A Descriptive Study of Eye Movement Data from Statistical Perspective

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Abstract

Studies on Eye Movements have become a de facto for human interaction studies and cognitive researches. Commercialization of eye tracking as tools and techniques for serious business needs has intensified its wide perspectives. In this research study, we aim at the statistical exploration of eye movement data for visual perception by thorough investigation into the existing association and correlation among the parameters of eye movement data generated from eye tracking system. At first, we experimented and collected big data of eye tracking for analyzing its descriptive nature. Further, after data cleansing and preparation processes, we examined and analyzed this terra-sized data from rigorous statistical perspective for better understanding of human perception and cognitive processes. A simplified statistical approach to elaborate the data led towards meaningful and novel data insights.

Keywords: *Eye Movements, Statistical Analysis, Cognition, Data Insights*

1. Introduction and background

Studies on eye movements have become one of the key intensive research studies in today's economic and social environments. There are a number of reasons for its growths from diverse perspectives. Tremendous opportunities exist in terms of human centric applications and utilizations in the area of business, usability, marketing, community, all kinds of science, and technology [1-3].

The process of eye movements consists of consistent movements of eyes as well as shift in the focus of the eye gazes. Human eyes undergo through this process of gaze shift because of the tendency to perceive the degree of detail visible in the central direction of eye gaze or focus [3-25].

A focused visual element of the Object of interest helps in the formation of focus of attention to the eyes accordingly during the process of eye movements. The shifts in visual focus of eye movements depend on a number of factors including visual effects, cognitive factors, point of current interest in, etc.

Although these influencing factors cannot be identified individually, yet we may sense its joint effects in eye movements. The recorded tracks of eye movements tend to tell these certain historical background of inherent effects and influencers [3-14].

In descriptive statistics, we try to describe the relationship between variables in a sample or population. The descriptive statistics provide a summary of data in the form of mean, median, mode and so on. Further, it will explain and describe the extent to which the observations cluster around a central location, e.g. central tendency and the spread towards the extremes in terms of the degree of dispersions [26-33].

In addition to these, we emphasize in analyzing the correlation or coexistence of the data variables of eye movement data because the correlated data can lead towards a significant relation among the existing processes of cognitive nature.

Therefore, by analyzing such a data that are generated by the movements of human eye can be very interesting and significant to understand the underlying mechanism of eye movements and its tendency along with key characteristics of eye tracks.

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

Cognition and visual perceptions are gradual and sequential processes that evolved to generate in human minds during the scene viewing. The sequential underlying visual perception processes and the dynamics of cognitive mechanism that propagate such a sequence are interrelated and there exist a number of significant associations. Qualitatively, we identify those associations and relations among the existing in-between processes and scenarios that we record in tracking system by the movements of human eyes. Quantitatively, there are a number of correlations and covariance among numerous parameters of eye movement data. The measurements and visualizations of those significant correlations and covariance can unveil the inherent and underlying visual perception processes and human cognitive mechanism. Moreover, quantitative analysis can in turn, tell us about the sequenced and classified processes along with the dynamic interaction of human cognition.

A number of sited literatures have revealed and contributed the significance and the tremendous knowledgebase in this research area. Most of the literatures have studied and described the psychological, cognitive, business, biological, social, human centric domains [1-14] [16-25].

In the context of current research study, the statistical analysis can provide a significant meaning to the meaningless eye movement data, thereby being the life into a lifeless data. Moreover, it can identify and estimate the hidden relations among the underlying cognitive processes of eye movement mechanism in terms of the relationship among various parameters of eye movement data.

2. Objectives of present study

The purpose of this research study is to identify and determine the statistical aspects and quantities to elaborate the data collected from eye movements of participants. The quantitative analysis of this eye movement data is essential for quantitatively understanding of human eye movements and exploration of knowledge insight into the concerned data, e.g. the eye movement data.

The main objective of the current research work is to find and visualize those associations and variances among the existing intermediate processes and states that we observe in tracking system by the movements of human eyes quantitatively. We can achieve and describe these visualized outcomes by analyzing the eye movement data with statistical methods. As cognition and visual perceptions are perpetual and chronological processes that developed and engendered in human minds during the scene viewing, the consecutive underlying visual perception processes and the dynamics of cognitive mechanism that transmit such a sequence are interrelated and there exist a number of significant associations and correlations. These can be sensed in terms of existing correlations and covariance among various parameters of eye movement data.

The estimations and visualizations of those noteworthy correlations and covariance can bring to light the inherent and underlying visual perception processes and human cognitive mechanism. Moreover, quantitative analysis can in turn, tell us about the sorted and organized processes along with the dynamic interaction of human cognition.

During the eye movements, we gathered a large size of data whose understanding is an essential part of this research study. Without knowing the concerned data, it is not possible to tell the whole narrative about the data and the involved phenomena. Therefore, it is necessary to analyze data of prime concern, e.g. the data collected from eye movements.

However, statistical measurements are not the whole story about the data but it does a fair amount of work in quantifying the interrelation and the human interaction in between the recorded data of eye movements.

By putting in numbers and finding the hidden relation among the data, we may able to identify the existing strong perspective of human cognition in terms of data evidence. The statistical analysis is one of the best analysis approaches that can be used for better understanding of the data collected from eye movements and do a complete data insights of the concerned data.

3. Experimental setup

We experimented with a famous portrait, the Green Hill, (as shown in figure 1) for the collection of eye movement data as well as interpretations of the same Object.

Figure 1. The Green Hill portrait as Object of experimentation.

In eye tracking system, the system illuminates infrared light for tracking the eye movements. The camera, connected to the system, captures the location of viewer's eyes in terms of movement during experimentation time. As the viewer moves his/her eyes to look a new location of the scene, the camera records new movement also. This process of recording continues subsequently. The system generates eye movement tracks and heat maps using the captured data that is utilized for further analysis.

The schematic diagram of eye tracking system and basic processes involved during eye tracking experimentation is represented in Figure 2.

Figure 2. Eye tracking system with operational processes.

The traces of eye movements are taken in diverse layouts as per analyst's suitability. Among them, there are two most common formats are Heat Map and Sequenced Gazing with circle of concentration. In Heat Map, the track of eye is recorded as illumination and intensity of infrared light rays. This is based on Energy Therapy Technique (ETT). In Sequenced Gazing, the eye tracks are entered as numbered circles with their areas indicating the time duration of eye gazing in those areas respectively [3-15].

4. Method and data collection

The methodology that we employed in this experimentations and study were based on quantitative analysis. The statistical tools and techniques were employed to bring significant outcomes.

For the purpose, 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 the selected famous artistic portrait, the Green Hills (Object) as shown in figure 1.

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. The scenes were shown 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 portrait was presented to the Subjects in comfortable manner. During this time span, the Subjects viewed the portrait with their normal eyes and focused attention on the elements of the Object (portrait).

5. Statistical analysis

In this phase of the study, we examined and analyzed the data collected from eye movements statistically. Such an enormous size of data could be analyzed by employing R statistical programming environment. The process of data analysis began after a tedious process of data cleansing.

We collected a large size of data that is approximated as 1.01 TB (Terabytes). The process of data cleansing and data preparation for data analysis took large amount of time during the study.

At first, we started with building up data frames of individual data sets. By binding on the individual data frames, we finally created a complete data frame of eye movements consisting of all of the data collected from eye movements of all participants.

Statistical description of the collected eye movement data turned out to be as shown (Table 1) below. 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 (LCalib, RCalib)
6. the left and right cross sectional positions in terms of left and right eyes (LFound, RFound)
7. the left eye's X coordinate, Y coordinate, and diameter of focused circle (LX, LY, LD)
8. the right eye's X coordinate, Y coordinate, and diameter of focused circle (RX, RY, RD)
9. the positional accuracy of eye movement's gaze in terms of logical; FALSE or TRUE (Lost*)

In our data sets of eye movements, we cleaned the data for the cases where the accuracy was TRUE logically, e.g. we took all the data sets by cleaning eye movement data where the Lost*, inaccuracy were FALSE. The respective statistical quantities were computed in columns for every eye movement parameters as below.

1. Serial numbering of variables (vars),
2. number of sample points or observations (n),
3. the means of respective eye movement's parameters (mean),
4. standard deviation (sd),
5. medians of eye movement's parameters,
6. the mean of set of numbers by removal of 10% extreme observations (trimmed),
7. absolute deviation around the median (mad),
8. the minimum value of observation or point (min),
9. the maximum value of the observation or point (max),

10. the range of observation variables from maximum to minimum (range),
11. the distortion or the skewness of observation variable from central tendency (skew),
12. the sharpness of the peak of frequency distribution curve (kurtosis),
13. standard errors of sampling distribution (se),

Table 1. The statistical description of the collected eye movement data

	vars	n	mean	sd	median	trimmed	mad	min	max	range	skew
Time[msec]	1	18807	2.040914e+04	2.294206e+04	1.248438e+04	1.542159e+04	1.107317e+04	1.56200e+01	1.013906e+05	1.01375e+05	1.89
Time[Ticks]	2	18807	6.342300e+17	4.036515e+13	6.342540e+17	6.342344e+17	2.965200e+12	6.34164e+17	6.342680e+17	1.04000e+14	-0.98
GazeX	3	18807	6.367600e+02	3.374100e+02	6.540000e+02	6.318000e+02	4.092000e+02	0.00000e+00	1.279000e+03	1.27900e+03	0.10
GazeY	4	18807	5.746000e+02	1.584000e+02	5.680000e+02	5.698400e+02	1.556700e+02	3.00000e+00	9.590000e+02	9.56000e+02	0.21
Diameter	5	18807	2.770000e+00	4.700000e-01	2.800000e+00	2.710000e+00	4.400000e-01	1.60000e+00	4.900000e+00	3.30000e+00	1.25
LCalib	6	18807	1.000000e+00	0.000000e+00	1.000000e+00	1.000000e+00	0.000000e+00	1.00000e+00	1.000000e+00	0.00000e+00	NaN
LFound	7	18807	1.000000e+00	0.000000e+00	1.000000e+00	1.000000e+00	0.000000e+00	1.00000e+00	1.000000e+00	0.00000e+00	NaN
LX	8	18807	6.387600e+02	3.397100e+02	6.550000e+02	6.344000e+02	4.092000e+02	-3.36000e+02	1.716000e+03	2.05200e+03	0.10
LY	9	18807	5.847600e+02	1.901300e+02	5.690000e+02	5.727900e+02	1.556700e+02	-1.40000e+01	2.272000e+03	2.28600e+03	1.52
LD	10	18807	2.740000e+00	5.000000e-01	2.800000e+00	2.670000e+00	0.000000e+00	1.60000e+00	5.200000e+00	3.60000e+00	1.75
RCalib	11	18807	1.000000e+00	0.000000e+00	1.000000e+00	1.000000e+00	0.000000e+00	1.00000e+00	1.000000e+00	0.00000e+00	NaN
RFound	12	18807	1.000000e+00	0.000000e+00	1.000000e+00	1.000000e+00	0.000000e+00	1.00000e+00	1.000000e+00	0.00000e+00	NaN
RX	13	18807	6.381200e+02	3.455000e+02	6.520000e+02	6.305000e+02	4.106800e+02	5.00000e+00	2.217000e+03	2.21200e+03	0.26
RY	14	18807	5.809900e+02	1.913600e+02	5.660000e+02	5.676600e+02	1.601200e+02	2.10000e+01	2.685000e+03	2.66400e+03	1.81
RD	15	18807	2.790000e+00	4.800000e-01	2.800000e+00	2.760000e+00	0.000000e+00	1.60000e+00	4.600000e+00	3.00000e+00	0.68
Lost*	16	18807	NaN	NA	NA	NaN	NA	Inf	-Inf	-Inf	NA

	kurtosis	se
Time[msec]	2.83	1.672900e+02
Time[Ticks]	-1.01	2.943383e+11
GazeX	-0.99	2.460000e+00
GazeY	0.30	1.160000e+00
Diameter	2.75	0.000000e+00
LCalib	NaN	0.000000e+00
LFound	NaN	0.000000e+00
LX	-0.86	2.480000e+00
LY	7.30	1.390000e+00
LD	4.91	0.000000e+00
RCalib	NaN	0.000000e+00
RFound	NaN	0.000000e+00
RX	-0.44	2.520000e+00
RY	9.91	1.400000e+00
RD	0.54	0.000000e+00
Lost*	NA	NA

As we can observe from this statistical description, the skewness of Time [Ticks] indicates that the distribution is negatively skewed and has longer left tail, which is different from other parameters that are positively skewed and have longer right tails.

In addition, Time [Ticks], GazeX, LX, and RX have negative kurtosis. This shows that there are light-tailed distributions for these parameters whereas there are heavy tailed distributions for other parameters.

Moreover, the covariance and correlational studies of these parameters of eye movement data turned out to be more interesting as shown in Table 2. The estimation shows the considerably strong relation among Time [msec] and GazeX, Time [msec] and GazeY, Time [msec] and Diameter, Time [msec] and LX, Time [msec] and LY, Time [msec] and RX, Time [msec] and RY, Time [msec] and RD.

Table 2. Correlational matrices of eye movement's parameters.

	Time[msec]	Time[Ticks]	GazeX	GazeY	Diameter	LCalib	LFound	LX	LY	LD	RCalib
Time[msec]	1.00000000	-0.66029026	0.15415280	0.22492362	0.0888467916	NA	NA	0.15285800	0.1829996666	0.01761721	NA
Time[Ticks]	-0.66029026	1.00000000	-0.09865609	-0.19125422	-0.3265164679	NA	NA	-0.10234911	-0.1185996750	-0.19505212	NA
GazeX	0.15415280	-0.09865609	1.00000000	0.25584232	-0.1176638018	NA	NA	0.99690962	0.2300376071	-0.08048627	NA
GazeY	0.22492362	-0.19125422	0.25584232	1.00000000	0.0315184678	NA	NA	0.25715417	0.9368979879	-0.01006985	NA
Diameter	0.08884679	-0.32651647	-0.11766380	0.03151847	1.0000000000	NA	NA	-0.09822186	0.0006913397	0.95200702	NA
LCalib	NA	NA	NA	NA	NA	1	NA	NA	NA	NA	NA
LFound	NA	NA	NA	NA	NA	NA	1	NA	NA	NA	NA
LX	0.15285800	-0.10234911	0.99690962	0.25715417	-0.0982218616	NA	NA	1.00000000	0.2331989388	-0.06110136	NA
LY	0.18299967	-0.11859967	0.23003761	0.93689799	0.0006913397	NA	NA	0.23319894	1.0000000000	-0.02731274	NA
LD	0.01761721	-0.19505212	-0.08048627	-0.01006985	0.9520070228	NA	NA	-0.06110136	-0.0273127371	1.00000000	NA
RCalib	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	1
RFound	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
RX	0.14785944	-0.08723055	0.99251555	0.24298003	-0.1220967346	NA	NA	0.98552076	0.2234623805	-0.08363369	NA
RY	0.22493840	-0.18560985	0.25627851	0.92810689	0.0177526664	NA	NA	0.26350449	0.9431070450	-0.02379925	NA
RD	0.15390599	-0.43000975	-0.14434733	0.07158092	0.9479186882	NA	NA	-0.12682960	0.0297627218	0.80493618	NA
Lost	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

	RFound	RX	RY	RD	Lost
Time[msec]	NA	0.14785944	0.22493840	0.15390599	NA
Time[Ticks]	NA	-0.08723055	-0.18560985	-0.43000975	NA
GazeX	NA	0.99251555	0.25627851	-0.14434733	NA
GazeY	NA	0.24298003	0.92810689	0.07158092	NA
Diameter	NA	-0.12209673	0.01775267	0.94791869	NA
LCalib	NA	NA	NA	NA	NA
LFound	NA	NA	NA	NA	NA
LX	NA	0.98552076	0.26350449	-0.12682960	NA
LY	NA	0.22346238	0.94310705	0.02976272	NA
LD	NA	-0.08363369	-0.02379925	0.80493618	NA
RCalib	NA	NA	NA	NA	NA
RFound	1	NA	NA	NA	NA
RX	NA	1.00000000	0.24248608	-0.14966574	NA
RY	NA	0.24248608	1.00000000	0.05918169	NA
RD	NA	-0.14966574	0.05918169	1.00000000	NA
Lost	NA	NA	NA	NA	1

The visualization of the existing correlations among different parameters of eye movement data in terms of correlation plot was found to be as shown below. The colors of the visualization indicate the strengths of correlation among the existing parameters of eye movement data. The blue color indicates the strongest correlation between the parameters whereas the red color indicates the weakest correlation among the parameters. The high to low color intensities for blue colors show level of correlations among the concerned parameters accordingly. The high to low color intensities for red color indicate the degree of weakness in correlation among the concerned parameters correspondingly. White color indicates nonexistent correlations among the respective parameters.

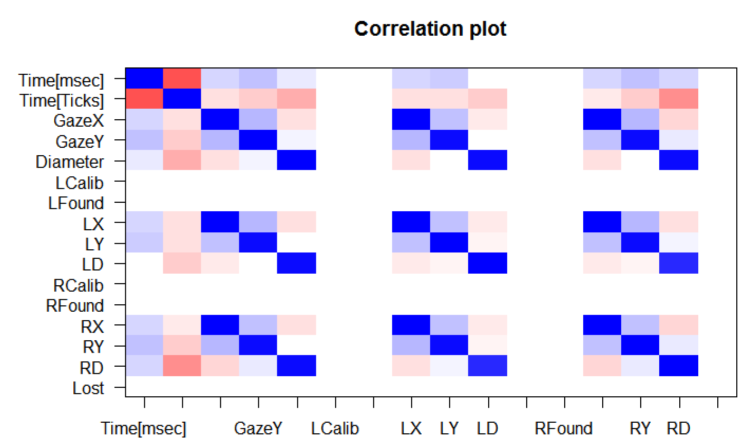

Figure 3. The correlation plot of all parameters of eye movement data.

As shown by the visualized plot of correlation, we observed that there are very strong correlations among the parameters themselves. The weakest correlations exist between Time [msec] and Time [Ticks], Time [Ticks] and RD, Diameter and Time [Ticks], LD and Time [Ticks], etc.

In addition, the most valuable result comes in the shape of moderate but considerable amount of correlations between Time[msec] and GazeX, Time[msec] and GazeY, Time[msec] and Diameter, etc. We confirm again these inferences by pairing plot of covariance among the parameters as in figure 4.

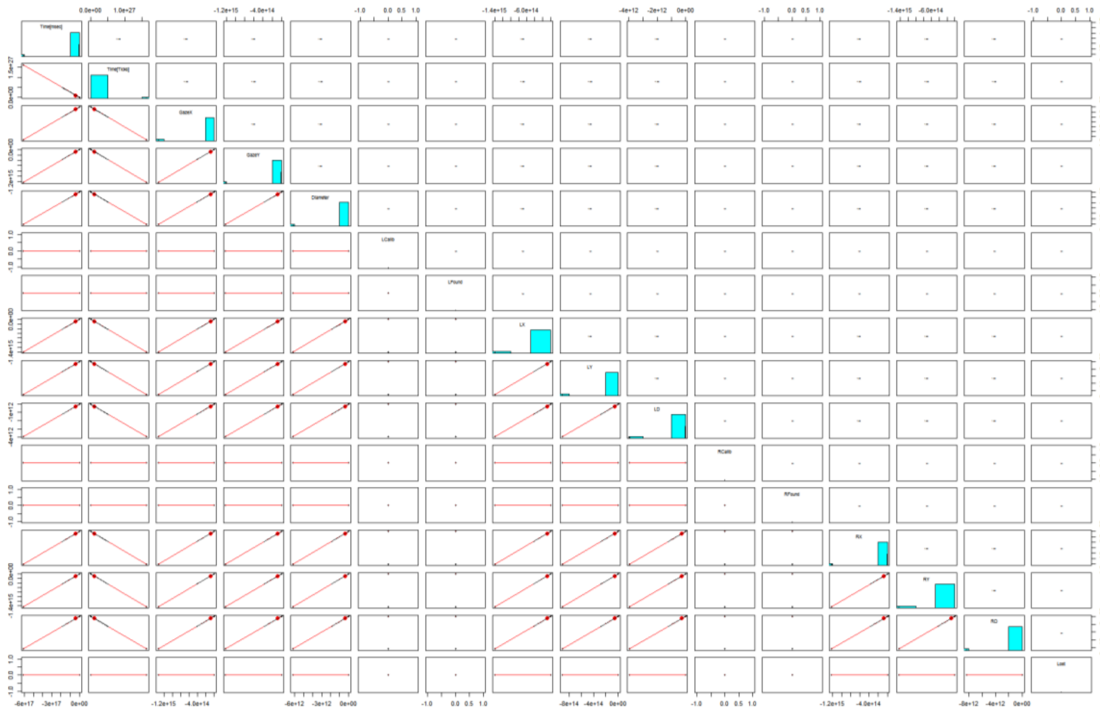

Figure 4. Covariance among the parameters in pairwise manner.

6. Data interpretation and discussion

By analyzing the eye movement data, we come across our conclusive remark that there are significant and very essential covariance and correlations among a number of parameters of eye movement data.

The existence of such correlations among the parameters leads towards our strong consideration of coexisting processes of cognitive nature during the phenomena of eye movements.

The existing strong correlation among the coordinates of gaze and time in milliseconds as well as strong correlation among left and right eye's coordinates with time in milliseconds are one of the important outcomes. This indicates that the eye gazes during the eye movements propagate with time to find and involve with the elements of the portrait. Therefore, they traversed in scan path manner to retrieve information from various elements of the portrait. The shifting of eye gazes, i.e. the gaze coordinates as well as left and right eye's coordinates with time are information seeking and are trying to see as much information as possible. That is why there is a strong correlation among these parameters.

In addition to these, we receive negative correlations among Time [Ticks] and the rest of the parameters of eye movement data. The strongest negatively correlated data exists between the parameters, time in milliseconds and the Time [Ticks]. This means that by the time flow, the Time [Ticks] decreases. As Subjects, get more visual attention and perception with time during portrait viewing, the ticks' time decreases.

The correlation between the time in milliseconds and the diameter of the gaze focus indicates that as the time moves on subsequently, the diameter of eye gaze focus increases. This shows that the focus of attention during the eye movements increases by time flow. This is obvious as the Subjects get into the focus of interest, i.e. the elements of Object (the portrait) afterwards with time.

Therefore, the existing levels of positive correlations among significant parameters and negative or nonexistent correlations among other parameters conclude that there are intermediary cognitive processes that are dependent to one another rather interrelated to one another.

Hence, the parameters for Time [msec], Diameter, LD, RD, LX, RX, LY, and RY indicating considerable to high levels of positive correlations lead us towards the understanding of coexisting processes of dependent nature during the eye movements for scene viewing.

Moreover, it must be clearly noted as well that these eye movement data came from participants of normal eye movements. Hence, the existing correlations are widely observed within the parameters of the eye movement data up to reasonable and adequate levels.

However, the outcomes for correlations and covariance among the parameters of eye movement data would be drastically different from the outcome that we visualized in this research work. As the data come from abnormal eyes by abnormal eye movements, the existence of correlation and covariance can hardly be seen among the outcomes of visualized inferences.

In addition, the evolved visual perception processes are proceeded cognitively by the mechanism of associative relevance that lies under the hood of analogical thinking. The existence of correlations and covariance among the parameters evidenced these complex but concrete mechanism of human dynamic cognition and visual perceptions.

The processes of analogical thinking and associative relevance that propel and propagate the sequential visual perception phenomena are the potential candidates and significant reasons behind these correlations and covariance that we measure and visualized in our descriptive analysis.

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