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TASK-DEPENDENT PARAMETERS OF ATTENTION MEASURED BY TWO EYETRACKERS

This paper presents the motivation and results of identifying the point of observer's interest with use of the infrared eyetracker. This research is an introductory part of our project aiming at finding the irregularity of medical data distribution in electrodiagnostic signals by analysis of expert's eye trajectory during the routine recording inspection. For the novelty of our approach, before the eyetracker was used in cardiologists, various tests had to be completed to assess the accuracy and the dynamic properties of the human oculomotoric system during simple visual tasks. The experiments were completed on three untrained volunteers each performed 20 simple tasks with use of OBER2 eyetracker. A part of results was verified using another system based on the electric dipole features of the eyeglobe. The final results are very important for the further research giving many practical considerations for the experiment itself and setting the borderlines for expected accuracy.

1. INTRODUCTION

1.1. MOTIVATION

The graphical form of data presentation is currently found the most communicative and experts are inspecting charts all over the world. The knowledge they use is often difficult to express and their experience can hardly be simulated with an algorithm. Despite the difficulties in description of the features extraction performed by humans, generally it is easy to remark that the experts focus on certain parts of the scene or just glance the other regions. The physiology of perception suggests that the parts being visually more attractive contain the information of higher importance than the surroundings. In consequence it is believed that a trained expert's eye after the initial orientation is first oriented towards the more important parts of the scene and spends more time to analyze the regions containing higher degree of information density.

This belief is the foundation of the method we plan to apply to assess the distribution of diagnostic information in an electrocardiogram. Similar approach may be applied to investigation of perception of other kind of signals or images, especially when a non-uniform information density is expected. The perceptual model appropriate for each class of

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images (e. g. VEP charts or MRI images) may be useful in developing the dedicated compression algorithms, assessment of distortions level or organizing transmission over a narrow bandwidth telecommunication network.

1.2. REPRESENTATION OF PERCEPTION IN OCULOMOTORIC SIGNAL

The analysis of the eyeglobe trajectory during manual inspection of electrocardiograms is expected to approximate the answer for a very difficult question of diagnostic information distribution in time.

However, before the eyetracker is applied to a cardiologist, all limitation of the method must be thoroughly investigated in order to avoid false conclusions.

In particular the following issues need to be considered:

- how accurately the eyeglobe position approximates the current visual target
- what visual processes accompanies the search for the data and what is their contribution to the total inspection time
- what are the dynamic properties of the visual perception system and the oculomotoric system in humans
- what is a correlation of the time the eyeglobe spends at a particular location (fixation time) and the amount of information gathered from this location

In this introductory paper only the following basic issues are concerned:

- stability of the eyeglobe position while focussing on a unique constant target.
- reaction delay, search speed and fixation time after a sudden dislocation of unique target
- stability of the eyeglobe position while voluntary focussing on subsequent constant targets
- speed of search for a new target while voluntary focussing on subsequent constant targets
- comparing the time devoted to voluntary focussing on subsequent identical constant targets (also called: fixation time)

2. MATERIALS AND METHODS

2.1. HUMAN RESOURCES

Three healthy male volunteers (aged: 22, 23 and 23) took part in the experiments. They were untrained and never performed such visual tasks before. Each participant performed 10 trials of two different visual tasks described hereafter. The trial time was 16 s. and the subsequent trials were separated by a relaxation of 10 min. Between the first and the second visual task a pause of 24 hours was applied. For technical reasons, candidates wearing glasses were not concerned by the experiment. Each visual task was performed by indirect daylight in a quiet laboratory room. The CRT monitor of a diameter of 17 inches was viewed from the distance of 40 cm, thus the visual angle was 47 deg horizontally and 35 deg vertically.

2.2. VISUAL TASKS

Visual tasks are simple pre-determined scenes presented on a computer CRT display. In principle, the displayed scene is the unique input to the visual system of a human under test. Although all the background inputs (sounds, touch) cannot be eliminated, it is necessary to reduce particularly these influencing the oculomotoric system.

Before attempting to perform the visual task, the person under test is briefly instructed by the staff. The instruction must be formulated so as they not provide information or suggestion on the expected result.

Two different visual tasks were in use during the experiment:

- pursuit of the unique white point (sized 16 x 16 pixels) suddenly changing its position on the black background (see fig. 1). The instruction for this task reads: "keep up to this point" and thus the visual and oculomotoric reaction is imposed by the target moves.
- observation of the steady white rectangular contour (4 pixels in width - see fig. 2) with an instruction reading: "look at this figure". The selection of targets, there order and the fixation time devoted to each of them are at the observer's choice.

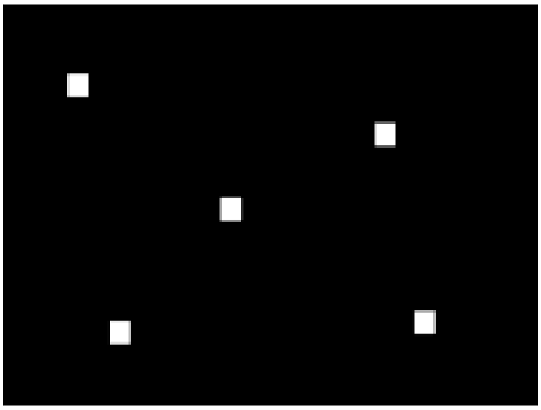

Fig. 1. Test pattern for the visual task one (subsequent positions of the target are displayed alltogether)

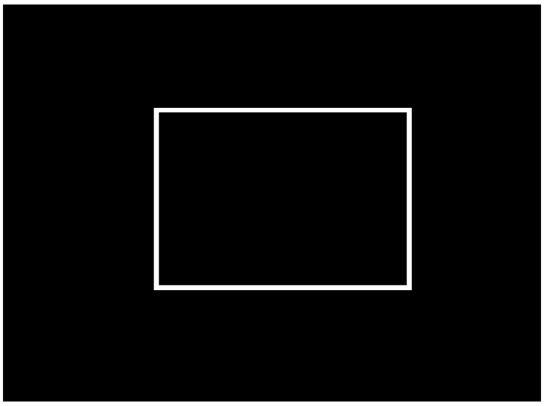

Fig. 2. Test pattern for the visual task two

2.3. EYETRACKING SYSTEMS

Two eyetracking systems were used for investigate the observer's eyeglobe trajectory:

- Ober2 is an infrared-reflection-based eyetracking system measuring the position of each eyeglobe in two dimensions (horizontal and vertical) independently [3] [9]. The visual range set during the initial calibration is discretized by analog to digital converter of 12-bit resolution. In the geometrical condition of our experiment the least significant bit (LSB) corresponds to 0.011 deg horizontally and 0.009 deg vertically. The data acquisition was performed in two horizontal channels for the visual task one and in all four channels for the visual task two with the sampling rate of 300 Hz. The current target position was memorised in the disk file along with the data representing the eyeglobe position.

- BioPot is a custom-developed single channel acquisition system for biopotentials featuring the intelligent setup of the voltage range. It was applied to the recording of horizontal eyeglobe positions thanks to the Dubois-Reymond phenomena [1], [2], [6], [7], [8] manifesting itself by appearance of a spontaneous electrical dipole between the *cornea* (+) and the *iris* (-). The circular motion of the eyeglobe may be thus represented by the potential's difference induced in the surface electrodes positioned closely to the eyes. The measurement was calibrated to the frames of the visual field that corresponds to the quantization of 0.015 deg/LSB. The sampling rate was 300 Hz in order to comparing easily the resulting signals to those gathered with infrared method. The synchronisation of the data stream with the target position was done off line by the software.

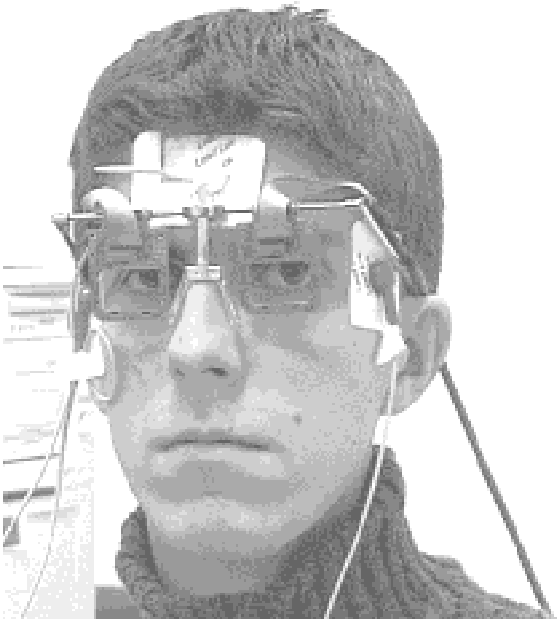

Fig. 3. Volunteer performing visual tasks equipped with two different eyetrackers. Goggles are part of the system OBER 2 and the surface electrodes acquire the potentials induced by the dipole-featured eyeglobe

The use of two different eyetracking systems is very important to localise the sources of difference between the visual target position and the reported orientation of the eyeglobe [4], [5]. The inaccuracy caused by the eyetracking system, including the calibration error, unstable geometrical relations and the acquisition errors may be found as system-dependant and varies from one eyetracker to another. For the target experiment on cardiologists, the appropriate guidelines on how to avoid these errors have to be issued. Another source of inaccuracy is the human visual and oculomotoric system. This error is hardly reducible because of the physiology of perception and may be found as observer-dependant. The only way to estimate the correct results is to carry out the experiment on the sufficient large population and to apply statistics.

2.4. PARAMETERS OF EYEGLOBE POSITIONNING

The visual task one (see 2.2.) provides the data for successful measurement of the basic dynamic parameters of the mechanism of eyeglobe positioning (see fig. 4):

- the stability of the eyeglobe position while focussing on a steady target is the variance of eyeglobe position during a period of fixation (fixation accuracy)
- the reaction delay is the interval of time between the target displacement and the end of fixation on the previous position on the scene (delay)
- search speed that is the maximum angular speed of the eyeglobe during the period of searching a new target (speed)
- tuning time is a period of correcting the eye position after the new target is found.

The visual task two was expected to highlight those of the eyeglobe positioning properties that depend on the voluntary choice of visual targets. The instruction for this task is very general and leaves a large degree of freedom to the observer. No temporal constrains were applied except for the reasonable total recording time. The observer was expected, but not told, to choose the rectangle's corners as the subsequent targets and to focus on them in the natural order (clockwise or counter clockwise). The cases when the observer did not fulfil these expectations were excluded from the final statistics. The remaining data allow the measurement of (see fig. 5):

- stability of the eyeglobe position as the variance of eyeglobe position during a period of fixation (fixation accuracy)
- search speed - the maximum angular speed of the eyeglobe during the period of searching a new target (speed)
- fixation time – the period devoted to focussing on subsequent identical targets (*t1*-*t4*)

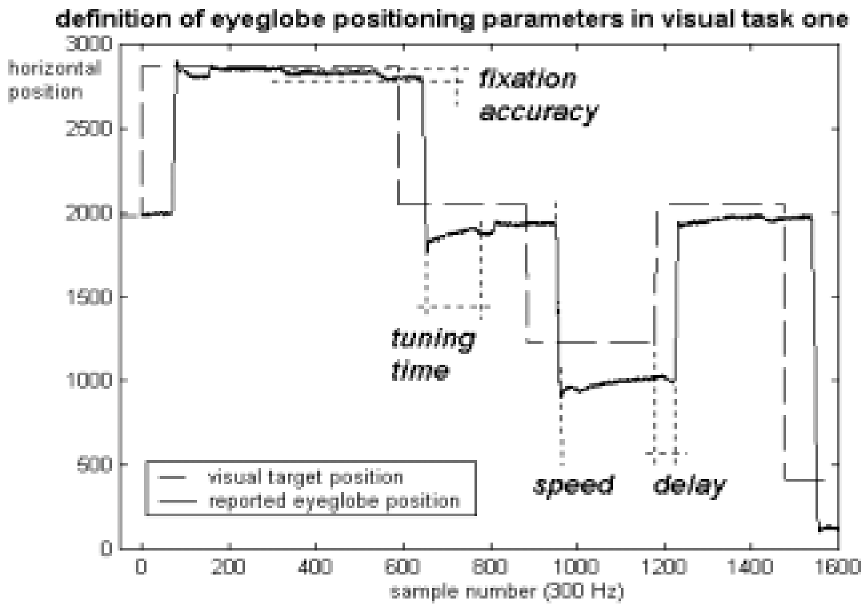

Fig. 4 Definition of eyeglobe positioning parameters in visual task one. The plot represents the horizontal eyeglobe position (solid line) during the pursuit of a suddenly displaced target. Target's position displayed with dashed line

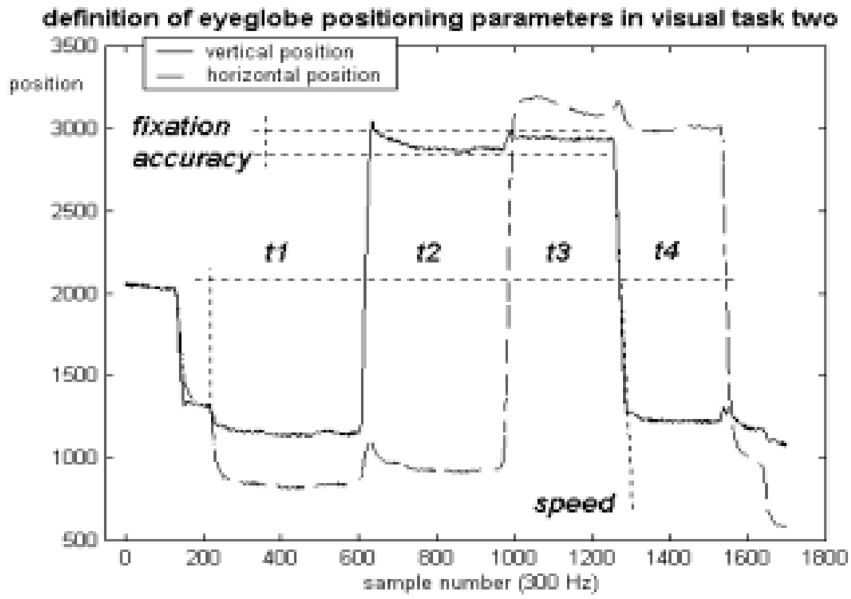

Fig. 5 Definition of eyeglobe positioning parameters in visual task two. The plot represents the vertical and horizontal eyeglobe positions (solid and dashed lines respectively) during the voluntary observation of the rectangular contour. The corners were focussed in following order: lower left (*t1*), upper left (*t2*), upper right (*t3*) and lower right (*t4*)

3. RESULTS

3.1. RESULTS FOR THE VISUAL TASK ONE

Results for the visual task one were calculated using the custom-developed Matlab procedure over all the 30 data streams gathered during the experiment. All transients free from artifacts were considered by the statistic processing. The final result is displayed in table 1.

Table 1. Average results of visual task one

eyetracker system	fixation accuracy [deg]	fixation delay [ms]	maximum speed [deg/s]	tuning time [ms]
Ober2	0.0923 ± 0.0276	156.11 ± 20.11	658.5 ± 167.4	173.21 ± 62.35
BioPot	0.3413 ± 0.1207	156.11 ± 20.11 ♣)	1126.5 ± 83.15	31.71 ± 7.40

3.2. RESULTS FOR THE VISUAL TASK TWO

Results for the visual task two were calculated using the custom-developed Matlab procedure over 19 data streams if the observer fulfil the presumptions on the regular focussing the corners. The final result is displayed in table 2.

Table 2. Average results of visual task two

eyetracker system	fixation accuracy [deg]	maximum speed [deg/s]	fixation variance {*t1...t4*} [%]
Ober2	0.1182 ± 0.033	556.5 ± 121.0	13.46
BioPot	0.5037 ± 0.3648	1302.8 ± 563.99	♠)

3.3. RESULTS ON COMPARING THE EYETRACKERS

Despite of problems with synchronization of the BioPot outcoming signal to the position of the target controlled by Ober2, we got very similar results using two different eyetracking systems. The synchronization was done by a Matlab procedure coded for this purpose with use of the iterative approximation algorithm. The percentage of differences in eyeglobe positioning is summarized in table 3, while the figure 6 displays the example of synchronized data.

♣ The result for BioPot and Ober2 is identical because of synchronization of the BioPot signal where the Ober2 signal was a reference.

♠ The measurements using BioPot were performed in horizontal dimension only. This made the rectangle's corners located one below the other difficult to distinguish in the oculomotoric signal.

Table 3. Percent Root-mean-square Difference (PRD) of synchronized signals from both eyetrackers under test [%]

Trial No	Observer No		
	1	2	3
1	7,95	23,48	-
2	9,43	13,46	10,20
3	7,76	22,68	15,17
4	8,95	18,91	8,94
5	12,61	23,27	11,99
6	9,90	27,63	10,13
7	11,00	12,67	15,26
8	9,00	18,43	12,94
9	8,45	19,80	10,22
10	12,26	14,11	-
average	9.73	19.44	11.85

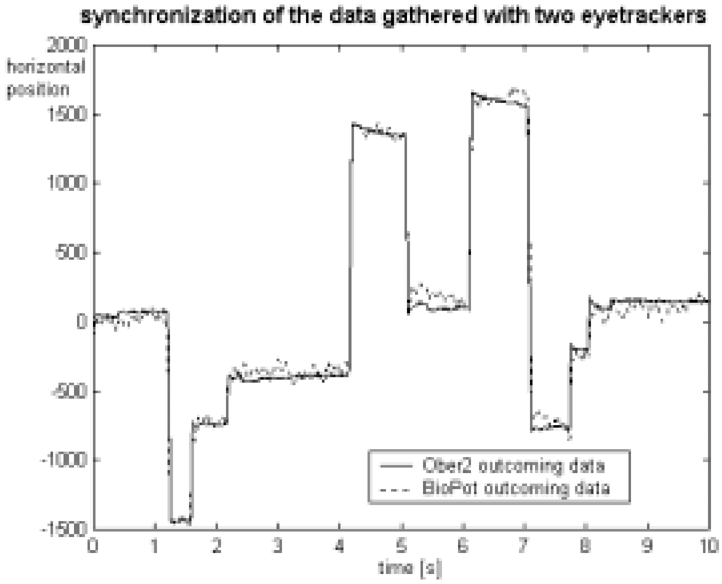

Fig. 6. Example of synchronized horizontal data from Ober2 and BioPot eyetracking systems

4. DISCUSSION

The research reported in this paper was expected to give a general view of the practical aspect of visual tasks, the accuracy of the eye positioning in static and dynamic condition, the sources of errors and the methods to eliminate external interferences. These expectations are fulfilled and the interpretation of obtained results highlights the topics and directions for the future research.

The fixation accuracy, as reported by Ober2 system, is better than 0.1 deg giving a strong support to our general idea of estimation of the diagnostic information distribution in the electrocardiogram based on the pursuit of the expert's eye. Even assuming the inspection of a standard chart (25 mm/s) from a standard distance of reading (40 cm), the accuracy of eyeglobe positioning corresponds to 27.9 ms of the ECG strip. Focussing the attention on every ECG wave may thus be reliably represented in the eyetracker's output data. The worse results, reported by BioPot recorder, are caused by the lower immunity of the low-energy biopotentials representative to the eye position to the background activities (i.e. EEG, and others).

The dynamic parameters: fixation delay and fixation time proves that the behaviour of the visual-oculomotoric may be modelled with use of the control theory methods. In the aspect of measurements of the time of the eyeglobe fixation on the particular piece of the scene, it is important to identify and properly compensate the phenomena accompanying the change of visual target.

The large difference of maximum speed obtained with use of both eyetrackers has not found any explanation up to now.

During the voluntary observation of the steady white rectangular contour the fixation accuracy is lower than in case of a single point. That corresponds to the idea of the visual task two, where the observer was expected, but not told to focus on the rectangle's corners. The standard deviation of the maximum eye velocity as measured with the Ober2 system, shows no significant difference between both visual tasks. The physiological background for this is that the observer's eye velocity during target search depends mainly on the properties of the oculomotoric system, and is not influenced by the stimulation method.

The last comment concerns the very promising result of the rectangle corners' fixation variance. Assuming that the corners' attractivity was the same, we got very little variance of the amount of time devoted by the eyeglobe to glance them. This value sets the borders of confidence for assessment of attractivity of particular components in a scene.

The future work should go further into the investigation of perception and highlight the static and dynamic differences of positioning both eyes in the same target. This will probably involve the role of the dominant eye. Another research must be done to determine the relations of the fixation time on a particular component in a scene and the amount of information gathered from there. These relations are necessary to interpret the trace of cardiologist's eyeglobe in context of the inspected electrocardiogram.

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