A Quantitative Analysis of Eye Tracking Data for Descriptive Statistics

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Abstract

Eye tracking studies have significantly improved since last two decade and are flourishing with time. The objective of this research study is to investigate the normality within the parameters of eye tracking data for identification and estimation of intermediate processes of visual perception and cognition during the normal eye movements in scene viewing. In this research, we experimented and collected valuable eye tracking data of participants generated from eye tracking system. The collected eye tracking data was analyzed quantitatively using descriptive statistics for understanding inherent cognitive processes and human interactions. Data interpretations in terms of statistical description have determined substantial findings for human cognition and visual perception.

Keywords: *Eye Tracking, Statistics, Cognition, Visual Perception*

1. Introduction and background

Eye tracking has become one of the sophisticated and significant research studies of this modern world. Recently, commercial eye tracking products are adapting the latest tools and techniques of data science and machine learning to improve the processes and to better predictive outcomes [1-4].

It is the measurement of eye activities in terms of human cognition, especially visual perception. It can be applied to eye virtualization for socialization, eye movement analysis as well as iris detection. Moreover, the eye tracking has advanced towards more unparalleled dimensions, like argument reality, machine vision, artificial intelligence, electronics and telecommunications, sensor-based technologies, in addition to, commonly known areas, like marketing, business, human behavior, commerce, social network, user experience, reusability, and so on [1-4].

During eye tracking stage, we make use of cognitive process including metacognitive process, in addition to analogy based associative relevancy mechanism that is happening consistently. These underlying processes generate crucial interrelations that create resultant patterns of eye fixations. Therefore, it is essential to estimate and measure the existing relationships and parametric dependency and variability within these generated and collected data of eye tracking [3-24].

Statistical analysis of data is consistent and realistic methodologies in research. The study implicates with carrying out preparation, modeling, and data collection, in addition to investigating, extracting meaningful elucidation and detailing of research findings [25-36].

Statistical approaches and studies are frequently used to interconnect research findings and to reinforce assumptions and offer integrity to the research practice and inferences. Statistical analysis is indeed the means to provide us estimated results when the activities we are interested in are extremely convoluted or indefinite in their exact characteristics [25-36].

By analyzing the data quantitatively, we can understand and set up firm ground about the parametric dependency and reliance of eye movements on the cognitively evolved visual perceptions that controls and traces these processes. This in turn, can leads us towards better comprehension of human mind where visual perception gets evolved by means of eye movements of human.

Human eye movements generate a series of patterns that can be tracked and recorded using eye tracking systems. The recorded tracks in terms of data analysis are indeed a data distribution that can be identified estimated by statistical methods. A significant amount of variation can exist between a data distribution collected from the eye movements of normal person who moved eyes normally and data distribution collected from the eye movements of abnormal person who moved eyes abnormally.

The term abnormality on normality not only comes from statistical perspective but also remains under the hood of cognitive and visual perceptional processes that are consistently dominating in-between the entire scenario of eye movements during scene viewing. The inherent processes and the dynamics of mechanism that involve in the visual perception and cognition of human mind propagate through a series of substantial intermediary phases like, sensation, visual attention, associative relevance, analogy, metacognition, and so on. An investigation into the data generated from eye tracking of normal eye movements can reveal the patterns or distributions as normalized and interrelated rather completely abnormal data distributions. These transitional phases, processes and their interrelations can be understood by analyzing the generated eye tracking data quantitatively and this is the motive of current study.

2. Objective of present study

Our main motive is to investigate the eye tracking data for normality among the parameters of the data. Quantitatively, the normality distribution is analytic visualization of the data for the normal form of parameters that are generated by eye tracking system during the recording of eye movements.

The study about the normality of the data distribution is able to bring about the understandings related to normal eye movements that are initiated by and streamed by inherent processes of cognition and visual perception in normal manner. In fact, the data insights are essential for comprehension of these human visual perception and cognition.

In this research study, we investigate the eye tracking data collected from participants' eye movements. The data is analyzed quantitatively using the statistical methods. The statistical methods that are employed on the eye tracking data, can describe the characteristics and relationships among various parameters of eye tracking data.

By analyzing the data quantitatively, we can identify and measure various parameters of eye tracking data. These measurements are essential part of this research work. By analyzing the data, we can explore the data insights that are significant for establishing the inherent mechanism of cognitive processes and the dynamics of visual perception.

The analyzed outcomes and existing relationships among the parameters in terms of numeric quantities are strong evidences that reflect the undergoing phenomena of human cognition and visual perceptions. By mentioning these values and interpreting their meanings through data interpretations, we can establish a consolidated pitch for our research findings.

3. Experimental setup and procedure

At first, we selected an artistic scenery, Green Hills, for our experimentation. The reason to choose this artistic scenery was having numerous cognitively built in human emotions and feelings that were our utmost agenda to trace or record these cognitively generated human activities during eye movements of the Subjects, i.e. participants.

The experimental setup consisted of eye tracking system that was used for recording of eye movements. In eye tracking system, the system illuminated infrared light for tracking the eye movements. The camera, connected to the system, captured the location of viewer's eyes in terms of movement during experimentation time. As the viewer moved his/her eyes to look a new location of the scene, the camera recorded new movement also. This process of recording continued subsequently. The system generated eye movement tracks and heat maps using the captured data that was utilized for further analysis.

The schematic diagram of eye tracking system and basic processes involved during eye tracking experimentation was represented in Figure 1.

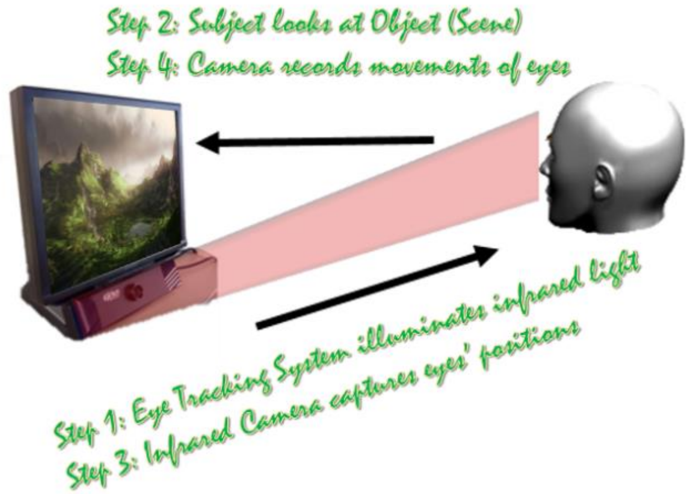

Figure 1. Operational processes of eye tracking system with Green Hill scenery.

In our experiments, we studied track of eye movements as the sequenced gazing of viewer's eye movements, which was generated by the system, during scene viewing. These were the dynamic shifts of eye gaze in scene viewing. By these eye fixations, tracking pattern was generated by eye tracking system that records the human eye movements.

4. Method and data collection

We selected 40 participants from a number of fields randomly, aging from 19 years to 45 years. Further, we assigned these participants (Subjects) to view selected famous artistic scenery (Object).

Their eye movements were closely monitored as they viewed 32 bits full-color artistic scenes. The Objects, the scenes were displayed on a computer monitor. We have shown the scenery at a resolution of 1280 × 1024 pixels and subtended 15 degree horizontally by 10 degree vertically at a viewing distance of 75 centimeter. Eye position was sampled from an Eye Tech Digital Systems TM3 16 mm Eye Tracker, and tracking data was parsed into sequenced gazing with circles of concentration.

The Subjects' heads were held steady in advance prior to experimentation. Prior to the first trial, Subjects completed a procedure to calibrate the output of the eye tracker against spatial positions on the display screen. This procedure was repeated regularly throughout the experiment to maintain high level of accuracy. Subjects were initiated to view the scenes freely.

The scene was presented to the Subjects in very comfortable mode. During the time span, the Subjects viewed the scenes with their normal eyes and focused attention on the Object, i.e. the scene.

5. Statistical analysis

During this phase of analysis, we analyzed statistically the eye tracking data for estimation and evaluation of existing parameters of the data population in terms of numerous data samples.

Although we conducted and carried out a number of statistical analysis for this eye tracking data, yet we presented those results that seemed to be appealing for conclusive remarks and did viable evidences within our statistical population.

We computed and analyzed all of our data generated by eye tracking system using R environment.

We started with the computation of the statistical summary of the collected eye tracking data that turned out to be as shown in Table 1.

The parameters of eye movement data intended such as,

1. the tracking time in millisecond (Time[msec]),

2. ticking time during eye movements (Time[Ticks]),
3. gaze X and Y coordinates (GazeX, GazeY),
4. the diameter of eye movement focused circle (Diameter),
5. the left and right calibrations of the eye tracking device in terms of left and right eyes
6. (LCalib, RCalib)
7. the left and right cross sectional positions in terms of left and right eyes (LFound, RFound)
8. the left eye's X coordinate, Y coordinate, and diameter of focused circle (LX, LY, LD)
9. the right eye's X coordinate, Y coordinate, and diameter of focused circle (RX, RY, RD)
10. the positional accuracy of eye gaze in terms of logical; FALSE or TRUE (Lost)

Table 1. The statistical summary of the collected eye tracking data

Time[msec]	Time[Ticks]	GazeX	GazeY	Diameter	LCalib	LFound	LX
Min. : 15.62	Min. :6.342e+17	Min. : 0.0	Min. : 3.0	Min. :1.600	Min. :1	Min. :1	Min. :-336.0
1st Qu.: 6000.00	1st Qu.:6.342e+17	1st Qu.: 344.0	1st Qu.:465.0	1st Qu.:2.500	1st Qu.:1	1st Qu.:1	1st Qu.: 347.0
Median : 12484.38	Median :6.343e+17	Median : 654.0	Median :568.0	Median :2.800	Median :1	Median :1	Median : 655.0
Mean : 20409.14	Mean :6.342e+17	Mean : 636.8	Mean :574.6	Mean :2.767	Mean :1	Mean :1	Mean : 638.8
3rd Qu.: 22234.38	3rd Qu.:6.343e+17	3rd Qu.: 887.0	3rd Qu.:676.0	3rd Qu.:2.800	3rd Qu.:1	3rd Qu.:1	3rd Qu.: 886.0
Max. :101390.62	Max. :6.343e+17	Max. :1279.0	Max. :959.0	Max. :4.900	Max. :1	Max. :1	Max. :1716.0

LY	LD	RCalib	RFound	RX	RY	RD	Lost
Min. : -14.0	Min. :1.60	Min. :1	Min. :1	Min. : 5.0	Min. : 21	Min. :1.600	Mode :logical
1st Qu.: 466.0	1st Qu.:2.20	1st Qu.:1	1st Qu.:1	1st Qu.: 345.0	1st Qu.: 460	1st Qu.:2.200	FALSE:18807
Median : 569.0	Median :2.80	Median :1	Median :1	Median : 652.0	Median : 566	Median :2.800	
Mean : 584.8	Mean :2.74	Mean :1	Mean :1	Mean : 638.1	Mean : 581	Mean :2.794	
3rd Qu.: 678.0	3rd Qu.:2.80	3rd Qu.:1	3rd Qu.:1	3rd Qu.: 888.0	3rd Qu.: 677	3rd Qu.:2.800	
Max. :2272.0	Max. :5.20	Max. :1	Max. :1	Max. :2217.0	Max. :2685	Max. :4.600	

In this statistical summary of the collected eye tracking data, the data population for this eye tracking data indicated normal tendency and all the parameters of eye tracking data had no abnormality. Further, the parameter, Time [Ticks], had exponential factor in its measurements. Moreover, all the parameters of eye tracking data had numeric data quantities except for the parameter, Lost, that had nonnumeric data quantities, Boolean or logical data.

Statistically, by measuring kernel density of the parameter (Diameter), it turned out to be (figure 2):

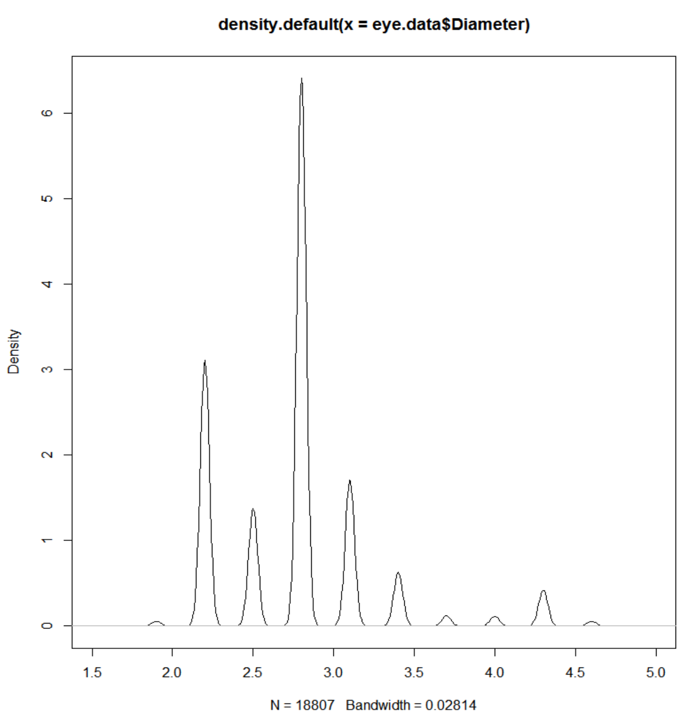

Figure 2. Statistical plot of density of parameter, Diameter.

The multiple peaks of the curves within the plot indicated that there were significant variations in the kernel density with respect to the size of the diameter. The Diameter parameter had obviously discrete values for the distribution as well.

The kernel density of parameter (Time [msec]) was plotted as in figure 3:

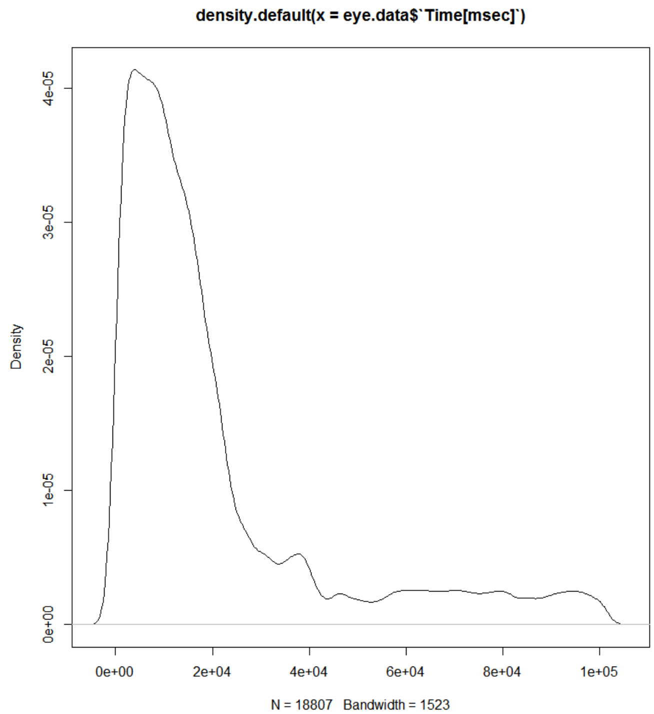

Figure 3. Statistical plot of density of parameter, Time [msec].

As shown in the plot, the density of Time [msec] parameter had continuous values for entire distribution. Moreover, the peak of density curve seemed to shift towards left side, i.e. the value of density distribution had largest value for initial time span and thereafter significantly decreased afterwards as the time elapsed during eye movements for the scene viewing. This means the participants became more concentrated during the later time span from 3e+04 onwards in viewing scene in comparison to initial phase as they randomly focused attentions a lot of times over a number of portions within the scene.

The kernel density of Diameter parameter within the bandwidth of Time [msec] parameter was found to be as in figure 4.

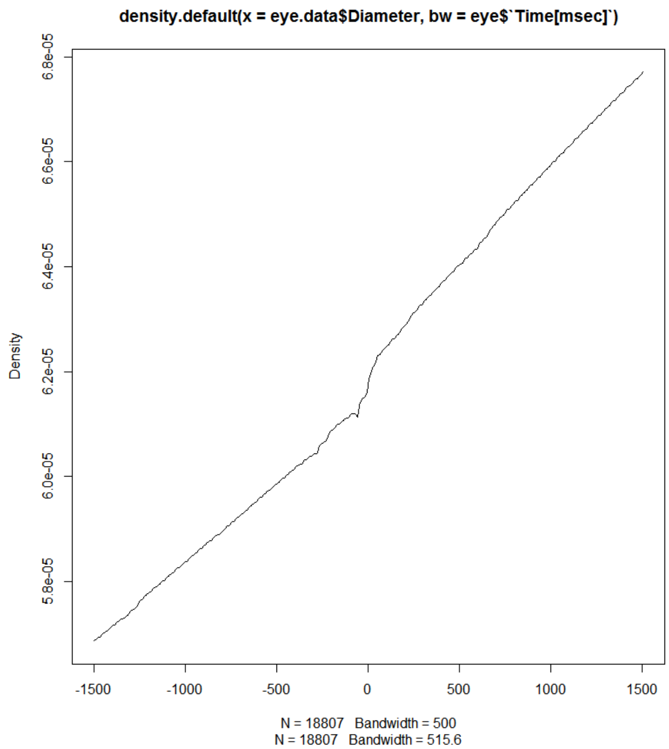

Figure 4. Statistical plot of density of Diameter within bandwidth of Time [msec].

The density of Diameter parameter indicated a consistent and approximate linearity within the bandwidth of Time [msec] of the eye tracking. Further, it showed the kernel densities for positive as well as for negative values.

Additionally, we plotted kernel density for GazeX parameter within the bandwidth of GazeY. It turned out to be as in figure 5.

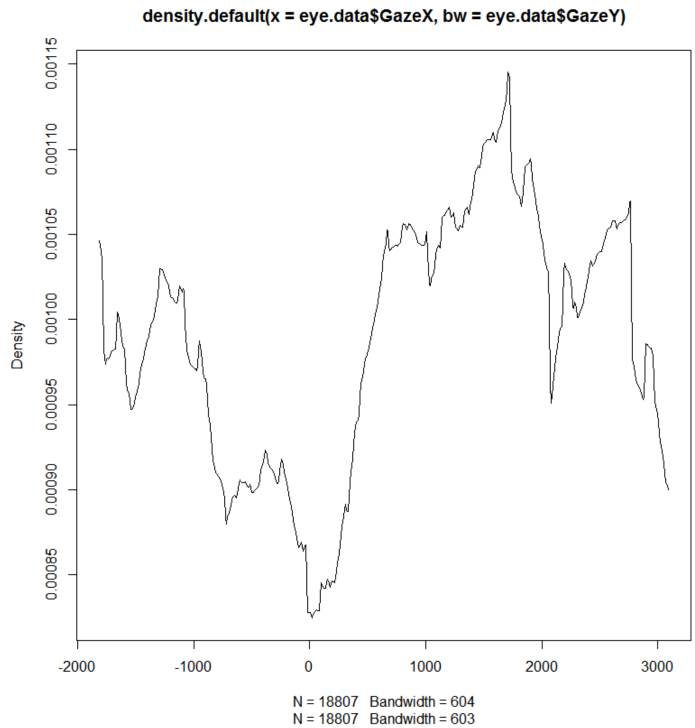

Figure 5. Statistical plot of density of GazeX within bandwidth of GazeY.

As indicated, the parameter GazeX within the bandwidth of GazeY had significant variations. The high level of fluctuation in the values existed from minimum to maximum densities as well as for positive and negative ranges of parameter GazeX.

Based on all of above findings, we finally plotted pairwise densities of all parameters as shown in figure 6. The scatter plot of matrices with bivariate scatter plot of parameters along with individual histogram, Pearson correlation, and the best-fit linear regression modeled line together with correlation ellipse.

The parameters are represented along with histograms with their names. The order of parameters is visualized as from the top left side until the bottom right side of the figure.

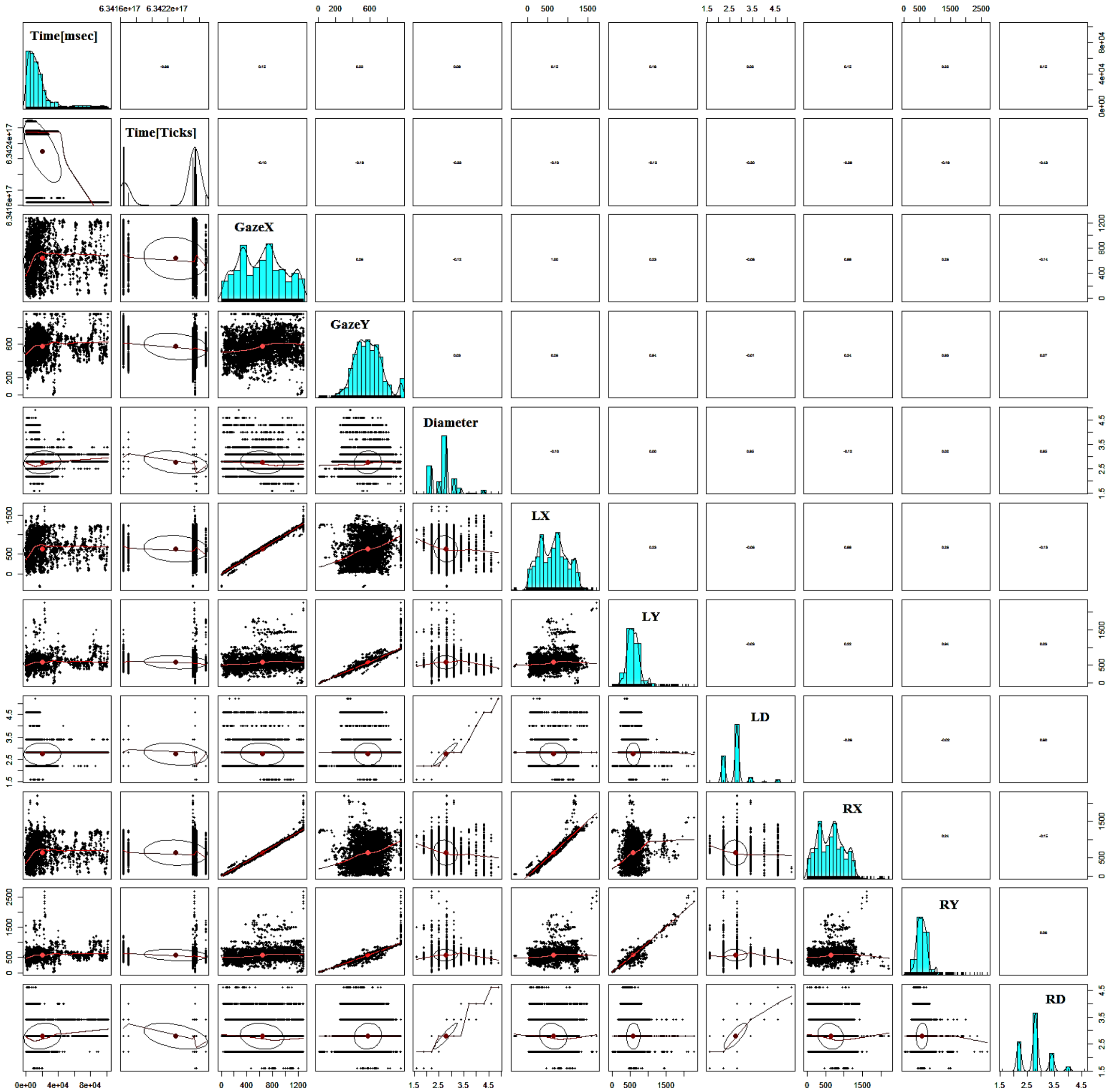

Figure 6. Bivariate scatter plot of all parameters along linear regression line and correlation ellipse.

From the above plot, we pointed out that there were discrete values of parameters, Diameter, LD, and RD. The values were found to be within certain range but had multiple peaks or maxima as well as minima as zero valued quantities.

Moreover, due to discrete values of parameters (Diameter, LD, RD), the best-fit linear regression lines were not straight lines rather a series of connected lines among Diameter and LD, Diameter and RD, and LD and RD, respectively. The correlation ellipses stayed within the points of observation for every case. This meant strong correlations were observed among individual pairings.

In addition to these, there existed the best-fit linear regressions among LX and RX, LY and RY, GazeY and LY, GazeY and RY, GazeX and LX, GazeX and RX respectively. The correlational ellipses were found to be negligibly small. That indicated that there were considerably very strong correlations among individual pairings.

6. Data interpretation and discussion

In this section, we interpret and visualize the data plotted from various aspects and perspectives. It must be noted that the data is generated from the human eye movements. Hence, we may be able to interpret the data in terms of the underlying mechanism of human cognition and the dynamics of visual perception.

As we observed from the scatter plot that the visualized histograms resembled the density distribution as well. Further, the visualization confirmed our results of kernel densities for various parameter of eye tracking data. Most of them turned out to be not unimodal normal distribution rather bimodal or even multimodal normal distributions. Nonetheless, they were found to be normal up to significant levels. Such visualizations of normal distributions appeared due to the existence of underlying normal eye movements of participants that normally passed through a series of transitional cognitive processes and visual perception.

However, based on our findings, we are sure and certain that for abnormal eye movements, the visual perceptions and cognitive processes cannot be as normal as possible. Therefore, due to biased or inabilities, the complexity can lead towards the abnormal data distribution generated from abnormal eye movements. Although rather than going for a comparative analysis of normal eye movements and abnormal eye movements, we emphasized and verified our finding based on normal eye movements. At first hand, it seemed pointless but the viability and gravity of our evidenced visualizations appeared to be more up front than virtual ground. Moreover, the analyzed outcomes are very effective and predominant in proving the point of normality that was the main concern during this entire research works.

The discrete values of (Diameter, LD, and RD) parameters and having maxima as well as minima within density plots indicated that there were certain and finite sizes of circular foci generated during eye tracking phenomena. We visualized the same outcomes by visualizing the parameters in the scatter plot as histograms. The confirmation indicates the existence of discrete focuses generated by the eyes of participants with their normal eyes during the eye movements in scene viewing.

This was in accordance with the observations found by experimentations. The fixations were found to be of certain values and none of them was found to be continuous valued. During eye tracking processes, the pause or stop in eye movements, i.e. fixations occurred due to visual attention, memory transfer and decisive visual perception.

Further, the existence of the best-fit linear regression lines and strong correlation among individual parameters, like Diameter, LD, and RD might be interpreted as following. The diameter of those circular foci generated from eye tracking phenomena along with left and right diameters of circular foci generated from left eye and right eye of the participants were dependent on one another. The coordinated and joint movements of both eyes (left and right) persisted for entire eye tracking process during visual perception resulted in generation of final eye track. This indicated that both eyes (left and right) were unidirectional and correlated. The point of focus or spotlight of the eye gaze (which were resultant of both eyes) traversed the path of eye tracks with complete accordance.

The best-fit linear regressions among LX and RX, LY and RY, GazeY and LY, GazeY and RY, GazeX and LX, GazeX and RX and considerably very strong correlations among them might be interpreted as following. Within two dimensional space of coordinates (X and Y) that generated eye tracks in terms of resultant eye gaze made of GazeX and GazeY, there were two additional reference frames, each of two dimensions as well. These two-dimensional spaces were created by human left and right eyes (such as LX and LY, and RX and RY) respectively.

The resultant focus of eye gaze that was tracked and recorded by eye tracking system had a complete dependency on left and right eye gazes in terms of coordinates as well. Therefore, the coordinates in terms of foci of left eye, right eye, and resultant eye gaze were moving and focusing on object of interest together.

Furthermore, although the coordinates might differ for different reference frames of left or right eyes, yet the coordinates of focus or spotlight moved in the same manner for every reference frames. Therefore, there occurred very strong relationship among them in terms of coordinates of different reference frames.

We confirm by the scatter plot of the parameters of eye tracking data as well that there exist significant levels of normality among a number of parameters of eye tracking data that is possible only if the data is normally distributed and that comes from the movements of normal eyes of humans.

This indicated that the normal eye movements generated normal data distribution by undergoing through the normal processes of sensation, visual attention, associative relevance, analogical thoughts, visual perception, and metacognition.

7. Acknowledgement

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