Quantitative Analysis of Relationship Between Visual Attention and Eye-Hand Coordination

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Abstract: In perception and activity tasks, continuous visual tracking of the performed activity requires continuous eye motion. Besides writing and reading, the cooperative work of eyes and hands is a key factor when drawing and at certain motions (e.g. ball catching or throwing); during the exact execution of motions, eye-hand coordination has the utmost importance. The development of eye-hand coordination plays a key role in education too, regarding several subjects, i.e. writing, drawing, technique and lifestyle, and of course, at complex motion sequences. Modern info-communication tools play an even more significant role in supporting education, where human-computer interfaces similar to the systems introduced in this paper are very significant. In this paper, by analysing certain features describing computer mouse cursor motion, examined during the execution of the Trail Making Task, what correlation is there between visual attention and eye-hand coordination. Based on the statistical correlation analysis results of data, it was determined, that the fixation parameters of eye and hand motion are in negative correlation with visual attention, while the distance between the look and the mouse cursor's motion are not correlated to each other.

Keywords: eye-hand coordination; Trial Making Task; correlation analysis

1 Introduction

In perception and activity tasks, continuous visual tracking of the performed activity requires continuous eye motion. Besides writing and reading, the cooperative work of eyes and hands is a key factor when drawing and at certain motions (e.g. ball catching or throwing); during the exact execution of motions, eye-hand coordination has the utmost importance. In education, its development in different tasks has highlighted significance regarding several subjects. Analyses related to eye-hand coordination problems play a major role in early detection and proper therapy, specification of development.

More and more studies deal with the analysis of human motion. The human motion's image-based computer observation, recording and evaluation provide several opportunities for example in the development of human-computer interfaces [1] [2], in the exploration of certain motion problems, analysis of motions [3] [4] [5], analysis of certain learning processes [6] or even in human-robot cooperation, or robot-based rehabilitation [7].

Humans are able to reach and catch target objects, despite different circumstances, even if the object's position changes. This ability is enabled by eye-hand coordination. The simultaneous studies of eye and hand motions are required to understand this behavior. For example, to continuously and precisely track a moving object or line, the appropriate eye-hand coordination is necessary. In such types of tasks, keeping the look close to the target is important; the stable retina is critical for proper control [8].

The internal process performing eye-hand coordination has a complex control, specified by the complex of cognitive abilities [9]. Eye-hand coordination is such a sensory mechanism that controls eye and hand motions as a single unit [10].

In this paper, the eye-hand coordination is analysed during the Trail Making Test. Trail Making Test is widely used to analyse neurocognitive abilities, and to test normal functions [11]. The test primarily serves as a measure of visual searching or scanning, visuospatial sequencing, although, during its execution, rapid eye-hand coordination plays a key role. [12].

The analysis of eye-hand movements was examined using the gaze and mouse fixations and average gaze mouse path distance while solving the Trail Making Task. The [13] includes the results of descriptive statistics.

2 Eye-Hand Coordination

People have very developed abilities to track and catch moving objects changing their position. This brain-controlled ability is called eye-hand coordination. Eye-hand coordination is a complex process because it includes the visual control of both eyes and hands while using eye movements to optimize vision at the same time.

Eye and hand motion analyses are performed mainly regarding fix position targets, and there are fewer studies regarding moving targets [14]. In certain studies, tracking of moving target with the eye was examined [15], whilst in others, the joint tracking of moving target with the eyes and hands [16].

Three methods are widely used to analyse human motion: passive, wearable detector and the pointer. In the case of the passive solution, the camera is placed in a fix position, usually opposite to the testing subject; thus, the image area is fix [17]. In the case of a wearable detector, the device is attached to the body, which may be even a wearable camera [18] [19] [20]. The pointer approach is based on that we look to the direction where we would like to do something. The eye-tracking method is applicable to monitor the look. In this case, two cameras attached to the head are used, the first camera returns the view seen by its user, while the other monitors the eye motion and determines the look's direction accordingly. Several manufacturers produce such devices to be worn as googles [21].

The eye-hand visual-motoric controlling system implements a closed-loop visual regulation, although such feedforward abilities are required, that help to forecast the motion's track [22]. The internal process performing the eye-hand coordination has a complex control, specified by the complex of cognitive abilities [22]. Eye-hand coordination is such a sensory mechanism that controls eye and hand motions as a single unit. The brain has first to solve the geometric transformation between the world perceived by the eyes and the body-centered world to achieve these motions. Second, the brain has to work out a plan how to reach the object and assess the motoric motion of the hand in the coordinate system relative to the body, taking the information and the hand's actual position perceived by the eyes into consideration [23]. Moreover, during the assessment of the motoric motion, the size, shape, motion, and orientation of the object to be caught must be considered.

No united theory exactly describing eye-hand coordination has been worked out yet, and it is not yet clarified either, to what extent does information stored in the memory participate in motion planning. First, according to studies, the brain uses information that is both continuous visual and stored in the memory, depending on their reliability. If continuous visual information is reliable, then the brain primarily relies on it during motion planning [24]. If the reliability of the continuous visual information is getting worse, then the brain starts using information stored in the memory to plan the motion. In the case of worse visibility, the hand motion becomes uncertain.

From the aspect of eye-hand coordination, the direction of the look's fixation is a key factor since prior to catching an object, the look is directed onto the object to be caught for a longer period [25]. Fixations are stable fixed right until catching the object; however, fixations directed to the object are no longer necessary then.

Accordingly, fixations have a triple role in motion planning:

- different fixations are necessary to map the environment and to determine the position of the object to be reached;

- based on the fixations in the right points, and their sequences, the brain is able to assess the human body's coordinate system relative to the world's coordinate system [25];
- The brain stores the position of the detected objects in the memory and the sequence of positions recorded during fixations, thus enabling motion planning depending on the task to be achieved.

3 Trial-Making Test

Trail Making Test (TMT) one of the most widely used tools of neuropsychological examinations. The goal of TMT is to check the visual attention, the processing speed, visual searching, analysis of motoric performance and fast eye-hand coordination. [26] [27] [28].

The PEBL (The Psychology Experiment Building Language) version of the test consists of three parts that must be executed as quick and accurate as possible. During the TMT-A1, 25 randomly assorted numbers must be interconnected in increasing order (1–2–3–4, etc.) (Fig. 1) and similarly with the sequence of the letters (A-B-C-D, etc.) in TMT-A2. TMT-A measures visual attention and scanning, and speed of eye-hand coordination. In the TMT-B, similarly, but the numbers (1–13) and letters (A–M) alternate sequentially (1–A–2–B–3–C, etc.) (Fig. 2). TMT-B additionally, assesses working memory and executive functions. The results of each part are determined by the TMT test solving time and errors. The test solving time expresses the result of visual attention and scanning because the errors in select next cell increase the time of solution.

The Trail-making task's PEBL version is able to run the test according to ‚retain original configuration [29], and new tests generated during each new running, although the application of automatically generated tasks is recommended since it enables partial examinations.

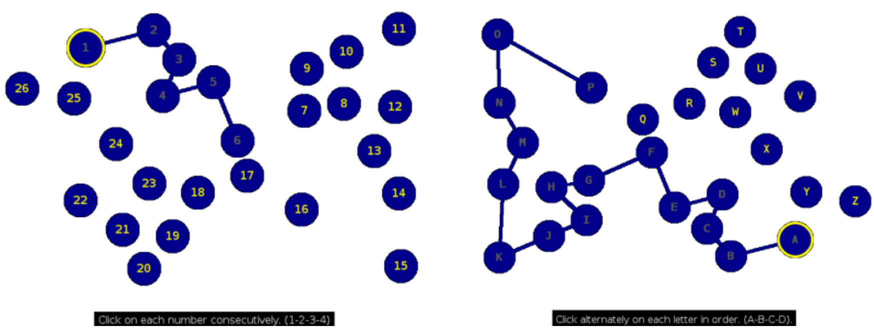

Figure 1
PEBL Trail Making Task Test A1 and A2

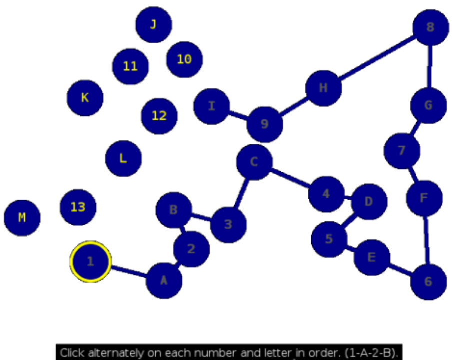

Figure 2
PEBL Trail Making Task Test B

4 Eye and Mouse Cursor Tracking

The recording of the eye movement was made using a GP3 Eye Tracker (Fig. 3), which has 0.5-1° view angle accuracy, 60 Hz sampling, and is appropriate for general research purposes. The recording and analysis of eye and mouse motion parameters were made using the OGAMA (OpenGazeAndMouseAnalyzer) software. The application records the eye and mouse cursor trail in a database and determines the specific parameters of the motion, and provides other evaluation opportunities too.

Figure 3
Gazepoint GP3 Eye Tracker

5 Methods

5.1 Participants

Eleven men and eight women participated in the TMT - Eye-hand coordination test on a voluntary basis. Their age varied between 10 and 70 years. The age and gender distribution of testing subjects are listed in Table 1.

Table 1
Participants

Age	**Number of test subjects**	
	Male	***Female***
10-20	1	1
20-30	3	2
30-40	3	2
40-50	2	1
60-70	2	2
Total	**11**	**8**

5.2 Procedures

During the performance of the PEBL Trail-making task, the eye-tracking system and OGAMA software were applied to record eye-hand coordination data (Fig. 4). During the test, using the Gazepoint Control software establishing communication with the GP3 eye tracker, and the gaze and mouse path was recorded by OGAMA software after the calibration process, thenfurther statistical analysis was performed following the tests. The eye and mouse movement was recorded separately during the three partial tests. The data analysis was carried out offline by statistical methods.

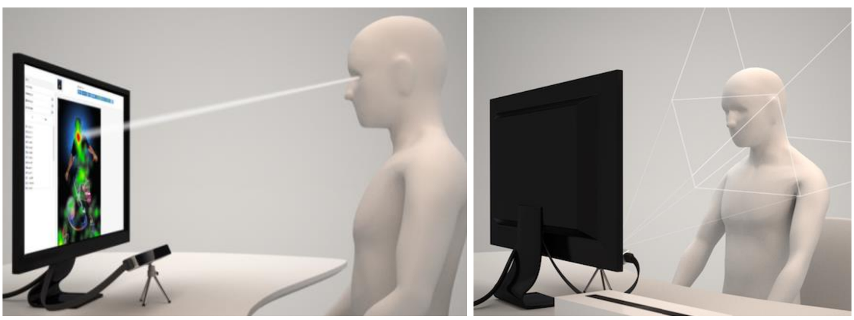

Figure 4
Eye-tracking setup [?]

5.3 Analysis

The variables: gaze fixations, average gaze mouse path distance and mouse fixations are examined because mainly, these parameters are related to eye-mouse motion features in the coordination. These parameters are the dependent and the duration time of the Trail Making Task is the independent variable. These parameters are measured at the ratio level.

The linear relationship is assumed between these examined variables and was examined by scatterplots. Scatterplot was used to plot the dots of examined variables, and then visually inspected the linearity showing the Fit Line in the scatterplots. Outliers are checked using Box plots. Normality is examined of each variable separately by Shapiro-Wilk test and Q-Q plots. In the case of a normally distributed variable, the Pearson correlation is used, if not, the nonparametric Spearman correlation is applied.

6 Results

The next chapters summarize the quantitative results of statistical correlation analysis of gaze and mouse tracking parameters while solving TMT-A1, TMT-A2 and TMT-B tests. The results of the three main steps are summarized: investigation of the linear relationship and outliers; normality test; results of Pearson or Spearman correlations.

However, it should be mentioned that OGAMA software also provides the opportunity to conduct qualitative tests, for example, attention map or scan path of gaze or mouse cursor motion (Fig. 5).

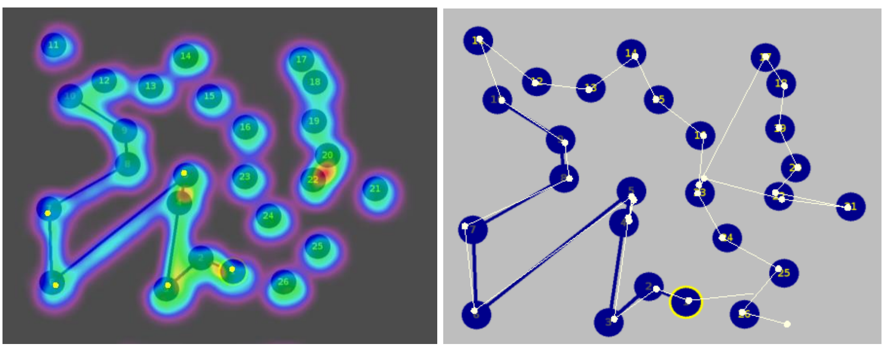

Figure 5

Example gaze attention map and scan paths of mouse cursor while solving TMT-A1 [?]

6.1 Correlation Analysis for TMT-A1 Task

6.1.1 Investigation the Linear Relationship and Outliers of TMT-A1 Task

Fig. 6 shows the scatter plots of gaze fixations count, average gaze mouse path distance and mouse fixations count. As shown in the plots, the gaze and mouse fixations counts are in a linear relationship with TMT-A1 Task solving time, but average gaze mouse path distance dots do not fit a line. According to Box plots (Fig. 7), the results of Test subject 13, 18 and 19 consists outliers (showing "*") which should, therefore, be ignored in further analysis.

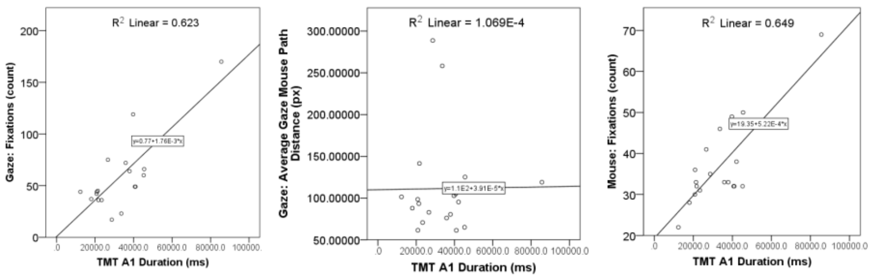

Figure 6
Scatter plot results of TMT-A1 gaze-mouse parameters

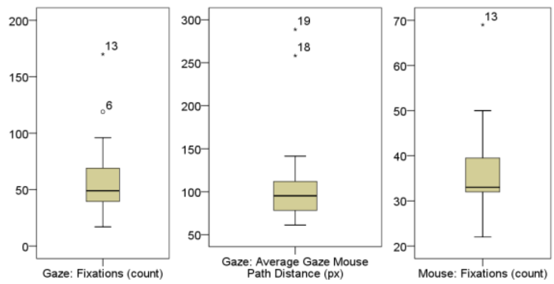

Figure 7
Box plot results of TMT-A1 gaze-mouse parameters

6.1.2 Normality Test of TMT-A1 Task

Fig. 8 shows the Q-Q plots of the examined gaze fixations count, average gaze mouse path distance and mouse fixations count parameters. The values do not fit well on the line y=x, so the normal distribution is not approximated for gaze and mouse fixations; however, it can be approximated for average gaze mouse path distance. The quantitative results in Table 2 confirm this statement because the Sig. of Shapiro-Wilk test is less than 0.05 for gaze and mouse fixations.

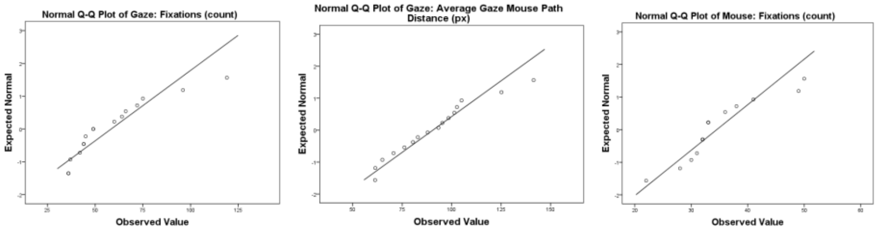

Figure 8

Q-Q plots of TMT-A1 gaze-mouse parameters

Table 2

Tests of Normality for TMT-A1 gaze-mouse parameters

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Gaze: Fixations (count)	.219	16	.039	.850	16	.014
Gaze: Average Gaze Mouse Path Distance (px)	.133	16	.200*	.945	16	.419
Mouse: Fixations (count)	.270	16	.003	.875	16	.032

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

6.1.3 Correlations of TMT-A1 Task

Based on the results of the normality test Pearson correlation is calculated for Average Gaze Mouse Path Distance, and Spearman correlation for gaze and mouse fixations while the independent variable is TMT solving duration time (Table 3).

Table 3

Correlations of TMT-A1 gaze-mouse parameters

		Gaze: Fixations (count)	Gaze: Average Gaze Mouse Path Distance (px)	Mouse: Fixations (count)
TMT Duration (ms)	Correlation Coefficient	.571*	.194	.508*
	Sig. (2-tailed)	.013	.456	.031
	N	18	17	18

*. Correlation is significant at the 0.05 level (2-tailed)

The value of correlations showing medium correlation and significant relationship for Gaze (r = .571, n = 18, p = .005) and Mouse Fixations (r = .508, n = 18, p = .005) which is statistically significant and smallweak relationship for Average Gaze Mouse Path Distance (r = .194, n = 17, p = .456).

6.2 Correlation Analysis for TMT-A2 Task

6.2.1 Investigation the Linear Relationship and Outliers of TMT-A2 Task

Fig. 9 shows the scatter plots of gaze fixations count, average gaze mouse path distance and mouse fixations count. As shown in the plots, the gaze and mouse fixations counts are in a linear relationship with TMT-A2 Task solving time, but average gaze mouse path distance dots do not fit a line. According to Box plots the results (Fig. 10) of Test subject 18 and 19 consists outliers (showing "*") which should, therefore, be ignored in further analysis.

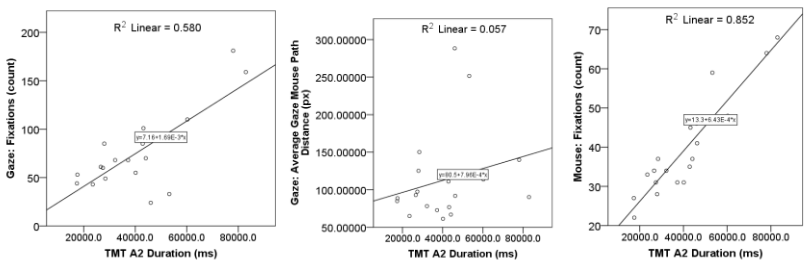

Figure 9

Scatter plot results of TMT-A2 gaze-mouse parameters

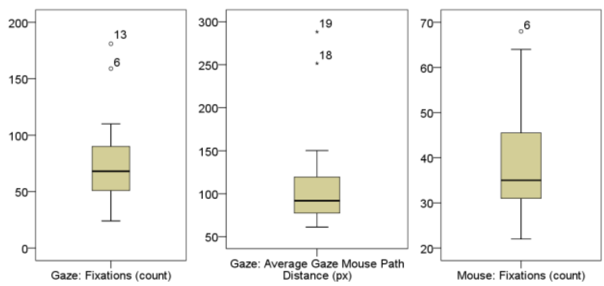

Figure 10

Box plot results of TMT-A2 gaze-mouse parameters

6.2.2 Normality Test of TMT-A2 Task

Fig. 11 shows the Q-Q plots and normal distribution is not well approximated for gaze and mouse fixations; however, it can be approximated for average gaze mouse path distance. The quantitative results in Table 4 confirm this statement because the Sig. of Shapiro-Wilk test is less than 0.05 for gaze and mouse fixations.

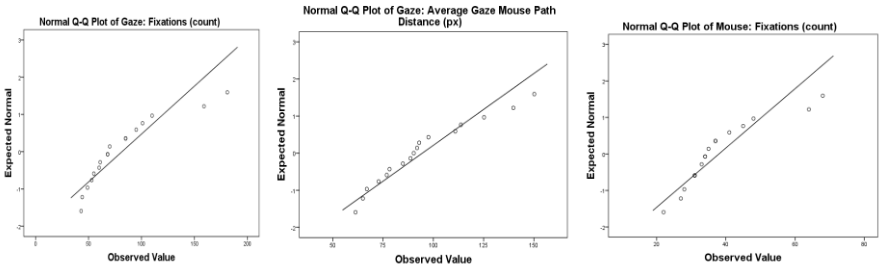

Figure 11

Q-Q plots of TMT-A2 gaze-mouse parameters

Table 4

Tests of Normality for TMT-A2 gaze-mouse parameters

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Gaze: Fixations (count)	.206	17	.055	.834	17	.006
Gaze: Average Gaze Mouse Path Distance (px)	.171	17	.198	.929	17	.211
Mouse: Fixations (count)	.238	17	.011	.848	17	.010

a. Lilliefors Significance Correction

6.2.3 Correlations of TMT-A2 Task

Based on the results of the normality test Pearson correlation is calculated for Average Gaze Mouse Path Distance, and Spearman correlation for gaze and mouse fixation while the independent variable is TMT solving duration time (Table 5).

Table 5

Correlations of TMT-A2 gaze-mouse parameters

		Gaze: Fixations (count)	Gaze: Average Gaze Mouse Path Distance (px)	Mouse: Fixations (count)
TMT Duration (ms)	Correlation Coefficient	.537*	.227	.892**
	Sig. (2-tailed)	.018	.382	.000
	N	19	17	19

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The value of correlations showing medium correlation and significant relationship for Gaze (r = .537, n = 19, p = .018) and high correlation, strong relationship for Mouse Fixations (r = .892, n = 19, p = .000) which is statistically significant and small relationship for Average Gaze Mouse Path Distance (r = .227, n = 17, p = .382).

6.3 Correlation Analysis for TMT-B Task

6.3.1 Investigation the Linear Relationship and Outliers of TMT-B Task

Fig. 12 shows the scatter plots of gaze fixations count, average gaze mouse path distance and mouse fixations count. As shown in the plots, the gaze and mouse fixations counts are in a linear relationship with B Task solving time, but average gaze mouse path distance dots do not fit a line. According to Box plots, the results (Fig. 13) of Test subject 19 consists of outliers (showing "*") which should, therefore, be ignored in further analysis.

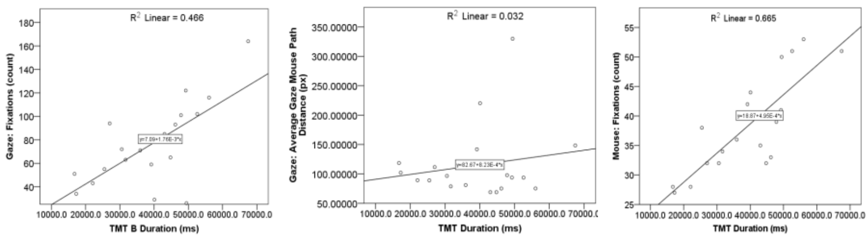

Figure 12

Scatter plot results of Trail Making Task B variables

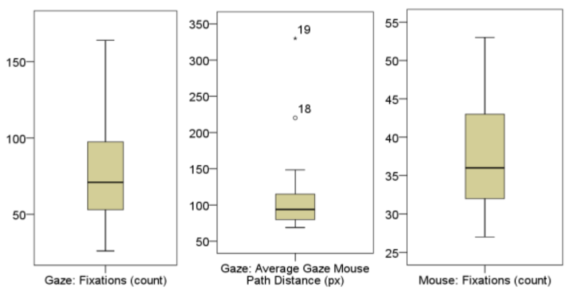

Figure 13

Box plot results of Trail Making Task B variables

6.3.2 Normality Test of TMT-B Task

Fig. 14 shows the Q-Q plots and normal distribution is approximated for gaze and mouse fixations; however, it can not be approximated for average gaze mouse path distance. The quantitative results in Table 6 confirm this statement because the Sig. of Shapiro-Wilk test is less than 0.05 for the average gaze mouse path distance.

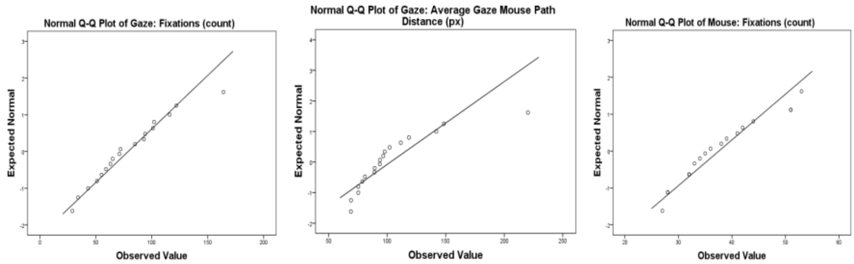

Figure 14

Q-Q plots of Trail Making Task A2 variables

Table 6

Tests of Normality for TMT-A2 gaze-mouse parameters

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Gaze: Fixations (count)	.134	18	.200*	.957	18	.548
Gaze: Average Gaze Mouse Path Distance (px)	.231	18	.012	.778	18	.001
Mouse: Fixations (count)	.132	18	.200*	.919	18	.126

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

6.3.3 Correlations of TMT-B Task

Based on the results of the normality test Spearman correlation is calculated for Average Gaze Mouse Path Distance, and Pearson correlation for gaze and mouse fixation while the independent variable is TMT solving duration time (Table 7).

Table 7

Correlations of TMT-B gaze-mouse parameters

		Gaze: Fixations (count)	Gaze: Average Gaze Mouse Path Distance (px)	Mouse: Fixations (count)
TMT Duration (ms)	Correlation Coefficient	.683**	.164	.815**
	Sig. (2-tailed)	.001	.515	.000
	N	19	18	19

**. Correlation is significant at the 0.01 level (2-tailed).

The value of correlations showing medium correlation and significant relationship for Gaze ($r = .683$, $n = 19$, $p = .001$) and high correlation, strong relationship for Mouse Fixations ($r = .815$, $n = 19$, $p = .000$) which is statistically significant and small relationship for Average Gaze Mouse Path Distance ($r = .164$, $n = 18$, $p = .515$).

7 Discussion

The rapid execution of the Trail Making Task that affected the test time and served as the independent variable of the test mainly depends on the visual attention and rapid and quick eye-hand coordination. Since the quick solution of the task depends on the visual searching, the precise and rapid motion of the look from the fixation directed onto the next target to the mouse cursor target, the test was aimed on the evaluation of this activity. In the execution of the appropriate task, the coordination of eyes and hand depends on the visual attention, search, primarily the number of the look's fixation and moving the mouse cursor into position quickly and precisely, the test primarily focused on them, to analyse the fixations as targets, and on the average distance regarding moving of the look relative to the mouse cursor. By the post-processing of eye motion and mouse cursor motion recorded during the execution of the three versions of the Trail Making Task, the aforementioned parameters were received. Based on the results, the eye movements and the mouse cursor motion's fixation number is in medium or strong relevance with the test's execution time, which was proven to be significant. Since there is an opposite relationship between the test's execution time and the level of visual attention, the fixation numbers negatively correlate with visual attention. These results refer to that by more efficient visual attention, quicker visual searching, the shorter task execution reduces the number of fixations of both eye motion and mouse cursor movement, so the look is quickly directed to the next target without recording intermediate points. In case of the distance between the look and the mouse cursor, however, a negligible correlation was experienced, meaning that the trail of the look and the mouse cursor compared to each other does not significantly depend on the visual attention level and the searching agility. Relative to the look's faster or slower motion; the mouse cursor moves in similar speed, so closer visual attention, quicker visual searching, the eye's more purposeful motion involves the quicker and more precise motion of the mouse cursor, i.e. the hand. Based on this, the agility of the eye-hand coordination is in a positive relationship with visual attention, so these factors correlate with each other. For the future, it is also appropriate to examine how age influences the results.

Conclusions

In this paper the visual attention and hand coordination was examined by analyzing certain features of eye- and computer mouse cursor motion. Based on the statistical correlation analysis results of data, it was determined, that the fixation parameters of eye and hand motion are in negative correlation with visual attention, while the distance between the look and the mouse cursor's motion are not correlated to each other. Visual attention and proper eye-hand coordination have key significance from the aspect of the proper execution of several human activities like tool usage, manual machining for example; thus the recognition of potentially occurring coordination problems, its development, reduction of problems are all important factors. The results may help to detect eye-hand coordination problems, which may be the cause of problems occurring in writing and drawing abilities, this helping to specify the necessity of eye-hand coordination development. According to the above, the development of eye-hand coordination plays a key role in education too, regarding several subjects, i.e. writing, drawing, technique and lifestyle, and of course, at complex motion sequences. Modern infocommunication tools play an even more significant role in supporting education [30]-[35], where eye-hand coordination is important factor such as gamification [36], VR based education [37]-[43] project-based teamwork [44] or other visual, interactive systems [45]-[49].

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