scanpath analysis,
human visual system,
perception skills

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SCANPATH ANALYSIS IN OBJECTIVE EVALUATION OF READING SKILLS

The paper presents the research on the human reading technique and text perception strategies. Main novelty is the use of scanpath recording and processing for objective evaluation of reading skills and capability of error compensation. The research was founded on visual tasks consisting in presentation of prepared texts, eye trajectory acquisition and assessment of comprehence degree. Our result show that gaze point statistics represent well the observer performance and skills in fast reading. The average human tolerance for errors is very high and outperforms any known optical character recognition software.

1. INTRODUCTION

1.1. RESEARCH AIM AND SCOPE

Scanpath analysis has been currently recognized as a valuable tool for objective assessment of human perception. The scanpath analysis is used to reveal disorders of human sight sense, but new technical applications of scanpath using are recently emerging [2], [7]. Commonly given examples are: perception-based visual information design (e.g. advertisement, websites) and intelligent man-machine interfaces for disabled people [1].

The goal of this paper is to demonstrate the potential application of this method to assessment of reading skills in various aspects. Although first area of interest was only to correlate of selected scanpath parameters with reading speed, the scope of our research was extended to distorted text reading and foreign language reading and reveals points difficult to the reader.

1.2. FAST READING TECHNIQUE

Reading skills are usually cultivated at school, but rarely reading technique is optimally taught at this stage. Reading is then a cultural-background motivated perceptual habit (eg. western culture reader intuitively starts reading at the left edge). The motoric habits from childhood, sufficient to read and understand a simple message, remain in adults, although not optimal in professional live in the information society of today.

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Text messages perceived by human visual system 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 a preliminary text glace anticipates every actual reading.

This is a background of recent methods for fast reading training. Main assumption is that 100% understanding of every word is not necessary for correct interpretation of the whole message. Consequently, some portions of text may be perceived in larger blocks significantly increasing the reading speed a the cost of not noticeable degradation of comprehension. The training consists in cultivation of three skills:

- enlarging of visual field,
- elimination of vocal repetition,
- tolerance for temporal understanding problems.

Enlargement of visual field is particularly noticeable in the scanpath and this motivated our hope that scanpath analysis may efficiently contribute to the reading skills assessment.

2. MATERIALS AND METHODS

2.1. INFRARED EYETRACKING TECHNIQUE

The OBER-2 infrared reflection based eyetracker [4] was used in our visual research. The head-mounted goggles illuminate each eyeglobe with four adjacent spots of total power of 5 mW/cm^2 in 80ms infrared pulses (wavelength 940nm) 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 speed up to 2000 samples per second during the presentation limited by the 32k samples data buffer. Since the sensor captures the visible light as well, a double sampling method is used for the sidelight discrimination. This specific time-differential measurement relates the actual infrared reflection readout to the sidelight background captured ca. 80ms before the LEDs become active. This measurement method eliminates the influence of all common light sources and allows the device to achieve the angular resolution of 0.02 deg.

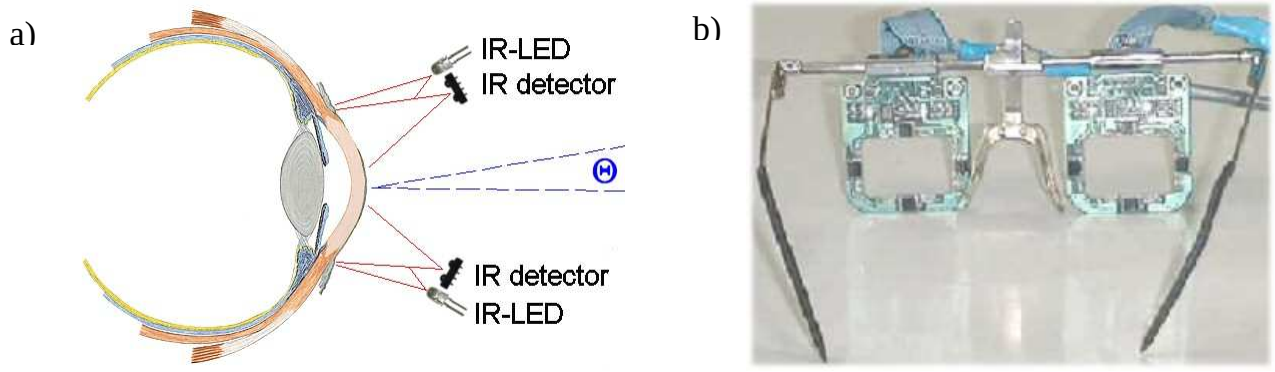

Fig. 1 Details on the Ober-2 eyetracker (a) physical principle and (b) general overview of goggles.

2.2. VISUAL TASK METHODOLOGY

The experimental part of our research was based on a series of visual experiments [3], [6]. These required a participation of a human volunteer performing sequentially a set of visual tasks. Every new observer answered a questionnaire specifying his or her degree of fast reading expertise and sight defects if any. Next, the observer was instructed as he or she would be expected to read the text displayed on screen at a maximum speed. Moreover, before each visual task, the observer performed a calibration procedure providing an individual scanpath transposition matrix. The matrix is calculated from differences between standard calibration rectangle coordinates and corresponding scanpath trace and used for correction of geometrical issues as far the eyeglobe capturing conditions are maintained. Each visual task consisted of three stages:

- the observer received a certain standardized knowledge and was motivated to complete the information from the scene,
- the observer scrutinized the scene in an unrestricted manner, however only 8 initial seconds of scanpath signal were analysed,
- the observer announced the completion of the task.

Since the scanpath is sensitive to unexpected observer's behaviour or other human factor, therefore high degree of co-operation is essential. The scanpath was accepted if the measured degree of text comprehence was greateer than 60%. Eight healthly volunteers (5F+3M) participated in the visual experimetns 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, that is approximately in a two months interval.

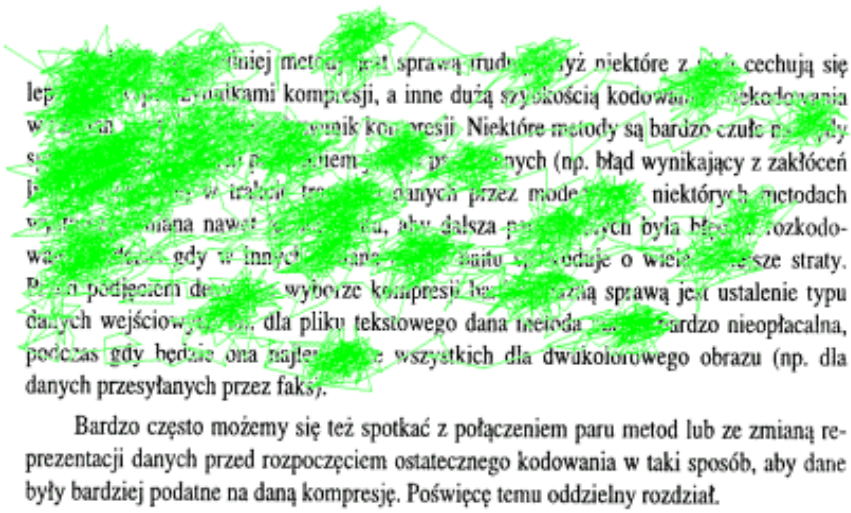

Fig. 2. Example of text reading screen with dominant eye scanpath superimposed

2.3. PREPARATION OF TEST SCENES

The scenes displayed for visual tasks were taken with corresponding comprehence check questionnaire from a fast reading handbook or prepared purposely by a computer software [5]. The software was used to mixing letters in the words accordingly to the programmed error rate. Usually the

progressive rate was used, that means first lines were relatively correct and the difficulty level was increasing in next lines. Only Polish texts were used in visual experiments. Text length was set accordingly to the fastest reader in order to avoid the ambiguity of scanpaths after completion of the visual task.

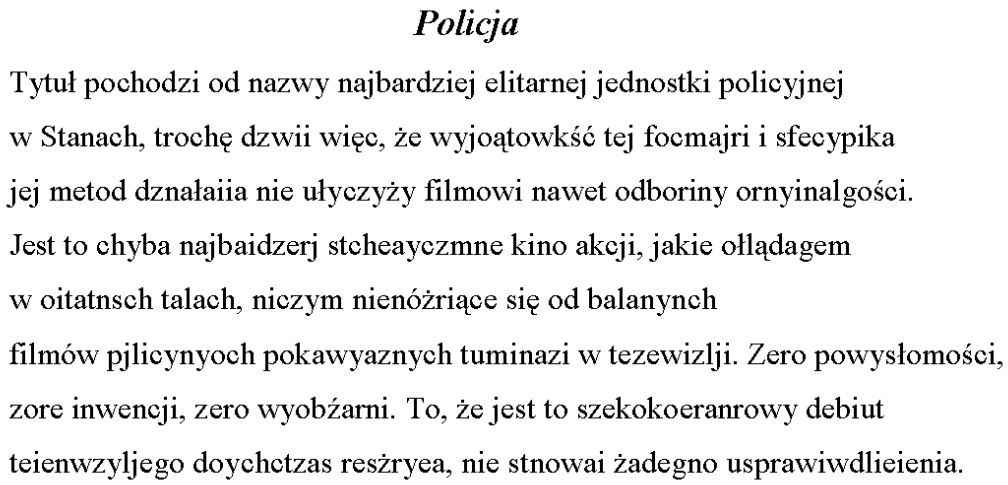

Fig. 3. Distorted text example

Although the reading is usually linear from the left to the right, the prolonged gaze and returns to the middle of the line indicate difficulties. The experiment aimed at studying the human capabilities of text reconstruction and classification of the words by their importance in message understanding. This experiment had two applications: adaptive error correction in a message transmission system and objective skills assessment in foreign language reading

2.4. SCANPATH SIGNAL PROCESSING

Each visual experiment provides a four-column matrix representing raw eyeglobe coordinates at the evenly spaced time points. Prior to the reading, the observer is asked to gaze at the corners of displayed calibration rectangle. Identification of these gaze points in the eyetrack allows to calculate display-relative coordinates from the A/D converter output.

All signal processing routines were developed in Matlab with regard to the aims of visual experiments. Main stages of this calculation include:

- detecting the true confines of visual perception in the scanpath: the end of initial idle time and the completion time,
- qualification of each foveation point in the scanpath as belonging to the particular text section
- averaging of the number, duration and order describing 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 assessment of fast reading technique used and in error correction used when reading a distorted text.

3. RESULTS

3.1. FAST READING SKILLS

Main statistics of detected focuss attention points are summarized in table 1. Second left column contains average reading speed at a comprehence level of at least 60%.

Tab. 1. Focuss 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		**-0,96**	**0,98**	**-0.93**

The correlation (r-Pearson) of the reading speed with selected scanpath featyures is very high, the scanpath statistics are good estimators of reading speed.

3.2. ERROR CORRECTION SKILLS

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

- both eyes should move towards the left
- the return should begin after the line scanning start and before reaching the line end - jumps reaching margins were not considered,
- length of return was expressed as percentage of total line length

The average return length was 18,615mm i.e.10,95% (±6,44%) of the line length. Considering that the average text line contains 12,8 gaze points, we conclude that:

- text interpretation failure causes gaze return to the last perceived text section
- averach character count per gaze point is 5,84 which is inferior than the result of unconstrained reading.

4. DISCUSSION

High correlation of the scanpath statistics with the conventionally measured reading speed justifies our initial assumption of their usefullness to the objective assessment of reading skills. Similarly these statistics may also be used as progress estimators in fast reading training.

The visual reconstruction of distorted text revealed high capability of human brain to anticipate or complete a truncated message. As long as the text was comprehensible to the reader no return events were observed. In case of doubts, the observer intuitively returned to the last identified word. This common strategy may be used for objective assessment of fluency in foreign language reading. The statistic and classification of words difficult to the reader may quantitatively represent readers skills.

With all the reported funcionality, the scanpath is very sensitive to the voluntary observer cooperation during visual tasks. Poor co-operation or misunderstanding of visual task rules was the main reason for exclusion of 18% of records from the scanpaths 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: psychophysiological status, drugs, climate influence etc.

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