Measuring Reading Characteristics Using Eye Tracking and a Context Adapting Classification System

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ABSTRACT
This abstract introduces a new automated method of measuring reading patterns by analyzing eye properties via an eye tracking platform and context analysis. The method utilizes eye tracking data and stimulus text properties in a way that makes it possible to identify reading fixations and reading patterns with a high accuracy compared to looking at fixations only. This helps doing a fast initial analysis on how the text is cognitively perceived and thereby provides easier access to valuable high level information on how the text is comprehended.

Author Keywords
Eye Tracking, reading analysis, gaze analysis, text recognition.

ACM Classification Keywords
I. Computing Methodologies, I.5 Pattern Recognition, I.6 Simulation and Modeling.

INTRODUCTION
The eye tracking and context based method for quantifying reading is implemented in Attention Tool® a software for measureing eye tracking, human emotional activation and reading patterns on visual stimuli within consumer research. The reading metrics are obtained by using the output from a non-intrusive (remote) eye tracking hardware running at 60 Hz and an image processing system identifying the stimulus characteristics. Each gaze pattern is extracted from the respondents' eye via the eye tracking device while the respondent is exposed to the stimulus. Utilizing the knowledge about the stimulus characteristics, the reading results are classified and delivered directly as a quantified output of the reading patterns. Via the eye tracker the software furthermore collects and analyzes several subtle changes within the respondent's eye gaze characteristics, blink characteristics, and pupil change characteristics in order to determine the emotional activation (Arousal) and traditional eye tracking metrics.

READING
Reading is a process in which the eyes are fixated on successive locations in a text while information is brought into the processing system of the brain. Reading Meter in Attention Tool® detects the reading pattern of the eyes by combining different methods.

Fixations, Saccades and Reading Patterns
During reading the eyes move across the text in a sequence of fixations where the eyes are steady, separated by fast movements called saccades. The eyes do neither fixate on each letter in a word nor sequentially from word to word. Skilled readers skip words and make regressions to material already read about 15% of the time. The fixation duration is on the range from 100 to over 500 milliseconds the average is 200-250 msec. The distance which the gaze travels during each saccade is between 1 and 20 characters the average being around 7-9 characters. Thus there is a considerable variability in fixations and saccades both between readers and for the same person reading a single passage of text [1]. Figure 1 below shows an example of saccade length and how letters around a fixation are perceived.

Fixation and saccade length, the probability of fixating a word and the number of fixations on individual words can be related to cognitive processing as is done in the E-Z Reader model [3,4] Reading Meter focuses on whether a text block is read or not, without taking other cognitive processes into account and displays the resulting statistics.

Gaze Behavior and Text
Fixation alone cannot reveal if the subject is reading but the

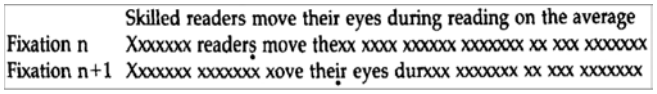

Figure 1. Line one represents a normal line of text. Line two represents a 17 character window (fixation point indicated by the dot) and the third line presents a window for the subject's next fixation. In line two and three, original letters are replaced by x's. [2]

saccade pattern can give a good indication. The longer the text, the more obvious is the reading pattern and the system can predict reading with more certainty. Gaze behavior for some objects is similar to that observed for reading a small block of text. For example when a face is observed, the subject usually gazes from one eye to the other repeatedly and down to the mouth. A similar pattern is often observed for smaller text blocks. Figure 2 shows an example of a face and a small text block with the corresponding gaze patterns that are similar in character.

As a line of text becomes longer, the number of fixations along the text increases and therefore more reliable results can be expected from Reading Meter. For a text block of only three words or less it is almost impossible to detect a reading pattern, as the number of fixations is most likely too low. In addition to looking at the fixations and saccade pattern the underlying system also analyses the properties of the text in the stimulus, this image processing based approach provides additional information about the underlying text. Based on this information the system can conclude that fixations across the text are due to reading actual text and not looking at e.g. a face, the robustness and certainty of the reading detection improves the longer the text blocks. Furthermore information about text size helps the system to detect the pattern as the saccade varies proportionally with the text characteristics. Therefore the system analyses the stimulus to detect underlying text through image processing in addition to the gaze analysis. This is explained in the final section.

Figure 2. Gaze patterns while looking at a face and a short text block.

How Many Words Are Needed for a Good Reading Analysis?

It is difficult to say how many words are needed for perfect reading analysis, as the number of fixations is the crucial factor. It is not possible to predict how many fixations are expected for a word of a certain length as the average number of fixations within a word is not proportional to the number of letters in the word [1] But with a line of five words or more, experience with Reading Meter has given a good outcome where all reading patterns were detected. In a recent benchmark study the accuracy of the reading system showed that less than 15% error could be expected in 97% of the cases.

RESULT METRICS

How Many Readers and How Much Read

The yellow sticky note in figure 3 shows two results: *Readers*, which is the number of respondents who read something within the region and *Read(%)* which is the average amount of text read by the respondents. The Pink label shows the order of the area with most readers - assigning the lowest number to the region with the highest number of readers in the stimulus.

Using simple gaze analysis from traditional eye tracking it is possible to select a text area using an Area Of Interest (AOI) tool to determine how many subjects looked into the selected area. The subjects that looked into the area might have been reading all the text, a few words or simply just looked somewhere within the area without reading a word. If you are interested in knowing if the text was actually read, by how many respondents and how much of it was read on average, you need to apply reading analysis, looking closer at what type of "looking" was going on, on what type of content. The figure below shows the information provided by the Reading Meter analysis. For this image 13 out of 30 subjects read some part of the text (Readers: 13/30) and on average they read around 40% of text (Read(%): 40%).

Reading Intensity Map

The Reading Intensity Map in Reading Meter is a measure of how much time respondents spent reading a particular part of the text. It is normalized to the total number of respondents. Figure 4 shows statistical output from Reading Meter for four different text areas along with the

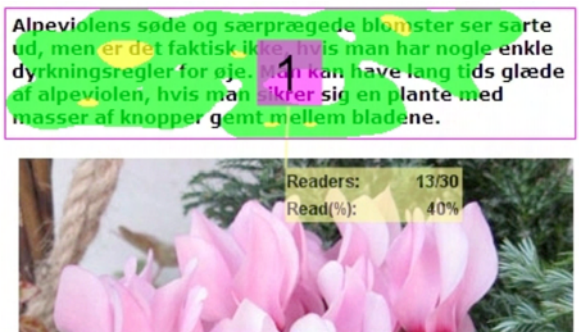

Figure 3. Reading analysis result example.

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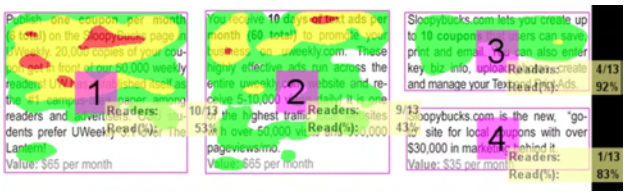

Figure 4. Reading Intensity Map.

corresponding intensity map which has three colors: red, yellow and green. The colors interpret the following:

- ***Green:*** Low reading intensity areas have attracted less than 30% of the total reading time. This can be because the readers read fast or because few readers read this text.
- ***Yellow:*** Medium reading intensity marks an area where 30-60% of the time was spent. These areas have usually been read by around half the respondents.
- ***Red:*** High reading intensity area is where more than 60% of the reading time was spent. It is often seen at the start of a text clause because many respondents read only the first line. It can be observed on text that is attention grabbing due to different font type, size or color. High intensity area can also be observed in semantically or syntactically ambiguous sentences due to regressive saccades [3].

In the example in figure 4 most of the text was read by someone in area one, two and three which are green. As only one reader was detected in area four there is no Intensity Map. The yellow color in area one shows us that most readers has reading fixations on the first six lines of text. The red area indicates that most of the respondents read these lines or that many of the respondents had many reading fixations on particular words such as "SloopyBucks" as illustrated in the high intensity reading fixation area in text box 1.

READING METER PROCESS

Reading Meter in Attention Tool® is based on several processes as illustrated by the flow diagram in figure 5. In short, the user selects a text area and if the Image Processing System detects sufficient amount of text within the area, a reading analysis is performed, using information about the underlying text and gaze behavior in the area. Reading Meter then provides statistics about reading for the selected text area. The Image Processing is used for automatic text detection. The text features extracted include information about the text location and characteristics such as text size and length. The user is asked to approve the number of lines detected by the system. The Gaze Analysis system extracts the fixations from the gaze data for every respondent. It calculates fixation location and duration, saccade directional speed and acceleration.

The Reading Pattern Analysis uses the gaze features to detect reading patterns. This method is based on a classical

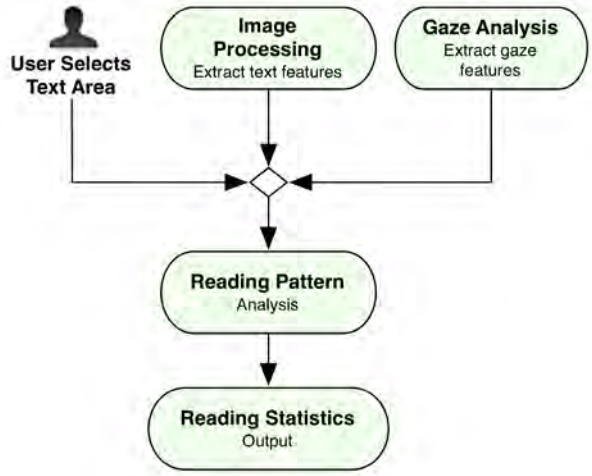

Figure 5. Flow diagram for reading analysis in Attention Tool. User selects a text area and if text is detected within the area a reading analysis is performed. The reading pattern is analyzed using information about the text characteristics in combination with the gaze data. At last statistics for the text area are provided.

approach to reading pattern analysis, where the probabilities of the saccades being part of a reading pattern or not, is based on its speed and direction. These probabilities are added together throughout time, meaning that if many reading-saccades appear in a row the probability that this gaze behavior is due to reading increases. If the subject looks into another area the probability sum is initialized. To improve this reading detection algorithm, Reading Meter also takes gaze acceleration and the information about the underlying text into account to provide a good estimate on reading behavior.

CONCLUSION

The automatic approach to reading analysis proves to be quite robust on standard product material used in consumer tests. The precision of the system depends on two main factors; 1) the quality of the eye tracking data and 2) the success of the image processing system identifying the text. Further evaluation of the performance is currently ongoing to improve the accuracy of the system.

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