may be determined in accordance with a reading task to be performed, for example skim reading or in depth reading. Values for at least one parameter of the scrolling may be determined in accordance with user preference.

- 25 The pause may be a pause on a particular word in the line of text, and the corresponding fixation may be a fixation on the same word in the same line of text, or in different text. The duration or text position of the corresponding fixation in the eye movement data may be an average duration or text position in eye movement data from a plurality of test subjects.

- 30 A duration of the or each pause may be at least 30 ms, optionally at least 50 ms, further optionally at least 100 ms, further optionally at least 200 ms. A duration of the or each pause may be less than 1 second, optionally less than 500 ms, further optionally less than 300 ms. Different pause durations and/or positions may be used for different words, for example words of different length, frequency, complexity or familiarity.

- Pause duration may be determined based on an equation linking pause duration to word length and word frequency. Pause duration may be moderated based on a speed setting.

- 35 The at least one parameter of the scrolling may comprise a duration or length of at least one text movement. The duration or length of the at least one text movement may be based on a duration or length of a corresponding saccade in the eye movement data. The text movement may itself be referred to as a saccade or

text saccade. The duration of a text movement may be referred to as a saccade duration. The length of a text movement may be referred to as a saccade length. The length of the at least one text movement may comprise a distance over which the text moves while performing the text movement. The distance may be measured as, for example, a distance in millimetres and/or a number of characters by which the text moves.

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A length of the or each text movement may be at least 1 character, optionally at least 3 characters, further optionally at least 5 characters, further optionally at least 7 characters. The length of the or each text movement may be less than 10 characters, optionally less than 8 characters, further optionally less than 6 characters. Different text movement lengths may be used for different words, for example words of different length, frequency, complexity or familiarity. A duration of the or each text movement may be between 10 ms and 100 ms, optionally between 20 ms and 50 ms, further optionally between 20 ms and 35 ms.

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The text movement may be a text movement between particular words in the line of text, and the corresponding saccade may be a saccade between the same words in the same line of text, or in different text.

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The duration or length of the corresponding saccade in the eye movement data may be an average duration or text position in eye movement data from a plurality of test subjects. The length of the saccade may comprise a distance from a first point in the text on which a user's eye is fixed at the start of the saccade to a second point in the text on which the user's eye is fixed at the end of the saccade.

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By basing pause parameters and/or text movement parameters on the parameters of fixations and/or saccades in natural eye movements, the text display method may mimic a natural pattern of eye movement, which may result the text display method seeming natural to a user. The text may be displayed in a manner that takes into account the actual content of the text (for example, the sentence) being displayed, for example word lengths or word frequencies. In deciding how to take into account the sentence content, the text display apparatus may utilise data on how a word or sentence is read, either by a population or by at least one individual. The text display apparatus may be considered smart. The text display apparatus may be considered to adapt to the sentences that it is provided with and/or a user that it is presenting to.

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A value for at one parameter of the scrolling may vary within the line of text. For example, different pause durations may be used for different words or portions of words in the line of text. In some circumstances, different parameter values (for example, different pause durations, text movement lengths and/or different text movement durations) may be used for different words in a sentence, for example for adjacent words.

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In some circumstances, different parameter values may be used for words of different lengths. For example, a longer pause duration may be used for longer words. Different parameter values may be used based on the complexity or familiarity of words. For example, a longer pause duration may be used for more complex and/or less familiar words. Different parameter values may be used based on the frequency at which each word occurs, for example how often each word appears in a language corpus.

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The text display may therefore appear to speed up and slow down even within a single sentence.

5 A duration of the or each text movement may be such that the text appears to move instantaneously from one position to a further position. The text may move between adjacent frames, such that the text is shown at a first position on a first frame, and is shown at a second position on a second frame which directly follows the first frame.

10 The screen may be configured to display a fixed number of frames per second, for example 25, 30, 50, 60, 120 or 240 frames per second. A frame refresh time may be 1 second divided by the number of frames per second. A duration of the or each pause may be an integer multiple of the frame refresh time.

15 The at least one parameter of the scrolling may comprise a scrolling speed. The at least one parameter of the scrolling may comprise a regression parameter. The regression parameter may comprise at least one of a number of words by which to regress, a number of characters by which to regress, a number of regressions.

The text display method may further comprise modifying the at least one parameter of the scrolling based on an input received from a reader.

20 The reader may input a reading speed. The modifying of the at least one parameter of the scrolling may comprise modifying at least one pause duration and/or at least one text movement duration in dependence on the input reading speed. The modifying of the at least one parameter of the scrolling may comprise scaling at least one pause duration and/or at least one text movement duration in inverse proportion to a change in reading speed.

25 The method may further comprise displaying on the screen a reading position indicator. The reading position indicator may be indicative of a position on the screen on which a reader of the line of text is intended to fixate while reading.

30 The method may further comprise displaying on the screen a progress indicator that is indicative of a position in the displayed text.

35 The scrolling of the line of text may be such that the centre of each word of the line of text is positioned at the reading position. The scrolling of the line of text may be such that the position in each word that is positioned at the reading position is dependent on a corresponding pause position in the eye movement data.

By providing a reading position indicator, a reader may know where to fixate while reading. The reading position indicator may be positioned in dependence on a reader's vision. For a reader with central vision loss,

the reading position indicator may be positioned differently from the position used for a reader without central vision loss.

5 The method may further comprise obtaining the measured eye movement data from the at least one test subject by measuring eye movement of the at least one test subject while the at least one test subject is reading at least one sample text.

10 The at least one sample text may be displayed as static text. The eye movement data may comprise a set of saccades and fixations made by the at least one test subject while reading the at least one sample text. The at least one sample text may be a standardised text, for example a text used in a standardised vision test.

15 The eye movement data may be measured from a single test subject, and the at least one scrolling parameter may be based only on the data from that single test subject. The eye movement data of the single test subject may be used to determine at least one scrolling parameter for a text display that is to be displayed to that subject at a subsequent time. By using a single test subject, a tailored set of eye movement data may be obtained. In some circumstances, the test subject may find text displayed using parameters based on their own eye movement data to be easier to read than text displayed using parameters based on someone else's eye movement data, or on averaged eye movement data.

20 The measured eye movement data may be obtained from each of a plurality of test subjects reading the same at least one sample text. The method may further comprise processing the measured eye movement data to obtain average eye movement data. The determining of the at least one parameter of the scrolling may be based on the average eye movement data.

25 The measured eye movement data may comprise an eye movement corpus. The measured eye movement data may be processed to obtain a range of eye movement data. By averaging data from a plurality of test subjects, eye movement data may be obtained that is representative of the eye movement data of a population. The measured eye movement data may be used to display text in a way that may be suitable for use by a range of readers, for example if the eye movement data is found to be consistent across a particular population of
30 readers.

35 Measured eye movement data for words in the at least one sample text may be extrapolated to words that are not in the at least one sample text. For example, a pause duration for a word in the line of text that is not part of the at least one sample text may be determined based on fixation durations for other words that are part of the at least one sample text, for example by determining trends in fixation duration against word length and/or word frequency.

In a further aspect of the invention, which may be provided independently, there is provided a method of determining text display parameters for a scrolling text display, the method comprising: obtaining measured eye movement data from the at least one test subject; and determining based on the measured eye movement data to determine at least one parameter to be used in scrolling text across the screen, such that the scrolling mimics eye movement of the at least one test subject. The measured eye movement data may be eye movement data of a population.

In a further aspect of the invention, which may be provided independently, there is provided a text display apparatus comprising a screen and a processor, wherein the processing is configured to scroll a line of text across the screen, the scrolling comprising: at least one pause in which the line of text does not move; and at least one movement in which the line of text moves between text positions; wherein at least one parameter of the scrolling is determined based on measured eye movement data from at least one test subject, such that the scrolling mimics eye movement of the at least one test subject.

The text display apparatus may comprise a head-mounted display system. Text may be displayed on one or more screens of the head-mounted display system. The head-mounted display system may comprise smart glasses. The head-mounted display system may comprise a smartphone headset.

The use of a head-mounted display system may benefit readers who have difficulty in maintaining a consistent head position, or readers who have difficulty in holding a hand-held device such as a tablet or e-reader.

The text display apparatus may comprise at least one of a computer, a portable computer, a laptop, a tablet, an e-reader, a smartphone, a handheld reading device, a handheld computing device, an assistive reading device, a television.

The screen may comprise at least one of a laptop screen, a tablet screen, a stand-alone screen, a television.

The text display apparatus may be further configured to record reading data.

The reading data may comprise eye movement data, blink rate data or pupillary response data. The text display apparatus may comprise a detector configured to record the eye movement data, blink rate data or pupillary response data. The detector may be part of a head-mounted display system.

The text display apparatus may be portable. The text display apparatus may be handheld. The text display apparatus may be an apparatus used by a reader for normal reading, for example for reading books, magazines, emails or websites.

In a further aspect of the invention, which may be provided independently, there is provided a reading system comprising: an apparatus comprising a screen and a processor configured to display a sequence of text to a reader in a reading process; and at least one processing resource configured to: obtain reading data representative of at least one property of the text and/or the reading process, and to process the reading data to identify changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader.

The at least one processing resource may process the reading data automatically.

Gathering feedback on a user's reading over an extended period of time may allow a clinician to determine whether there has been a deterioration in the user's sight or neurological function. The user may be a user with a known visual or neurological condition. The user may be a user who is considered to be at risk of developing a visual or neurological condition.

The reading system may be portable. The reading system may be handheld. The reading system may comprise an apparatus used by a reader for normal reading, for example for reading books, magazines, emails or websites. Obtaining reading data using a portable device may be convenient for a reader.

The apparatus comprising the screen and the processor may be portable. The apparatus comprising the screen and the processor may be handheld. The apparatus comprising the screen and the processor may be a text display apparatus. The system may comprise a communication resource configured to transmit the identified changes and/or the reading data to a remote location. The remote location may comprise a remote computing apparatus. The remote computing apparatus may comprise a remote server. The remote computing apparatus may comprise a remote workstation. The processing resource may be located in the remote location.

The system may comprise or be associated with a data store configured to store the reading data. The data store may be local to the screen and/or processor. The data store may be remote.

The remote computing apparatus may be part of a medical records system. The changes may be stored as part of the reader's medical records. Data on the remote computing apparatus may be accessible by medical professionals.

The system may be configured to obtain the reading data in a home or office environment. The system may be configured to obtain the reading data in the reader's normal or everyday environment.

The apparatus may be used by the reader in the reader's home. The apparatus may be used by the reader for routine reading. By processing the reading data, for example by processing the reading data automatically, subtle changes may be identified that may not be apparent to the reader themselves. Reading data may be

acquired much more often than a frequency of traditional vision testing. Changes in the reading data may be identified in a time period that is much shorter than an interval between traditional vision tests. Patients having known visual or neurological conditions may be monitored more frequently than if the patient were to be monitored by testing in a clinic.

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Readers in an at-risk population may be monitored more often than would be the case with traditional vision tests. By using the system to provide automated monitoring, it may be the case that a larger at-risk population may undergo regular monitoring than would be the case if a medical professional were required to administer the monitoring.

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The processing resource may be further configured to issue an alert based on one or more of the identified changes. The processing resource may be configured to issue the alert to the reader. The processing resource may be configured to issue the alert to a medical professional.

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The processing resource may compare one or more parameters of the reading data to a threshold value, and issue the alert based on the comparison. The threshold value may comprise a baseline value for the reader. The threshold value may comprise a normal value for a population.

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The processor may be configured to obtain the reading data from normal reading activities of the reader, the normal reading activities comprising reading text from the screen.

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The reader may not be required to perform dedicated reading tests. Reading data may be obtained from the reader's daily activities, for example reading a novel or a news article. Obtaining reading data from normal reading activities may be more convenient for the reader than performing dedicated vision tests. Better reader compliance may be achieved. The reading data may be representative of the reader's normal reading performance. Reading data may be acquired in an environment in which the reader normally reads, for example under light levels usually used by the reader.

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The processor may be configured to receive a selection of an item of content from the reader and to display at least part of the item of content on the screen on the screen. The obtaining of the reading data may comprise obtaining reading data relevant to the reader's reading of at least part of the item of content.

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The item of content may be any item that may be read by the reader in normal reading, for example a book, newspaper or magazine article, or website.

The processor may be further configured to deliver vision tests to the user via the screen. The obtaining of the reading data may comprise obtaining reading data from the vision tests.

The vision tests may comprise at least one of perimetry tests, reading speed tests, reading acuity tests, contrast visibility tests, contrast sensitivity tests and pupillary response tests. The vision tests may comprise standardised and reproducible test. Reading data obtained from vision tests may be interpreted using standard techniques. By providing the vision tests on an apparatus that may be used in the reader's home (for example, for routine reading), the tests may be provided much more often than tests in a surgery or hospital. The vision tests may comprise tests of screen visibility on the particular screen used. The changes in the reading data over time may comprise changes in performance in the vision tests.

The reading data may comprise at least one of text size, typeface, contrast, colour contrast, reading speed, reading duration, luminance. The text size may comprise a reading test-type equivalent size. The text size may be measured in terms of visual angle instead of letter height. The at least one property of the text may comprise at least one of text size, typeface, contrast, colour contrast, reading speed, luminance. The reading data may comprise at least one of an interocular presentation parameter, a bilateral presentation parameter. The reading data may comprise different parameter values for each eye.

The reading data may comprise a location of presentation. A reader may select a location of presentation to locate text on a preferred retinal locus. A change in location of presentation over time may be indicative of a change in the extent of the reader's vision.

The reading data may comprise eye movement data, blink rate data or pupil response data. The apparatus may further comprise a detector configured to measure eye movement data, blink rate data or pupil response data and to deliver the measured eye movement data, blink rate data or pupil response data to the processor. The apparatus may be the text display apparatus. The reading data may be obtained while the reader is reading text displayed using the test display method.

The visual or neurological deterioration may be due to, or the at least one condition may comprise, at least one of: amblyopia, dyslexia, macular disease, glaucoma, cognitive decline, dementia, a neurodegenerative disease, motor neurone disease, multiple sclerosis, Parkinson's disease, stroke.

The at least one condition may comprise a condition that causes at least one of optic neuritis, optic neuropathy, macular oedema. The at least one condition may comprise at least one of multiple sclerosis, glaucoma, diabetes, retinal vein occlusion, retinal dystrophy, uveitis, macular degeneration, age-related macular degeneration.

Changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader may comprise at least one of larger print size, increased illumination, increased contrast, a change in colour contrast preference in one eye, a change in colour contrast preference in both eyes.

Changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader may comprise at least one of a change in pupil response, a change in smooth pursuit eye movements, a change in saccadic eye movements.

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Changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader may comprise changes compared to baseline data. Reading data may be compared to normative datasets, for example to normative age-gender matched data sets. Changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader may comprise changes resulting in parameter values outside a normative range.

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The at least one processing resource may comprise a first processing resource and a second processing resource at a different location from the first processing resource. The first processing resource may be configured to obtain reading data representative of the at least one property of the text and/or the reading process. The second processing resource may be configured to process the reading data to identify changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader. The second processing resource may be located at the or a remote location.

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The apparatus may comprise at least one of a computer, a portable computer, a laptop, a tablet, an e-reader, a smartphone, a handheld reading device, a handheld computing device, an assistive reading device, a head-mounted display system, smart glasses, a smartphone headset.

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In a further aspect of the invention, which may be provided independently, there is provided a system comprising at least one processing resource configured to obtain reading data representative of at least one property of a sequence of text displayed to a reader in a reading process and/or of the reading process, and to process the reading data to identify changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader. The system may be configured to obtain reading data from a plurality of readers. The system may be accessible by medical professionals.

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In a further aspect of the invention, which may be provided independently, there is provided a reading system comprising: an apparatus comprising a screen and a processor configured to display a sequence of text to a reader in a reading process; and at least one processing resource configured to obtain reading data representative of at least one property of the text and/or the reading process, and to process the reading data to identify parameter values in the reading data that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader.

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The at least one condition may comprise a condition that causes at least one of optic neuritis, optic neuropathy, macular oedema. The at least one condition may comprise at least one of multiple sclerosis, glaucoma, diabetes, retinal vein occlusion, retinal dystrophy, uveitis, macular degeneration, age-related macular degeneration.

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In a further aspect of the invention, which may be provided independently, there is provided a method comprising obtaining reading data from a reader; automatically processing the reading data to identify changes in the reading data over time that may be indicative of visual or neurological deterioration in the reader; and automatically communicating the identified changes to the reader or to a further user.

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In another aspect of the invention, which may be provided independently, there is provided a computer program product comprising computer readable instructions that are executable by a processor to perform a method as claimed or described herein.

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There may be provided a method or system substantially as described herein with reference to the accompanying drawings.

Features in one aspect may be provided as features in any other aspect as appropriate. For example, features of a method may be provided as features of an apparatus and vice versa. Any feature or features in one aspect may be provided in combination with any suitable feature or features in any other aspect.

20

Detailed description of embodiments

Embodiments of the invention are now described, by way of non-limiting example, and are illustrated in the following figures, in which:-

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Figure 1 is a schematic illustration of a data gathering apparatus in accordance with an embodiment;

Figure 2 is a schematic illustration of a text display apparatus in accordance with an embodiment;

Figure 3 is a flow chart illustrating in overview a method of an embodiment;

Figure 4 is an illustration of one frame of a text presentation method in accordance with an embodiment;

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Figures 5a, 5b and 5c illustrate successive frames of a text presentation method in accordance with an embodiment;

Figure 6 is a schematic illustration of a text display apparatus in accordance with an embodiment;

Figure 7 is a flow chart illustrating in overview a method of an embodiment;

Figure 8 is a schematic illustration of a reading data collection apparatus in accordance with an embodiment;

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Figure 9 is a schematic illustration of a reading data collection apparatus in accordance with an embodiment;

Figure 10 is a plot of total reading time against word frequency;

Figure 11 is a plot of total reading time against word length;

Figure 12 is a plot of total reading time against number of fixations per word;

Figure 13 is a plot of mean reading speed;

Figure 14 is a flow chart illustrating in overview a text display method in accordance with an embodiment;

Figure 15 is a plot of reading speed using optical magnifier against reading speed using dynamic text on smart glasses;

5 Figure 16 is a plot of the number of participants that achieved their fastest reading speed from each of four methods (static, RSVP, horizontal smooth scrolling, biomimetic scrolling);

Figure 17 is a plot of mean reading speed for each of four text presentation methods (static, RSVP, horizontal smooth scrolling, biomimetic scrolling);

10 Figure 18 is a plot of responses to the question, 'Compared to reading large print from paper, did you find reading from the display to be...'; and

Figure 19 is a plot of responses to the question, 'Did you prefer reading from the display or from paper?'.

15 Figure 1 is a schematic illustration of a data gathering apparatus 10 in accordance with an embodiment. Figure 2 is a schematic illustration of a text display apparatus in accordance with the embodiment. In the embodiment, the data gathering apparatus of Figure 1 is used to gather eye movement data from a plurality of test subjects. The eye movement data from the plurality of test subjects is used to determine parameters for a text presentation method, biomimetic scrolling, that is used to present text on a display screen of the text display apparatus of Figure 2.

20 In some embodiments a single apparatus may be used as both a data gathering apparatus 10 and text display apparatus 20. In some embodiments, the data gathering apparatus 10 and/or text display apparatus 20 may comprise a plurality of connected apparatuses.

25 The data gathering apparatus 10 comprises a display screen 12, computing apparatus 14, camera 16, and head support 19. In some embodiments, no head support 19 is used. In further embodiments, any eye movement detector may be used in place of camera 16.

30 In the present embodiment, the computing apparatus 14 is a desktop computer, for example a PC. The computing apparatus 14 comprises a processor 18. In other embodiments, the computing apparatus 14 may be any suitable computing device. In some embodiments, the display screen 12 is integrated into the computing apparatus 14.

35 In the present embodiment, the data gathering apparatus 10 comprises a SR Research EyeLink 1000 Desktop mount system with a 2000 Hz camera upgrade. In other embodiments, any data gathering apparatus may be used that is configured to measure and record eye movement data.

The processor 18 is configured to display text on the display screen 12. In the present embodiment, the text comprises a plurality of individual test sentences. The test sentences are displayed one by one. Each test

sentence is displayed as a static display. In other embodiments, any sample text in any suitable text format may be used.

5 A test subject is positioned with their head supported by the head support 19 and their eyes facing the display screen 12. The test subject is instructed to read the text displayed on the display screen 12. The camera 16 records movement of one or both eyes of the test subject while the test subject is reading the displayed text. Eye movement data from camera 16 is stored by the processor 18.

10 In the present embodiment, eye movement data is recorded for a large number of test subjects (for example, 100 or more test subjects), each reading a large number of test sentences (for example, 100 or more sentences). In other embodiments, any number of test subjects may be used. Any suitable text may be used for testing.

15 It is known that when reading a subject's eyes may not move smoothly, but may move in a series of fixations and saccades. A fixation may be an interval in which the subject's eyes stay in one position, fixating on a point in the text. A saccade may be an interval in which the subject's eyes move along the text. The motion of the subject's eyes may also include one or more backwards saccades, in which the subject's eyes return to a previously-read part of the text. Backwards saccades may be referred to as regressions, and may occur about 10% to 15% of the time. Eye movements in reading may serve to direct light from target words onto the fovea, which may be the area of the retina with the highest visual acuity.

20 In the present embodiment, the eye movement data recorded for each of the test subjects is processed by the processor 18 to determine for each test sentence a plurality of fixations and saccades, each having associated parameters as described below.

25 For each fixation, the processor 18 determines a fixation position and a fixation duration. The fixation position is the position in the text that the subject is looking at during the fixation, for example the letter that the subject is looking at. The fixation duration is the length of time for which the subject's eyes are substantially still while looking at the fixation position. In some circumstances, a typical length of fixation may be around 250 ms, but there may be variation depending on text legibility, linguistic difficulty, reading ability and the aim of the reader.

30 For each saccade, the processor 18 determines a saccade duration and a saccade length. The saccade duration is the length of time during which the subject's eyes moved. The saccade length is the distance in the text by which the subject's eyes moved, for example a number of letters. In some circumstances, a typical saccade may last around 20 to 35 ms and may span 7 letters in English.

35 A total viewing duration for a word may be determined by taking the sum of all fixation durations of that word, regardless of whether the fixations on the word are regressions or not.

In normal reading, not every word may be fixated. Some words may be skipped. Some words may be refixated. Skipping probability, fixation probability and refixation probability may be calculated for each word.

- 5 A pattern of fixations may be plotted on a one dimensional plot which has horizontal sentence position as its axis.

10 In some embodiments, an analysis of eye movement may be simplified by considering each eye movement to be either a fixation or a saccade. Smooth pursuit eye movements may not be considered. Smooth pursuit eye movements are generally used to track a moving object, so may not be used to read static text. Finer eye movements such as microsaccades (involuntary saccades during fixation), drifts (slow curved movements between microsaccades), and tremors (very fast small oscillations superimposed on drifts) may not be considered.

- 15 The analysis of eye movement data may be simplified by considering only horizontal eye movements. In practice, fixations may occur above or below a line of text being read.

20 The analysis of eye movement data may be simplified by defining the motion of saccades using start and end positions and saccade duration, without considering precise movement of eye motions between fixations. A saccade taking the shortest route between the start and end positions may be assumed.

25 The processor 18 aggregates the eye movement data from the plurality of test subjects. In the present embodiment, the processor 18 determines, for each test sentence, average values for fixation position, fixation duration, saccade duration, and saccade length. In other embodiments, different parameters may be determined. Any suitable statistical measures may be determined for each parameter, for example range, mean, and standard deviation.

30 In the present embodiments, correlations and linear regressions are calculated for a population in order to translate word characteristics (for example, word frequency and word length) that are available for any given text into parameters of biomimetic scrolling.

35 Figure 2 is a schematic illustration of a text display apparatus 20 comprising a display screen 22 and computing apparatus 24. In the present embodiment, the computing apparatus 24 is a desktop computer, for example a PC. The computing apparatus 24 comprises a processor 28 configured to display text on display screen 12 using biomimetic scrolling. In other embodiments, the computing apparatus 24 may be any suitable computing device, for example a laptop, tablet, smartphone, or e-reader. The computing apparatus 24 may be an assistive reading device, for example a device that is configured to provide text display for a reader with

low vision. The computing apparatus 24 may be portable or handheld. In some embodiments, the display screen 22 is integrated into the computing apparatus 24.

In use, processor 28 displays text on display screen 22 using a biomimetic scrolling text presentation method. The biomimetic scrolling method is configured to mimic natural eye movements made when reading. Biomimetic scrolling may also be referred to as saccadic scrolling, since the text display of biomimetic scrolling may mimic saccadic movement of the eye. Parameters of the biomimetic scrolling method are determined using the eye movement data obtained using the data gathering apparatus 10 of Figure 1.

Biomimetic text presentation software may be installed on processor 28, for example a biomimetic text presentation app. The biomimetic text presentation software may be configured to instruct the processor 28 to perform each of a set of actions described below.

Figure 3 is a flow chart illustrating a method of an embodiment. At stage 30 of the method of Figure 3, the camera 16 measures eye movement data for a plurality of test subjects reading a plurality of sentences. At stage 32, the processor 18 translates the eye movement data obtained by the camera 16 into a series of saccades and fixations. At stage 34, the processor 28 of the test display apparatus 20 uses the measured saccades and fixations to determine a set of biomimetic scrolling parameters for text display. In other embodiments, the biomimetic scrolling parameters are determined by processor 18 of the data gathering apparatus 10, or by any other suitable computing device. At stage 36, the processor 28 displays a sentence to a reader on display screen 22 using the determined biomimetic scrolling parameters.

Figure 4 is a schematic illustration of an example of a biomimetic scrolling text display displayed on display screen 22. In use, a line of text 40 scrolls intermittently from right to left. The intermittent scrolling is configured to mimic natural eye movement. The intermittent scrolling comprises a set of pauses and a set of text movements. The text movements may be called saccades or text saccades, by analogy with the saccades made by the eye when reading. A length and duration of a text movement may be referred to as a saccade length and saccade duration.

A reader is instructed to look at a reading position on the line of text 40. The reading position is a position on which it is intended that a reader should fixate while reading the text as it is displayed by biomimetic scrolling. In the present embodiment, the reading position is indicated by a pair of arrows 24, which may be referred to as reading position indicators. The reading position is a position on the text that is located between the arrows 42. In other embodiments, any suitable reading position indicator may be used. For example, a color or size of the displayed text may be used to indicate a part of the text on which the reader should fixate.

Initially, the line of text 40 is displayed such that the arrows 42 point to a first position in the text, which may be referred to as a first pause position. The line of text 40 remains with the arrows 42 pointing to the first pause position for a first pause duration.

5 The line of text 40 then moves horizontally from right to left in a first text movement. The line of text 40 moves from right to left by a number of letters. The number of letters may be referred to as the first text movement length, or a first saccade length. The line of text 40 moves to a position in which the arrows 42 point to a second pause position in the text. In other embodiments, the line of text may move in any suitable direction. For example, the line of text may be in a language that is read from right to left, and the line of text
10 may therefore move from left to right. The line of text may be in a language that is read vertically and the line of text may move vertically upwards or downwards.

The time taken to move the line of text 40 between the first pause position and second pause position may be referred to as the first text movement duration, or a first saccade duration. If the first text movement duration is
15 zero, the line of text 40 moves directly from the first position to second position without assuming any intermediate positions. If the text movement duration is non-zero, the line of text 40 scrolls smoothly from the first position to the second position. The time taken to scroll from the first position to the second position is the first text movement duration.

20 The line of text 40 remains with the arrows 42 pointing to the second position for a second pause duration. The line of text then continues to be moved by the processor 28 in a sequence of alternating text movements and pauses.

By moving the text intermittently in a sequence of text movements and pauses, the biomimetic scrolling
25 method mimics the eye movement of a reader. Instead of the eye moving in a sequence of fixations and saccades, the eye of the reader is intended to be held still while the text moves relative to the eye in a sequence of pauses and text movements that may mimic the fixations and saccades that may occur during normal reading of static text.

30 In the present embodiment, each text movement duration is set at zero. Each pause position is set to be in the middle of a word, which may be referred to as the optimal viewing position (OVP) for that word. It has been found that the OVP (the position in which a reader should fixate) may not be identical to the preferred viewing location (PVL; the location where readers do fixate). In other embodiments, the pause positions may be set at the PVL or at any other position determined using the eye movement data.

35 In the present embodiment, there is a pause at every word of the line of text 40. The text movement lengths are determined using the distances between words. The pause duration for each pause is based on the eye

movement data. In other embodiments, there may be some words that are not paused on, or a single word may contain more than one pause.

For a given word, the pause duration is chosen to equal the total reading time of that word in the eye movement data, which may be defined as the sum of all fixation durations on that word, averaged over all of the plurality of subjects. For each word, a pause duration may be, for example, between 50 and 500 ms.

One parameter that can be adjusted in some embodiments is a number of pauses per word. There may be zero (corresponding to a skipped word), one (corresponding to a fixated word) or two (corresponding to a refixated word). Use of more pauses may be possible, but may be likely to be used only by low vision users reading highly magnified text.

In further embodiments, each pause position is based on an average fixation position in the eye movement data. For example, in the example shown in Figure 4, one of the average fixation positions determined from the eye movement data may be between the 'i' and 'g' of 'delight'. The processor 28 may cause the text to pause at a position such that the arrows 42 point to a pause position between the 'i' and 'g' of 'delight'.

In some embodiments, text movement durations are based on measured saccade durations. For example an average saccade duration for a given saccade may be used to determine a text movement duration for a corresponding text movement. In some embodiments, a text movement duration may be, for example, between 20 and 50 ms.

In the present embodiment, parameters of the scrolling are based on average values for those parameters in eye movement data from a plurality of test subjects.

In a further embodiment, parameters of the scrolling are determined by directly translating fixations and saccades from a single test subject. Each fixation made by the test subject is translated into a pause in the text display, the pause duration being the same as the fixation duration and the pause position being at the same point in the text as the intended reading position (i.e. the point in the text on which the test subject fixated is placed between the arrows 42). Each saccade made by the test subject is translated into a text movement, the text movement duration being the same as the saccade duration. In some embodiments, eye movement data from an individual is used to determine parameters for a text display to be displayed to that individual. The text display may be tailored to an individual.

In some embodiments, text movement durations and/or pause durations are based on frame rates of the display screen 12. The display screen 12 may have a fixed or programmable frame rate, which may also be referred to as a screen refresh rate. The frame rate may be expressed as frames per second, or Hz.

A movement of the text may be performed between one displayed frame and the next displayed frame.

Each frame may be displayed for a frame refresh time which is 1 second divided by the number of frames per second. A pause in the text display may be of one or more frame refresh times.

5

For example, a frame rate may be 25, 30, 50, 60, 120 or 240 frames per second. A frame refresh time may correspondingly be, for example, 1/25 s, 1/30 s, 1/50 s, 1/60 s, 1/120 s or 1/240 s. A pause may be an integer multiple of the frame refresh time. In some circumstances, a maximum pause length may be set. For example, a maximum pause time of 1 second may be used.

10

In the present embodiment, the text displayed to a reader using the text display apparatus of Figure 2 comprises the same sentences as were displayed to the test subjects using the data gathering system of Figure 1. Parameters for a given sentence may be determined using eye movement data measured for that sentence. For example, an average fixation duration for a given word may be used to determine a pause duration for that word.

15

In further embodiments, the text displayed to the reader on the text display apparatus 20 of Figure 2 comprises different sentences from the sentences that were used to collect the eye movement data. The processor 28 may determine values for the biomimetic scrolling parameters from the eye movement data using any suitable method. For example, pause positions or durations obtained for a given word may be used for that word even when it is used in a different context. Trends may be obtained from the eye movement data and applied to different texts. Eye movement data may be extrapolated to sentences for which eye movement data has not previously been measured.

20

25

In some embodiments, the eye movement data is used to determine a relationship between fixation duration and word length. In general, longer words may correspond to longer fixations. If a word is to be displayed that is not part of the text used in testing, the length of the word and the determined relationship between fixation duration and word length is used to determine a pause duration for that word.

30

In some embodiments, the eye movement data is used to determine a relationship between fixation duration and word frequency. A reader's gaze may dwell longer upon low frequency (less common) words than on high-frequency (more common) words. If a word is to be displayed that is not part of the text used in testing, the frequency of the word and the determined relationship between fixation duration and word frequency is used to determine a pause duration for that word.

35

In the present embodiment, each line of text 40 that is displayed comprises a single sentence. The screen 22 is then cleared before displaying a next sentence. In other embodiments, the line of text 40 may comprise one or more sentences, or may comprise a fraction of a sentence. Any length of text may be scrolled, for example

depending on the use of the text. In some embodiments, a pause length on the last word of a sentence may be increased relative to other pauses. Data on the transition between sentences may be incorporated. For example, eye movement data may be analysed to determine a fixation time at the end of a sentence. The fixation time at the end of the sentence may be translated into a corresponding pause time.

5

Text display (for example, a number of sentences displayed at a time) may be influenced by the content and context of the reading materials, or by individual user-driven preferences.

10

The display of text by the text display apparatus 20 may be considered to provide a smart method of text presentation. Some known methods do not take into account the actual content of the text (for example, sentence) being displayed, for example word length or word frequency. Instead, those methods may use parameters that simply designate a size and rate of a step (for example, a number of characters). In the present embodiment, the scrolling method may take into account the content of the sentence. In deciding how to take into account the sentence content, it may utilise data on how those words or that sentence is read (either by a population or by that individual). It may adapt to the sentences it is fed and the user it is presenting to.

15

In the present embodiment, the reader who is reading text on screen 22 is given control of a number of display parameters including one or more biomimetic scrolling parameters. In some embodiments, the reader may change other reading parameters, for example text size, typeface, contrast, or image enhancement parameters. The reader may change a number of sentences displayed. In some embodiments, input from the data and/or data relating to the reader is used to provide a bespoke text presentation for that reader.

20

In the present embodiment, the processor 28 displays on the screen 22 a user interface through which the reader may control the controllable parameters (for example, by selecting from a list or using a dial or slider). The user interface may be provided by biomimetic text presentation software, for example a biomimetic text presentation app. User-driven preference may be delivered through the app. The reader may change values of one or more biomimetic scrolling parameters relative to initial values that were determined based on the eye movement data.

25

The user may increase or decrease pause durations. In one embodiment, the reader inputs a value on a percentage scale and the computing apparatus 24 changes all the pause durations in accordance with the percentage scale, for example by changing all pause durations to 90% or 110% of their original length.

30

The user may change text movement durations. In one embodiment, the reader may change text movement durations by a percentage. In another embodiment, the reader may change text movement durations from zero to non-zero, for example by inputting a value for the text movement durations.

35

The reader may be given control over scrolling speed. A change in the speed setting, measured in words per minute (wpm), proportionally increases or decreases the pause duration on each word. In some embodiments, the change in the speed setting also increases or decreases text movement durations.

- 5 In one embodiment, a range of pause durations is scaled according to an overall scrolling speed which is set by the user. For a scrolling speed of 360 wpm, pause durations may be, for example, between 50 ms and 350 ms. If scrolling speed is decreased, pause durations may be increased proportionally.

- 10 In some embodiments, the reader may change pause positions and/or text movement lengths. In some embodiments, the reader may change biomimetic scrolling parameters for individual words, or based on a position of a word in a sentence (for example, pausing longer at the end of a sentence). In some embodiments, the reader may change the relationship between pause duration and word length, or the relationship between pause duration and word frequency.

- 15 In different embodiments, the reader may be given control of different parameters. In some embodiments, parameter values may be selected by someone other than the reader, for example by a medical professional. Any suitable user interface may be used to allow control of parameters.

- 20 In the embodiment of Figure 3, data collected on eye movement parameters is used to define the horizontal movement of a line of text past a particular point which serves as the location of fixation for a steady gaze. The series of fixations and saccades performed while reading static text is reverse engineered to move the text by biomimetic scrolling. The movement of text mimics eye movements.

- 25 By making the text make the movement rather than the eye, in some circumstance reading speed can be significantly increased. The method of Figure 3 maintains the regular line of text view which is familiar to users, and may include the benefit of parafoveal preview. The eye is intended to remain steady. There may be no blurring effects from moving text.

- 30 The use of biomimetic scrolling may result in a display that is natural and intuitive to readers since it mimics the eye's natural movement when reading. In some circumstances, reading speed may be increased over some other reading methods, for example by reducing the amount of eye movement required. In some circumstances, an amount of eye movement used to read text displayed using biomimetic scrolling may be less than an amount of eye movement used to read static text. In some circumstances, an amount of smooth pursuit eye movement used to read text displayed using biomimetic scrolling may be less than an amount of smooth pursuit eye movement used to read continuously scrolling text.
- 35

Figures 5a to 5c are illustrations of successive frames of a text display of a further embodiment. One implementation of biomimetic scrolling is to use arrows 42 to direct the gaze to a fixation point on the screen.

The text is organized into a single line 40 which moves past the arrows 42 and pauses at various points and for various durations according to the pre-defined settings. In the embodiment of Figures 5a to 5c the settings are as follows:

1. Pause duration: The length of time the sentence pauses between the arrows 42. This is varied according to the word of focus, with shorter, more common words requiring a shorter pause duration.
2. Pause position: The position in the sentence which pauses between the arrows 42. There can be zero, one or more pauses on a single word, depending on its commonness and length.
3. Saccade duration: The length of time between frames. This can either be set zero for instantaneous transition or to a duration of the order of milliseconds.

Each fixation position, x , may be converted into a sentence position, s , such that the fixation position is located between the arrows. Each sentence in an eye movement corpus begins with 6 spaces and ends with a full stop, and each character has the same width due to the use of a monospaced font. Fixation positions are given in pixels of the eye tracker where $x = 9$ is one character from the start of the sentence. How this relates to pixels of the window displaying the sentence is dependent on the font size, F , according to Equation 1 below:

$$s = s_0 - \frac{1}{15}Fx \quad (\text{Equation 1})$$

s_0 is the initial position from which point the sentence moves to the left when reading left-to-right. There is a linear relationship between font size and width of characters, where character width equals 3 fifths of font size. Dividing this by 9 (where $x/9$ is the number of characters), we arrive at the factor of one fifteenth in Equation 1.

In the embodiment of Figures 5a to 5c a number of settings are readily controllable by the user:

- Scrolling speed – a multiplicative factor to modulate pause and saccade durations.
- Controlling the target position of the text.
- A control to simulate the natural regression behaviour of reading – going back to a previous word.

Other ways to emphasize the target word are possible, such as colouring it, making it bold, or changing its relative size.

The user interface also incorporates an interactive progress indicator 44 to illustrate the position in the text at which it is currently located. Through interacting with this progress indicator, the text position can also be moved. Figures 5a, 5b and 5c show successive positions of the line of text 40 and corresponding displays of the interactive progress bar 44.

In some embodiments, the reader is provided with a regression button (not shown) which provides a control that may simulate natural regressions. In one embodiment, when the reader presses the regression button, the

sentence steps back by one word. In another embodiment, when the reader presses the regression button, the sentence steps back from its current pause position to a previous pause position.

In some embodiments, the eye movement data may be used to determine a regression parameter, for example a number of words by which to regress, a number of characters by which to regress, or a number of regressions.

Non-continuous scrolling of text may mimic the natural eye movements of saccades and fixations. Eye tracking data may be incorporated into text presentation. Regression functionality may be introduced as a user control.

In the embodiments described above with reference to Figures 2 to 5c, text is displayed to the reader using biomimetic scrolling. The text is displayed on a display screen 22 coupled to a computing apparatus 24 comprising a processor 28.

In a further embodiment, the biomimetic scrolling text is displayed to the reader on one or more display screens 52 that form part of a head-mounted display system 50. An example of a head-mounted display system 50 is schematically illustrated in Figure 6.

Displaying text on a head-mounted display system may be convenient for readers who may have difficulty using a hand-held device such as a tablet or e-reader, for example some readers having Parkinson's disease, MS, or neurodegenerative diseases that may impair the ability to use conventional hand-held devices. Displaying text on a head-mounted display system may also be convenient for applications such as speed-reading, autocue, voice to text for translation, or providing text cues for sensory deficits, for example deafness.

Head-mounted display system 50 comprises a small screen 52 held near to a reader's eye 60, and at least one optical component 54. The screen 52 is configured to display an image comprising the scrolling text display. The at least one optical component 54 is configured to magnify and focus the image from the screen 52 onto the reader's eye 60.

Head-mounted display system 50 further comprises a computing apparatus 56 comprising a processor 58. The processor 58 is configured to control the text display that is displayed on screen 52. In some embodiments, the computing apparatus 56 is integrated into the head-mounted display system. In some embodiments, the computing apparatus 56 is connected to the head-mounted display system 50 by a wireless or wired connection. For example, in some embodiments the computing apparatus 56 is a smartphone and the text display is controlled using an app on the smartphone.

When the reader views the image on the small screen 52, the at least one optical component 54 magnifies and focuses the image such that it appears to be displayed at a distance further from the reader's eye 60 than the

distance at which the screen 52 is placed. A virtual screen 62 may be considered to be present at the apparent distance of the image. The apparent distance of the virtual screen may be at a comfortable distance from the eye.

5 Dotted lines 64 show a path of light from the small screen 52 to the eye 60. Dashed lines 66 show a virtual path of light from the virtual screen 62 as perceived by the reader.

10 In Figure 6, only one screen 52, optical component 54 and eye 60 are shown. In some embodiments, the reader uses two eyes 60 to view a text display. The head-mounted display system 50 comprises a respective screen 52 and respective optical component 54, or set of optical components 54, for each eye 60. In other embodiments, a single screen 52 is used for both eyes. Different parts of the single screen 52 may be used to provide the same image, or different images, to each eye 60.

15 In the present embodiment, the head-mounted display system 50 provides an opaque text display, such that the reader cannot see their surroundings while reading the text display. In an alternative embodiment, the head-mounted display system 50 provides an at least partially transparent text display, such that the reader may be able to see some or all of their surroundings in addition to the text display. A head-mounted display system having at least partially transparent display may be referred to as smart glasses.

20 In further embodiments, a head-mounted display system comprises a smartphone headset. The smartphone headset comprises a smartphone and a support frame configured to support a display screen of the smartphone at a predetermined distance from the reader's eyes. The smartphone display screen is configured to display an image comprising a text display. The smartphone display screen may be configured to display two images, one for each eye.

25 A reader who is reading text on screen or screens 52 of head-mounted display system 50 may be given control of certain scrolling parameters and/or other display parameters, for example biomimetic scrolling parameters, reading speed, text size, typeface, contrast, or image enhancement parameters. A reader may be given control of retinal locus or location of presentation. For example, a patient with central vision loss may wish to align
30 the text display to a preferred retinal locus rather than to the fovea. A location of content displayed on the screen may be tailored to an individual reader. In some embodiments, parameters may be controllable by a person who is not the reader. For example, parameters may be set by a medical professional.

35 Using a head-mounted display system 50, different input may be provided to each eye. The head-mounted display system 50 may be capable of presenting asymmetric visual stimuli. The different input may be in dependence on ocular dominance. In some embodiments, the input provided to each eye is controllable by the reader or by another individual. Some readers with certain conditions, for example AMD, may use different, and possibly changing, settings for each eye, for example different contrast settings.

A text display on a head-mounted display system 50 may be used for a mobility or navigational aid. With text displayed on a head-mounted display system 50, a reader may not have to hold a book or to keep their head still in order to read. This may be useful for patients with certain conditions affecting their hand or head movement, for example Parkinson's. Using a head-mounted display system 50, text can be presented in the reader's field of view even if the reader's field of view is limited, for example by central vision loss.

In further embodiments, a text display apparatus is configured to monitor a reader's reading and to acquire reading data representative of one or more reading parameters. The reading data may be representative of at least one property of the text that is displayed. The reading data may be representative of at least one property of a reading process. The text display apparatus, or a further apparatus, is configured to analyse the reading data to identify changes in the reading data that may be representative of visual or neurological deterioration in the reader, or of the presence of a condition. The condition may be a visual or neurological condition. The condition may be a condition that has not previously been diagnosed in the reader. In some embodiments, software (for example an app) serves as both a person-specific reading tool and a diagnostic for monitoring.

A flow chart representative of a method of monitoring reading is illustrated in overview in Figure 7. In the embodiment of Figure 7, reading is monitored using the text display apparatus 20 of Figure 2. In other embodiments, any suitable apparatus or combination of apparatuses may be used. The apparatus may be any apparatus comprising a screen on which text can be displayed. The text may or may not be displayed by biomimetic scrolling. In some embodiments, the apparatus is configured to present vision tests to the reader via the screen.

In the embodiment of Figure 7, the text display apparatus 20 is configured to display text that is selected by the reader for reading. The user-selected text may comprise any text that the reader wants to read, for example text of a letter, book, newspaper or magazine article, website, or instruction manual. The text display apparatus 20 is used by the reader for reading at home, in the office, or in other non-medical environments.

At stage 70 of Figure 7, the processor 28 records reading data while the reader is reading user-selected text. In the present embodiment, the reading data comprises the reading speed, text size, typeface and contrast used by the reader, and the length of time that the reader spent reading. Each of the recorded parameters is a parameter that is changeable by the reader.

The processor 28 records the reading data over time. The processor 28 may record the reading data over an extended time. For example, the processor 28 may record reading data for a week, for a month, or longer. Reading data may be acquired during all the time in which a reader is reading, or a portion of the time in which the reader is reading. Reading data may be acquired continuously while the reader is reading, or may be sampled.

At stage 72, the processor 28 processes the recorded reading data to identify changes in the reading data. For example, over time the reader may have changed a display speed at which they are reading, or a text size used for reading.

5

At stage 74, the processor 28 determines whether any change identified at stage 72 may be indicative of visual deterioration. In other embodiments, the processor 28 may additionally or alternatively determine whether any change identified at stage 72 may be indicative of neurological deterioration. The processor 28 may determine whether any change identified at stage 72 is indicative of the presence of a condition, for example a condition that has not previously been determined to be present in the reader.

10

In the present embodiment, changes that may be indicative of deteriorating vision include an overall increase in text size with time, an overall change in contrast with time, an overall decrease in reading speed with time, and an overall decrease in time spent reading with time (for example, reading time per session, per day or per week).

15

Some changes that are identified by the processor 28 may be changes that are considered not to be indicative of deterioration. Changes that may not be indicative of deterioration may include, for example, periodic changes to the parameters to account for variations in light levels or to account for the reader's tiredness. In some such cases, parameters may change within a day but may not result in a net change over a longer time period such as a week or a month.

20

In other embodiments, any appropriate changes may be identified as being indicative of possible deterioration or of the possible presence of a condition.

25

At stage 76, the processor 28 informs the reader of any changes that may be indicative of deteriorating vision. For example, the processor 28 may email the reader, or the processor 28 may display a warning screen the next time the reader uses the text display apparatus 20. In other embodiments, any suitable alert may be used. The alert may be triggered when one or more parameters of reading data cross a threshold value or change by more than a threshold value.

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In some embodiments, the processor 28 informs a further person of any changes that may be indicative of deteriorating vision, instead of or in addition to informing the reader. For example, the processor 28 may inform the reader's doctor, optician, nurse or any suitable medical professional. The processor 28 may inform the reader's relative or caregiver. The processor 28 may prompt the reader, medical professional or other person to arrange a medical appointment to test whether the reader's vision has actually deteriorated. A community eyecare evaluation may be scheduled. An appointment at a specialist eye unit may be made or accelerated.

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In some embodiments, for example in embodiments where the reader has an existing eye condition, any deterioration is notified to the reader or to another individual. In other embodiments, only deterioration below a threshold level is notified. For example, a notification may be made if the reading data indicates that a reading performance of an individual has dropped below what is considered to be normal for their age and gender.

At stage 78, the processor 28 transmits data to a central server (not shown) at a remote location using a communication resource (not shown). The remote location may be, for example, in a different room, building, street, or town from the reader. In the present embodiment, the data transmitted to the central server includes the changes that may be indicative of deteriorating vision. In other embodiments, the data transmitted to the central server includes some or all of the reading data recorded for the reader. In other embodiments, data is transmitted to any suitable remote location, for example to any suitable remote computing apparatus.

In further embodiments, the text display apparatus is configured to record reading data but may not process the reading data. The text display apparatus sends the reading data to a remote computing apparatus, for example the central server. A processing resource of the remote computing apparatus is configured to process the reading data to determine changes that may be indicative of a visual or neurological deterioration or condition. In other embodiments, the reading data may be processed by any suitable processing resource.

The central server is configured to receive and store reading data from a plurality of readers. The central server may be part of a medical records system. The central server may be located in a medical facility that is remote from the reader. Data on the central server may be accessible by one or more medical professionals.

In further embodiments, any suitable reading data may be recorded, which may or may not include values for parameters listed above. Any suitable changes in the reading data may be used to indicate a possibility of visual or neurological deterioration or of a condition.

In the embodiment of Figure 7, the reading data is obtained during normal reading activity by the reader, for example reading activity in the reader's home. The reader is not required to participate in particular reading tests. Reading data may be recorded during all of the reader's reading activities. Alternatively, reading data is recorded periodically, for example at intervals determined by the processor 28. In each case, the reading data is recorded while the reader is reading user-selected content.

In other embodiments, some or all of the reading data is obtained while the reader is participating in vision tests, for example vision tests that are delivered on the text display apparatus 20 of Figure 2.

In one embodiment, processor 28 of the text display apparatus 20 of Figure is configured to present one or more types of vision test to the reader. The processor 28 may be configured to present the vision tests to the reader on a regular basis, for example to present to the reader a weekly vision test or set of vision tests. In some embodiment, the processor 28 is configured to present one or more vision tests to the reader when requested by the reader or by another individual (for example, a medical professional).

The processor 28 processes the reading data obtained from the vision tests (for example, from weekly vision tests) to identify changes and determine whether the changes may be indicative of deteriorating vision. In other embodiments, the processor 28 processes the reading data to identify changes that may be indicative of a neurological deterioration, or of the presence of a condition. In some embodiments, the processor 28 processes the reading data obtained from the vision tests in combination with reading data obtained during normal reading of user-selected texts.

A vision test may comprise, for example, a reading speed test, a reading acuity test, a contrast visibility test, a contrast sensitivity test, a perimetry test, or a pupillary response test.

In some embodiments, the vision tests are designed to correspond to standardised tests that measure aspects of the reader's vision in a standardised way. The vision tests may be designed to be independent of the testing medium (for example, the screen 22 of the test display apparatus 20) and to yield an absolute measurement of vision (for example, acuity or contrast sensitivity).

In some embodiments, the vision tests are screen visibility tests that are designed to measure the performance of the reader's vision in seeing or reading from the particular display used. Screen visibility tests may not yield an absolute measurement of vision. However, repeated use of screen visibility tests may allow changes in a reader's ability to read from a particular screen to be identified. Screen visibility tests may test, for example, a text size or contrast level that is the limit of what an individual reader can read on the screen that they are using. A screen visibility may test an extent of visibility, which may measure how much of the screen is visible to the reader.

In the present embodiment, the processor 28 identifies changes in the reader's test performance over time. If the reader's test performance has decreased between one week and the next week (or over any suitable interval), the processor 28 determines that the reader may have experienced visual (or neurological) deterioration or that the reader may have developed a condition. Results of repeated tests may be compared to baseline results. In some embodiments, the reader is notified any time that their test performance has decreased. In some embodiments, a reader is notified only if their test performance drops below a threshold test performance, for example a test performance that is considered to be normal for their age and gender.

In the present embodiment, the processor 28 conducts a reading speed test by presenting sentences to the reader at different speed and testing the reader's comprehension. If the reader's maximum measured reading speed has decreased from one week to the next, the processor 28 informs the patient, medical professional, or another person that the reader's vision may have deteriorated. In other embodiments, performance in any suitable vision tests may be measured.

The processor 28 may transmit vision test results to the central server. The vision test results may be stored in the reader's medical records.

In the embodiment described above with regard to Figure 7, changes in reading data are used to warn of possible visual deterioration. In other embodiments, changes in reading data may be used for other purposes. For example, a change in one or more display parameters that are selected by the reader may be used to automatically change other display parameters that are not directly changeable by the reader.

In some circumstances, reading data may be recorded during the normal reading of the reader without the reader having to participate in many (or any) vision tests. Acquiring data during normal reading may be convenient for the reader, since it may not involve any disruption to the reader's normal activities. Acquiring data during normal reading may allow a large amount of data to be acquired. Acquiring data during normal reading may allow passive monitoring of an at-risk population, or of the general population,

In some embodiments, the apparatus used to acquire reading data is the same text display apparatus that is used routinely by the reader for reading, for example the reader's desktop computer, laptop, tablet, e-reader or assistive reading device. In some embodiments, reading data is only acquired for readers with known visual or neurological conditions. In some embodiments, any user of the text display apparatus may be informed of changes that may indicate visual or neurological deterioration or presence of a condition, whether or not that user is already known to have a visual or neurological condition.

In further embodiments, the reader is instructed to use a further apparatus for reading or for performing vision tests that is not the reader's normal reading apparatus. In some embodiments, the further apparatus is a dedicated test apparatus. For example, the reader may be instructed to use the further apparatus at specified times.

Using the method of Figure 7, reading data may be obtained in a reader's own home. Reading data may be obtained more often than traditional vision tests, for example vision tests performed in a surgery or hospital by an optician or ophthalmologist. Acquiring reading data regularly (whether from normal reading or from repeated testing) may allow possible deterioration in vision to be detected more quickly than would be the case using traditional eye testing. The reader may be tested in an environment more similar to the environment in which the reader usually reads.

In embodiments described above, the processor 28 is configured to identify changes in reading data (for example changes in parameters used or in results of vision tests) and to notify the reader or other individual of possible deterioration based on those changes. In other embodiments, the processor 28 may notify a reader or other individual of a possible eye condition based on the reading data, even if there has been no change in the reading data. For example, the processor 28 may notify the reader based on an initial set of reading data or on reading data that is consistent with time. The processor 28 may issue a warning if the reader's reading data indicates unusually poor vision for the reader's age and gender. The processor 28 may issue a warning if the reading data is inconsistent with what is known about the patient's visual and/or neurological conditions, for example if a reader who is not expected to have a visual condition performs poorly in a vision test.

In some embodiments, the processor 28 is configured to identify parameter values that may be indicative of at least one condition based on reading data. The reading data may be data that is obtained at a single time. The reading data may be data that is obtained over time. The processor 28 may be configured to identify parameter values indicative of a condition which causes optic neuritis, for example multiple sclerosis. The processor 28 may be configured to identify parameter values indicative of a condition which causes optic neuropathy, for example glaucoma. The processor 28 may be configured to identify parameter values indicative of a condition which causes macular oedema, for example diabetes, retinal vein occlusion, retinal dystrophy, drug toxicity, uveitis. The processor 28 may be configured to identify parameter values that are indicative of AMD. Optic neuritis, optic neuropathy or macular oedema may affect reading, may be painless, and unless picked up early and treated may lead to progression and irreversible sight loss. The processing of reading data by the processor 28, for example data from routine reading, may in some circumstances allow earlier detection of potentially serious conditions.

In the embodiment of Figure 7, the text display apparatus 20 is used to acquire reading data. The reading data comprises values for parameters that may be set by the user, such as text size or contrast. In other embodiments, an apparatus is used that is configured to acquire further types of reading data, for example eye movement data, blink rate data or pupil response data.

Figure 8 is a schematic illustration of a reading system comprising reading test apparatus 80 that is configured to acquire reading data which comprises eye movement data, and a remote server 89. The reading test apparatus 80 comprises a screen 82, a computing apparatus 84 comprising a processor 88 and a communication resource 87, and a camera 86. The reading test apparatus 80 may be portable. The reading test apparatus 80 may be useable wherever a user would like to read, for example at home or in the office. The reading test apparatus 80 may be of a size that is convenient for the reader to use. For example, the reading test apparatus 80 may be handheld.

In further embodiments, the camera 86 may be replaced by any eye movement detector. In some embodiments, the reading test apparatus 80 also comprises a light sensor, which may be configured to mitigate against variations in ambient lighting. The reading test apparatus 80 is configured to transmit reading data to remote server 89.

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In one mode of use, processor 88 displays user-selected text on screen 82. The camera 86 records the reader's eye movements while reading and sends eye movement data to the processor 88. In another mode of use, processor 88 displays a vision test to the user on screen 82. The camera 86 records the reader's eye movements while participating in the vision text and sends eye movement data to the processor 88.

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The processor 88 processes the eye movement data determines whether there is any aspect of the reader's eye movement data that may be indicative of deteriorating vision. In some embodiments, the processor 88 processes the eye movement data in combination with other reading data. In other embodiments, the eye movement data is processed in a processing resource of the remote server 89, or in any other suitable processing resource.

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Communication resource 87 sends data from the processor 88 to the remote server 89. The communication resource 87 may comprise, for example, a wireless antenna or internet connection. The data may represent the changes in the reading data, or may comprise the reading data itself.

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In further embodiments, the reading test apparatus 80 comprises a detector (for example, a camera) configured to measure pupil response. The recorded reading data may comprise pupil response data. Vision tests delivered to the user may comprise pupillary response tests.

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In some embodiments, the reading test apparatus 80 comprises a detector (for example, a camera) configured to measure blink rate. The recorded reading data may comprise blink rate data. In some embodiments, a single camera may be used to measure two or more of eye movement, pupil response and blink rate.

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The apparatus of Figure 8 may provide continuous or periodic monitoring of reading data. In some embodiments, eye movement data, blink rate data and/or pupil response data may also be recorded while the reader is not reading.

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In further embodiments, any type or types of reading data may be recorded. Multi-modal testing may be used. Multi-modal testing may provide better or faster indications of changes that may indicate deterioration, or may allow a larger number of possible changes to be assessed (for example, changes in eye movement in addition to changes in parameter settings).

Specific components of eye movement data, for example pursuit and saccadic characteristics, may be mapped at baseline and compared with normative age-gender matched datasets to highlight deviations from optimality and change over times. Eye movement signatures may be compared. Cognitive decline eye movement signatures may be determined. Results may be compared with normal populations and in aging.

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Reading test-type equivalent size, luminance, contrast and colour contrast may be used as descriptors for the reading data.

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In some circumstances, diseases affecting the macula may lead to a preference for larger print size, increased illumination and contrast, and shifting preference in colour contrast for each eye and both together. Changes in print size, illumination, contrast and/or colour contrast may be considered to be indicative of the possible presence or progress of macular disease.

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Any appropriate action may be taken if changes indicative of possible deterioration are identified. In one embodiment, for at-risk groups (for example type 2 diabetics at risk of developing maculopathy or elderly individuals at risk of developing age-related macular degeneration), the identification of changes that may indicate deterioration triggers a community eyecare evaluation to determine whether referral is needed. For patients with an established maculopathy who are receiving intravitreal therapy, identification of changes that may indicate deterioration may result in access to a specialist eye unit being fast-tracked.

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For patients known to have diseases affecting the macula, a threshold for each eye (for example a threshold of optotype characteristics such as text size) may be established. The thresholds may be used as a metric against which change may be measured. An alert may be issued if thresholds are crossed. For normal individuals without disease, or for those at-risk (where at-risk may be defined based on one or more of lifestyle, systemic co-morbidity, or genetic risk susceptibilities), parameters (for example, optotype characteristics) may be plotted against normative datasets. A threshold may be set for triggering optometric service evaluation.

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In some embodiments, a camera (or other detector) for measuring eye movement data, blink rate data, pupil response data or any other suitable data is mounted on a pair of glasses, on a head-mounted display system, or on another wearable device.

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In some embodiments, a head-mounted display system is used as a reading test apparatus. Data may be recorded for one or both eyes. In some circumstances, different input may be provided to each eye. Vision tests may be presented separately to each eye.

Using a head-mounted display system as a reading test apparatus may provide a wearable technology reading device that may also perform monitoring to identify possible deterioration in vision.

Figure 9 is a schematic illustration of an embodiment of a head-mounted display device 90. The head-mounted display device 90 comprises a commercially available head-mounted display device which in this embodiment is an Epson Moverio 200. The head-mounted display device is used to display an image, for example an image comprising text.

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The head-mounted display device 90 comprises a right screen 91 and a left screen 92; a backward-facing camera and/or sensor 94, and a forward-facing camera and/or sensor 96. In use, at stage 100 a processor (not shown) receives an input, for example a text input, a voice to text input, or an OCR (optical character recognition) input. At stage 102, the processor processes the input into a format for presentation, for example using biomimetic scrolling and/or image enhancement.

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At stage 104, an algorithm app prepares a user interface and provides displays to right and left screens 104, resulting in an image display 110 being visible to a user of the head-mounted display device 90.

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In further embodiments, component parts may include a display module, camera (forward and back facing), wire and wireless Bluetooth connections, software app user interface, image recognition and OCR input feed. A suite of presentations may use sample input and a user-directed algorithm presented using an app incorporating biometric scrolling and a series of forced choice options to determine preferred parameters including, for example, text font and size, colour contrast, luminance, scrolling speed, interocular and bilateral presentation parameters. These characteristics may form a baseline dataset for detecting change over time.

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A method may be provided for reading text using modified scrolling text presentation in health and disease. Algorithms and app designs may be provided for individualising text presentation for PC, tablet, phone and head-mounted displays. There may be utilisation of data derived from the apparatus of Figure 9 as a platform for diagnostics in developmental, ocular, cognitive and neurological disease.

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A method and read-out may be used for exploiting an enhancing near visual function capability as an enabling aid, visual rehabilitation device, pre-clinical diagnostic, monitoring tool and/or point of care self-assessment test-kit which may then be integrated with optometry, primary care and hospital-based ophthalmic and systemic paper-based and electronic datasets.

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An apparatus and method may provide self-testing of visual function, point of care psychophysics evaluation, tele-diagnostics, virtual clinic environments and/or any medical, non-medical, gaming and daily activity which utilises text-based information with stereo-multimedia or holographic displays.

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Software may be written and integrated. The software may have an algorithm and an app-user interface to navigate preferred text presentation in a stepwise and staircase design which may allow reading capability to be maximised. Baseline characteristics of parameters defined by neuro-ophthalmic and ocular determinants

may be of diagnostic and monitoring value as measured of eye and/or CNS (central nervous system) structure and function. Data may be captured in real time. The captured data may reflect measurable physiological processes governing one or more of reading, blink-rate, macular function and pupillary responses indicative of conscious, subconscious and autonomic activity and responses to the cognitive challenge in text scanning and reading.

A device according to an embodiment (for example, the embodiment of Figure 9) may advance reading capability in both health and disease and may be a tool to acquire deep phenotyping data in preclinical detection and disease monitoring in eye and neurological disorders including, for example, amblyopia, dyslexia, macular disease, glaucoma, cognitive decline, dementia, neurodegenerative diseases including motor neurone disease, multiple sclerosis, Parkinson's disease and stroke.

In the embodiment of Figure 9, a developer kit for the head-mounted display device was a platform used to write text presentation software. A strategy to allow user preference was adopted.

A display may be tailored to specific needs of a user, for example a patient. For example a display may be tailored in terms of preferred retinal locus, image enhancement, colour contrast and screening a location of a presentation. Input to each eye may be modulated as ocular dominance alters. Ocular dominance, or other parameters, may change over time for any patient with changing vision, for example with AMD progression. Text may be displayed on a reader's preferred fixation position, which in some circumstances may shift over time with disease progression.

Text may be presented by reverse engineering eye-tracking used by a healthy population. An improvement in reading speed from biomimetic scrolling has been demonstrated in a clinical trial.

Beyond AMD, an application of biomimetic scrolling and/or head-mounted display may be extended to a wider population of patients with sight-limiting eye and neurological diseases, for example glaucomatous visual field loss, stroke-related visual neglect and hemianopia, Parkinson's disease and MS or neurodegenerative diseases which may impair retinal or optical nerve function, disrupt ocular motility and/or impair the ability to use conventional hand-held devices.

A platform may be adapted, for example using a next model Moverio 300 that incorporates light sensors and cameras. The apparatus may mitigate against variations in ambient lighting (which may optimise reading capability), capture data in diagnostics and/or monitoring (for example, pupillary responses and eye-tracking movements) and/or adapt a patient's self-selected optimal reading algorithm to sense change over time in neuro-ophthalmic functioning. The apparatus may be used as a method to detect pre-clinical disease for cognitive decline and dementia. Cognitive decline and dementia may impact pupil responses, smooth pursuit eye movements and/or saccadic eye movements.

Sampling data as a domiciliary point of care instrument in the course of an individual using the apparatus as a non-intrusive wearable piece of technology (for example, as one may wear a pair of ordinary looking spectacles) may allow the apparatus to have a function as a continuous monitoring device for at-risk populations.

For individuals who do not have eye disease, the apparatus may have application in hands-free reading speed example, head-mounted display autocue for delivering presentations, voice to text for real time translation and/or to allow text cues for other sensory deficits, for example deafness. Further benefit may also be realised in the reading capability of children with dyslexia especially those who show a specific response to spectral hue and intensity. Individuals having amblyopia (a cause of uniocular poor vision) who require eye occlusion therapy may be improved by the apparatus's capability to present asymmetric visual stimuli.

Biomimetic scrolling may provide a rapid reading technology that may be capable of enhancing function for normally-sighted and/or sight impaired individuals using digital display. The forms of digital display used may include, for example, large-screen, laptop, tablet, phone and/or head-mounted display hardware.

A further embodiment is now described of a method comprising gathering eye movement data and displaying text using biomimetic scrolling, the biomimetic scrolling using parameters based on the eye movement data.

Biomimetic scrolling may translate average eye movement behaviour into the movement of a line of text. Biomimetic scrolling may seek to emulate the success of methods such as rapid serial visual presentation in boosting reading speed, whilst maintaining the familiar line of text appearance.

In the embodiment described below, the parameters of biomimetic scrolling are described and then tested in a reading speed study with 30 participants. Reading with biomimetic scrolling is found to enable all participants to read faster than with continuous scrolling, on average by a factor of 5 time, and almost half to read faster than with rapid serial visual presentation, with a statistically equal average.

Biomimetic scrolling may combine a benefit of speed reading that may be present in RSVP with a benefit of parafoveal preview that may be present in continuous scrolling. Eye movements while reading have been studied, particularly with the advent of high-accuracy eye-trackers. Eye movement research is applied by characterizing the movement of the gaze as it proceeds through a sentence, then designing a text presentation format in which a line of text moves with these characteristics. An effect may be that, whilst the eye remains steady, the text moves through the fixation point in a way comparable to that of regular reading.

When reading a line of text, our gaze does not move smoothly across it, but moves in short, rapid steps called saccades, then fixates briefly in a particular location before making the next saccade. This leads to three

parameters that define eye movement during reading: fixation duration, saccade length and saccade duration. Eye movements can be tracked to determine the quantity of these parameters.

We use these parameters to define the movement of the text past a particular point which acts as the location of fixation for the steady gaze. Fixating at this point is encouraged by displaying arrows on the screen, for example as shown in Figure 4 (arrows 42). Figure 4 is an illustration of one frame of the text presentation method, with the rectangular outline defining the boundaries of the screen 22, and the arrows 42 and text 40 showing what is displayed on the screen. The arrows 42 define the location for the gaze to fixate.

The method of text presentation (biomimetic scrolling) mimics the saccadic movements of the gaze. The method is based upon eye movement data.

A simple version of biomimetic scrolling may be to directly translate the chain of fixations and saccades of an individual reading a particular sentence into the movement of that sentence. The sentence is initially positioned such that the first fixation position is between the arrows, then after pausing there for the duration of the first fixation the sentence takes the duration of the first saccade to move to the second fixation position, and so on until the final fixation.

Figure 14 shows an algorithm for biomimetic scrolling according to the data on the eye movements of an individual reading a line of text. s_i is the sentence position corresponding to the i^{th} fixation; d_i is the duration at which the sentence pauses in position; t_i is the i^{th} step duration. A biomimetic scrolling process starts at stage 130 of Figure 14, at which time $i=0$. At stage 132, the processor 18 displays a sentence in a position s_i . There is then a delay of d_i seconds at stage 134. At stage 136, the processor 18 determines whether i equals the number of fixations for the sentence. If so, the process ends at stage 140. If not, i is incremented to $i+1$ at stage 152. At stage 152, the processor moves the sentence to position s_i over the course of t_i seconds. The flow chart then returns to stage 134. Stages 134, 136, 150 and 152 are repeated until the sentence is completed.

The chain of fixations and saccades is different for different individuals, resulting in subject-specific text movements. There are, however, common patterns in the data. Next we describe the collection of eye movement data in reading single lines of text and how this data informed the choice of parameters for saccadic scrolling.

An eye-tracking reading experiment was performed to obtain a corpus of eye movement data.

Each participant read the same 150 single sentences. Sentences averaged 12 words in length (range = 7 to 16 word). Each sentence was presented on a single line and had a mean of 68 characters (characters include letters and spaces, range = 55 to 80 characters).

Forty young adults who were students at the University of Edinburgh and 27 older adults from the community participated in the eye-tracking reading experiment. The young adults (7 men and 33 women) averaged 22.2 years of age (range = 18 years to 29 years), and the older adults (14 men and 13 women) averaged 72.7 years of age (range = 66 years to 83 years). All participants had normal or corrected-to-normal vision.

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Eye movements were recorded with an SR Research EyeLink 1000 Desktop mount system. It was equipped with a 2000 Hz camera upgrade, allowing for binocular recordings at a sampling rate of 1000 Hz for each eye. Data from the right eye were analyzed. The experiment was implemented in SR Research Experiment Builder.

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Sentences were presented in black bold 11-pt Courier New font on a grey background on the horizontal centerline of the monitor (800 × 600 resolution). Participants were seated 90 cm in front of a 21-inch monitor with the head positioned on a chin and forehead rest. At the straight-ahead viewing position letters subtended 0.28° of visual angle (center-to-center spacing).

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A 9-point system-controlled EyeLink calibration procedure was used. At the beginning of each trial, a central fixation check was performed to verify calibration accuracy, and recalibration was carried out if necessary. The sentence was presented on the centerline of the monitor with a horizontal offset of 54 pixels from the left screen boundary. Participants pressed a button on the controller once they finished reading the sentence. The display was then cleared and there was an inter-trial interval of 1 second before the next fixation cross was presented. To ensure that subjects read the sentences and not just moved their eyes, 30 randomly selected sentences were followed by an easy comprehension question, requiring a three-alternative choice response.

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Gaze raw data were parsed into sequences of fixations and saccades using SR Research Data Viewer, using the default parameters. Those data were converted into an interest area report, which provides a columnar output of eye movement data for each word in a sentence, separately for each participant.

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Some parameters of biomimetic scrolling are presented. There may be many viable combinations of these parameters. Different parameters, or different combinations of parameters, may suit various contexts. A particular set of parameters has been chosen for testing.

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One parameter of biomimetic scrolling is the pause duration of the text as it passes between the arrows 30. The pause duration may be considered to be equivalent to a fixation duration in normal (non-scrolled) reading.

In the present embodiment, pause duration was chosen to equal the total reading time of a given word. The total reading time of a word was defined as the sum of all fixation durations on that word, averaged over all participants in the eye movement corpus. This was possible as the sentences used in the reading speed study were the same as those used in the eye movement corpus.

A method is proposed to allow extrapolation of the eye movement data to sentences for which eye movement data is has not previously been measured.

It is known that a reader's gaze may dwell longer upon low-frequency (less common) words than on high-frequency (more common) words. Figure 10 is a plot of total reading time against word, averaged over the 67 participants of the eye movement corpus. Word frequencies are expressed on a logarithmic Zipf scale which ranges from around 1 (very low-frequency) to around 7 (very high-frequency). In Figure 10, words included in multiple sentences are included multiple times with the same Zipf but not necessarily with identical reading times.

In the results shown in Figure 10, word frequency is correlated with the average dwell time ($r = -0.81$). A line of best fit was calculated using the method of least squares, giving a gradient of -61 ± 1 ms/Zipf and intercept of 567 ± 6 ms. This linear relation may provide a way to estimate the total reading time, and hence a suitable pause duration, from the word frequency.

Figure 11 is a plot of total reading time against word length, averaged over the 67 participants of the eye movement corpus. In the results shown in Figure 11, there is a correlation between total reading time and word length ($r = 0.84$). The line of best fit was calculated using the method of least squares, giving a gradient of 37 ± 1 ms/letter and an intercept of 45 ± 3 ms. This may provide a further way to estimate total reading time and hence to choose an appropriate pause duration, this time based on word length. Word length and word frequency may be correlated. In some embodiments, only word length (and not word frequency) is used to set pause duration. In some embodiment, only word frequency (and not word length) is used to set pause duration. In some embodiments, a combination of word length and word frequency is used to set pause duration.

In normal reading, it may be the case that not every word is fixated. There is a probability, p_0 , that the word will be skipped; a probability, p_1 , that it will be fixated once; and a probability, p_2 , of refixation (more than one fixation).

A parameter of biomimetic scrolling may be a number of times that the text will pause on a particular word. Figure 12 is a plot of the total reading time against number of fixations per word, both averaged across all 67 participants in the eye movement corpus. In the results of Figure 12, the number of fixations (which may be considered to be equivalent to pause count) and the total reading time (which may be considered to be equivalent to pause duration) are highly correlated ($r = 0.97$).

In some embodiments, only the pause count (and not the pause duration) is varied with word. In some embodiments, only the pause duration (and not the pause count) is varied with word. In some embodiments, both pause count and pause duration are varied with word.

In the present embodiment, it is chosen to fix pause count as 1 for every word and to modulate pause duration.

Another parameter of biomimetic scrolling may be the position along the word at which to pause. In normal (non-scrolling) reading, an optimal viewing position (OVP; the position where readers should fixate) may not be identical to a preferred viewing location (PVL; the location where readers do fixate). Findings from single-word and text reading studies suggest that word center may be the optimal position for word processing. The preferred viewing location, on the other hand, may be slightly left of word center. Both the OVP and PVL may be affected by word length.

In the present embodiment, it was chosen to set the pause position as the center of the word instead of choosing the pause position according to data from the eye movement corpus. In other embodiments, the pause position is set according to data from the eye movement corpus.

Saccade duration may be another biomimetic scrolling parameter that may be adjusted. In the present embodiment, the mean saccade duration of the eye movement corpus is 36 ms. As this is so short, the saccade duration is set to zero, meaning instantaneous movement between words.

The pause duration and saccade duration together set a speed with which the text scrolls. As scrolling speed may be a parameters over with the user would have control, it is set as a multiplicative factor to proportionally modulate pause duration. Thus a change in the speed setting, measured in words per minute (wpm) proportionally increases or decreases the pause duration on each word.

It is hypothesized that biomimetic scrolling may enable users with normal vision to read at a faster rate than continuous scrolling, as biomimetic scrolling may be more similar to natural eye movements than continuous scrolling. As biomimetic scrolling and RSVP both may remove the need for eye movements, it may be expected for reading speeds using biomimetic scrolling to be similar to reading speeds using RSVP. In order to test this, a study was carried out with 30 participants (different to those from the eye movement study), aged between 19 and 62, with a split of 16 males and 14 females.

Three text presentation methods were used: Continuous scrolling, in which a line of text entered from the right of the screen and smoothly scrolled across the center until it disappeared off the left side; RSVP, in which words were displayed one at a time with equal duration in the center of the screen; and biomimetic scrolling, with parameters set based on eye movement data as described above (text movement duration = 0, pause duration = total reading time of a given word, pause position = word centre). In the case of biomimetic scrolling, the participants were instructed to keep their eyes fixed between the arrows 42 and read the words as they came into view.

Sentences used for the reading speed study were selected from those sentences used in the eye movement study. Sentences that were between 12 and 14 words long and with a total number of characters between 68 and 76 were chosen. 40-pt, Courier New font, with white letters on a black background, was viewed from about 50cm on an LCD screen with horizontal width of 34cm and brightness of 210 cd/m² for white. The Python programming language, with the Kivy library, was used to implement the text presentation strategies, user interface and record the data.

The order of presentation methods was randomized. Each method was set to begin at a speed of 120 wpm. At the end of each sentence a multiple choice comprehension question was asked, with three choices plus a fourth option to indicate when they did not know the correct answer. The same speed level was used twice, then increased to the next level, with each level separated by 120 wpm. The testing would end when they selected “I don’t know” four times in a row, or when it reached 1920 wpm for biomimetic scrolling and RSVP or 600 wpm for continuous scrolling. These ceiling levels were high enough not to constrain any participants. The maximum reading speed was taken as the maximum speed level at which both questions were correctly answered.

All 30 participants achieved a higher reading speed using biomimetic scrolling than continuous scrolling. Comparing with RSVP, 13 read faster with biomimetic scrolling, 14 with RSVP and 3 achieved equal speeds. Figure 13 shows reading speed averaged over all the participants for each presentation method. The results suggest that biomimetic scrolling is almost 5 times faster than continuous scrolling, whereas reading speed appears to be similar for biomimetic scrolling and RSVP. Bar 120 shows reading speed using biomimetic scrolling. Bar 122 shows reading speed using continuous scrolling. Bar 124 shows reading speed using RSVP.

For statistical evaluation, data were analyzed with a linear mixed-effects model (LMEM) with by-subject random intercepts, using the *lmer* program of the *lme4* package for R. To evaluate the effect of presentation method on reading speed (wpm), we used treatment contrasts in which the biomimetic scrolling condition served as the reference group. Consequently, the intercept for the fixed effect “presentation method” estimates the mean value for the biomimetic scrolling condition. The two slopes estimate the difference between continuous scrolling and biomimetic scrolling and between RSVP and biomimetic scrolling. For the LMEM we report regression coefficients (*b*), standard errors (*SE*) and *t*-values ($t = b/SE$). A two-tailed criterion ($|t| > 1.96$) was used to determine significance. In the LMEM, the estimated reading speed for biomimetic scrolling was 952 wpm ($SE = 60.4$, $t = 15.62$). For continuous scrolling, reading speed was significantly slower ($b = -748$, $SE = 78.7$, $t = -9.50$); specifically, mean reading speed was down to 204 ($952 - 748$) wpm. When reading with the RSVP method, mean reading speed did not differ significantly from the biomimetic scrolling condition ($b = 52$, $SE = 78.7$, $t = 0.66$).

Biomimetic scrolling is a form of line-stepping text presentation in which the sentence moves in a sequence of saccades and pauses with respect to a fixation point on the screen. The choice of length and duration of these

saccades and pauses is made with reference to eye movement data in order to mimic normal reading. Like RSVP, biomimetic scrolling may save time by reducing or removing eye movements. This speeds up reading both by removing the time needed to make the saccade and the time needed to program it, typically approximately 180 to 250 ms. The time taken to program a saccade may refer to the cognition time required to decide in which direction to make the saccade and where to make the next fixation.

Using an algorithm to define the saccades on behalf of the reader may impose on them an average, ignoring differences in eye movement behavior among individuals. These differences may have been in evidence in the reading study. Equal numbers of participants achieved a higher reading speed with biomimetic scrolling and RSVP. This may suggest that text presentation may not admit a one-size-fits-all approach and having additional methods may benefit more people. There is scope for further research on tailoring biomimetic scrolling to individuals by using that individual's eye movement data rather than an average.

For a biomimetic technique to be used for reading outside of an experimental setup, control may be given to the reader. Speed control has already been discussed. Tailoring the other parameters of biomimetic scrolling, such as pause duration and viewing position, is also possible. Regressions are an important part of reading which cannot be imposed on the reader and their absence in RSVP may have limited its success. User control may be a key topic for further research.

No practice was given to participants before starting the reading speed trial. With RSVP, the gaze automatically remains on the single word at the center of the screen. But with biomimetic scrolling, as words are still present to either side of the center, participants have a choice whether to keep their eyes steady or move them with the words. For this reason, giving the participants no practice may have adversely affected performance on biomimetic scrolling more than RSVP. Further work may investigate the effect of practice on reading speed using biomimetic scrolling. Further work may monitor eye movements while reading biomimetic scrolling text.

Reading speed is just one measure of the success of a text presentation method. Subjective measures of user comfort and satisfaction may also be used to determine the comparative potential of the biomimetic scrolling technique. In addition, only a basic level of comprehension was tested after reading a single sentence. The effectiveness of biomimetic scrolling under sustained reading conditions and its effect on comprehension compared to normal reading is yet to be determined.

Biomimetic scrolling may enables reading at almost 5 times the rate of continuous scrolling. It may directly incorporate knowledge about reading and may provide an alternative to RSVP as a speed reading technique.

In a further study, head-mounted display systems were evaluated for macular degeneration. The macula is a part of the retina. The macula makes up the central 17° to 18° of the visual field. That is about the length of a hand viewed with an outstretched arm. Macular disease may result in a loss of central vision.

- 5 Age-related macular degeneration (AMD) is the most common type of macular disease. AMD is the leading cause of blindness in much of the Western world. Peripheral vision may be unaffected.

- 10 The ratio of low vision to blindness is estimated to be 10:1 in Europe. Blind does not necessarily mean no light perception. Low vision aids currently available may include a cane, audio description, sensory substitution, optical or electronic magnification, or vision enhancing glasses. Low vision aids may be divided into two categories: a first category of aids that translate visual information into alternative sensory information, such as sound or touch (sensory substitution) and a second category of aids that adapt visual information to render it more visible to the user.

- 15 An example of a head-mounted display system has been described above with reference to Figure 6. Smart glasses may provide augmented reality. Smart glasses may provide a partially transparent display. An example used in the evaluation of head-mounted display systems is the Epson Moverio B-200, which has a field of view of 23°. Smart glasses may act like normal glasses in that sight is not blocked.

- 20 A smartphone headset may be used for virtual reality. One famous budget version, Google Cardboard, comprises a smartphone with a cardboard support frame. An example used in the evaluation of head-mounted displays was a Homido with an LG G3 smartphone. The LG G3 smartphone has one of the highest pixel densities at 538 ppi, so pixels may be barely visible even when used close to the eye. A field of view may be 100°. A giant, bright display may be provided with little more than a smartphone.

- 25 High tech aids for low vision have been reviewed, for example in review paper Moshtael H, Aslam T, Underwood I, Dhillon B. *High Tech Aids Low Vision: A Review of Image Processing for the Visually Impaired*. Transl Vis Sci Technol, 4(4) 2015.

- 30 The evaluation of head-mounted display systems had several aims. The evaluation was intended to test the display itself, not use it to its maximum potential. The evaluation aimed to answer several questions. How much of the display can a user see and how well can they see it? How well can they read from the display in terms of speed and text size? What is the user's subjective opinion of the display and headset?

- 35 Smart glasses and a smartphone based headset were tested. A perimetry test was adapted to measure an extent of visibility. A Radner reading test was adapted for smart glasses to measure reading speed. A questionnaire was used to gather subjective information about visibility, comfort and prospective use.

In a trial showing indicators at a plurality of screen positions, participants saw at least 45% of the points, except for two participants who were registered blind. All but one could read from both the smart glasses and the smartphone headset. 70% found it easier or the same to read from the smart glasses than from large print on paper. 91% found it easier to read from the smartphone headset than from large print on paper.

5

50% preferred reading from smart glasses than from paper. 33% preferred reading from the smartphone headset than from paper.

10

Using the smart glasses, a range of text presentation methods may be used. A range of options may be provided to suit a wide variety of needs. A size setting may be set according to reading acuity. Contrast may be suited to macular disease. Dynamic presentation options, like scrolling, may be used. RSVP may be used.

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In general, the eye does not move smoothly across text, but in a succession of fixations and saccades. Therefore, biomimetic scrolling is hypothesised to allow faster reading rates than continuous scrolling, at least in some circumstances.

Continuous scrolling and biomimetic scrolling were compared.

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There were 23 participants, 16 of whom completed all parts of the trial. All had macular degeneration. 17 were female and 6 were male. They had an age range between 60 and 91, with an average age of 81. All had experience of using optical magnifiers.

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All but two had an improved reading speed when reading with the smart glasses as compared to reading with an optical aid. 70% preferred reading from the smart glasses.

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Compared to reading large print from paper, 42% found the smart glasses to be much easier, 42% found the smart glasses to be a little easier, 5% found the smart glasses to be the same, and 11% found the smart glasses to be a little harder.

Improvement in reading speed over an optical magnifier was found in 84% of cases. A subjective preference for smart glasses was found in 70% of cases. The flexibility of a dual display may be of benefit. The display may be tailored to the user. A camera may be added for live feed.

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As described above, a text presentation method in accordance with an embodiment was tested on the normally sighted and found to match the speed of RSVP and increase the speed of scrolling text by a factor of approximately five. A question of interest is, if text was presented in a way that mimicked natural eye movements whilst reading, in the way patients read before acquiring a visual impairment, could reading be enhanced?

An investigation of dynamic methods of text presentation on those with macular disease is performed. Thus, RSVP, scrolling and biomimetic scrolling are compared to static text. The primary outcome measure is reading speed. In addition, the subjective preference of participants is considered. Through testing these methods, and adjusting the size and colour contrast of the text to the participant's preference, the text is then individually tailored. This tailored text, presented on the digital display on the smart glasses, is next compared to reading with the participant's habitual optical aid. Just 9 out of 23 participants (39%) have had experience using electronic low vision aids, and even fewer use them habitually. However, all participants have used optical low vision aids, and most use them habitually. In addition, optical low vision aids, usually a magnifier of strength appropriate to their eyesight with a built-in light, are frequently provided by the low vision clinic at the Princess Alexandra Eye Pavilion, Edinburgh. Thus, it was decided to compare the smart glasses tailored text display to the participants' habitual optical aid.

Certain settings for parameters of biomimetic scrolling were used for the study involving normally sighted participants. Different settings were used for the study involving the visually impaired in order to take into account the different needs.

The perceptual span is defined as the width of the window of characters used in a fixation to plan the subsequent saccade. Not all the characters in the perceptual span can necessarily be recognized, so the visual span is defined to count the number of recognized characters in a fixation. In English, the perceptual span for the normally sighted is 4 characters left of fixation and 15 characters right of it, and the visual span is around 10 characters. Forward saccade length is an indirect measure of perceptual span, and was found to decrease from 7.5 letters in control subjects to between 1 and 4 letters in subjects with age-related maculopathy. To compound this issue, the use of magnified text decreases the field of view.

For the normally sighted study, the number of pauses per word was set to a constant of 1 as it was assumed that each word could be recognized during this single pause. This is not necessarily a reasonable assumption for subjects with AMD, especially for longer words and for patients requiring larger text size. Therefore, for the partially sighted study, multiple pauses along the length of a single word were allowed.

The number of pauses, p , was primarily determined by the word length, with longer words taking more pauses. To convert between word length and number of pauses a variable of letters-per-pause, w , was introduced. The number of pauses is then the quotient of the number of letters, l , by the letters-per-pause, rounded to the nearest integer, as in equation 2.1. The minimum number of pauses was set to 1.

$$p = \left\lceil \frac{l}{w} \right\rceil \quad (\text{Equation 2.1})$$

The value of w was chosen according to the font size used by the subject. For smaller font sizes, below about 80, $w = 8$. This effectively meant that, like the settings in the normally sighted study, there was one pause per

word. For most participants, $w = 6$, meaning most words had just one pause, but the longest words per paused upon twice.

Font size was set on a scale of 100 to 900 using the font size setting of the Kivy Python library. For the participants using very large font, over around 280, $w = 3$, meaning words 5 letters and longer were paused upon multiple times. The settings were checked with the participant before commencing testing and altered upon their request. In order to reduce the number of pauses for high frequency long words, a small additive term was also included for words with a frequency, f , above a certain threshold, f_{thresh} .

Word frequency is measured according to the logarithmic Zipf scale and was obtained from the SUBTLEX-UK word frequency database for British English. The additive term was linearly scaled to word frequency with a gradient of m and constant of c .

$$p = \begin{cases} \left\| \frac{l}{w} + fm + c \right\|, & f \geq f_{thresh} \\ \left\| \frac{l}{w} \right\|, & f < f_{thresh} \end{cases} \quad (\text{Equation 2.2})$$

The gradient and constant were set such that the maximum size of the additive term, given by the highest frequency word ('the', $f = f_{max} = 7.67$), would be small compared to the main term; this maximum size was set to -0.2, as in equation 2.3. The additive term should then fall to zero at the frequency threshold, thus the gradient and constant could be calculated according to the simultaneous equations 2.3 and 2.4. The frequency threshold was set to 5.8 on the Zipf scale so that only high frequency words were reduced in pause number.

With these settings, $m = -0.085$ and $c = 0.45$.

$$f_{max}m + c = -0.2 \quad (\text{Equation 2.3})$$

$$f_{thresh}m + c = 0 \quad (\text{Equation 2.4})$$

The viewing position, the position at which the word paused between the arrows, needed to be defined to permit multiple pauses. For words with n pauses, the viewing positions were centrally positioned in each $1/n$ section of the word. Thus for words with a single pause, the viewing position was set as the centre; for two pause points, viewing positions were at one quarter and three quarter positions; for three pauses points, viewing positions were at one sixth, half and five sixths positions.

In the normally sighted study, the number of pauses was kept constant but the length of each pause was varied. This was decided because the number of fixations and the fixation duration were found to be so highly correlated ($r = 0.97$). As some variability is introduced in the pause number in the partially sighted study, it was decided to only vary the pause duration in order to reduce the duration for very high frequency words.

Thus words over 6.5 on the Zipf scale were reduced in pause duration by one half.

Combined with the dynamic text options, the optimal text characteristics for AMD were researched in the literature. Previous studies have investigated the effects of text size, chromatic contrast, font or typeface, boldness, letter and word spacing. The settings that were found suitable for the majority of people with AMD were used as the default settings. However, a key aspect of our methodology is tailoring to the particular needs of the user. Therefore, for some of the parameters an option was given to the user to tune the default settings for them. This was not possible for all parameters due to the constraints of time with the patients.

One of the most important settings for enhancing reading speed may be the text size. A trade-off is required between a size large enough so that it is easily legible, but small enough that it does not decrease field of view. The font size was chosen as the critical print size, the minimum text size at which reading speed is at a maximum. After being shown a sample sentence, the participant was given the choice to increase or decrease this size at their preference.

It has been found that a yellow background to black letters was preferred by the majority of AMD subjects, compared to blue, green and red. Therefore, this was provided as an option, along with black letters on a white background and white letters on a black background. Participants were given the choice between the three.

Choice of font or typeface is another consideration. One study found that the Courier font was a better font for reading at font sizes close to reading acuity in AMD, compared to Times New Roman, Arial and Andale Mono. Therefore, Courier was chosen as the font for our study, and no choice was given to participants. A recent study trialled a font specially developed for peripheral vision and found it to improve letter and word recognition in the periphery but not reading speed.

The Courier font was set to bold as one of the first participants suggested this was preferable. Subsequently, this option was not offered to other participants. One study was conducted to investigate whether increased boldness increases reading speed in the central or peripheral vision, and found it either remained invariant or, for high levels of boldness, decreased.

Letter spacing, word spacing and line spacing are three other parameters of text presentation. Increasing spacing is intended to reduce the effects of crowding, meaning that text or objects close together are difficult to recognise. A study on letter spacing found increasing the spacing did not increase reading speed in central vision loss. A study on word and line spacing found that both double word and double line spacing achieved the highest reading speed in macular disease. However, another study found that line spacing did not improve reading speed in AMD. Standard letter, word and line spacing were used in our study.

With the text size, colour, font, boldness and letter, word and line spacing fixed, sentences are displayed in one of the dynamic display options: Static (non-dynamic), RSVP, horizontal continuous scrolling (leading or times square), and biomimetic scrolling. The order of dynamic display options was randomised.

In order to minimise any lexical differences between sentences, the sentences from the Radner Reading Chart were used with permission from Wolfgang Radner. The sentences are standardized in terms of their difficulty and syntactical structure, and the number and length of words used.

5

Oral reading speed was the primary outcome measure for assessing the effectiveness of the visual aids. Reading speed using their habitual optical magnifier was then measured using the Radner reading chart. Reading speed was measured at the smallest print size readable with the magnifier without straining (down to a minimum letter size of 0.5 M) as well as at the size above, and the maximum of these speeds used. Participants wore their habitual reading correction (if any).

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For the smart glasses, participants wore their habitual distance correction (if any) as the screen is focused at infinity. For the three dynamic text presentation methods, RSVP, continuous scrolling and biomimetic scrolling, the investigator set the speed of text presentation and initiated it. The speed of the first sentence was set to be well below their threshold, with each new sentence increased in speed until the subject was unable to keep up. The maximum reading speed was taken as the speed at which no more than two errors were made.

15

Through testing the 4 different methods of text presentation, the strategy which enables the fastest reading speed for each individual was discovered. In addition, the individual's preference for the text/background colour and for text size was found. In sum, the size, colour and dynamics of the text on the smart glasses was tailored to the particular needs of the individual.

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The reading speed achieved with this tailored approach on the smart glasses is compared, in Figure 15, with the reading speed achieved using the optical aid habitually used by the individual. It shows a scatter plot of the reading speed achieved using the optical aid against that achieved with dynamic text on the smart glasses. The line of equal speed is also plotted, with points above the line indicating a faster speed for the smart glasses.

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Participants 115 and 116 did not bring an optical aid with them to the study as they reported that they did not use one to read. Therefore, their results reading from paper at their critical print size are used instead. Participants 112, 118, 120, 125 and 129 had vision too poor to read from the smart glasses display and thus are not included in this plot.

30

15 out of 18 participants read faster using the tailored text on the smart glasses than using the optical magnifier. The mean ($\pm$ standard error) reading speed using the smart glasses was 122 ± 15 wpm and using the optical aid was 74 ± 9 wpm. This is a statistically significant difference as confirmed by a paired-sample t test, $t(17) = -4.61$, $p < 0.001$.

35

The four text presentation methods – biomimetic scrolling, continuous scrolling, RSVP and static text – were also compared. It was found that each of the methods enabled the maximum reading speed for a proportion of the participants. Figure 16 shows these proportions for each method. Figure 16 shows the number of participants that achieved their fastest reading speed out of each of the four methods of static, RSVP, horizontal smooth scrolling and biomimetic scrolling. This plot is included in order to illustrate the range of preferences across the sample, suggesting that the inclusion of a range of options will assist more individuals than a ‘one size fits all’ approach. It does not, however, take into account the size of the reading speed differences.

The mean reading speed for each text presentation method is shown in Figure 17. Figure 17 is a plot of mean reading speed for the four text presentation methods of static, RSVP, horizontal smooth scrolling and biomimetic scrolling. Although biomimetic scrolling has the highest reading speed, the differences between each method are small.

Data were analysed with a linear mixed-effects model (LME) with by-subject random intercepts, using the lmer programme of the *lme4* package for R. To evaluate the effect of presentation method on reading speed (wpm), we used treatment contrasts in which the RSVP condition served as the reference group. Consequently, the intercept for the fixed effect presentation method estimates the mean value for the RSVP condition. Three additional fixed effects estimate the difference between RSVP and any of the other conditions. For the LME we report regression coefficients (b), standard errors (SE) and t-values ($t = b/SE$). A two-tailed criterion ($|t| > 1.96$) was used to determine significance at the alpha level of .05 [24]; effects with $|t| > 1.645$ indicated marginal significance. In the LME, the estimated reading speed for RSVP was 95.25 wpm ($SE = 13.45$, $t = 7.08$). For biomimetic scrolling, there was a marginally significant increase in reading speed ($b = 16.88$, $SE = 9.31$, $t = 1.81$); specifically, mean reading speed was increased to 112.13 ($95.25 + 16.88$) wpm. The reading speed for continuous scrolling did not differ significantly from the RSVP condition ($b = 8.63$, $SE = 9.31$, $t = 0.93$). The same was true for the static reading condition ($b = 5.44$, $SE = 9.31$, $t = 0.58$).

At the end of the trial, participants were asked 2 questions. The first was, “Compared to reading large print from paper, did you find reading from the display to be...”, with 5 response options: Much easier, a little easier, the same, a little harder or much harder. The proportion of participants responding to each option are shown in Figure 18. The second question was, ‘Did you prefer reading from the display or from paper?’. The responses to this question are shown in Figure 19.

In further embodiments, each eye is presented with its own display screen or portion of display screen using a head-mounted display system, for example smart glasses. Different presentations may be provided to each eye, or text may be presented to only one eye, with the screen or portion of screen for the other eye being turned off. In some circumstances, a reader may prefer to have text presented only to their stronger eye.

It will be understood that the present invention has been described above purely by way of example, and that modifications of detail can be made within the scope of the invention.

5 Each feature disclosed in the description and (where appropriate) the claims and drawings may be provided independently or in any appropriate combination.

CLAIMS:

1. A reading system comprising:
5 an apparatus comprising a screen and a processor configured to display a sequence of text to a reader in a reading process; and
at least one processing resource configured to obtain reading data representative of at least one property of the text and/or the reading process, and to process the reading data to identify changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition
10 in the reader.
2. A system according to Claim 1, wherein the reading process comprises scrolling a line of text intermittently across a screen in a sequence of text movements and pauses, the scrolling mimicking a natural pattern of saccadic eye movement.
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3. A system according to Claim 1 or Claim 2, wherein the reading data comprises values for at least one parameter of the scrolling over time, the at least one parameter of the scrolling comprising at least one of a pause duration, a pause position, a text movement duration, a text movement length, a scrolling speed, a relationship between pause duration and word length, a relationship between pause duration and word
20 frequency.
4. A system according to Claim 3, wherein different values of the at least one parameter of the scrolling are used for different words within the line of text.
- 25 5. A system according to Claim 3 or Claim 4, wherein the values for the at least one parameter of the scrolling are dependent on content of the line of text, the content comprising at least one of word length, word frequency, word complexity, word familiarity.
6. A system according to any of Claims 3 to 5, wherein the at least one parameter of the scrolling is
30 controlled by the reader.
7. A system according to any preceding claim, wherein the reading data comprises eye movement data obtained during the reading process.
- 35 8. A system according to any preceding claim, further comprising a communication resource configured to transmit the identified changes and/or the reading data to a remote location.

9. A system according to any preceding claim, further comprising a data store configured to store the reading data.
- 5 10. A system according to any preceding claim configured to obtain the reading data in a home or office environment.
11. A system according to any preceding claim configured to obtain the reading data in the reader's normal or everyday environment.
- 10 12. A system according to any preceding claim, wherein the processing resource or one of the processing resources is further configured to issue an alert based on one or more of the identified changes.
- 15 13. A system according to any preceding claim, wherein the processor is configured to receive a selection of an item of content from the reader and to display at least part of the item of content on the screen on the screen, and wherein the obtaining of the reading data comprises obtaining reading data relevant to the reader's reading of at least part of the item of content.
- 20 14. A system according to any preceding claim, wherein the processor is further configured to deliver vision tests to the user via the screen, and wherein the obtaining of the reading data comprises obtaining reading data from the vision tests.
15. A system according to any preceding claim, wherein the reading data comprises at least one of text size, typeface, contrast, colour contrast, reading speed, reading duration, luminance.
- 25 16. A system according to any preceding claim wherein the reading data comprises eye movement data, blink rate data or pupil response data, the apparatus further comprising a detector configured to measure eye movement data, blink rate data or pupil response data and to deliver the measured eye movement data, blink rate data or pupil response data to the processor.
- 30 17. A system according to any preceding claim, wherein the visual or neurological deterioration is due to, or the condition comprises, at least one of: amblyopia, dyslexia, macular disease, glaucoma, cognitive decline, dementia, a neurodegenerative disease, motor neurone disease, multiple sclerosis, Parkinson's disease, stroke.
- 35 18. A system according to any preceding claim, wherein the changes in the reading data over time that may be indicative of visual or neurological deterioration and/or the presence of at least one condition in the reader comprise at least one of: larger print size, increased illumination, increased contrast, a change in colour contrast preference in one eye, a change in colour contrast preference in both eyes.

19. A system according to any preceding claim, wherein the at least one processing resource comprises a first processing resource and a second processing resource at a different location from the first processing resource.

5 20. A text display method comprising scrolling a line of text across a screen, the scrolling comprising:
at least one pause in which the line of text does not move; and
at least one text movement in which the line of text moves;
wherein at least one parameter of the scrolling is determined based on measured eye movement data
from at least one test subject, such that the scrolling mimics eye movement of the at least one test subject.

10 21. A method according to Claim 20, wherein the at least one parameter of the scrolling comprises a duration or text position of at least one pause, and the duration or text position of the at least one pause is based on a duration or text position of a corresponding fixation in the eye movement data.

15 22. A method according to Claim 20 or Claim 21, wherein the at least one parameter of the scrolling comprises a duration or length of at least one text movement, and the duration or length of the at least one text movement is based on a duration or length of a corresponding saccade in the eye movement data.

20 23. A method according to any of Claims 20 to 22, wherein the text display method further comprises modifying the at least one parameter of the scrolling based on an input received from a reader.

24. A method according to any of Claims 20 to 23, further comprising displaying on the screen a reading position indicator, the reading position indicator being indicative of a position on the screen on which a reader of the line of text is intended to fixate while reading.

25 25. A method according to any of Claims 20 to 24, the method further comprising obtaining the measured eye movement data from the at least one test subject by measuring eye movement of the at least one test subject while the at least one test subject is reading at least one sample text.

30 26. A method according to Claim 25, wherein:
the measured eye movement data is obtained from each of a plurality of test subjects reading the same at least one sample text;
the method further comprises processing the measured eye movement data to obtain average eye movement data; and

35 the determining of the at least one parameter of the scrolling is based on the average eye movement data.

27. A text display apparatus comprising a screen and a processor, wherein the processor is configured to scroll a line of text across the screen, the scrolling comprising:

at least one pause in which the line of text does not move; and

at least one movement in which the line of text moves;

5 wherein at least one parameter of the scrolling is determined based on measured eye movement data from at least one test subject, such that the scrolling mimics eye movement of the at least one test subject.

28. A text display apparatus according to Claim 27, wherein the text display apparatus comprises a head-mounted display.

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29. A text display apparatus according to Claim 27 or Claim 28, wherein the text display apparatus is further configured to record reading data.

30. A system according to any of Claims 1 to 19, wherein the apparatus is the text display apparatus of any of Claims 27 to 29.

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31. A system according to any of Claims 1 to 19, wherein the reading data is obtained while the reader is reading text displayed using the method of any of Claims 20 to 26.

32. A system according to any of Claims 1 to 19 or 27 to 29, wherein the apparatus and/or text display apparatus comprises at least one of a computer, a portable computer, a laptop, a tablet, an e-reader, a smartphone, a handheld reading device, a handheld computing device, an assistive reading device, a head-mounted display, smart glasses, a smartphone headset, a television.

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33. A method comprising:

processing reading data obtained using a system according to any of Claims 1 to 19 to identify changes in the reading data over time that may be indicative of visual or neurological deterioration in the reader and/or of the presence of at least one condition.

25

34. A computer program product comprising computer readable instructions that are executable by a processor to perform a method according to any of Claims 20 to 26 or 33.

30

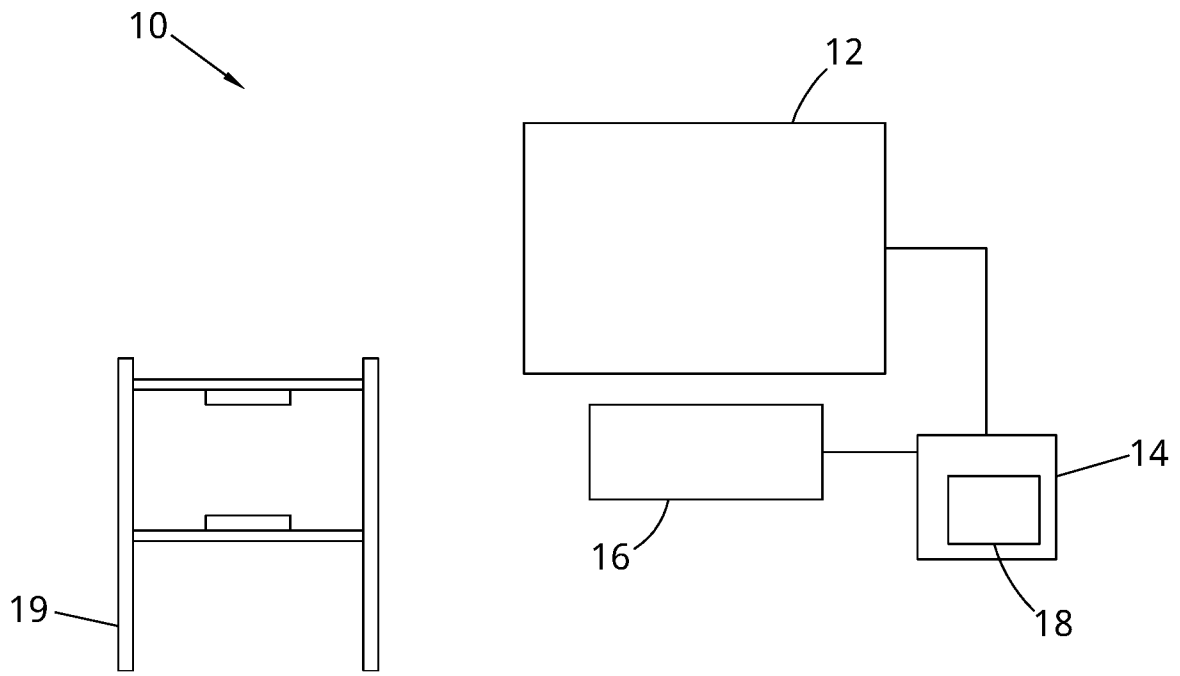


Fig. 1

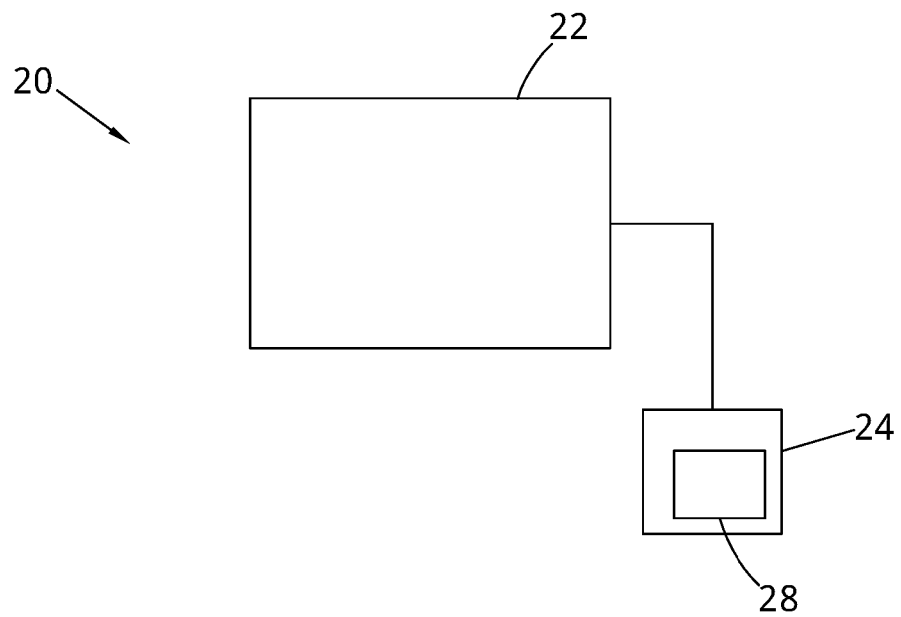


Fig. 2

2/11

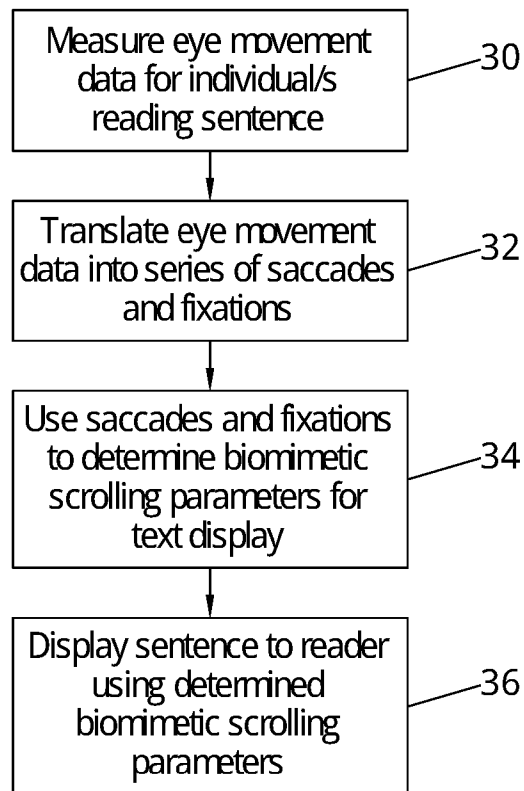


Fig. 3

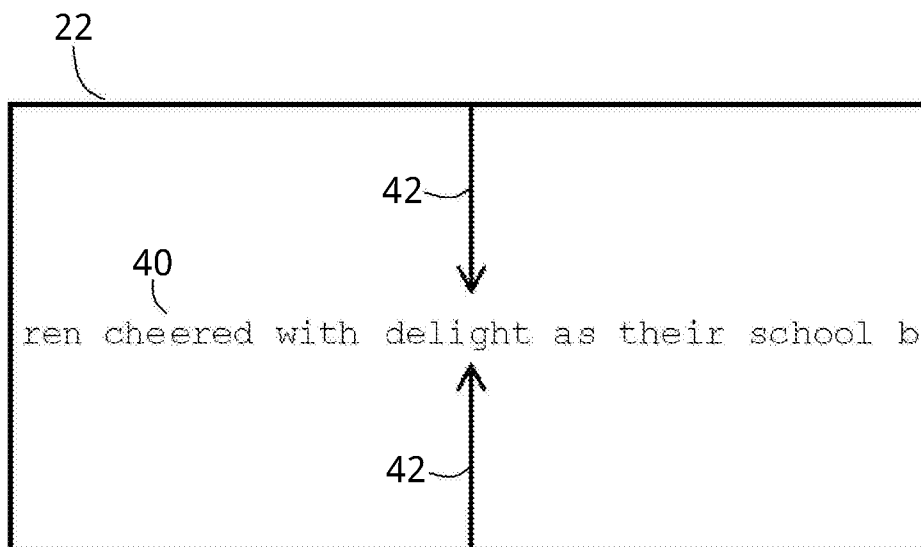


Fig. 4

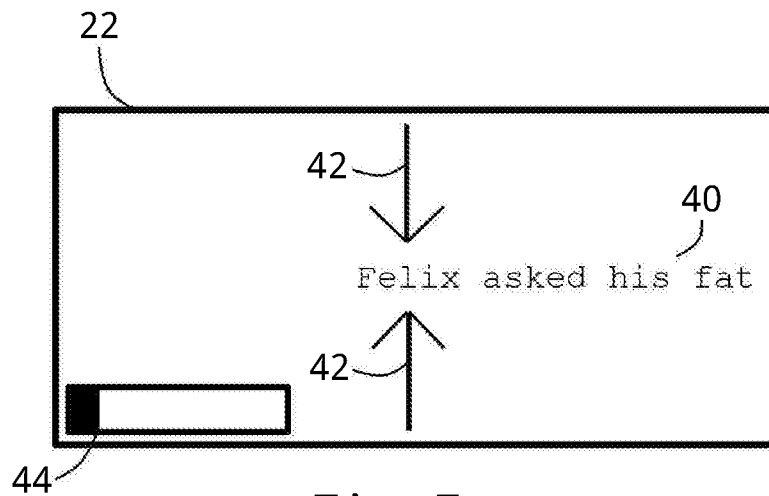


Fig. 5a

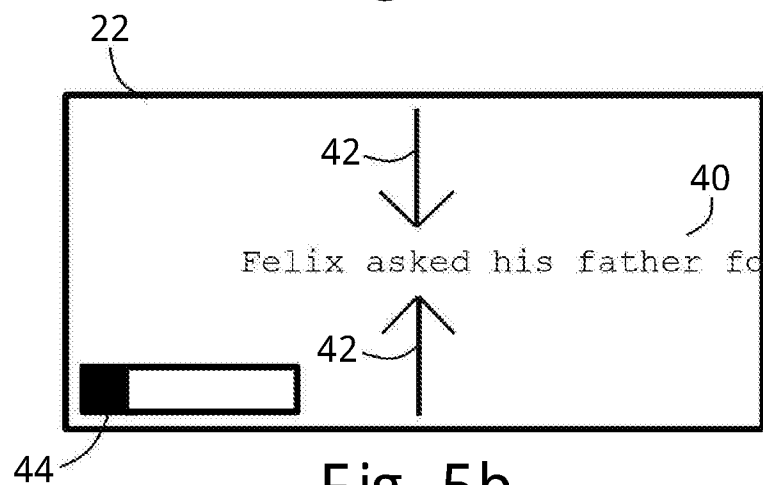


Fig. 5b

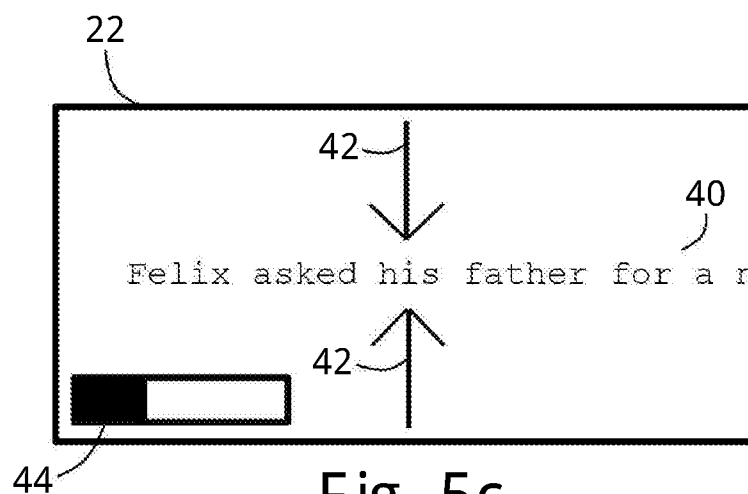


Fig. 5c

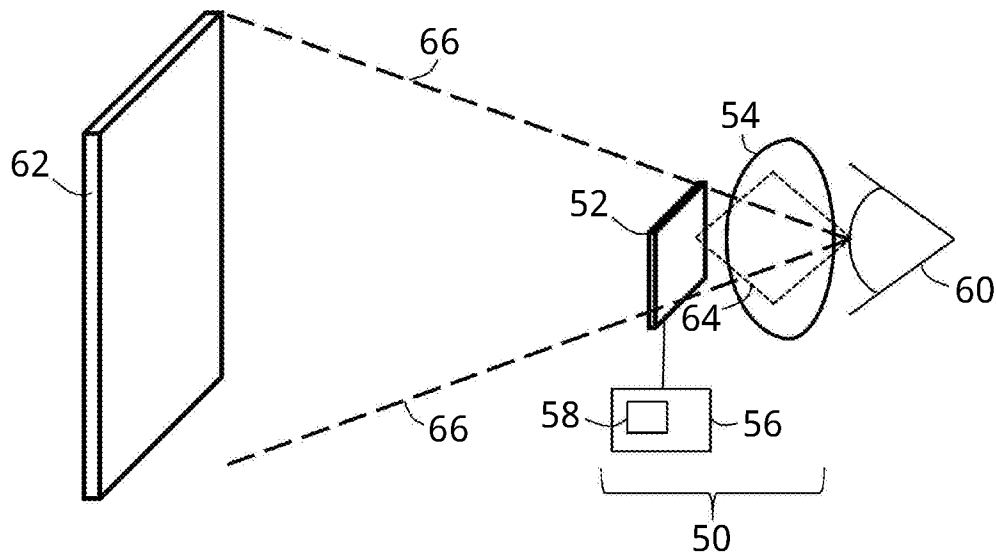


Fig. 6

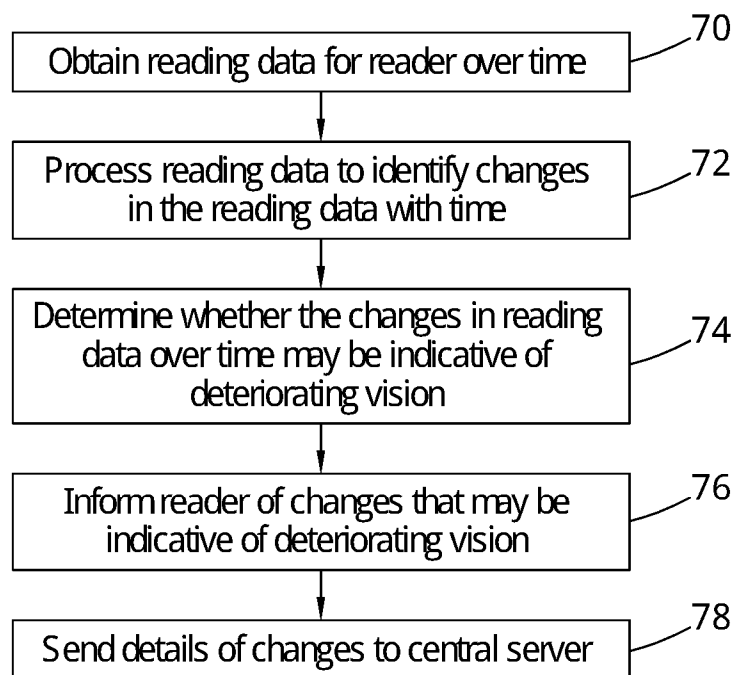


Fig. 7

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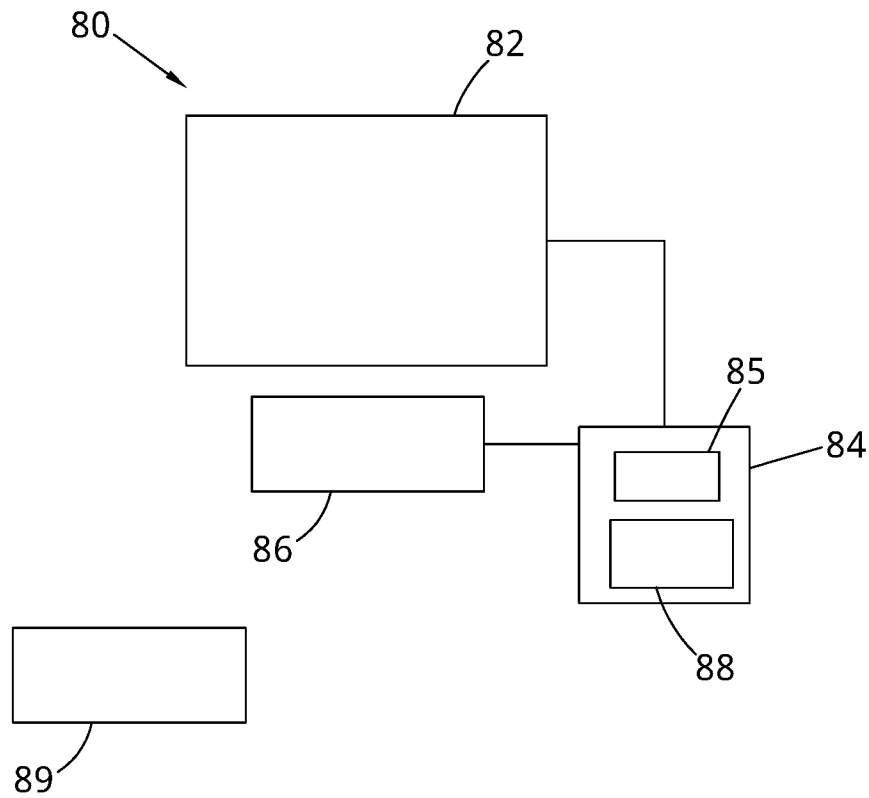


Fig. 8

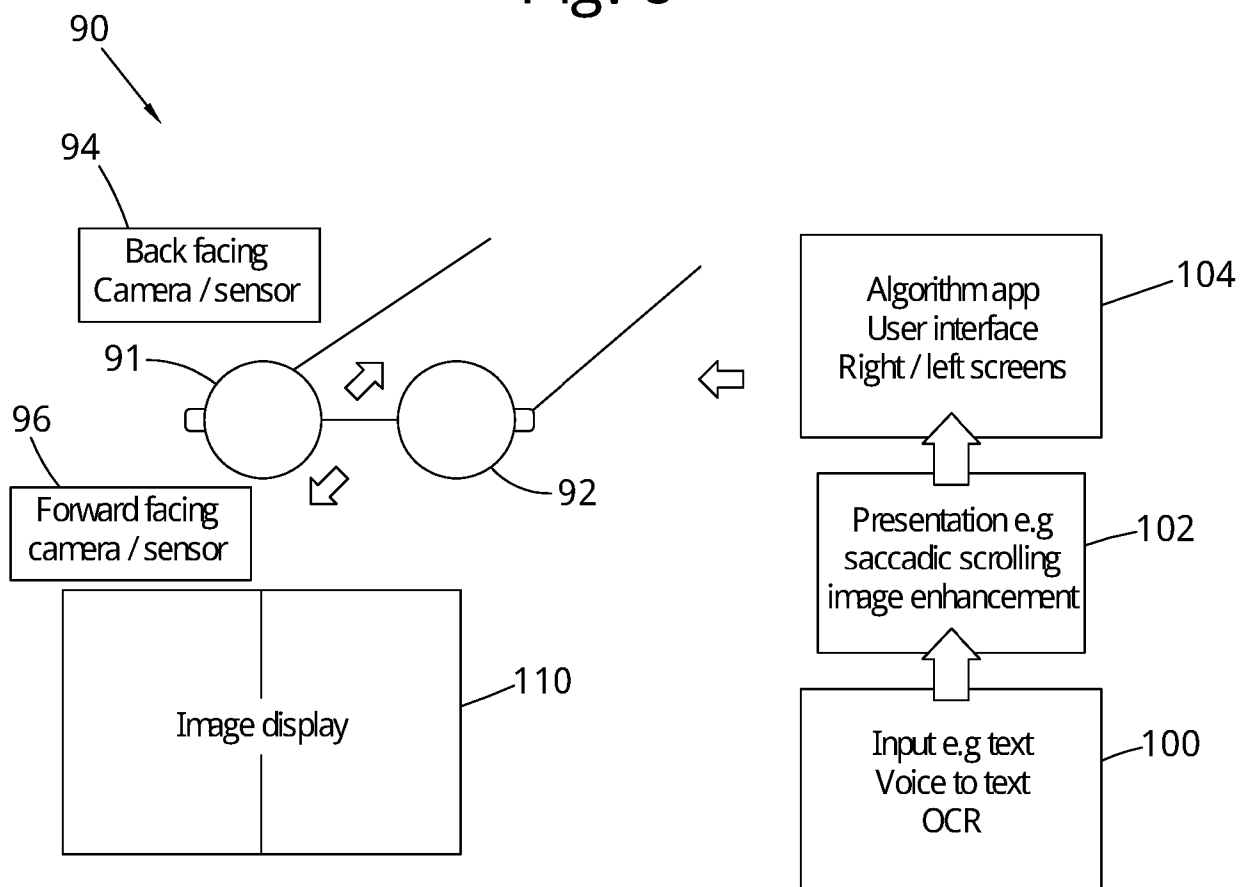


Fig. 9

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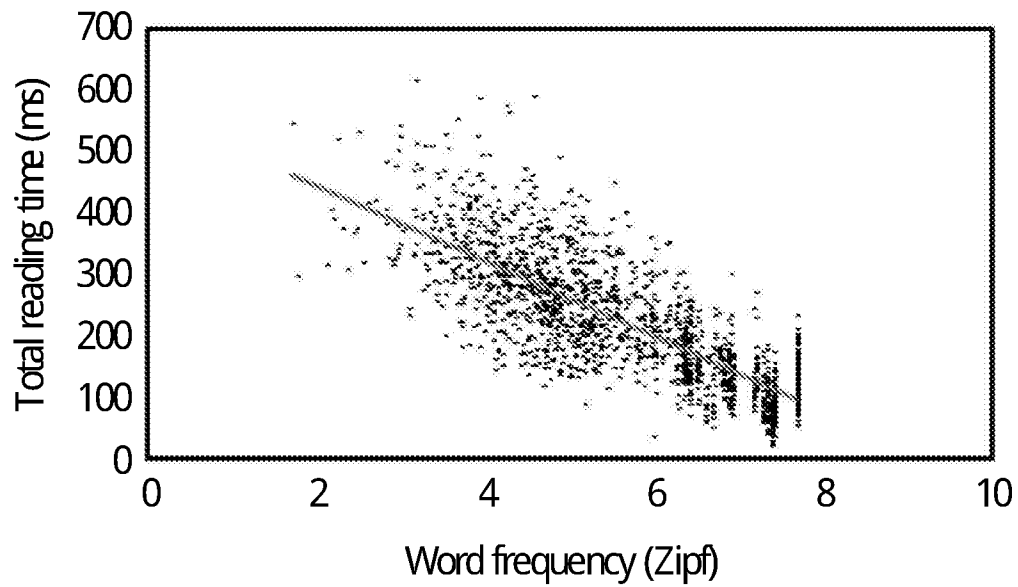


Fig. 10

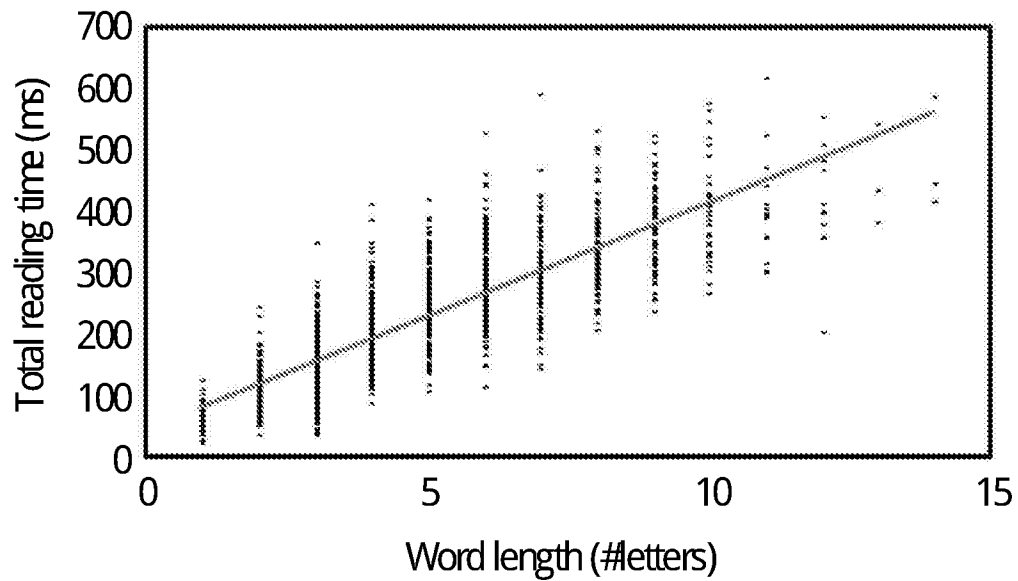


Fig. 11

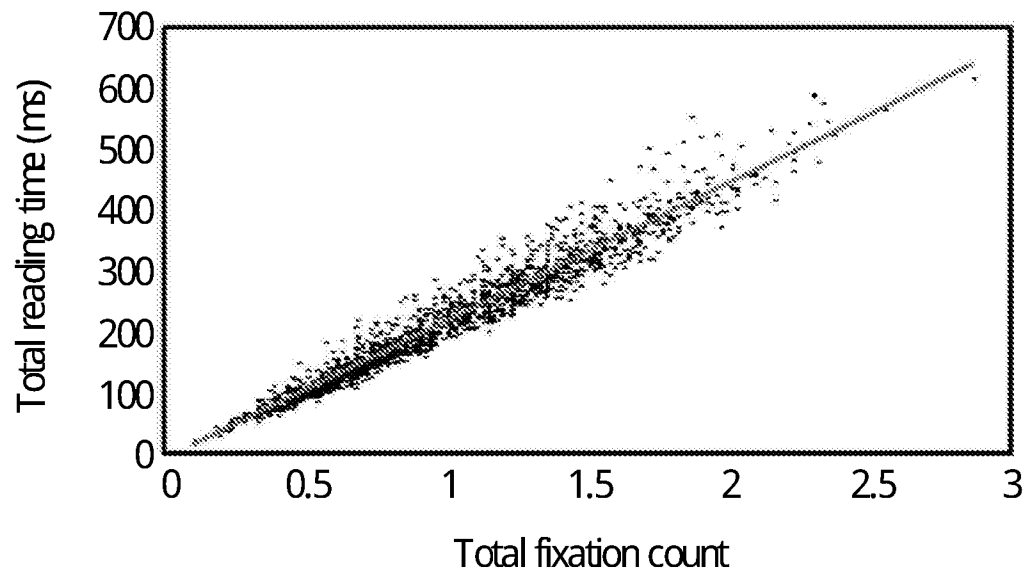


Fig. 12

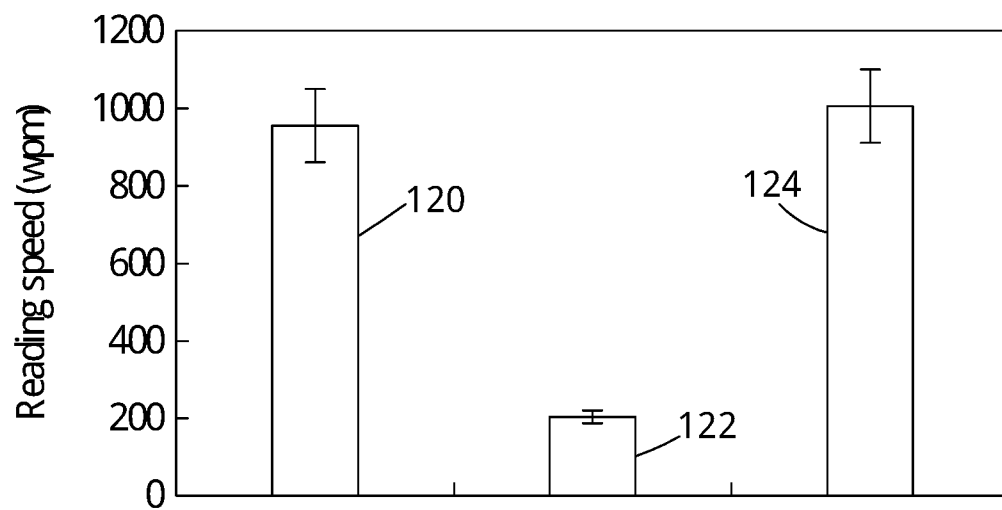


Fig. 13

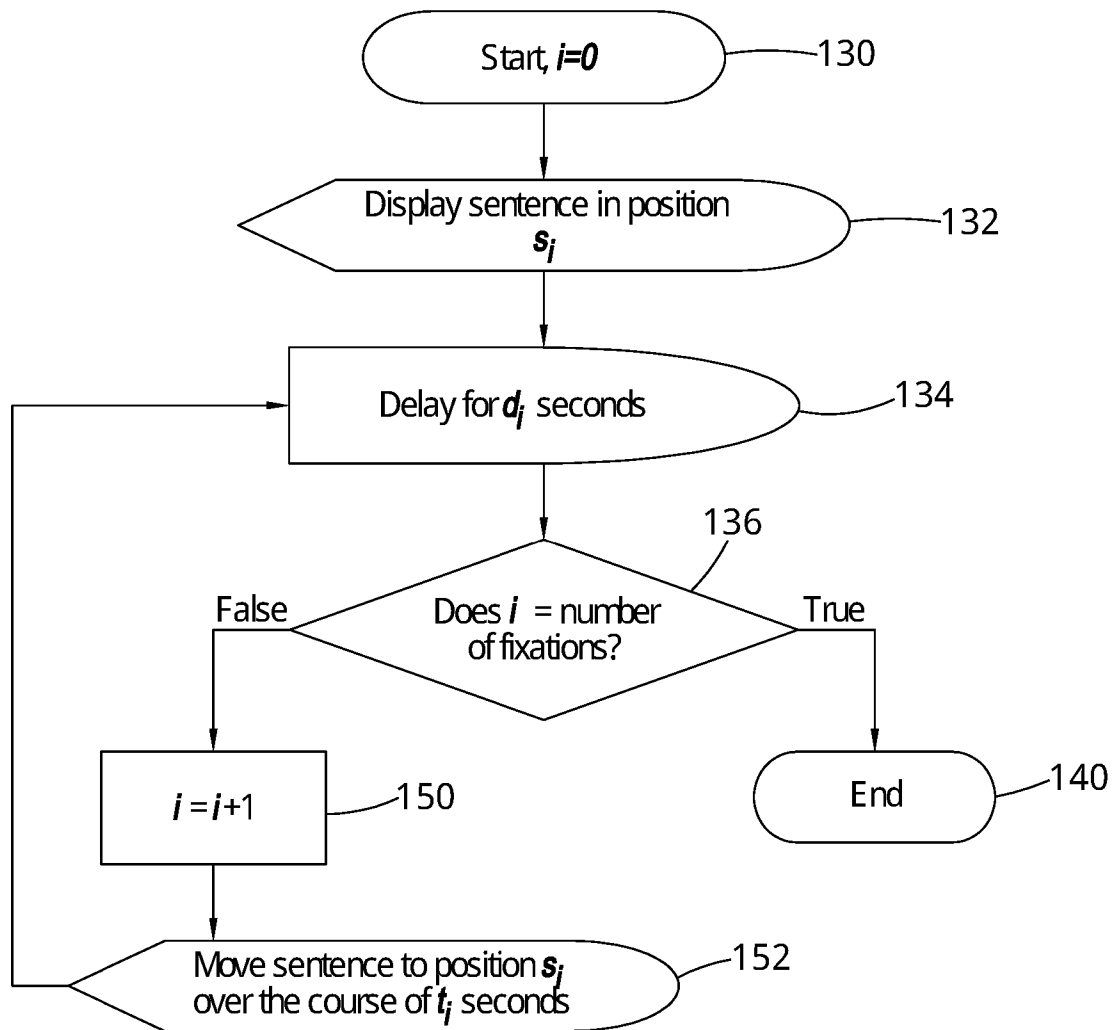


Fig. 14

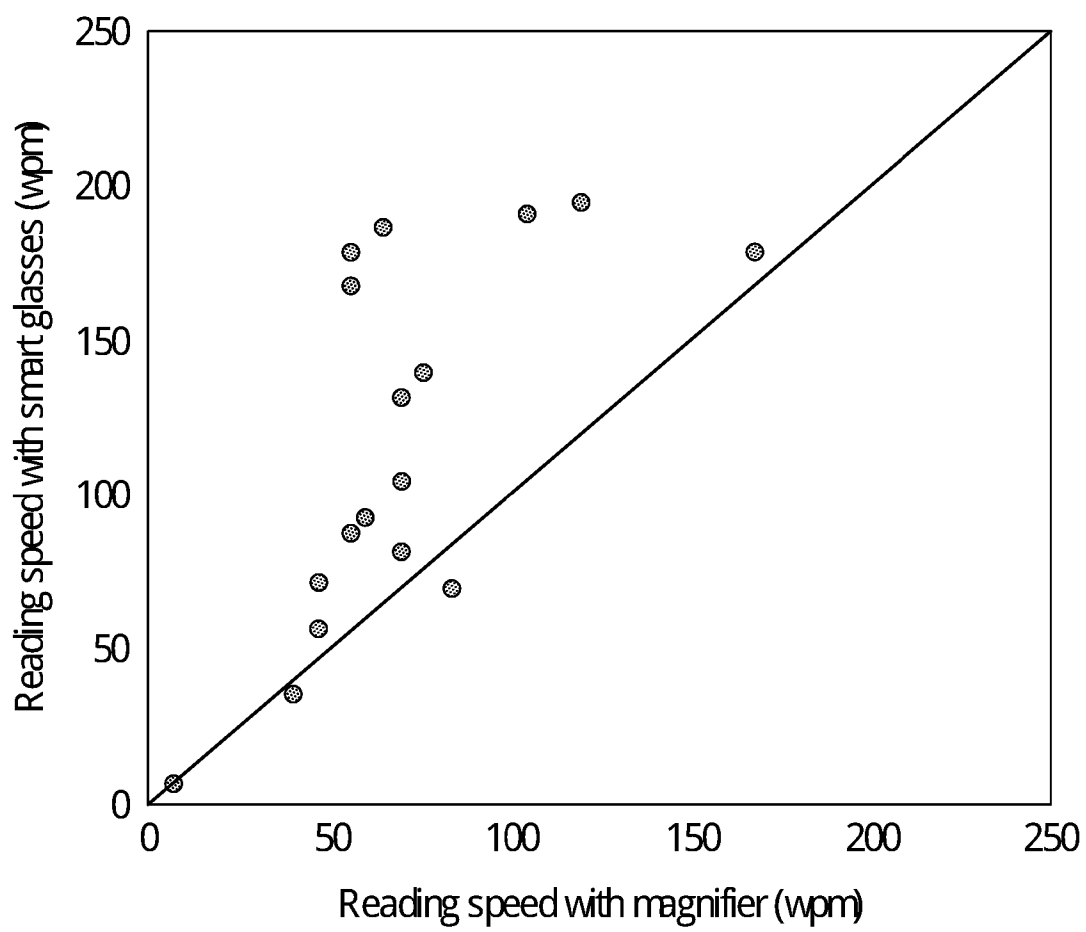


Fig. 15

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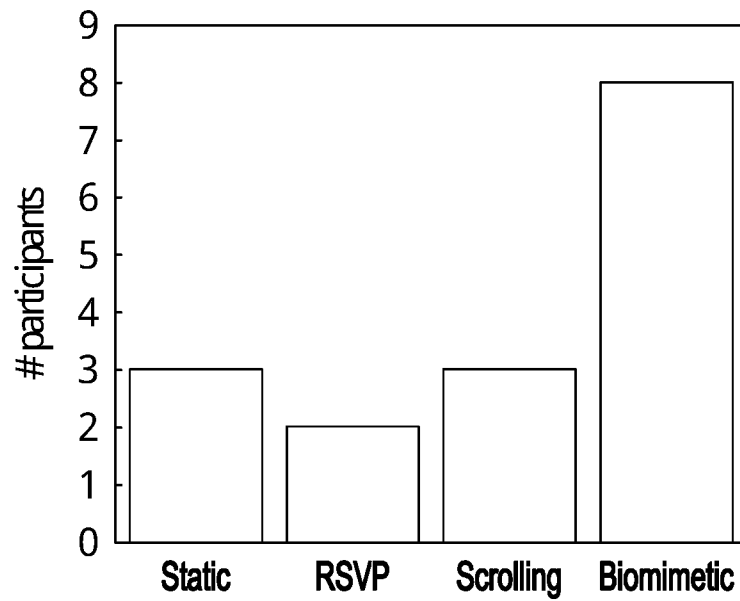


Fig. 16

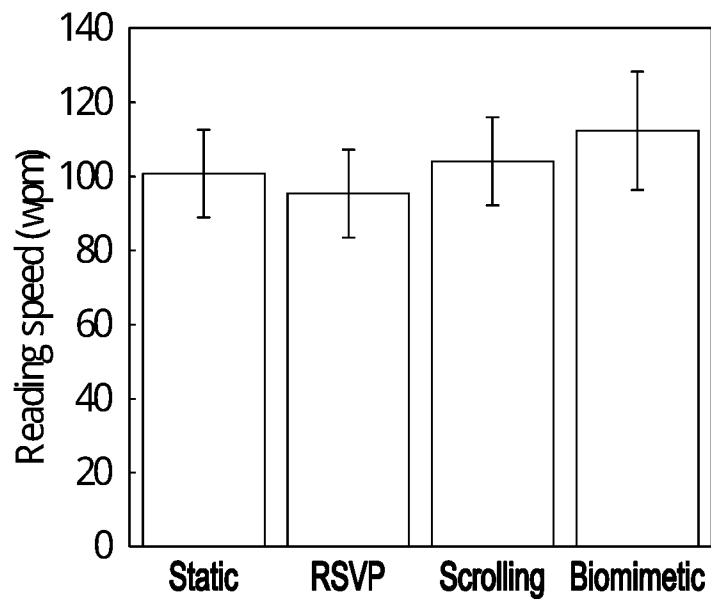


Fig. 17

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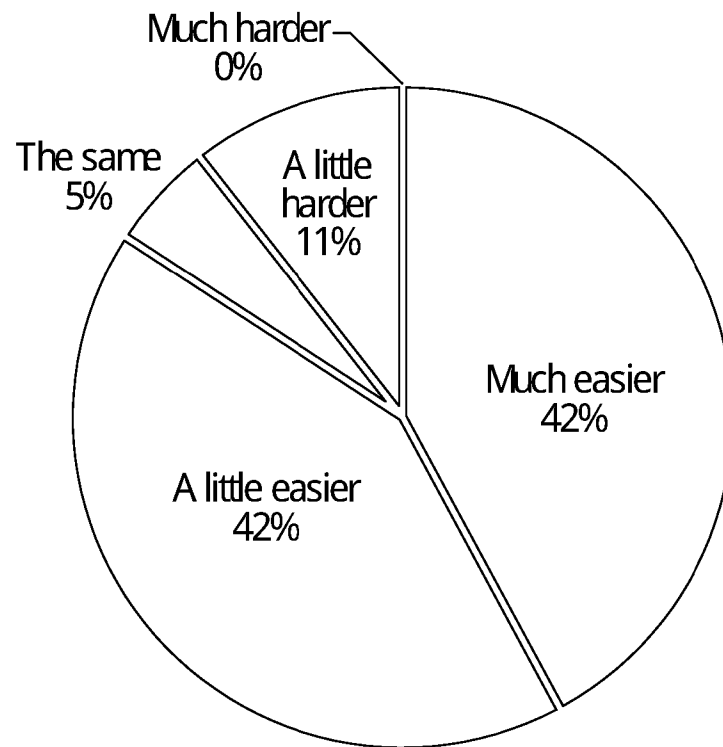


Fig. 18

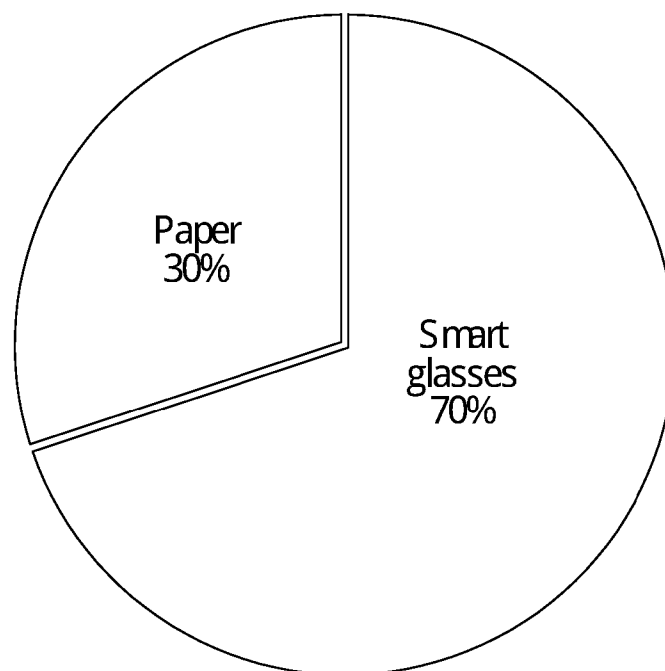


Fig. 19