A Computational Perspective of Eye Tracking Data for Descriptive Analysis

Gufran Ahmad
Global IT Consultancy for Innovations, India
gufran.researcher@gmail.com

Abstract

Eye tracking researches have significantly contributed towards tremendous knowledgebase of human cognition and visual perception. In this study, we aim at identification and estimation of intermediary and interrelated cognitive and visual perception processes during scene viewing in terms of data visualizations for normality of eye tracking data. We started with experimentations and collections of eye tracking data of participants generated from eye tracking system. After completion of the processes of data cleansing and selection, a series of computational measurements were carried out on the collected eye tracking data statistically for understanding the very nature of the data corresponding to the recorded eye movements. Finally, the inherent cognitive processes and visual perception within the tracked data were expounded and presented as evidences in terms of data interpretations and data visualization of the eye tracking data.

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

1. Introduction and background

The measurements in tracking eye movements have become more precise and accurate day-by-day. Discrete and continuous sets of various measurements for a number of characteristics and features interrelated to eye tracking relate and correspond to tremendous human centric visual attention and visual perception. Thanks to the innovative discoveries and commercialization of this promising research area that are expanding and advancing in the shapes of novel tools and techniques [1-6].

The computations over these immense data generated by the eye tracking need specialized techniques and practices that can provide substantial data insights and in turn, reveal unique findings. A computational viewpoint of these large data can divulge and visualize related inherent cognitive processes as well as elaborate underlying mechanism of visual perception in terms of computed statistics for better understandings [3] [6-28].

Sited literatures have shown a wide glimpse of numerous computations over eye tracking data. The importance of quantitative measurements has always been interesting for certain reasons including the comprehension of human cognition as well as visual attention and visual perception. The estimation of visual attention and visual perception in terms of quantities can illustrate and convince better than other approaches effortlessly [5-28].

The current research study concentrates on computational perspectives of eye tracking data from distinctive statistical approaches that involve a number of important parameters and variables of eye tracking data for the participants' data and single object (a scenery). These approaches can ensure better data qualities and optimal outcomes as the data cleansing, data extraction, and data merging processes during the data preparation phase have been carried out prudently.

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 [5-27].

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 [29-42].

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 [29-42].

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.

2. Objective of present study

The main objective of current research work is to identify, estimate, and understand the inherent or underlying dynamics and mechanism of human cognition as well as the intermediate visual perception processes via the visualizations and analysis of eye tracking data statistically.

In this research study, we investigate the eye tracking data collected from participants' eye movements. We computed and analyzed the eye tracking data quantitatively using the statistical methods. The computational methods that are employed on the eye tracking data, can describe the characteristics, attributes, and interrelations among various variables of eye tracking data.

By analyzing the data quantitatively, we can identify and measure various variables 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.

During the phase of data preparation, we thoroughly carried out a series of data science practices as well as statistical procedures. Data munging, data cleansing, data extraction, loading, and data merging are the essential steps for the completion of this phase of data preparation.

The data visualization is a significant phase of this study. In this phase, we investigate all possible characteristics and properties of all the variables statistically. The computed numeric quantities and descriptive graphs that are produced by statistical computations are mapped and visualized with the inherent cognitive processes as well as visual attention and perception. The analyzed outcomes and existing relationships among the variables 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.

The Schematic representation of the study plan is shown below as flowchart (figure 1).

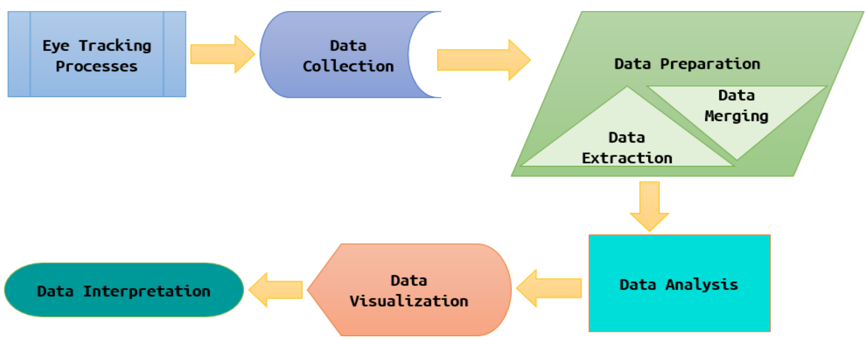


Figure 1. The flowchart of the current study.

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 2.

Figure 2. 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 scenery 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 scenery.

5. Data analysis and data interpretation

During this phase of analysis, we analyzed statistically the eye tracking data for estimation and evaluation of existing variables 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 variables 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 variables of eye tracking data had no abnormality. Further, the variable, Time [Ticks], had exponential factor in its measurements. Moreover, all the variables of eye tracking data had numeric data quantities except for the variable, Lost, that had nonnumeric data quantities, Boolean or logical data.

The visualization of the data, in terms of boxplots of all variables of eye tracking data revealed the exact assumptions as can be observed below (in figure 3) that showed relativistic and parametric representations.

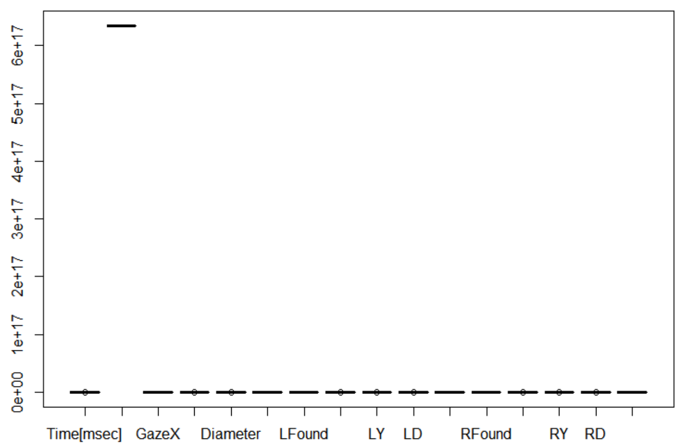


Figure 3. Boxplots of variables of eye tracking data.

In this next phase, we plotted a set of probability distributions for all numeric variables of eye tracking data. The probability distribution curves for all the variables are shown below in figure 4.

The plotted curves stood as the probability distributions of variables; Time [msec], Time [Ticks], GazeX, GazeY, Diameter, LX, LY, LD, RX, RY, and RD, starting from top to bottom and left to right within every subsequent rows respectively.

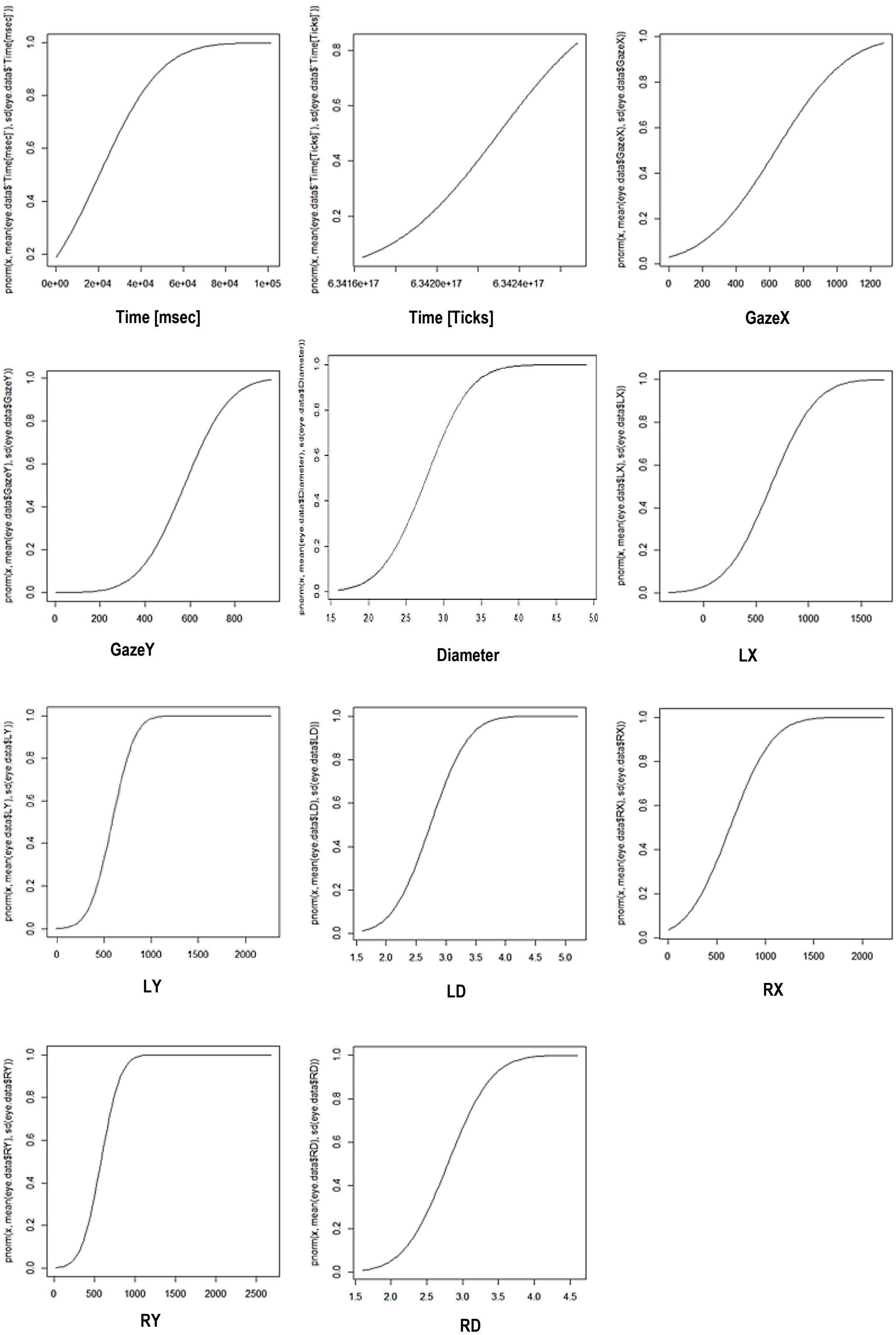
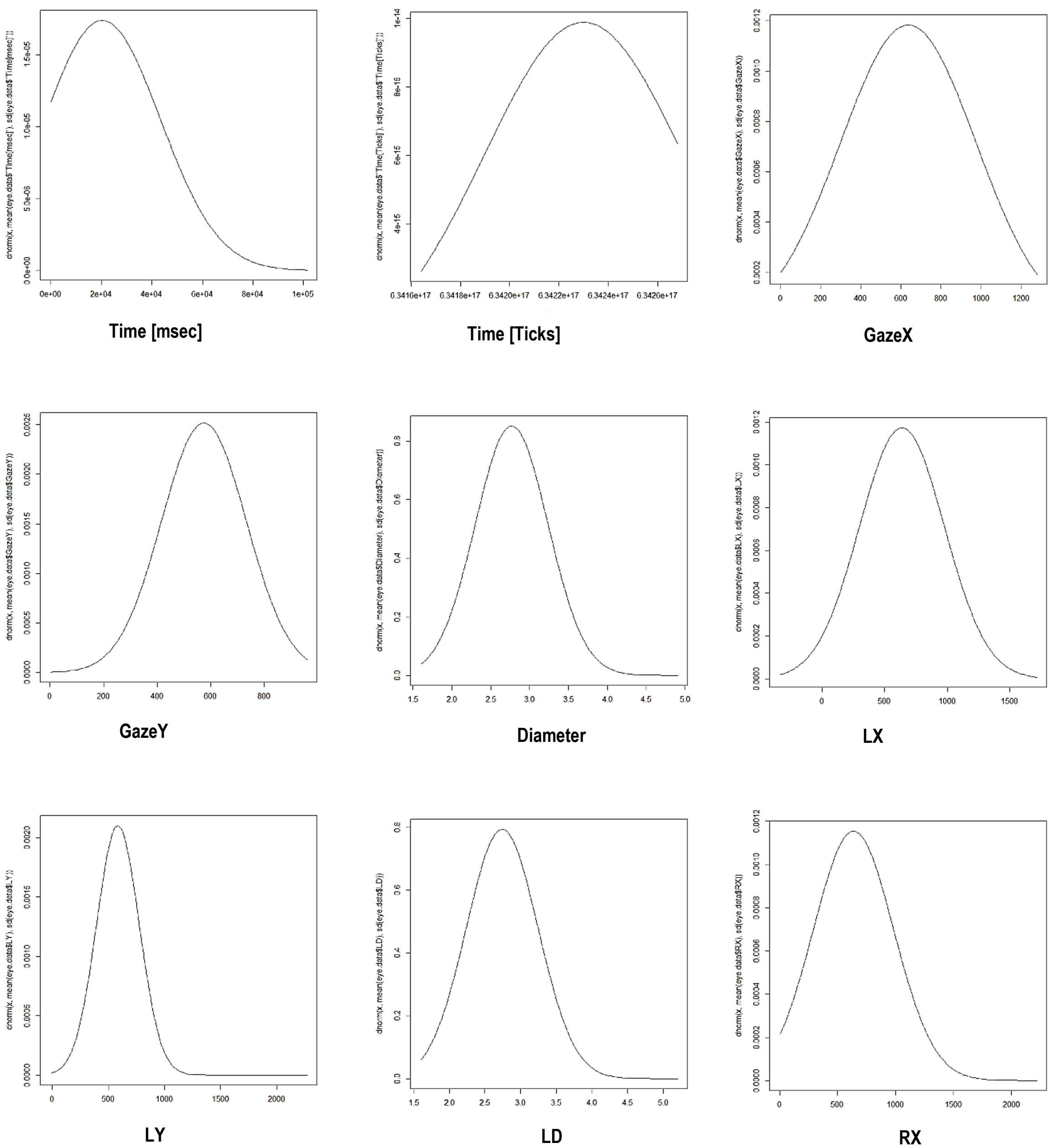


Figure 4. The probability distributions of variables of eye movement data.

As we observed from the visualized plots, there existed good normal curves of probability distributions for the variables (RD, RY, RX, LD, LY, and LX). Moreover, there seemed variables (Diameter, GazeY, GazeX), as normal curves for probability distributions up to certain extents. However, the variables (Time [Ticks], and Time [msec]) did not comply with normal probability distribution curves as indicated by the plots of these variables.

Further, to ensure the normality of the variables, we plotted the probability density distributions of all numeric variables of eye tracking data.

The plots of probability density distributions of these variables were visualized as shown in figure 5 below.



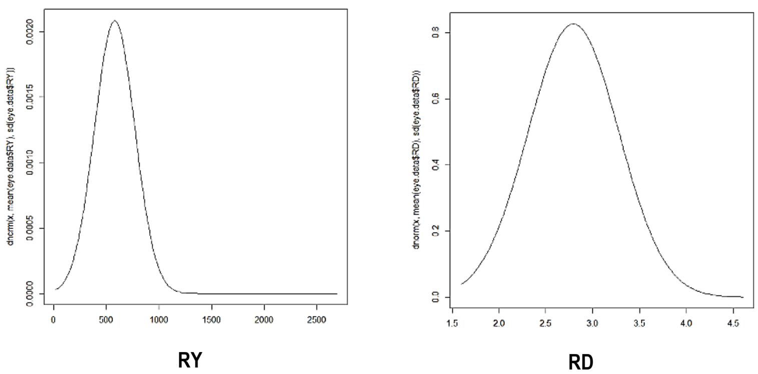


Figure 5. The probability density distributions of variables of eye tracking data.

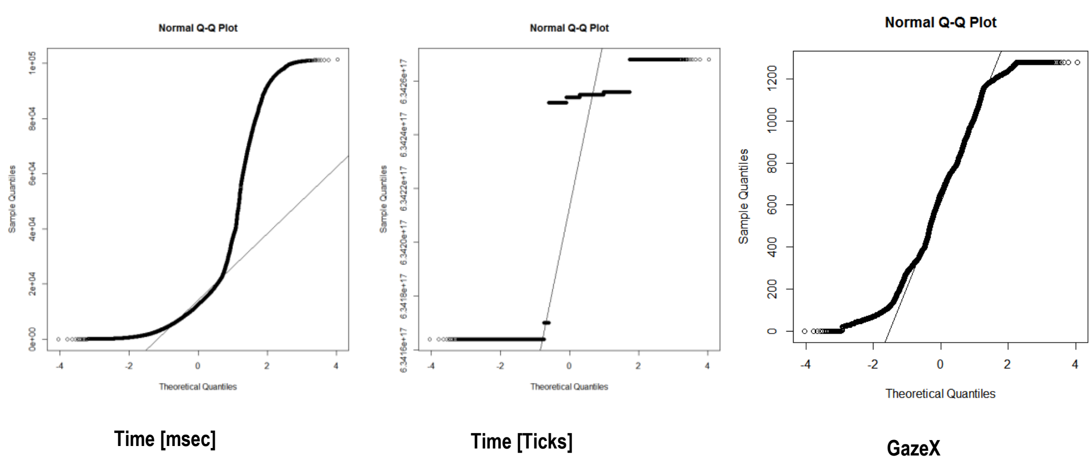
There seemed to be good probability density distributions for the variables (RD, RY, RX, LD, LY, LX, Diameter, GazeY, and GazeX). Except the variable (GazeX), rest of the variables (RD, RY, RX, LD, LY, LX, Diameter, and GazeY) had relatively smaller standard deviations. Moreover, the sharp peaks were observed for variables (LY and RY) that indicated higher kurtosis existed for them.

However, there appeared the variables (Time [msec], Time [Ticks]) as not perfect normal or Gaussian curves. Both of these variables had shifted towards right skewed and left skewed respectively. Moreover, both of them showed only single tails rather than both tails. These factors indicated that there seemed to a fair amount of abnormality in these variables.

Though we visualized the normality of variables of eye tracking data in terms of plotted curves of probability distributions and probability density distributions, yet these computational viewpoints needed further verifications in terms of normal Q-Q plots (plot of theoretical versus sample quantiles).

Hence, to validate and confirm the normality of the variables of eye tracking data, we plotted Quantile-Quantile Plots. In the Q-Q plot of certain variable, we added a line to a "theoretical quantile", which passes through the probabilities of quantiles, by default the first and third quartiles.

The schematic representations of plotted normal Q-Q plots were shown in figure 6 below.



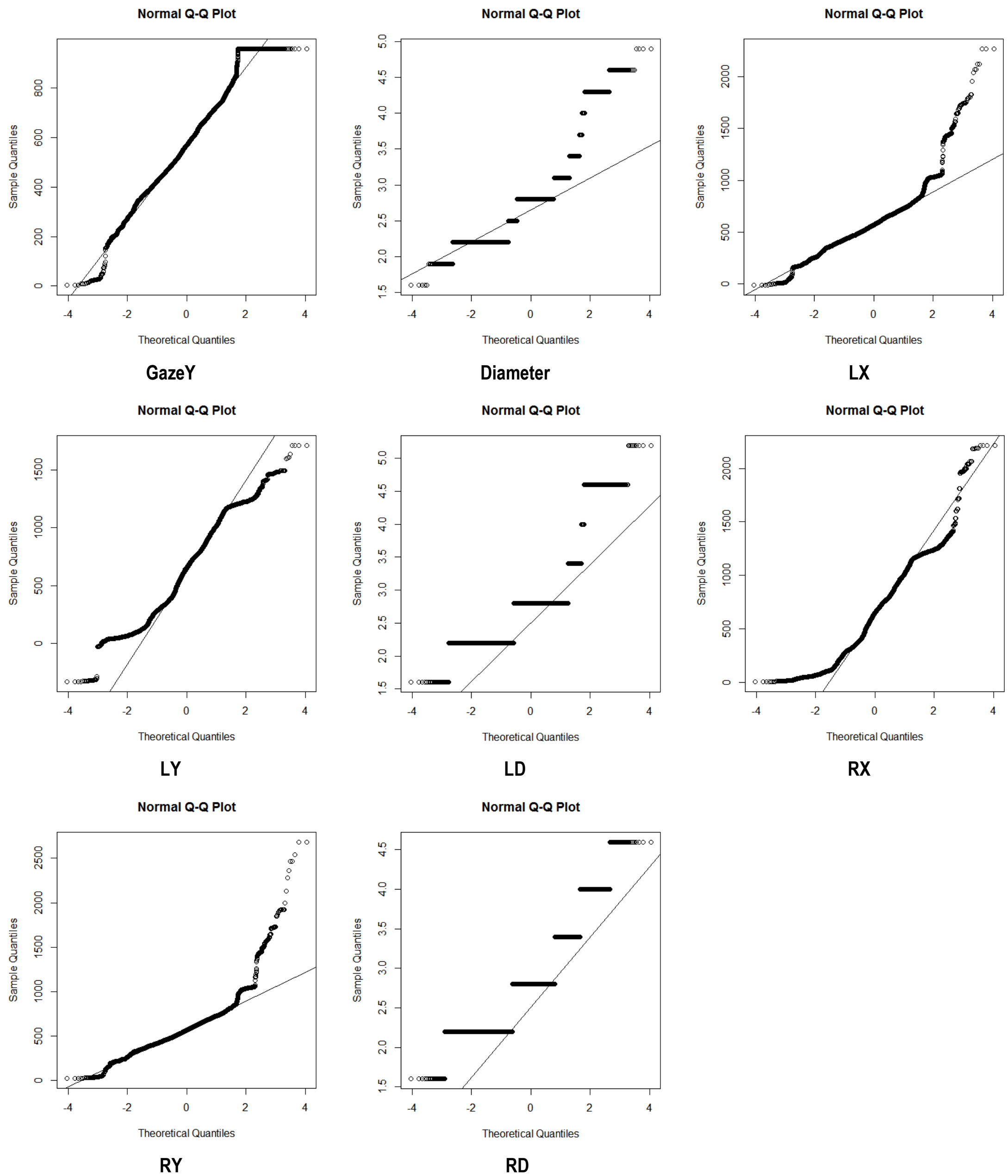


Figure 6. The normal Q-Q plots of variables of eye tracking data.

As we observed and visualized from the plotted curves of variables of eye tracking data, the normality of variables turned out to be obvious. As indicated by the plots of variables (Time [msec] and Time [Ticks]), the normal Q-Q lines did not follow the curves. Therefore, the normality of these variables did not pass through successfully our validation test of normal Q-Q criteria to become normal up to certain extent. This showed the abnormality of these variables.

The normal Q-Q plots of variables (GazeX and GazeY) visualized the fact that the normal Q-Q line relatively fitted up to larger extent. However, both ends (upper right and lower left) of the curves did not fit with the normal Q-Q lines respectively. Hence, the normality of the both variables (GazeX and GazeY) had verified up to considerable extent.

In addition to these, the normal Q-Q plot for variable (Diameter) indicated significant drift in upper right section of the curve from normal Q-Q line that ensured the normality of the variable. Therefore, the variable failed to be considered as normal.

Further, the computed Q-Q plots for variable LX relatively complied with our normal Q-Q line at the lower end values of the curve but deviated completely at the upper end values (upper right side). This indicated the existence of normality of variable LX up to certain extent.

Furthermore, the variable LY indicated higher level of normality as the normal Q-Q line seemed quite fit through the curve but failed relatively at both ends of the curve. Nonetheless, the normality of the variable can be considered relatively.

The variable LD had shown better normality tendency than Diameter variable but still lacked marginally to be approved as normal. The Q-Q line did not fit widely over the observations. That led the visualized curve to be considered as abnormal.

Next, the computed curve for variable RX seemed to abide by normality mostly. Although the curve did not fit completely at the both ends (upper right and lower left sections), yet the normal Q-Q line passed through primarily. Thus, we considered the variable RX as normal predominantly.

The visualized curve for the variable RY turned out to be normal for the most part but showed drastic deviations at the upper right portions of the curve as the curve departed radically from the normal Q-Q line. Thus, we considered the normality of variable RY up to certain and considerable extent.

The computed curve for the variable RD can be visualized as being principally and typically normal at the first glance but there seemed the problem of unfit normal Q-Q line for the plotted curve of variable RD. Hence, we established the variable RD to be abnormal.

Finally, Q-Q plots along with density functions have given an in depth insights of data for analyzing and visualizing. By explorations and Q-Q visualizations of the variables for eye tracking data, we validated and verified the normality among the variables of the data. Moreover, we understood the ongoing and underlying processes of visual perception under the guidance of dynamic mechanism of human cognition in terms of existed and estimated numerous variables of eye tracking data.

6. Conclusion

Therefore, we concluded that the variables representing coordinates for the eye tracking data appeared to be significantly qualified for normality. These outcomes ensured that there were no abnormalities in visionaries of normal eyes. The left and right eyes of every normal participant had indicated their normality in person and as inference, in addition to the data representation and data visualization for their eye movements.

Finally, these computed and visualized data interpretations were based on the experimentations and data collections of normal eye movements. The participants were physically fit and viewed the scenery by their normal eyes without any abnormality in their visions. Chances and outcomes might be different for abnormal eyes and in turn, abnormal patients. There can be possibility of abnormal data computations and visualizations for those abnormal cases.

7. Acknowledgement

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8. References

[1] Michael Burch, Lewis Chuang, Brian Fisher, Albrecht Schmidt, Daniel Weiskopf, Eye Tracking and Visualization: Foundations, Techniques, and Applications, Springer International, 2017.

[2] Aga Bojko, Eye Tracking: The User Experience, a practical guide to research, New York: Rosenfeld Media, 2013.

[3] Andrew T. Duchowski, Eye Tracking Methodology: Theory and Practice, Springer International, 2007.

[4] Monica Koller, Thomas Salzberger, Gerhard Brenner and Peter Walla, "Broadening the range of applications of eye-tracking in business research," Analise, Porto Alegre, vol. 23, no. 1, pp. 71-77, 2012.

[5] Gufran Ahmad, Yukio Ohsawa and Nishihara Yoko, "Cognitive Impact of Eye Movements in Picture Viewing," International Journal of Intelligent Information Processing, vol. 2, no. 1, pp. 18, 2011.

[6] Jana Holsanova, Discourse, Vision, and Cognition, New York: John Benjamins Publishing Company, 2008.

[7] Gufran Ahmad, "Dynamic Shifts in Visual Focus of Eye Movements Emphasize Associative Relevancy", Research in World Economy, vol. 6, no. 4, pp. 18-28, 2015.

[8] Gufran Ahmad, "Visual Focus of Attention Actively Associates Relevancy in Eye Movements", Journal of Business Theory and Practice, vol. 3, no. 2, pp. 209-223, 2015.

[9] Gufran Ahmad, "Eye Fixation curves along Analogical Thinking in Scene Viewing," International Journal of Engineering and Industries, vol. 6, no. 1, pp. 54-62, 2015.

[10] Gufran Ahmad, "Dynamics of Eye Gazing rely on Associative Relevance in Scene Viewing," Journal of Convergence Information Technology, vol. 9, no. 2, pp. 35-42, 2014.

[11] Gufran Ahmad, "Associative Relevance Based Stimulus Shifts Focus in Eye Movements", International Business Research, vol. 8, no. 10, pp. 25-34, 2015.

[12] John M. Henderson and Andrew Hollingworth, "High-level Scene Perception," Annual Review of Psychology, vol. 50, no. 1, pp. 243-271, 1999.

[13] Gufran Ahmad, "Flow of Analogical Thoughts Controls Eye Movements in Scene Viewing", Journal of Next Generation Information Technology, vol. 5, no. 4, pp. 118-125, 2014.

[14] Gufran Ahmad, "Analogy Influences Eye Movements during Scene Viewing", Proceedings of International Conference on Computing and Convergence Technology, Republic of Korea, pp. 14, 2013.

[15] Kenneth Holmqvist, Marcus Nystrom, Richard Andersson, Richard Dewhurst, Eye tracking: A comprehensive guide to methods and measures, Oxford University Press, 2010.

[16] John K. Tsotsos, A Computational Perspective on Visual Attention, London: MIT Press, 2011.

[17] Frans W. Cornelissen, Enno M. Peters, John Palmer, "The Eyelink Toolbox: Eye tracking with MATLAB and the Psychophysics Toolbox", Behavior Research Methods, Instruments, & Computers, Volume 34, Issue 4, pp 613–617, 2002.

[18] Gerhard Krieger, Ingo Rentschler, Gert Hauske, Kerstin Schill, Christoph Zetzsche, "Object and scene analysis by saccadic eye-movements: an investigation with higher-order statistics", Spatial Vision, Volume 13, Issue 2, pages 201 – 214, 2000.

[19] David Noton, Lawrence Stark, "Scanpaths in Eye Movements during Pattern Perception", Science, Vol 171, Issue 3968, 1971.

[20] Lawrence Stark and Stephen R. Ellis, "Scanpaths Revisited: Cognitive Models Direct Active Looking," in Eye Movements: Cognition and Visual Perception, R. A. M. J. W. S. Dennis F. Fisher, Ed., Hillsdale: Lawrence Erlbaum Associates, 1981, pp. 193-226.

[21] Robert Snowden, Peter Thompson and Tom Troscianko, Basic Vision: An introduction to visual perception, Oxford University Press, 2012.

[22] Keith Rayner, Eye movements and visual cognition: scene perception and reading, New York: Springer Verlag, 1992.

[23] Simon P. Liversedge, Iain D. Gilchrist and Stefan Everling, The Oxford Handbook of Eye Movements, Oxford University Press, 2011.

[24] John. M. Henderson and Andrew Hollingworth, "Eye movements during Scene Viewing. An Overview," in Eye Guidance in Reading and Scene Perception, G. W. Underwood, Ed., Oxford: Elsevier, 1998, pp. 269-293.

[25] Roger P. G. Van Gompel, Martin H. Fischer, Wayne S. Murray and Robin L. Hill, Eds., Eye Movements: A Window on Mind and Brain, Elsevier, 2007.

[26] Zenzi M. Griffin, "Why look? Reasons for eye movements related to language production," in The integration of language, vision, and action: Eye movements and the visual world, H. a. Ferreira, Ed., New York, Psychology Press, 2004, pp. 213-247.

[27] James E. Hoffman, "Visual Attention and Eye Movements," in Attention, H. Pashler, Ed., London, Psychology Press, 1998, pp. 119-153.
[28] Benjamin Martin Bly,David E. Rumelhart, Eds., Cognitive Science, Academic Press, 1999.
[29] Hugh Coolican, Research Methods and Statistics in Psychology, Psychology Press, 2017.
[30] Bryan F. J. Manly, Jorge A. Navarro Alberto, Multivariate Statistical Methods: A Primer, CRC Press, 2004.
[31] Fred Pyrczak, Making sense of Statistics: A conceptual overview, Routledge, 2016.
[32] Peter Dalgaard, Introductory Statistics with R, Springer Science+Business Media, 2008.
[33] Michael J. Crawley, The R book, John Wiley & Sons, 2012.
[34] R. Mark Sirkin, Statistics for social sciences, Sage Publications, 2006.
[35] Schuyler W. Huck, Reading Statistics and Research, Pearson Education, 2012.
[36] Joseph F. Healey, The Essentials of Statistics: A tool for social research, Cengage Learning, 2016.
[37] Kevin J. Keen, Graphics for Statistics and Data analysis with R, CRC Press, 2010.
[38] Maria L. Rizzo, Statistical Computing with R, Chapman & Hall / CRC, 2008
[39] Jared P. Lander, R for everyone: Advanced analytics and graphics, Addison-Wesley Professional, 2017.
[40] Benjamin S. Baumer, Daniel T. Kaplan, Nicholas J. Horton, Modern Data Science with R, CRC Press, 2017.
[41] Tilman M. Davies, The book of R, No Starch Press, 2016.
[42] Andrea Cirillo, RStudio for R Statistical Computing Cookbook, Packt Publishing, 2016.