Workflow Diagrams and Pupil Dilatation in Eye-tracking Testing

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***Abstract*—Eye-tracking devices produce a huge amount of data. One of them is the diameter of pupils. The presented test explore the change of diameter pupils while reading the workflow diagrams from QGIS Processing Modeler. The evaluation describes the change of diameter as a consequence of increasing mental labour while fulfilling the task on workflow diagram. The presented measuring compares the same workflow diagram without task (free-viewing mode) and the same diagram with the task. The result of comparison verifies the hypothesis that diagram with task bring some mental effort and this phase is distinguishable in the graph of pupil diameter from the eye-tracking measurement.**

I. Introduction

Eye-tracking devices capture the respondents gaze on a monitor. The eye-tracking measurements produce a huge amount of data. The analyses very often used the values as scan path, the position, time and count of fixation, length and count of saccades, total test time. One of measured eye parameter is the diameter of the pupils. The change of pupil diameter can be investigated during the respondents gaze on stimulus.

The analysis of pupil dilatation is not very often utilized in eye-tracking research. Some previous researches from the field of psychology and medicine exist. Medicine says that the change of human pupil is mainly influenced by illumination. In 1964, Hess and Polt mentioned that diameter of human pupil also changes under the influence of difficulty of solved task. They state that changes in pupil size during the solving of simple multiplication problems can be used as a direct measure of mental activity [1].

Contemporary research tries to verify that the pupil dilates as a consequence of attentional effort. Moreover the dependence is linear; the effects of input attentional pulses on the pupillary response are additive [2]. Kang and Wheatley [3] tested that the temporal pattern of pupil dilatation dynamically follows the conscious attention. The respondents heard the music. Real-time changes in stimulus salience motivated the pupil dilation. The cognition load verified by Hosian and Yeasin [4], also Rosiek and Sajka [5]. The cognition load in reading the text by 11-age students was measured by Červenková et al. [6].

The presented test covers workflow diagrams as stimuli. Workflow diagrams are often used in geographic information systems to construct the steps of the process. The diagramming skills are one of the practical topics in education in the study branch geoinformatics at Palacký University in Olomouc, Czech Republic. Several tests try to describe the reading of diagrams, the difficulty in comprehension of diagrams by measuring in the eye-tracking laboratory. This article describes one part of the investigation. It is an evaluation of change of pupil dilatation during workflow diagram reading.

II. Material and Methods

A. Eye Tracker and Eye-Tracking Software

Eye tracker equipment SMI RED 250 with software SMI Experiment Suite 360° was used for the experiment. The SMI Experiment Center program was used for designing the experiment, and the SMI BeGaze software was used for visualization of results. The resolution of the monitor to record eye movement was 1920 × 1200 pixels. The sampling frequency was 250 Hz. The record produces 250 values of pupil diameter per second. The number of data very details for evaluation of pupil diameter. The statistics of eye-tracking data including the pupil diameter values were exported as text data. The data of pupil diameter were processed in Microsoft Excel sheet. The data was smooth to calculate trend of change. The original data contains some deviation and outlying data during blink when eye-tracker lost information. The filtration of data is necessary. For evaluation of change only trend of change was considered.

B. Eye-tracking test and stimuli

Workflow diagrams were used as stimuli for pupil dilatation testing. The diagrams were created in software QGIS, and its component labelled Processing Modeler. Software QGIS is one of Open Source geographical information systems (GIS). Geographical information systems are used for processing spatial data. The component Processing Modeler in QGIS is intended for drawing steps of the data process data in the graphical form of workflow diagram.

Graphical notation utilizes only three symbols. The symbols are a violet rectangle for input data, a blue rectangle for output data a white rectangle for function (Fig. 1). The direction of the process flow is depicted by round lines. The orientation of diagram is not strictly set. The diagram orientation could be from left to right or from top to down, or various orientations could be in one diagram. The arranging of symbols in the diagram is an author's choice.

The eye-tracking test contained 33 stimuli. All of them were work flow diagrams. The test consisted from two parts. The diagrams in the first part were showed

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without any task or question. This form of eye-tracking testing is called "free viewing". The time was 3 seconds for displaying of each stimulus. The stimuli were interleaved by fixation stimulus with a small black cross for 600 ms to assure the same start position of an eye before next stimulus. The first part contained 11 diagrams

In the second part of test the diagrams were accompanied by tasks. For one diagram was one task. The tasks were showed in the form of text on a previous stimulus. After task reading, the fixation cross was displayed in the centre of the monitor. The respondents fulfil the task by mouse click in the area of the diagram. The task was e.g. "Click on all input data." In some cases, the correct answer was one click (e.g. one input data). In other cases, the correct answer was two or more mouse clicks (e.g. more input data). The respondents did not know a number of correct answers (number of clicks) in advance. The second part of the test with diagrams that were accompanied by task contained 22 stimuli. The diagrams were various in complexities. Simple diagrams consisted from 3 rectangles. The most complicated diagrams contained from 20 to 25 rectangles. The display order of diagrams was random. The random order prevents the learning effect. When the order of stimulus is the same, the respondents remember some previous information from inspected diagrams.

The diagram No. 31 and 32 was chosen for evaluation of pupil diameter change caused by the mental load. The task connected to that diagram was "Find functions Fixed distance buffer". The respondent tried to find the function in the diagram and clicking on the correct white rectangles (Fig. 1). The function "Fixed distance buffer" is one of very common operation in GIS. This operation calculates buffer zone around the polyline that represents e.g. river or railway. The respondents are familiar with this operation; they know what it processed. The tested diagram contains 20 graphical symbols (rectangles). The first indicator is a white rectangle for finding the correct respondent answer. Secondly the respondents inspected the right label with the name of the function. The function "Fixed buffer distance" was used twice in the diagram. Moreover, five white rectangles are in the diagram. All represents also functions but different that requested "Fixed buffer distance".

C. *Evaluation of pupil change causes of mental load*

The number of respondents was 20 in the test of QGIS workflow diagrams. The respondent P12 is chosen for a demonstration of evaluation of pupil dilatation. The evaluation covers two diagrams No. 31 and No. 32 from the whole test. Both diagrams process the same steps and operations with the same input and output data. The difference is only in the orientation of workflow. The diagram No. 31 is oriented top-down (Fig. 1), the diagram No. 32 has a left-right orientation (Fig. 2). Both task diagrams were answered correctly by respondent P12. The same task for the second diagram was solved ("Find functions Fixed distance buffer").

D. *Eye-tracking measuring of pupil for diagram without task*

Firstly, the diagram without task (free-viewing) is evaluated. The time of displaying was constantly set to 3 seconds in eye-tracking testing for each stimulus. The short time was set intentionally. Older tests of diagrams from other software showed that longer free-viewing caused an aimless repetition of a gaze from the beginning to the end of a diagram. It was showed by scan path plot. The hard mental operations are not expected in free-viewing.

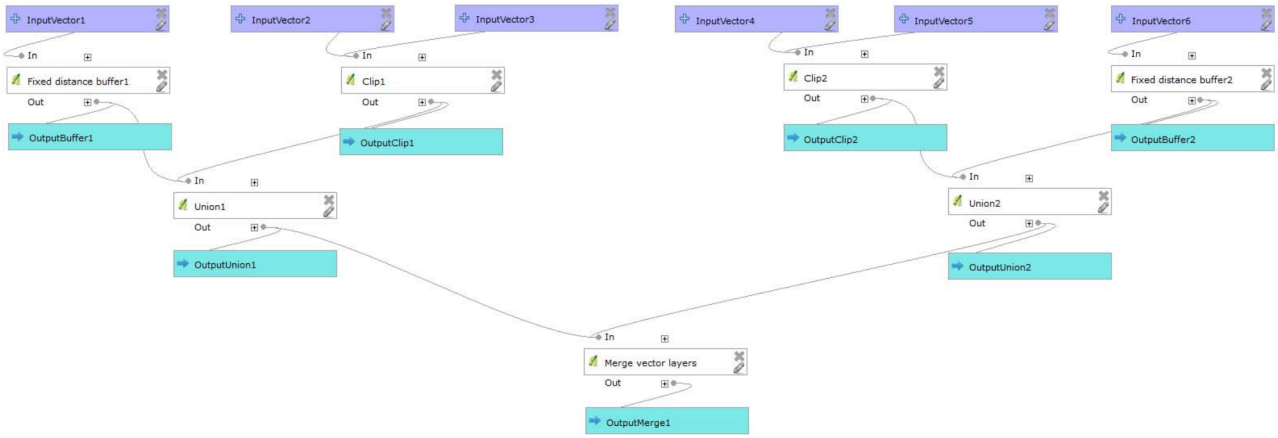

Figure 1. Workflow diagram No. 31 (top-down orientation) from Processing Modeler in QGIS

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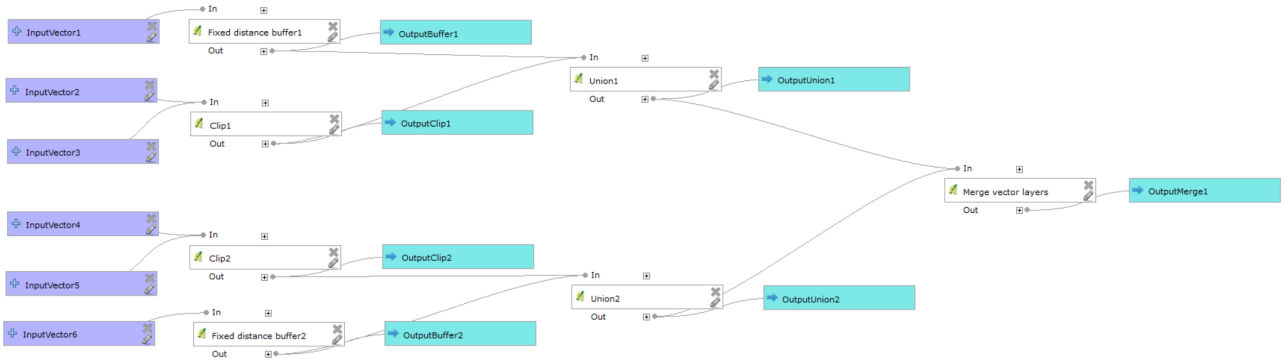

Figure 2. Workflow diagram No. 32 (left-right orientation) from Processing Modeler in QGIS

Eye-tracking equipment SMI records the diameter of both pupils. The shapes of the curves are nearly the same for both pupils. Therefore, only one pupil is enough for evaluation of dilatation change. Fig. 3 shows the shape of curves of both pupils in diagram No. 32 (Fig. 2) free viewing. We consider only left pupil (blue line) in all evaluation cases. The diagram shows also black line with smoothed trend of left pupil. The short peaks are not considered. Total time of displaying is 3 seconds. Literature mentioned that the pupil reacted less than 300 milliseconds (ms) in the case of mental load [7, 8]. Latencies to light are 150-400 ms. Therefore, the first 300 ms is not considered. The diameter of the pupil is from 3.35 to 3.18 mm. The change is up to 4%. The trend of the curve has steady decline. There are no significant increases or decreases of the curve for a longer time. Only average change that persists about 1000 millisecond could be considered. That means that other short time changes are artefacts. The last part of the diagram (2800-3000 ms) shows the situation of an eye blink. The eye-tracker lost the signal, and the values are not correctly recorded. So the last part is excluded from evaluation. The fluent decline means that there is no respondent's mental activity in this experiment.

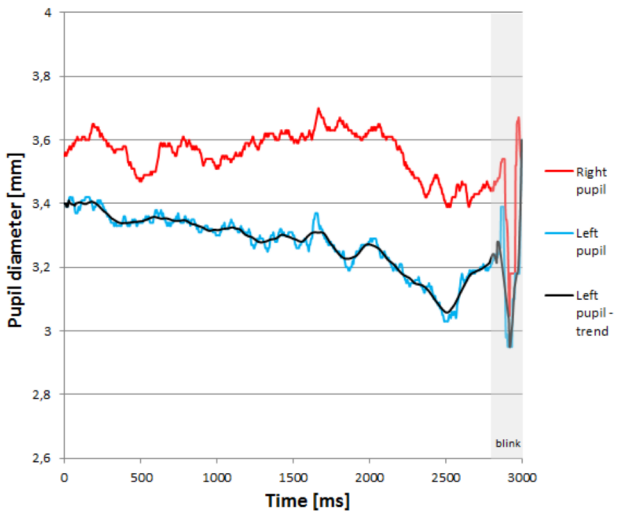

Figure 3. Pupil diameter for free-viewing phase of diagram No. 32

E. Measuring of pupil for diagram with task

Fig. 4 shows the graph for the same diagram No. 32 where the responded solved the task to find two operations „Fixed buffer distance". Total time of solution is 7 seconds. The stop of the solution was set by respondent. The respondents vary in total time of a solution of tasks. The only left pupil is depicted by the blue line, and the black line shows a trend that smooth small changes (artefacts). The respondent filed the task correctly. The time of the first click on the white is 2.35 second and the second click on the second white rectangle is 3.68 seconds. The events are showed by vertical green and red lines in Fig. 4.

The curve shows noticeable declines and increases of the pupil diameter. The started high diameter points to the high mental load caused by reading the previous stimulus with the task sentence. The respondent in the previous stimulus tries to comprehend and remember the task. It is high mental operation. The values are from 3.8-3.4 mm, maybe the influence of luminescence is there. His decline follows to 3.1 mm and persists about 1 second. Subsequently the increase follows up to 3.4 mm. During this increase, the first click is recorded (1.95 s). The answer is found very quickly because it is in the upper-right corner of the diagram. The respondents very often start reading from that place. It is influenced by reading habits of text.

The increasing follows up to 3.4 mm and the second click is recorded in the time 3.15 s from the beginning of the test. It is evident that the pupil has the biggest diameter in the phase of searching for the correct answer. After the second answer, the diameter declines to the 3.1 mm. In that last phase of viewing the respondent only scan once again the diagram and confirm his answers. The mental activity goes down. The changes of diameters reach 9%. The presented description of pupil dilatation arose from the simultaneous evaluation of pupil diameter graph and the scan path plot of the same stimulus. The connection of both information helps to find a reason why the increases and decreases exist. Fig. 5 shows the gaze plot of respondent P12. Two red diamonds mark the place where the respondent clicked (in that case the correct answers). The first part of scan path is depicted by yellow colour; fixations 1-21 have also yellow colour. The first fixation is in the centre of the diagram.

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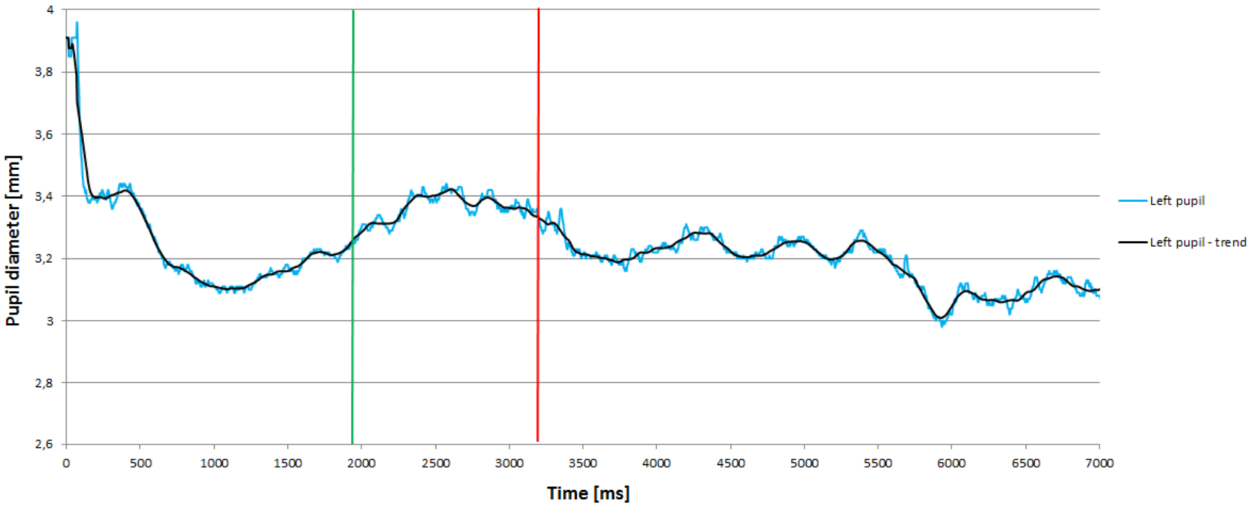

Figure 4. Diameter of pupil for diagram with task (No. 32)

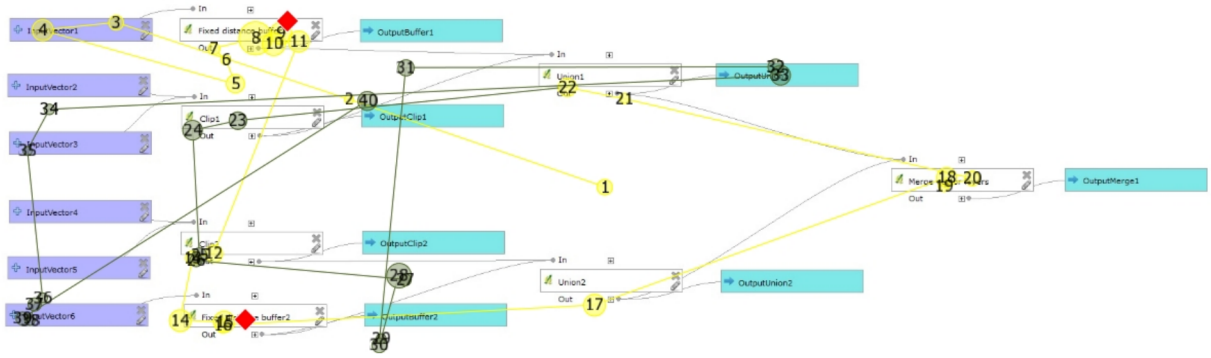

Figure 5. Scan path of respondent while solving the task (red diamonds are correct answers).

It is the effect of the previous black fixation cross in the centre of the monitor. The sequence of starting fixation corresponds to the reading from left-right. In the case that diagram is oriented from the left to right, the respondents also read the diagram from the left to the right. The respondent answered after fixation number 11 by the click to the area of the rectangle. The second answer is after fixation 16. The respondent continued with the scanning of the diagram and searching another correct answer. In that phase, it is evident high mental activity. Green scan path and green fixation (23 – 39) correspond to the decline of pupil diameter. The respondent only went true diagram once again and verified if fulfil all correct answers. These yellow and green colour distinguishing is custom setting that allow BeGaze software. The change of two colours was set at the time that divides the scan path to "the solution searching part" and "the confirmation part". This user setting helped to join information from pupil dilatation graph and scan path display. It is evident that the changes of diameter are greater in the viewing of the diagram with solving the task than a free-viewing diagram.

The presented description of pupil dilatation arose from the simultaneous evaluation of pupil diameter graph and the scan path plot of the same stimulus. The connection of both information helps to find a reason why the increases and decreases exist. Fig. 5 shows the gaze plot of respondent P12. Two red diamonds mark the place where the respondent clicked (in that case the correct answers). The first part of scan path is depicted by yellow colour; fixation 1-21 have also yellow colour. The first fixation is in the centre of the diagram. It is the effect of the previous black fixation cross in the centre of the monitor. The sequence of starting fixation corresponds to the reading from left-right. In the case that diagram is oriented from the left to right, the respondents also read the diagram from the left to the right. The respondent answered after fixation number 11 by the click to the area of the rectangle. The second answer is after fixation 16. The respondent continued with the scanning of the diagram and searching another correct answer. In that phase, it is evident high mental activity. Green scan path and green fixation (23 – 39) correspond to the decline of pupil diameter. The respondent only went true diagram once again and verified if fulfil all correct answers. These yellow and green colour distinguishing is custom setting that allow BeGase software. The change of two colours was set at the time that divides the scan path to " the solution searching part" and "the confirmation part". This

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user setting helped to join information from pupil dilatation graph and scan path display.

Next example of measuring of pupils is an evaluation of workflow diagram with the same depicted process but only the orientation of workflow is top-down (Fig. 1). The measuring is of the same respondent P12. The evaluation of graph of pupil diameter (Fig. 6) is joining with an exploration of scan path (Fig. 7). The total time of solution was nearly the same, 7 seconds. Blue line is original measured value. For better interpretation, the black trend line is depicted. At the start of measuring the left pupil has the diameter around 3.3 mm (Fig. 6). The decline reaches the diameter 3.055 mm. At that time the first answer respondent marked (a green line, 2.37 s). The followed decline reaches the value 2.9 mm and the second answer is marked. After second answer (a red line, 3.72 ms), the diameter increases surprisingly to the value 3.2 mm. It is assumed from scan path that careful searching follows in the diagram. It corresponds to a higher mental load of the respondent. About sixth second there is decline to the value 2.93 mm. The calming of the respondent is the result of satisfaction with finishing the task. The changes of pupil diameter are around 10%.

The scan path for the top-down graph (No. 31) is in the Fig. 7. The first series of saccades and fixation are coloured in yellow (up to 26th fixation); the second part is coloured in green. It is apparent that in "yellow" part the task was solved (red diamonds). In the "green" part, the respondent only scans the bottom part of the diagram. The phase of the "verify scanning" is missing in the gaze plot. It corresponds with the small decline and short "calm phase" of the respondent. The finishing part is different than in the case of the diagram No.32. The answer clicks are also recorded later than in diagram No. 32.

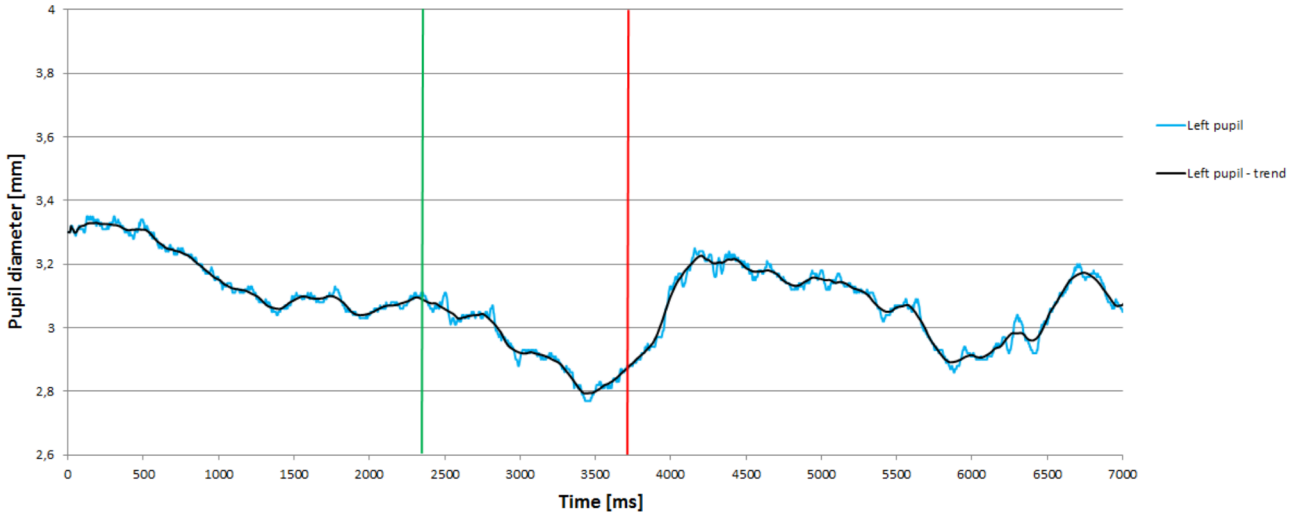

Figure 6. Diameter of pupil for diagram No. 31 with task

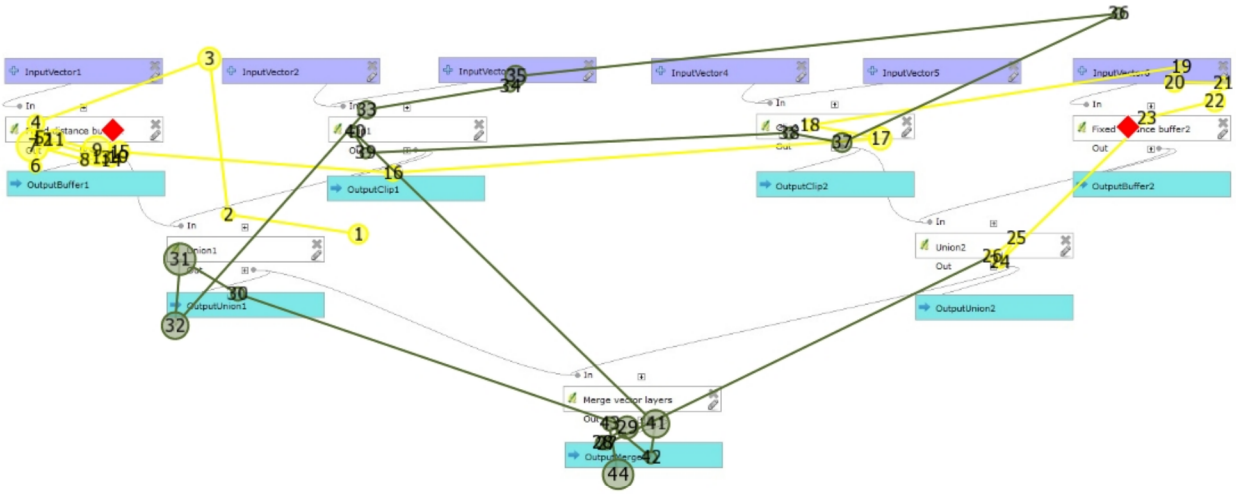

Figure 7. Scanpath of the respondent while solving the task No. 31 (red diamonds are correct answers).

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III. DISCUSSION

The first hypothesis was that the area with the high mental operation (high diameter of the pupil) would precede the mouse click to the correct answer. This hypothesis was not verified. The clicks on the diagram are earlier. The reason is that the pupil change has latency about 300 ms after increasing mental load. The mental effort perceives to the second part of measurement because the respondent try finds another correct answer. The final part of exploring stimuli brings the decline of diameter in all cases.

The evaluation of pupil graph needs the recalculation of values to smooth the shape of the curve. The trend of shape is more significant for evaluation. In that case when 250 values per second exits, the recalculation was used by the window of 39 neighbourhood values. The smooth trend is satisfactory but could be increased to the wider window.

IV. CONCLUSION

The presented investigation brings a comparison of three diagrams and their measured data of pupil diameter for the same respondent P12. The first two compare the same diagram with and without a task. It is evidence that diagram without task does not cause any mental effort. The change of diameter is about 4%. The change of diameter in the case of the diagram with the task is about 9%. The third diagram distinguishes only in the orientation of flow; the functionality is the same. The change of diameter is about 10%. There are nearly no differences. Both diagrams cause the same mental effort, and the orientation has no influence for the time of finishing of the task.

The presented respondent P12 is one of 20 respondents. It is the only example of evaluation reading of diagrams by one respondent. We displayed all other respondents. The procedure of reading and answering is very changeable in comparing each other. But the recognition of mental effort by the change of diameter could be interpreted for every respondent. The simultaneous investigation of pupil graph and scanpath is helpful.

The comparison verifies the hypothesis that diagram with task brings some mental effort. This mental effort is possible to recognize in graphs of pupil diameter for both two diagrams. The mental effort is caused by finding the white rectangle that represent the function. Moreover, the reading of label of the function is necessary. The presented results supplement investigation in the field of effective graphical notation for workflow diagrams.

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