Using Pupil Size as an Indicator for Task Difficulty in Data Visualization

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ABSTRACT

Changes in human pupil size are known to be correlated with task difficulty [1]. Here we explore the opportunity of using eye tracking to measure task difficulty in the specific context of data visualization. In particular, we use a controlled eye-tracking study to investigate the difference between two types of task difficulty, mental difficulty and visual difficulty, explore the time frames at which pupil size responds to changes in task difficulty, and investigate if pupil size can provide qualitative hints as to which part of a task people find difficult. We found that eye tracker reveals mental difficulty more precisely than visual difficulty (Fig.5). We also found a set of patterns of pupil size changes that are related with mental activity and we show that using pupil size in conjunction with gaze coordinates lets us make inferences about user cognition that would not be possible if looking at gaze coordinates alone.

Keywords: Eye tracker, pupil size, gaze point.

1 INTRODUCTION

Pupil diameter has been shown to be a measure of human stress and task difficulty [2] [3]. However, in data visualization, pupil size has not yet been integrated in standard eye tracking analysis [4]. Our motivation is to use the eye tracker for evaluating task difficulty by assessing pupil size. For this purpose, we took into account two types of task difficulty: mental difficulty and visual difficulty. To evaluate mental difficulty we created tasks involving arithmetic multiplication of two numbers. To assess visual difficulty we asked users to trace target curves in sets of multiple intertwined curves. Finally, we attempted to create a combined visual-mental difficulty test in the form of an area assessment task. We conducted a small user study on 18 users and asked them to do these three tasks. We recorded these users' gaze points and pupil size with an eye tracker. We found that eye-tracking measures such as eye-movement and pupil size can predict task difficulty. We found that pupil size can be a reliable indicator of mental difficulty but not for visual difficulty which is better predicted by number of fixations. Finally, we also quantify the response time of pupil size to changes in task difficulty.

2 RELATED WORK

Kahneman et al. [1] found that pupil diameter is a measure for mental activity and short-term memory load. As such, pupil diameter (PD) could be a valuable alternative of Galvanic Skin Response (GSR) signal to detect the stressed state of computer users. Ren et al. [2][3] presented an affective assessment approach to differentiate between relaxed and stressed states of the computer user. They used both PD and GSR signals for stress detection. They found that using the PD signal is a better option for stress detection than the GSR signal. Blascheck et al. [4] presented a survey on visualization techniques for eye tracking data. The survey reveals that pupil size has not been yet incorporated in visualization eye tracking research.

3 METHODS

Our goal was to evaluate human pupil size for different tasks with different difficulty levels. We wanted to find how human pupil size changes with changes in visualization, and how mental difficulty and visual difficulty could be evaluated by taking pupil size into consideration.

3.1 STUDY DESIGN

We considered two types of difficulty involved in typical visualization tasks: mental difficulty tasks and visual difficulty tasks. We used multiplication tasks to assess peoples' mental difficulty and curve tracing in sets of intertwined curves to assess visual difficulty. To examine a combination of mental difficulty and visual difficulty together, we used an area assessment task in which users find the larger object between two objects. For each task, we created stimuli of three ascending difficulty levels: 0, least difficult, to 2, most difficult. In multiplication tasks, a difficulty level zero involved the multiplication of two one-digit numbers with results less than ten (ex. 2×3), difficulty one multiplications were of two one-digit numbers with results greater than ten (ex. 7×9), and difficulty two multiplications were of one two-digit number and one single-digit number (ex. 43×8). In curve tracing problems, we created sets of curves and asked the user to follow a particular curve from its starting point to its end point. In difficulty zero tasks we included 3 relatively straight curves, difficulty one tasks contained 4 curves with a more winding profile, and difficulty two tasks contained 5 relatively jagged curves. Finally, in the area assessment tasks, two geometric objects, one circle and one oval, were shown to users who were asked to name the object with a larger area. For difficulty level 0, the larger object was at least 1.5 times larger than the smaller object and thus was easily distinguishable. As the difficulty level grew, the ratio between two areas was smaller and made the task harder.

In a user study, we collected data from 18 subjects, where 14 users were PhD students in computer science, and 4 users were undergraduate students in computer science. The user study lasted for about 40 to 45 minutes. There were 60 stimuli for each type of task and in total 180 stimuli for all three types of task. Every user got $10 for their participation and 4 users got the incentive bonus of $5 for being 80% accurate in their answers.

3.2 ANALYSIS

Users' gaze point coordinates and pupil sizes at those coordinates were recorded with an eye tracker. To analyse pupil size we developed a basic visualization containing a histogram of the pupil's size throughout the entire study, and gaze points and pupil size heat maps overlaid on each stimuli (Fig. 1). In every stimulus, we mapped gazes as circles centered at gaze-coordinates and having radii and color proportional to the gazes associated pupil size. For the color encoding we used standard heat map coloring: green for small pupil size and yellow for medium. We analyzed

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data anecdotally in two phases. In an exploratory phase, we tried to identify patterns in the data and formulate them into hypotheses. In a second stage, we manually processed the visual results for all users and counted the number of stimuli in which the hypotheses have been followed. We present the hypotheses in the next section.

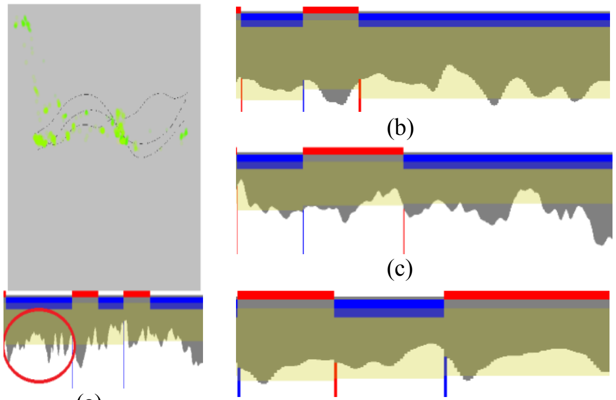

Figure 1: Histogram of pupil size and gaze points and pupil size heat map for a user. (a) Histogram of a stimulus is shown on highlighted area. Consecutively (b) multiplication (c) curve (d) area task histogram for three difficulty levels.

4 RESULTS

By observing these 18 users' pupil size and gaze coordinates in our analysis visualization, we found a number of interesting patterns of mental activity, gaze patterns, and pupil size. First, we found that the response of the pupil to a change in task difficulty occurs in approximately 250 milliseconds.

Second, the combination of gaze coordinates and pupil size indicates the mental activity of a user while performing multiplication. We found that our subjects had two different approaches to performing multiplication. One group broke down the numbers into two easier parts. For example, 63×7 became (60×7)+(3×7).While doing two-digit time's one-digit multiplication, this type of users usually ignored the MSB of the two-digit number. Such subjects also had higher pupil size while seeing the R.H.S number on multiplication tasks (Figure 2.1). Five users followed this hypothesis in 91.65% of the cases. For the second group of users, they used the standard carry strategy: to solve 63x7 they first did 3×7=21, put the 1 at LSB in the result, took the 2 as carry, then did 6×7=42 and added the carry with 42 and placed the LSB of the result at the end. These subjects had higher pupil sizes and more gaze points at the L.H.S number on multiplication tasks (Figure 2.2). Five users followed this hypothesis in 97.97% of the cases. These strategies match responses given by users at the end of the actual study.

Third, we found that for curve tracing the difficulty is given by the number of intersection points between the target curve and other curves. In the curve tracing task, from the gaze heat map, we saw that people had higher gaze points and larger pupil size on the intersection points than other parts of that stimulus (Figure 3). Ten users followed this hypothesis in 94.50% of the cases. However, the increases in pupil size at intersection points were not sufficient to reflect in the general average of curve tasks (Fig. 5).

Fourth, we also found that eye tracker reveals people are more unfamiliar with the area of the oval than the circle. If the difference between two areas was large users looked at the larger object; if the difference was small, and thus the task harder, they looked at the oval (Figure 4). Moreover, pupil size was greater for gazes focusing on the oval. Eight users followed this hypothesis in 78.24% of the cases.

Finally, in Figure 5 we show the divergence of pupil size from users' the average pupil size over the whole experiment. We averaged divergences for all users over different tasks categories. The figure indicates that pupil sizes were largest during multiplication tasks and that level two multiplications resulted in significantly larger pupil sizes than the other two multiplication levels. Within the other two types of tasks differences were smaller.

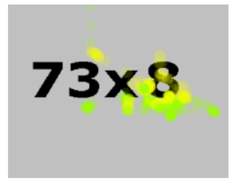

Figure 2.1: User focus on the R.H.S digit on multiplication.

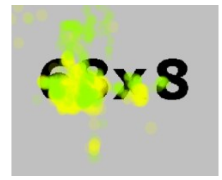

Figure 2.2: User focus on the L.H.S digit on multiplication.

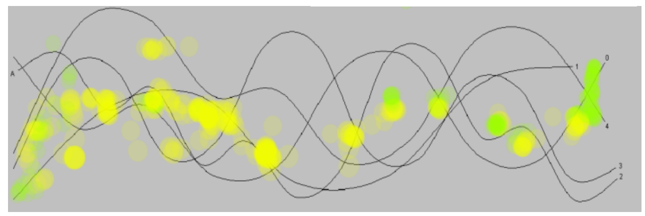

Figure 3: Larger pupil size and more gazes at the intersections in curve tracing task. (Yellow indicates larger pupil than green)

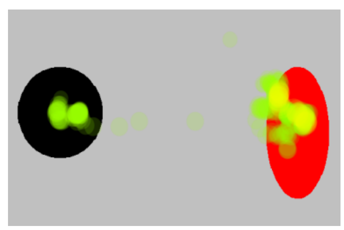

Figure 4: More gazes with larger pupil size on oval.

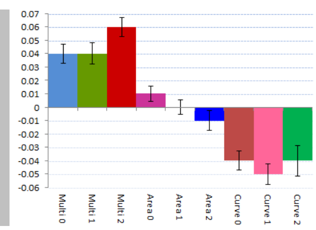

Figure 5: Deviation of pupil size in different tasks from average pupil size for all users.

5 CONCLUSION

Pupil size depicts mental difficulty more precisely than visual difficulty. However, it also finds which points of visualization make it harder or easier. We will extend our research for evaluating different types of visualization task difficulty level.

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