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Gaze Patterns in Art Viewing and their Dependencies on Expertise and Image Characteristics

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Abstract

To understand if art experts and novices view paintings differently, we conducted a series of experiments where we asked participants to look at digital images of paintings while we recorded their eye movements. The expert participants were recruited among students and faculty studying or practicing art. Novice participants did not study art-related disciplines. Half of the participants in each group received a free viewing instruction. The second half was told that they would be asked questions about the images they viewed. Gaze trajectories (scanpaths) were recorded using an SMI remote red 250 eye tracker. To analyze the differences between art viewing patterns of experts and novices, and for different instruction conditions, we employed Recurrence Quantification Analysis (RQA), which was successfully used in previous research [5] to reveal the influence of expertise in medical image viewing.

Our results indicate that expertise was, indeed, a significant factor influencing eye viewing patterns in terms of several extracted RQA measures. The instruction condition and painting type were also significant.

Introduction

Motivation

There are two types of saliency that influence visual attention and gaze behavior when viewing visual stimuli: bottom-up saliency, associated with conspicuous elements in the stimuli, such as intensity, contrast, color; and top-down saliency governed by cognitive factors, e.g. the given task, knowledge and expectations, [1], [2]. Art experts who either studied art and art history or had some form of art education are trained to pay attention to various aspects of paintings, including "low level" features of texture, form and color, as well as "higher level" characteristics related to the composition and the meaning of objects, artists' intentions and style. Therefore, artists and art experts learn to view paintings differently from novices who have no background or knowledge related to any form of art [3]. The motivation behind our research is to identify characteristics of viewing behavior, caused by the knowledge and expertise, that differentiate art experts and novices, and to study if these differences are linked to the quality of aesthetic experience during visual art viewing. In the present study, we focus on the analysis of the recorded eye movements of experts and novices while they were viewing digital images of paintings presented on a monitor screen. We use Recurrence Quantification Analysis (RQA) [4] to find the differences in gaze patterns. The RQA method has been previously applied to reveal differences in eye movements between expert dermatologists and novices when they were viewing medical images [5]. Using the RQA we obtain novel quantitative information on the role of expertise, viewing instruction and painting characteristics during art appreciation and their effects on visual attention as revealed in eye movements. This novel information can be used for teaching and museum curation purposes and to design methods for enhancing aesthetic experience.

Background

Research has been done to understand the scientific basis of aesthetic experience using eye tracking. The differences in gaze patterns can be studied by examining the scanpaths, fixations and saccades [6]. A scanpath represents a particular sequence of eye movements when viewing an image or a visual stimulus. Fixations are usually termed as points of focus, while saccades are rapid eye movements between fixation points. According to previous studies, viewing strategies of experts differ from novices [7]. Novices scan smaller portions of a painting when compared to experts [8]. Recurrence Quantification Analysis was used as one of the ways to differentiate experts and novices in medical field and significantly lower recurrence measures were observed for the experts when compared to novices [5]. In the present study, we use the RQA measures research to understand the differences between art experts and novices when digital images of paintings are viewed.

Study Description

Design and Participants

In our study, we implemented a 2x2x5 between-subjects experimental design with 2 expertise levels (experts and novices), 2 instruction levels (free viewing, and a follow-up questionnaire instruction), and 5 painting categories, from very abstract to realistic. The art expert group consisted of 24 students and faculty members, who were studying and/or teaching art and art-related disciplines. The novice group also consisted of 24 students and faculty from various majors with no background in visual art studies and those who were not specifically interested in paintings or any form of art. The participants for both groups were recruited from Rochester Institute of Technology, and included both female and male genders. The participants were screened for normal color vision and normal or corrected to normal visual acuity. The study has received RIT IRB approval.

Stimuli and Materials

The stimuli consisted of 60 digital high resolution images of fine art paintings representing 5 different categories: Abstract, Landscape, Portrait, Cityscape and Still life. The SMI Red-250 eye tracker was used with the dual display set-up where the images were shown on the full screen of one computer. The second computer was used to run the SMI software as shown in Figure 1.

Procedure

The participants sat at the distance of ~ 60 cm from the 20" display, where the images were presented on the 1680x1050 resolution screen. Before beginning the experiment, they were informed that their eye movements will be recorded.

The participants from the instructed group were told that they will be given a questionnaire at the end of the experiment on their understanding and impressions of paintings, while those from the non-instructed group were asked to freely view the images. The viewing time was not limited. The participants were told to view images as long as they wanted, and to say "next" when they wanted to proceed to the next painting. The images were displayed in a randomized order for every participant.

***Figure 1**. Experimental set-up with the SMI remote eye tracker.*

Analysis

The eye tracking data were analyzed using the SMI BeGaze software to export time, duration and locations of fixations for every participant and each image. The RQA [4] was then applied on the fixation data files to calculate recurrence measures for every image and participant. RQA is known to be a robust tool for fixation sequences analysis. It takes fixation durations and locations into consideration and allows to determine any repetitions in a scanpath, and the pixel locations in the images that are repeatedly fixated.

A brief description of this method proposed by [4] is given below. For a fixation sequence i with corresponding duration t_i, i = 1,2, . . .N, if two fixations are close to each other, then they are supposed to be recurrent. According to [4] the "closeness" r can be defined as

$$r_{ij} = f(x) = \begin{cases} 1, & if\ d(f_i, f_j) \leq \rho \\ 0, & otherwise \end{cases}$$

where d is the distance between two fixations, i and j; and ρ is radius. We use the ρ value of 64 pixels, which corresponds to 1.5 degrees of visual angle. RQA measures are usually calculated from the upper triangle of the recurrence plot (see Figure 2) because of the symmetry of the plot [4]. While doing this, the diagonal (incident line) is excluded because it does not give any useful information. We calculated the four RQA measures – *Recurrence*, *Determinism*, *Laminarity* and the *Center of Recurrence Mass* introduced by [4]. The sum of recurrences R can be mathematically represented as

$$R = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} r_{ij}.$$

Recurrence (REC) is defined, in percentage points, as how often observers re-fixate previously viewed image locations.

$$REC = 100 \frac{2R}{N(N-1)}$$

Determinism (DET) is a measure, which represents any kind of repeating gaze patterns as shown in Figure 2.

$$DET = 100 \frac{|D_L|}{R}$$

Here D_L is the incident line, also called the diagonal line, plotted from points, which are recurring. For the calculations, we use the line length (L) = 2.

Laminarity (LAM) is calculated from both horizontal (H_L) and vertical lines (V_L) of the recurrence plot as

$$LAM = 100 \frac{|H_L| + |V_L|}{2R}$$

The areas represented by the vertical rectangle in Figure 2 are places where the observers first fixated and then scanned those areas again at a later time in more detail with a series of consecutive fixations. On the other hand, the areas where they initially had a sequence of fixations and then, later, looked at the same area briefly are represented by the horizontal rectangle on the recurrence plot (Figure2).

Finally, the ***Center of Recurrence Mass*** (CORM) is the distance from the incident line to the set of recurring points:

$$CORM = 100 \frac{\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (j-i) r_{ij}}{(N-1)R}$$

When the CORM value is small, the re-fixations occur very close in time, and when the CORM value is large, the re-fixations are spread apart.

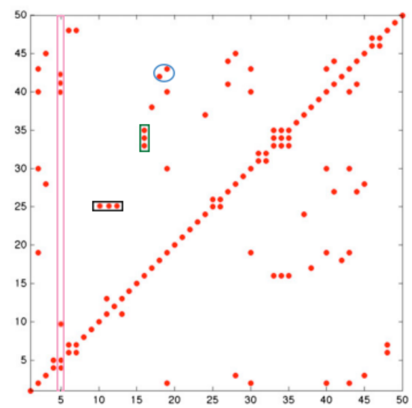

***Figure 2**. Recurrence plot (diagram). Illustration adapted from* [4]

The areas represented by vertical rectangle are places where the observers first fixated and then scanned those areas again at a subsequent time in detail. On the other hand, the areas where they first scanned in detail and then looked at the same area briefly are represented by the horizontal rectangle as in Figure2.

Figure 2 illustrates the recurrence diagram representing three recurrence measures – *Recurrence*, *Determinism*, and *Laminarity* for one participant described in [4]. The points in pink long rectangle show that fixations 40, 41 and 42 are recurrent with fixations 4, 5 and 9. This pattern contributes to the measure of *Recurrence*. The points outlined by the blue circle show that fixations 19-20 are repeated again in fixations 42-43. This produces a diagonal pattern, which is defined as *Determinism*. The points in the vertical green rectangle represent the image area first fixated at the 16th fixation and then scanned in detail at a later time during the consecutive 33, 34 and 35th fixations. In contrast, the points in the horizontal black rectangle show that this area was first viewed in detail with multiple fixations 10, 11 and 12 and then re-fixated briefly at a later time with the fixation 25. These patterns are referred to as *Laminarity*.

Results and Discussion

We ran a three-way ANOVA to evaluate the main effects of expertise, instruction and painting category on the recurrence measures. The expertise factor was found to be significant for the *Determinism*, the *Laminarity* and the *Center of Recurrence Mass*, but not for the *Recurrence* (Figure 3). The values for DET and LAM were significantly smaller ($p<0.0001$), while the CORM value was larger ($p<0.01$) for the expert group. This means that the novices had significantly larger number of consecutive fixations in the same local image areas compared to the experts. These repeated fixation sequences also occurred more closely in time relative to the expert group (CORM). In other words, the novices' eyes tended to linger in the same image areas significantly more often than did the experts' eyes.

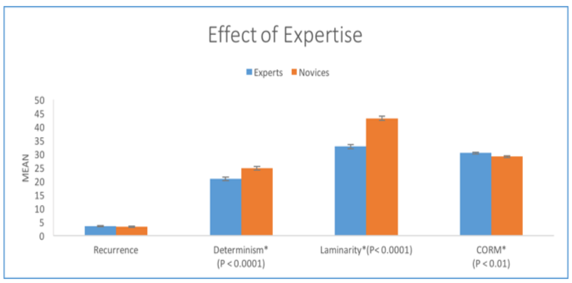

Figure 3. *Effect of Expertise on Recurrence Measures.*

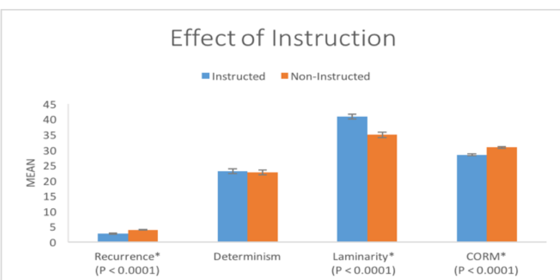

Figure 4. *Effect of Instruction on Recurrence Measures.*

As can be seen from Figure 3, experts have significantly higher CORM values and lower *Determinism* and *Laminarity,* than novices. The higher CORM value means that the re-fixations for the experts are separated farther in time, while lower DET and LAM demonstrate less local viewing compared to the novices. This combination of indices can be interpreted as to reflect a tendency to compare different scene elements and obtain overall impression of the painting.

At the same time, the lower CORM values and higher *Determinism* and *Laminarity* of novices show that they have more sequences of fixations of the same areas within a shorter time interval, but do not return to look at the same points again later as often. This type of behavior may reflect a lack of attention to the compositional structure of paintings, which has to do with the relationships between different elements, and therefore, signify the effects of expertise.

The main effect of the instruction factor was significant for the *Recurrence*, *Laminarity* and the CORM. Although the proportion of returning fixations captured by the *Recurrence* measure was significantly smaller in the instruction condition, the value for *Laminarity* increased ($p<0.0001$). The DET value also increased although not in a statistically significant way.

These findings suggest that when the observers are expected to answer questions about their understanding of paintings, their viewing behavior changes. Specifically, the observers revisit a smaller number of local image regions overall, at the same time they inspect those regions more carefully with a sequence of consecutive fixations. As reflected in the LAM value, they may glance at a point in the image briefly and then inspect this area for a longer period with multiple fixations. Conversely, they may look at the image location with the series of fixations initially, and then revisit the same place briefly later. The increase in the CORM value shows that these patterns occurred closer in time when the instruction was given.

Interestingly, the differences in gaze patterns between the groups with and without the instruction on the meaning of paintings resemble the differences between experts and novices. When given the instruction, the observers exhibit more sequences of consecutive fixations occurring closer in time, as they were focusing on analyzing and remembering specific objects on the paintings.

The main effect of painting category was significant for the *Recurrence*, *Laminarity* and *Determinism*. The highest values were obtained for Portrait images, and the lowest – for Abstract paintings, meaning that the highest proportion of re-fixations of the same areas were observed for Portrait images, and the lowest - for Abstract images. This result agrees with the observations that observers tend to fixate human faces during image viewing. Low recurrence values for abstract paintings can reflect diminished interest to these types of paintings among the participants.

Figure 5 provide an illustration for the results we obtained on the recurrence measures. It shows the eye movements of four different observers from four experimental groups as gaze plots recorded for the same painting. Gaze plots display eye movement sequence, location, order and duration of gaze fixations, which is represented as a radius of a circle.

Table 1: Recurrence measures for different painting categories. Mean values and standard errors of the mean in parentheses.

Painting Category	REC*	DET*	LAM*	CORM
Abstract	2.9 (0.23)	19.7 (1.12)	34.2 (1.26)	29.9 (0.49)
Cityscape	2.8 (0.27)	21.2 (1.26)	36.9 (1.42)	29.5 (0.56)
Landscape	2.3 (0.24)	21.3 (1.15)	34.8 (1.30)	30.0 (0.51)
Portrait	4.9 (0.23)	29.9 (1.10)	46.3 (1.25)	29.1 (0.49)
Still life	3.3 (0.23)	21.3 (1.10)	36.6 (1.25)	29.7 (0.49)

* *indicates statistical significance (p< 0.0001) of the painting category for the specified recurrence measure.*

Figure 5. *Gaze plots for four participants. The top row from left to right shows the eye movements of an expert and a novice both from the non-instructed group. The bottom row from left to right shows the eye movements of an expert and a novice, respectively, when instructed.*

There is a clear difference in the number and localization of fixations between the expert participant (top left image) and the novice participant (top right image) in the free viewing condition. There are fewer fixations for the expert, they are spread out and are shorter in duration compared to the novice. Multiple consecutive and returning fixations in nearing regions are seen for the novice. Similar differences can be seen between the second expert and the second novice for the instructed condition (bottom panel). A number of fixations, re-fixations and their duration are larger for the novice participant (bottom left) relative to the expert participant (bottom left). The gaze pattern shows multiple fixations in the relatively local regions of the image for the instruction condition, particularly for the novice observer.

Conclusion

We have provided experimental evidence that expertise, instruction and painting type significantly influence art viewing behavior by changing patterns of recurring fixations of the same points and locations on the painting. Novice observers demonstrate significantly higher number of repeated fixations and fixation sequences that occur in relatively compact areas of art images. The expert observers scan images with the fewer fixations and use larger amplitude saccades, as these observers appear to gather “gist” and relationship information on different image objects.

In the future, we plan to study the relationship between viewing behavior, image saliency and aesthetic experience.

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