

*scanpath analysis,  
human visual system,  
perception skill*

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## **MONITORING THE PROGRESS OF FAST READING TRAINING WITH USE OF THE EYETRACKER AND SCANPATH STATISTICS**

The research on the human reading technique and text perception strategies needs objective evaluation methods. Our proposal consists in the use of scan-path recording and eye track processing results as estimators of reading skills and capability of error compensation. Visual tasks, being principal investigation tool, were completed by arrangement of texts for presentation, eye trajectory acquisition and assessment of comprehension degree. Our results show that gaze point statistics represent well the observer performance and skills in fast reading even in free-spotting-based visual tasks. Additionally, we reveal very high human tolerance for errors, outperforming any known optical character recognition software.

### **1. INTRODUCTION**

#### **1.1. RESEARCH AIM AND SCOPE**

Current investigations of human perception often use the scan-path analysis as a valuable and objective tool. This method, previously recognized in medicine and used to reveal disorders of human sight or equilibrium senses, is now used in many emerging technical applications [2], [7], helping in perception-based visual information design (e.g. advertisement, websites), human behavior assessment and intelligent man-machine interfaces for disabled people [1].

The goal of the research presented hereby is to verify the usability of the scan-path method to the assessment of reading skills in humans. The primary area of interest was to correlate the selected scan-path parameters recorded in various visual tasks with the reading speed. The scope of our research was then extended to distorted text reading and foreign language reading.

#### **1.2. FAST READING TECHNIQUE**

Reading is introduced and practiced at school, but, due to the lack of necessity, rarely reading technique is optimally taught at this stage. Commonly used, reading becomes a cultural-background motivated perceptual habit (e.g. the western culture educated reader intuitively starts reading at the left edge). The motoric habits from childhood, sufficient to

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read and understand simple messages, usually remain in adults; nevertheless they are not optimal in professional live in the information society of today.

Text messages perceived by visual system of the human carry information of undefined importance. The perception strategy and human visual search for information attributes higher relevance to the expected message, neglecting any side information as noise. That suggests the role of an a priori knowledge or of a preliminary text glance that may anticipate every actual reading.

The variation of importance between subsequent words is a background of recent methods for fast reading training. Assuming that the full understanding of every word is not equally necessary for correct interpretation of the whole message, some portions of text may be perceived in larger blocks significantly increasing the reading speed at the cost of not noticeable degradation of comprehension. The training consists in cultivation of three skills:

- enlarging of visual field applying the short-term memory,
- elimination of vocal repetition as a bad habit,
- using common words associations to raise the tolerance for temporal understanding problems.

Enlargement of visual field is particularly noticeable in the scan-path and was a background of our research whether the scan-path analysis may efficiently contribute to the reading skills assessment.

## 2. MATERIALS AND METHODS

### 2.1. INFRARED EYETRACKING TECHNIQUE

The infrared reflection based eyetracker OBER-2 [4] was used in our visual research. The head-mounted goggles illuminate each eyeball with four adjacent spots of a total power of  $5 \text{ mW/cm}^2$ , in  $80\mu\text{s}$  pulses (wavelength  $940\text{nm}$ ), repeated at the sampling frequency. Four IR sensors per eye work in a pair-wise space-differential configuration and capture two-dimensional trace of each eye at the rate up to 2000 samples per second. The data gathered during the presentation are transmitted on-line or locally stored in the 32k samples data buffer. Since the sensor captures the visible light as well, a double sampling method is used for the sidelight discrimination. The ambient illumination is captured first, ca.  $80\mu\text{s}$  before the infrared diodes become active and next the actual infrared reflection readout is derived by the time-differential measurement. This measurement method eliminates the influence of all common light sources and allows the device to achieve the angular resolution of  $0.02 \text{ deg}$ .

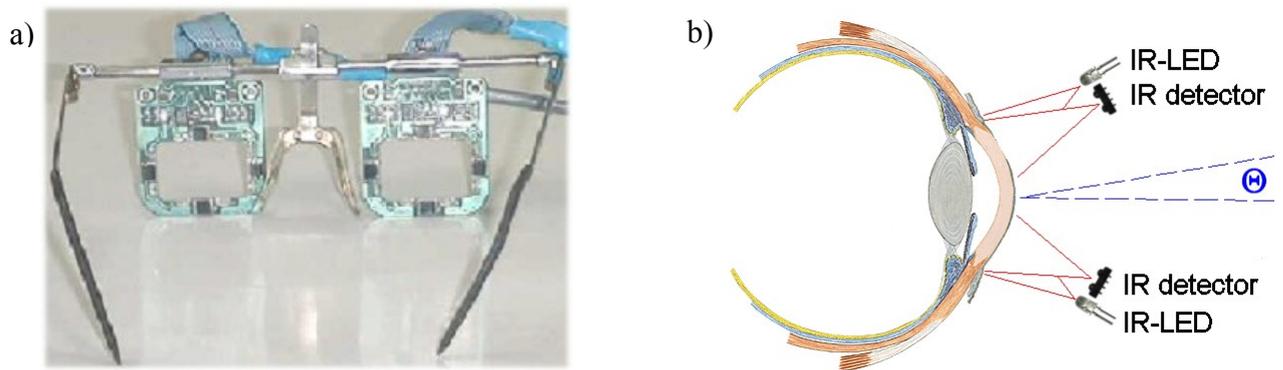


Fig. 1 Details on the Ober-2 eyetracker (a) physical principle and (b) general overview of goggles.

## 2.2. VISUAL TASK METHODOLOGY

A series of visual experiments [3], [6] were carried out with the aim to find the scan-path parameters best representing the reading skills. The visual tasks were performed in similar conditions by human volunteers. The degree of fast reading expertise was estimated for every new observer with use of conventional paper-based tests. Every possible sight defects should also be declared at this stage. The observer was then instructed for reading the text going to appear on screen at the maximum speed. The calibration procedure, providing an individual scan-path transposition matrix, was performed before each visual task. Assuming perfect observer cooperation, the matrix is automatically calculated from differences between the coordinates of standard calibration rectangle and corresponding scan-path trace. Each visual task included two principal stages:

- presentation of standardized initial information and motivation to complete the knowledge from the scene,
- presentation of the prepared text in parallel to the scan-path acquisition;

First eight seconds of the scan-path, when observer scrutinized the scene in an unrestricted manner, were analysed. If the observer announces the completion of the visual task prematurely, the remaining part of the scan-path is rejected.

Since the scan-path is sensitive to unexpected observer's behaviour or other human factor, therefore high degree of co-operation is essential. The scan-path was accepted if the measured degree of text comprehension was greater than 60%. Eight healthy volunteers (5F+3M) participated in the visual experiments at various stages of their progress in fast reading course. Unfortunately only two of them were followed during the course by making visual tasks at the beginning, at the end and two months after the course end, which is approximately in a two months interval.

...mniej metod jest sprawą trudną, gdyż niektóre z nich cechują się  
 lepszymi wskaźnikami kompresji, a inne dużą szybkością kodowania i dekodowania  
 w czasie rzeczywistym. Należy również pamiętać o wrażliwości kompresji. Niektóre metody są bardzo czułe na zmiany  
 w danych wejściowych, np. błędnie wyliczone dane (np. błąd wynikający z zakłóceń  
 lub błędów w trakcie transmisji danych przez modemy). Niektóre metody  
 wymagają nawet specjalnego oprogramowania, aby dalsza praca z nimi była możliwa. Rozkodo-  
 wanie danych odbywa się wtedy w inny sposób, niż przy kodowaniu, co powoduje o wiele większe straty.  
 Przed podjęciem decyzji o wyborze kompresji należy przede wszystkim ustalić typ  
 danych wejściowych. Na przykład dla pliku tekstowego dana metoda jest bardzo nieoptyczna,  
 podczas gdy będzie ona najlepszą z wszystkich dla dwukolorowego obrazu (np. dla  
 danych przesyłanych przez faks).

Bardzo często możemy się też spotkać z połączeniem paru metod lub ze zmianą reprezentacji danych przed rozpoczęciem ostatecznego kodowania w taki sposób, aby dane były bardziej podatne na daną kompresję. Poświęcę temu oddzielny rozdział.

Fig. 2 Example of text reading screen with dominant eye scan-path superimposed

### 2.3. PREPARATION OF TEST SCENES

The scenes displayed for visual tasks were taken from a fast reading handbook with corresponding comprehension check questionnaire or prepared purposely by computer software [5]. The software was used to simulate typing errors by mixing letters in the words accordingly to the programmed rate. Usually the progressive rate was used, displaying initial lines as relatively correct and increasing the difficulty level was increasing in next lines. Although the readers may have it in English or other foreign languages, only experiments with Polish texts were carried out. Text length was set accordingly to the fastest reader in order to avoid the ambiguity of scan-path after completion of the visual task.

#### *Policja*

Tytuł pochodzi od nazwy najbardziej elitarnej jednostki policyjnej  
 w Stanach, trochę dziwii więc, że wyjątkowość tej formacji i specyfika  
 jej metod działania nie ułczyży filmowi nawet odbiorcy oryginalności.  
 Jest to chyba najbardziej szlachetne kino akcji, jakie oglądaniem  
 w ośmiu latach, niczym nienóżące się od balansów  
 filmów policyjnych pokazywanych tuż w telewizji. Zero powystomosci,  
 zero inwencji, zero wyobżarni. To, że jest to szokujący debiut  
 teledzielnego doychczas reszty, nie stnowai żadnego usprawiedliwienia.

Fig. 3 Distorted text example

The reading process is considered as a linear process; from the left to the right, the prolonged gaze and returns to the middle of the line indicate information flow difficulties. The experiment aimed at studying the human capabilities of text reconstruction and

classification of the words by their relevance in message understanding. Two practical considerations are carried out directly from this experiment: adaptive error correction in a message transmission system and objective skills assessment in foreign language reading.

#### 2.4. SCAN-PATH SIGNAL PROCESSING

Each visual experiment yields a four-column matrix representing raw coordinates of the eyeball at evenly spaced time points. Identification of the gaze points corresponding to the corners of calibration rectangle in the eye track allows to calculate the scan-path transposition matrix and to distil display-relative coordinates from the A/D converter output.

All signal processing routines were purpose-developed in Matlab with consideration of the aims of particular visual experiments. Main stages of this calculation include:

- detecting the true temporal confines of active visual perception in the scan-path: the end of initial idle time and the visual task completion time,
- qualification of each foveation point in the scan-path as belonging to the particular text section
- averaging of the number, duration and order of foveation regions, separately for each text line in the display,

Apart of the foveation points statistics, the duration and order describing foveation regions reveal the perceptual strategy related to reading which is most interesting in two principal aspects: assessment of fast reading technique used and estimation of error correction skills when reading a distorted text.

### 3. RESULTS

#### 3.1. FAST READING SKILLS

Main statistics of detected focus attention points are summarized in table 1. Second left column contains average reading speed at a comprehension level of at least 60%. The correlation (r-Pearson) of the reading speed with selected scan-path features is very high. These scan-path statistics are very good predictors of reading speed.

#### 3.2. ERROR CORRECTION SKILLS

Among of 288 presentations of distorted texts containing on average  $74,7 \pm 9,2$  characters we detected 62 events of gaze return. The detection criteria were formulated as following:

- both eyes move towards the left
- the return begins after the line scanning start and before reaching the line end - jumps reaching margins of display area were not considered,

The length of the return was expressed as percentage of total line length. The average return length was 18,62 mm i.e. 10,95% ( $\pm 6,44\%$ ) of the line length. Considering that the average text line contains 12,8 gaze points, it is to remark that:

- text interpretation failure causes the gaze return to the last perceived text section,

- average character count per gaze point is 5,84, which is inferior to the result of unconstrained reading.

Table 1. Focus attention statistics in fast reading visual experiments

observer number	reading speed (words per minute)	scanpath features		
		gaze points per line	gaze point size [mm]	eye position variance in gaze point
1	250	9,1	18,68	3,5
2	300	7,3	23,29	3,4
3	550	6,1	27,87	3,1
4	700	5,8	29,31	2,85
5	1200	4,3	39,53	2,7
6	1100	4,1	41,46	2,9
7a	350	8,0	21,25	3,35
7b	720	5,7	29,82	2,95
7c	1150	3,8	44,74	2,6
8a	270	8,2	20,73	3,4
8b	450	6,8	25,00	3,05
8c	950	4,5	37,78	2,8
correlation with reading speed		<b>-0,96</b>	<b>0,98</b>	<b>-0.93</b>

### 3.3. EVOLUTION OF PERCEPTUAL HABITS IN RESULT OF FAST READING COURSE

Although the aim of fast reading training is the development of text-optimized perception, the general perceptual habits also change in a measurable way. Two female participants of a fast reading course participated in a supplementary series of visual experiments revealing the contribution of objects' features to their conspicuity. A series of progressively modified images were presented and the observer was asked to detect a change (Fig. 4).

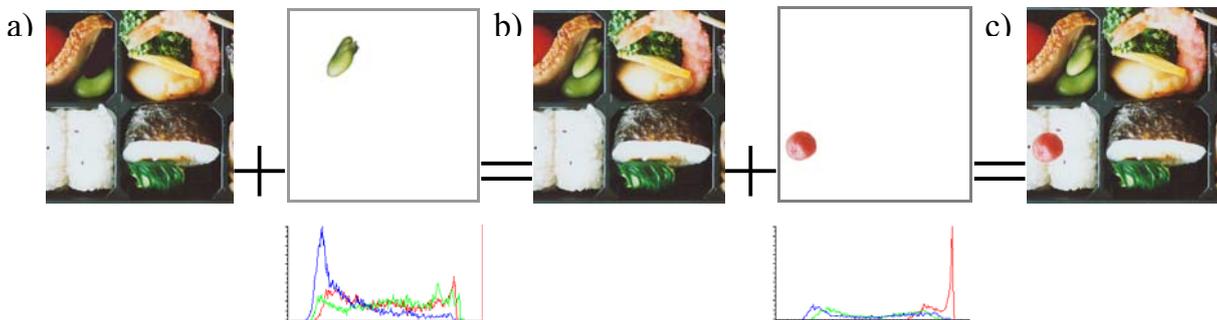


Fig. 4 Example of image sequence analysis (a to c); aiming at the estimation of color influence on details conspicuity, natural details are successively added to presented scene and the detail parameters are measured in RGB color space (only histograms are presented).

The images were modified by adding a natural object of increased amount of selected feature: size, distance to the display centre, brightness and colour in both RGB and HSL

spaces. In course of this experiment the physiologically derived statements on the prevalence of long-wave cones were confirmed by greater conspicuity of red changes in the scenes. However, we obtained also some unprecedented results e.g. greater conspicuity of objects when increasing their distance to the centre.

Artificial images are produced by a specialized procedure from given patterns, motion vectors and time-colour functions. Image analysis procedures are applied to original images to reveal the parameter changes implied by added or relocated details. As the altered image must remain natural, the parameters of added detail are no longer independent variables and their changes are not linear.

Table 2. Scanpath statistics of detail detection task in cumulative image series

Training time [weeks]	Focuss points number (average)	New detail detection time (average) [s]	New detail foveation time (average) [ms]
0	17,21	1,63	225
8	15,48	1,35	411
14	14,03	1,20	749

The reduction of focus points number by 18,5% is representative to enlargement of visual field what is one of principles of the fast reading technique. The average value of new detail detection time is implied by all three attention skills developed in course of fast reading training and conditioning the content understanding: the capacity, the continuity and the commutability. The reduction of detection time by 26,4% is a good estimate of the progress of fast reading training. The time of added detail foveation was greatly reduced with the training time. This value expresses the improvement of human ability of acquiring visual information from a single gaze point i.e. without the involvement of oculomotoric action

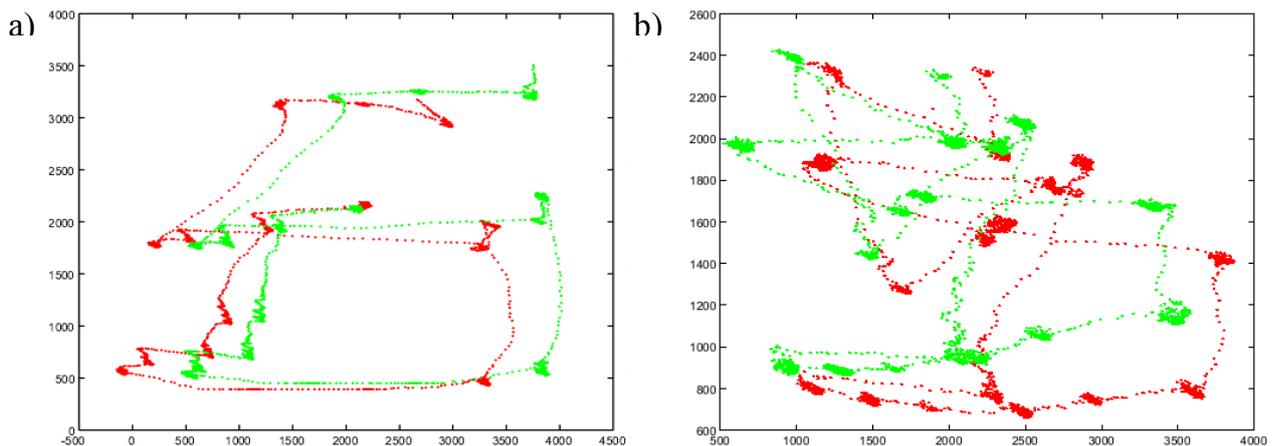


Fig. 5 Example of calibration scanpath from the same observer a) before the fast reading training, b) after 14 weeks of fast reading training.

. This value increased by 233% during the 14 weeks of fast reading training and seems to be the best indicator of reading skills in the visual experiment based on cumulative image series. The difference of scan-path implied by the fast reading training may also be expressed by other scan-path statistics (Fig. 5)

The use of scan-path statistics makes possible to use eyetracker for monitoring of the progress of fast reading training without of reading-related visual tasks. The fast reading observer is also more perceptive in free-spotting-based visual tasks.

#### 4. DISCUSSION

High correlation of selected scan-path statistics (gaze points per line, gaze point size and eye position variance in gaze point) with the conventionally measured reading speed justifies our initial assumption that they are useful for the objective assessment of reading skills. Similarly these statistics may also be used as objective estimators of progress in fast reading training.

The visual reconstruction of distorted text revealed high capability of human brain to anticipate or complete a truncated message thanks to the intelligent use of the associative memory. No return events were observed as long as the text was comprehensible to the reader. In case of doubts, the observer intuitively returned to the last identified word. The use of this common strategy for objective assessment of fluency in foreign language reading should be evaluated in the future. The statistic and classification of words difficult to the reader may quantitatively represent reader's skills.

With all the reported functionality and excellent informative value, the practical use of scan-path is limited due to its sensitivity to the voluntary observer cooperation during visual tasks. Misunderstanding of visual task rules or poor observer co-operation was the main reason for exclusion of 18% of records from the scan-path statistics. The result is also influenced by psycho-physiological factors difficult to control during the visual experiment:

- observer-dependent features varying from one person to another: eyesight defects influence, anatomy, perceptual and motoric skills etc.
- observer status-dependent varying for each person from one day to another: psycho physiological status, drugs, climate influence etc.

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