Investigating dynamic variables with eye movement analysis

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Abstract. The present study examines the joint function of the dynamic variables of "*duration*" and "*rate of change*". In particular, the study focuses on the investigation of the optimal range of values in the dynamic variable of rate of change, when the magnitude of changes is held constant while the variable of duration changes. Using eye movement analysis, an experiment is designed and performed. The study provides additional findings for the design of dynamic and interactive displays as it indicates crucial results for the function of fundamental design tools. Moreover, the enriched analysis of eye movement recordings demonstrates the importance of the methodology performed in cartographic research and experimentation.

Keywords: Dynamic variables, Eye movement analysis, Map perception

1. Introduction

The map as a symbolized image is a representation of selected geographical features and characteristics and their spatial relationships. The symbolized image of geographical space can be either a static representation or an animation. The essential graphic elements for the design of static maps introduced by Bertin (1967,1983) are called "*visual variables*" while the additional ones needed for animated maps introduced by DiBiase et al. (1992) are called "*dynamic variables*". According to the first approach of DiBiase et al. (1992), the list of dynamic variables consists of the variables of duration, rate of change and order. Additionally, MacEachren (1995) enriches the list of dynamic variables adding the variables of display rate, frequency and synchronization. Among the six dynamic variables, duration and order are considered to be the most important in map design (Kraak & Ormeling 2003). A full description of the definition and the function for each dynamic variable are provided by MacEachren (1995), Kraak & Ormeling (2003) and

Slocum et al. (2009). The study of fundamental design tools for animation design is crucial; many studies underline the need for further experimentation on their function (Kraak & MacEachren 1994, Xiaofang et al. 2005) and optimal limits in order to examine the way that they affect people's knowledge construction processes (Fabrikant 2005, Harrower & Fabrikant 2008).

The present study aims to enrich the existing research on the role and the function of dynamic variables in animation design, by testing the joint function of the dynamic variables of "*duration*" and "*rate of change*". The study focuses on the investigation of the optimal range of values in the dynamic variable of rate of change while the magnitude of changes is held constant and the variable of duration changes. "*Rate of change*" is defined as the ratio of the magnitude of changes in locations or attributes to the duration of the scene (DiBiase et al. 1992, Slockum et al. 2009). Therefore, changing the duration of the scene with a standard number of changes helps to establish the optimal perceived values for rate of change. The experiment is designed in accordance to eye movement analysis. The reaction of subjects is tested through eye movement recordings during free viewing conditions. Cartographic backgrounds with different levels of abstraction compose the visual scenes which become the stimuli of the experiment. In each stimulus only one change in location is depicted. The subjects perceive the map items, which change location in the map as moving objects. Hence, the feature of changing location is processed in a primary stage of vision and it is a preattentive feature.

2. Visual search in primary vision

During the process of observing a map, different visual processes occur. Knowledge on the mechanism of vision and perception can be utilized in the decision making process in cartographic symbolization. Several theories have been developed in order to explain the process of visual search during the observation of a visual scene. Many cartographic studies are based on visual search theories as they have been developed in the scientific field of psychology. A brief description about visual search theories related to map reading is presented by Michaelidou et al. (2005).

One of the most important aspects of the human visual system is the ability to recognize properties of the visual filed with one glance. The stage of vision which allows the visual processing before the attention is called "preattentive" stage and it was introduced by Neisser (1967). The features that become available during the primary stage of vision are called "*basic features*"or "*preattentive features*" (Wolfe 2000). Hence, visual attention can be said to be guided by the preattentive features (Wolfe 2005). These preattentive features *"pop-out"* during vision and are processed in a parallel stage. Mack et al. (1992) supported that preattentive feature are considered to be those basic to perception in the same way that the alphabet is basic to language. In a review study, Wolfe and Horowitz (2004) categorized the list of dominant and candidate preattentive features. Specifically, they grouped attributes by the likelihood to be processed preattentively or not (*"Undoubted"*, *"Probable"*, *"Possible"*, *"Doubtful cases"* and *"Probable non-attributes"*). They addressed the property of motion in the category of undoubted attributes, which means that a moving object on a visual scene is perceived in a parallel stage and the process of visual attention can be guided from this movement.

The element of motion is dominant in an animation map. Therefore, the theory of preattentive vision has a great impact in the process of map design. The findings of psychological studies offer crucial information on the mental processes, which occur during the observation of a cartographic background (static or animated).

3. Measurement of visual search performance in cartographic experimentation

Cartographic experimentation is considered appropriate in order to evaluate the effectiveness and the efficiency of graphic variables. Cartographic experiments bare many similarities with psychological experiments related to visual search and visual perception. Specifically, in relation to visual perception, Green (1998) suggested that *"Perception is just too complicated, so usability testing will always be required"*. In psychological experimentation studies, subjects are asked to search for a designated target in a visual scene with a specific feature among different distractors, or to execute other tasks such as object counting and texture segregation. Visual search experimentation also examines the case of free viewing observation without specific task.

The performance in visual search process can be measured through two different methodologies. The first one is the measurement of the speed and the accuracy of subject in identifying symbols (for example Lloyd 1997) while the second one is on eye movement recordings and analysis. The methodology of eye movements measurement called eye tracking, allows the recording of *"where"* a visual scene user is looking (*"point of regard"*) during the observation of a stimulus. Eye Tracking methodology and its applications have gained wide acceptance in different scientific fields (e.g. psychology, neuroscience, advertising etc). Especially, Eye Tracking has a principal role in computer interface evaluation (Brodersen et al. 2002). It is obvious that the analysis of graphical user interface (GUI) evaluation can be very useful in map design evaluation.

From the earlier studies in cartography (i.e. Jenks 1973) where eye movement analysis is used in order to examine the relationship between map reading and map design (Steinke 1987), Eye Tracking has become a widely accepted valuable method in cartographic research. Recent studies in cartographic research perform eye movement analysis to evaluate the effectiveness and the efficiency of visual variables (Garlandini & Fabrikant 2009) and the usability of cartographic animations (Opach & Nossum 2011).

4. Experimental design

An experiment has been designed in order to evaluate the joint function of the dynamic variables of “duration” and “rate of change”. More specifically, it examines the optimal range of values in the dynamic variable of rate of change while the magnitude of changes is held constant and the variable of duration changes.

4.1. Method

The methodology used for the performance of the present experimental study is eye tracking. During the observation of visual scenes, subjects' eye movements are recorded using the Viewpoint Eye Tracker® by Arrington Research. The eye tracking data are collected in the sampling frequency of 60Hz, which means that the temporal length between two successive records corresponds to approximately 16.67 msec. The spatial accuracy of the system lies between 0.25-1.00 degrees of the visual arc. A 19-inch computer monitor in the resolution of 1280×1024 pixels is used to present the visual scenes, while the distance between the subject and the stimuli monitor is 60 cm. For the detection of subject's visual center the Pupil Location Method is used. A full description of the experimental device can be found in a previous study (Krassanakis et al. 2011).

4.2. Stimuli

A blank (white image) and a cartographic background compose the visual scenes of the experiment. Each stimulus is designed in the resolution of 1280×1024 pixels, which is the same with the screen resolution of the computer monitor that is used for stimuli projection. The cartographic background (Figure 1) is a part of a topographic map. The cartographic background consists of a variety of different symbols, which represent different geographic information, such as contours, location names, transport and hydrological network. By interpreting Figure 1, it is obvious that there is remarkable difference in levels of abstraction between the blank base map and the cartographic one.

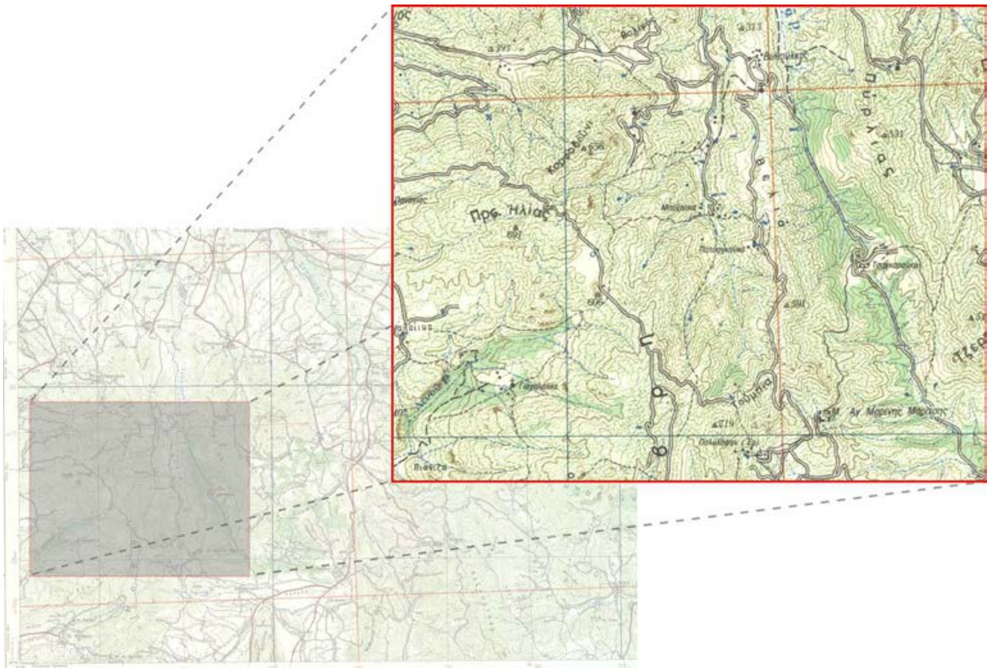

Figure 1. The cartographic background which composes one of the two base maps of the experiment.

In each stimulus (blank and cartographic), a point target with dimensions 15x15 pixels (width x height) is placed. The location of the point target changes in successive visual scenes while the background remains constant. Hence, the subjects perceive the change of the point symbol's location as a moving object. Totally, 98 different visual scenes are designed (49 visual scenes for each background). Moreover, 49 different targets' locations are selected (each target location is presented both in blank and cartographic background). The subjects' reaction is tested in different values of locations' distances, which refer to the distance in target location between two successive scenes. The different distances used for the design of stimuli can be classified in three categories: small (0-500 pixels), medium (500-1000 pixels) and large (1000-1560 pixels) distances. The experiment is performed in two parts (Part A and Part B). Each part examines different durations (t) of target's presentation in the visual scene. The target coordinates (in screen coordinate system), the successive distances selected and the duration of each target in the visual scene for each experimental part (Part A and Part B) can be seen in Table 1.

Target	X (pixels)	Y (pixels)	D (pixels)	t Part A (msec)	t Part B (msec)
T1	73	101	-	2000	700
T2	1039	743	1160	800	450
T3	270	873	780	400	300
T4	1245	86	1260	200	250
T5	932	78	300	2000	700
T6	465	455	600	600	350
T7	606	566	180	400	300
T8	1198	941	700	800	450
T9	1242	1008	80	600	350
T10	49	38	1540	200	250
T11	156	568	540	100	150
T12	1200	220	1100	2000	700
T13	861	250	340	3000	900
T14	288	864	840	600	350
T15	1221	47	1240	1000	500
T16	1252	155	100	800	450
T17	74	911	1400	100	150
T18	634	915	560	1000	500
T19	610	56	860	400	300
T20	1029	898	940	2000	700
T21	753	389	580	400	300
T22	324	489	440	800	450
T23	125	501	200	400	300
T24	1223	18	1200	600	350
T25	335	224	920	3000	900
T26	531	395	260	800	450
T27	212	950	640	3000	900
T28	1137	318	1120	200	250
T29	89	943	1220	100	150
T30	159	432	500	600	350
T31	810	741	720	2000	700
T32	1224	836	420	100	150

Table 1. The coordinates of targets, the distances between successive targets and the duration of each designed target.

Target	X (pixels)	Y (pixels)	D (pixels)	t Part A (msec)	t Part B (msec)
T33	79	179	1320	400	300
T34	329	53	280	1000	500
T35	1000	974	1140	1000	500
T36	543	392	740	200	250
T37	619	599	220	600	350
T38	448	938	380	3000	900
T39	1233	57	1180	800	450
T40	122	972	1440	100	150
T41	41	176	800	2000	700
T42	1244	612	1280	200	250
T43	77	39	1300	3000	900
T44	490	580	680	200	250
T45	1144	666	660	1000	500
T46	1025	678	120	100	150
T47	1004	644	40	3000	900
T48	1198	785	240	1000	500
T49	102	14	1340	2000	700

Table 1 (continued). The coordinates of targets, the distances between successive targets and the duration of each designed target.

Additionally, before and after the stimuli of the experiment an image with 5 fixed points (calibration image) is presented in order to test the accuracy and precision of the recording data. Subjects are asked to observe the calibration image before and after the stimuli presentation. Using the clustering algorithm fuzzy c-means, the cluster center around each fixed point, the distance between the center of the cluster and the original fixed points' coordinates and the mean distance are computed from the recording of raw data. An experiment dataset is analyzed only when the mean distance is under a maximum threshold for the observation of the calibration image before and after the stimuli projection.

4.3. Subjects

Totally 42 subjects (21 at each Part) participate in the experiment. Especially, in Part A 14 males and 7 females participate & and in Part B 12 males and 9 females participate. The subjects are volunteers, aged 19-60. Each subject is tested individually in a room of the Laboratory of Cartography of the National Technical University of Athens where the eye tracking equipment is installed. Subjects are asked to participate in an experiment while their eye movements are recorded. The experiment is performed under free viewing conditions without a specific task to complete. The instructions to the subjects refer to the observation of some stimulus in a computer monitor.

5. Results

The eye tracking protocol is analyzed with the open source software OGAMA (Voßkühler et al. 2008). The raw data of the eye tracking experiment are imported in the OGAMA software in order to compute the fixation movements in each visual scene. After testing the accuracy and the precision of the recording data, only the raw data of 32 from 42 subjects are used for the analysis. For the performance of the analysis the parameters which are selected are: 20 pixels is the maximum distance that a point can differ from the average fixation point and may still be considered as a part of the fixation, 5 points is the minimum number of samples that can be listed in a fixation and 31 pixels is the size of the buffer used to detect fixations (referred to as ring size). Moreover, for the generation of heatmap visualizations the kernel size is defined by the default value of OGAMA software.

The cases where the moving point symbol is detected and the ones that it is not are separated using the criterion of distance between the point symbol and each center of fixation clusters. In Figure 2, an example of point symbol detection and non detection in the blank and the cartographic background, is presented with the use of the heatmap visualization technique.

The fixations placed *"around"* the point symbol can be exported with the referred criterion of distance. Specifically, in each visual scene the mean and the total fixation duration around the point symbol, the total fixation duration of the visual scene, the percentage (%) between the duration around target and the total duration of visual scene, the number of fixations around target and in the total number in the visual scene and the percentage (%) between the number of fixations around target and the number of fixations in visual scene are computed. Having defined the limit of 20 pixels as distance criterion, the diagrams of detected and non-detected points produced are presented in Figure 3 for blank background and in Figure 4 for map background correspondingly. A point is characterized as non-detected when the number of fixations which are placed around it is equal to zero. In Figures 3 and 4 the limit of detected (red line in diagram) and non-detected (blue line in diagram) points are computed with the use of the convex hull area algorithm. The line of limit (black dashed line) is estimated as a middle line between the two limit lines (Figures 3 and 4).

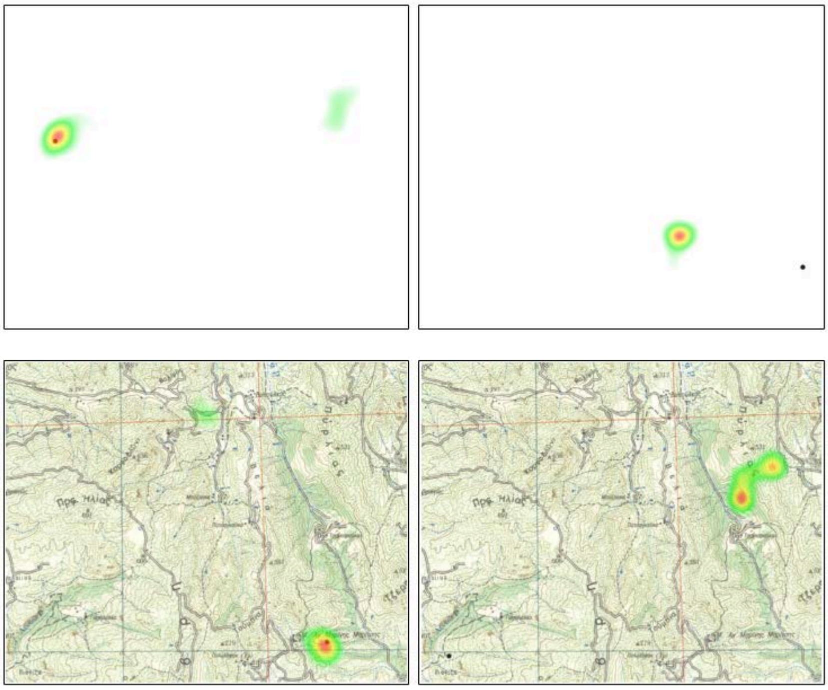

Figure 2. Heatmap visualizations in case of symbol detection (left) and symbol non detection (right).

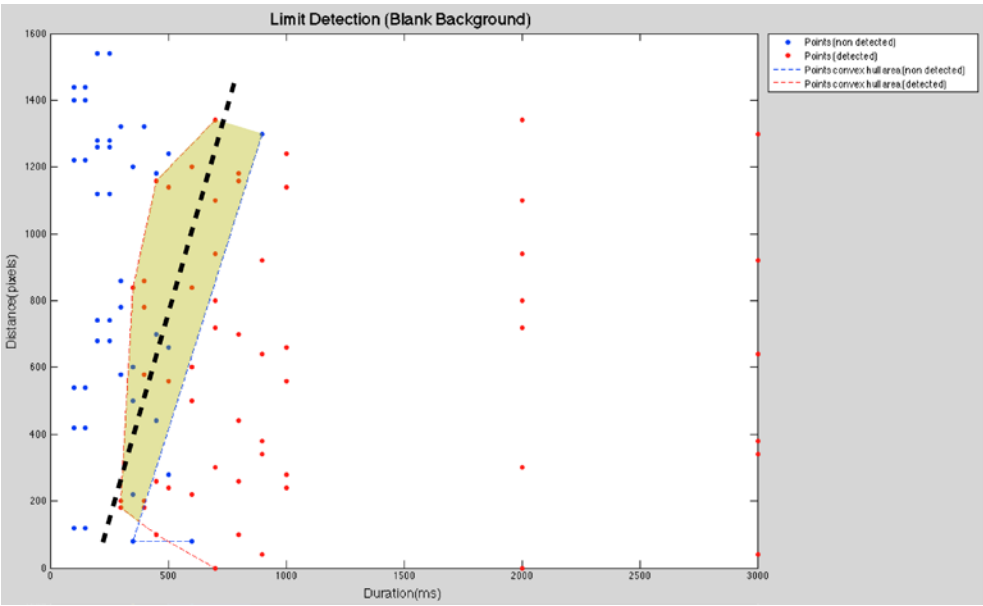

Figure 3. Detected and non-detected points in the case of blank background.

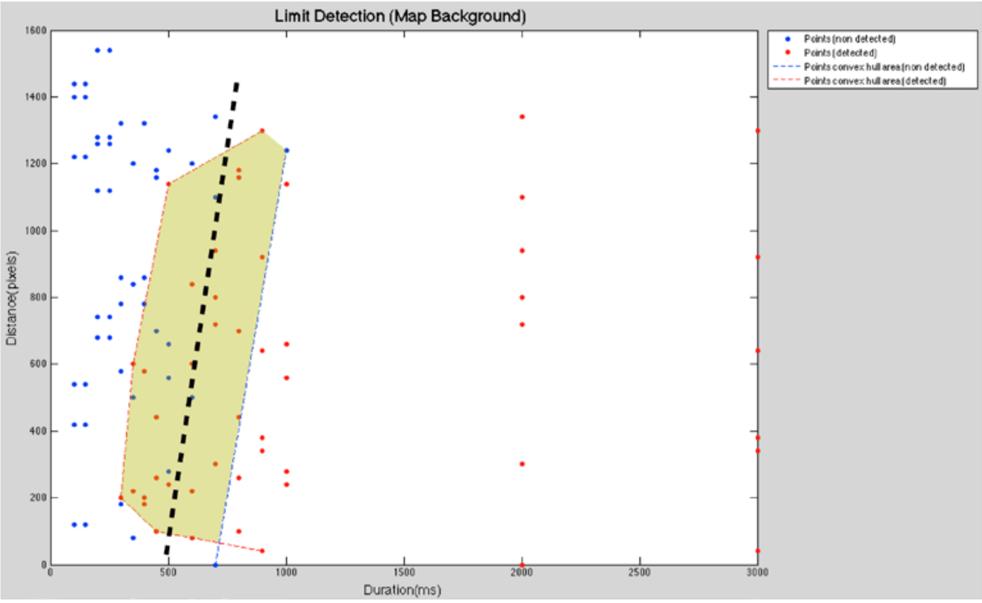

Figure 4. Detected and non-detected points in the case of map background.

As depicted in Figures 3 and 4, the relation between the duration and the distance is positive. This fact indicates that the reaction of subjects is faster when the amount of change in point symbol location is smaller and subjects perform less efficient and effective observations when the distance between the successive moving point symbols is increased. Moreover, different level of abstraction in base maps seems to affect the limit area where the two clouds of points (detected and non-detected) are separated. Specifically, in the case of cartographic background, the limit area is wider than the case of blank base map.

6. Discussion and Conclusion

The present paper describes an experiment designed and performed in order to investigate the optimum range of values of the dynamic variable of "*rate of change*" while the magnitude of changes is held constant (specifically equal to one change in position per visual scene) and the variable of duration changes. Subjects are tested under free viewing conditions while they observe a moving point symbol in a blank and a real cartographic background. The subjects' reaction is examined with eye movement recording and analysis.

The change of the position of a point symbol, while the background remains constant, can be perceived as a movement of an object of the visual scene. The element of motion is available in an early stage of vision, the preattentive stage (Wolfe & Horowitz 2004). The results of preattentive processing may influence the mental images before any activation of before knowledge and experience (Sluter 2001). It is obvious that the preattentive features have a crucial impact in map design. Ware (2004) suggests that the results of preattentive theory can be applied directly in symbol designing for information display. Examining this suggestion further, the results of preattentive processing can be used in map animation design. In an animation, motion, which is a preattentive feature, becomes a dominant element. Different values of dynamic variables can be translated as different motions of objects. The investigation of the limits in the range of dynamic variables' values has a great impact in map design. The results of the present experiment demonstrate that a limit zone can be defined so as to indicate the values of duration that a moving point symbol can be detected when it changes position in a visual scene. Moreover, the zone in the case of blank background differs in range to the corresponded zone in the case of the cartographic background. It is obvious, that the data portrayed in the cartographic map influence the reaction of the subjects so that they need additional time to respond to the physical properties of the stimuli, as is also suggested by Castner & Eastman (1984).

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