Journal of Korea Multimedia Society Vol. 18, No. 10, October 2015(pp. 1251-1260)
http://dx.doi.org/10.9717/kmms.2015.18.10.1251

Visual Attention by Screen Vectors: Independent, Continuing, Converging, and Diverging Vectors

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ABSTRACT

The measurement and evaluation of an audience's visual attention are crucial processes for the scientific production of various contents and services. It has been alleged that a vector exists between objects on a screen, but this has not been explored empirically. This study tested whether or not there are any positive correlations between screen vectors and viewers' eye movements. Participants were exposed to four groups of pictures representing an independent vector, continuing vector, converging vector, and diverging vector. The results showed that vectors on screens induced viewers' eye movements to the vector object by the directivity of the visual stimuli.

Key words: Eye Tracking; Screen Vector; Visual Perception; Screen Layout

1. INTRODUCTION

In general, vectors are viewed as physical or mathematical objects that have magnitude (i.e., length) and direction [1,2]. Often represented graphically as arrows, vectors are related to the cognition of spatial forces. The concept of vector space is important because abstract relationships such as physical processes and geometric properties can be visualized [3]. Currently, the term vector is also used for explaining computer data sets and indexing the balance of power between the graphic elements of a screen or meta data of big web site[3,4,5,6,33]. In this way, we can apply vector concept to movie and television screens. Vector in screen, or screen vector means the interaction power between visual elements in a screen.

The aesthetical composition of screens has long been considered a so called "sixth sense" area, depending on the director's personal decisions. In other words, there are principles of how to create visual content, but little research has actually tested them empirically. The intuitive method is still used for the genres of broadcasting and film making. But industry may need the method of composition to be more scientific and objective, than subjective or intuitive. That is, the motion picture industry needs to scientifically test the principles of how screen layouts could attract a viewer's attention.

Thus, this study attempts to examine a relationship between visual stimuli consisting of vectors on the screen and a viewer's perception. In this study, visual vectors are defined as a force of directivity that moves our visual attention. Screen vectors influencing a viewer's visual perception are important clues for understanding visual information processing. The aim of this research is to discover empirically how the directivity of visual vectors works for the viewer's visual attention, so

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※ This research was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean Government(NRF-2013S1A5A2A03045365)

that we can propose how to effectively compose scenes or graphics using vectors. If we have a better understanding of vectors in media production, we can use the screen space more effectively and control the screen directions. For example, the findings of this study will contribute not only to planning the placement of cameras before filming, but also to editing after shooting. Therefore, this study will enhance our understanding of staging for television or computer graphics. Furthermore, it will set forth a scientific approach to a visual communication area.

2. LITERATURE REVIEW

2.1 Visual literacy and gestalt theory

Visual literacy is the ability to understand visual images and to utilize them as a means of communicating with one another. Visual literacy can proactively operate as a device to cognitive enrichment. For example, if someone has not learned how to make visual media, they would have difficulties in creating it or managing postproduction work. Thus, novice media creators tend to use a continuous scene without much editing [7]. This suggests that some kinds of mental skills or representations are needed to improve visual literacy. This is termed “spatial intelligence” by Gardener [8], which is the process of building up mental representations of three dimensional realities for understanding the environment and interacting with it effectively.

In a two dimensional form like photography or graphic design, spatial intelligence can be tested by the understanding of basic elements of composition such as figure against its ground, focal point, frame, and lighting. Photographers, designers and producers create their work based on these elements of composition. Viewers also respond to these rules according to their visual literacy. Thus, understanding these basic principles is useful for both media creators to produce their work as intended, and media viewers to process visuals efficiently.

There are major field forces on the screen such as the main direction, vectors, psychological closure, figure and ground, asymmetry of the frame, and magnetism of the frame. Of these basic principles, the strongest force operating within the screen is a vector [6]. In addition, vectors were categorized as the most difficult ones to test empirically [9]. Thus, vectors are the main interest of this study.

2.2 Visual vectors as forces on screens

Vectors have had different usages in the research of various areas such as linguistics, engineering, the arts, and media. For the areas of linguistics and engineering, vectors are used mostly as a way of visualizing the data or phenomena to easily explain and comprehend them. For example, some cognitive linguistics researchers have tried to figure out processes in the mental space using the conceptual tools of geometry [3,10-12]. Vectors have also been studied in the areas of engineering and computer science for field visualization. The aim of scientific visualization is to display the measurements of physical quantities in order for them to be interpreted quickly and accurately [4]. Thus, the effort to evaluate existing vector visualization methods [13] has been made. Bachthaler and Weiskopf [2] built upon a technique for text based methods for vector field visualization to address the perceptual issues of animated flow visualization.

Further, vectors are still used in the engineering and computer science fields, but they are implemented to categorize or map artistic objects. For example, Gunsel, Sariel, and Icoglu [14] sought to develop a prototype system for classify paintings by using a nonlinear Support Vector Machine classifier [15] to discriminate the content of art paintings. There were two kinds of classifications, of the painter, and of art movements such as classicism, impressionism, cubism, and expressionism. Nakatani, Wang, and Nishida [16] proposed a prototype of automatic choreographic synthesis by transferring music structural elements to motion. During the process, the emotion vector in music was presented by the tempo, melody, harmony, key, rhythm, and pitch. Then, the emotion vector was programmed to map the dance motion.

In media studies, the concept of vectors is adopted using aesthetic or visual vectors, the major field forces for the composition within a screen [6]. He defines visual vectors as directional forces which move our sight from one point to another, which may be the most powerful force on the screen. Vectors on the screen include not only physical motion such as arrows, or objects in an array, but also implied vectors such as a car moving from one side to the other. The screen becomes a vector field where physical vectors, psychological vectors, and visual vectors work together.

Zettl [6] categorized three vector types, a graphic vector, an index vector, and a motion vector. A graphic vector is made of static composing elements which draw a viewer's attention with visuals such as an array of dots as lines. However, the direction of a graphic vector is vague. On the other hand, an index vector is formed by points in a specific direction. For instance, people point in a specific direction or look at a particular object. A motion vector is produced by a moving object or an object perceived as moving. A motion vector cannot be shown as a still picture. Regarding their main directions, vectors could be categorized into three types, continuing vectors (succeeding one another), converging vectors (one going against the other), and diverging vectors. Continuing vectors are created if index vectors or motion vectors are in the same direction. Converging vectors operate when index or motion vectors face toward each other, whereas diverging vectors are formed when index or motion vectors are in opposite directions.

Screens are full of various visual stimuli. Thus, the viewers must face the task of drawing pertinent meanings from those visual stimuli. This interaction between screens and viewers is a kind of psychological experience operating through the visual center of the viewers. In terms of the nature of visual perception, visual vectors with a screen, especially vector directions, are important elements which induce a viewer's attention and make the screen sensible.

2.3 Eye tracking and visual vectors

Self-reporting measures are an easy and useful way of collecting data. However, collecting perception data through self-reporting may be difficult because often people do not even realize how they perceive things, or they have some difficulty accurately describing the processes of their perception. In this respect, asking about perception is different than asking about retrospective thoughts or opinionated questions. For these reasons, this study employed an eye-tracking system to measure visual attention driven by different types of vectors.

An eye-tracking measure is an effective research tool which can answer the question of how people actually view objects. One's eye movements and eye fixations correlate strongly with one's interests and attention [17,18]. People tend to look at what attracts them, especially at what they find curious, novel, or unanticipated [19]. It is true that eye fixations do not necessarily always indicate the actual amount of cognitive effort used to process a stimulus at a spot of fixation. Nevertheless, when we pay attention to stimuli in our visual surroundings, the eye's point-of-regard is a very good index of the distribution of attention [20]. A computer system can use this information to infer the pattern of one's attention to objects displayed on screen. It can capture exact fixation frequencies and durations. Therefore, this method helps to draw meanings from actual eye movements.

The eyes move several times per second. A fixation lasts between 200 and 500 milliseconds and the rapid movements are called saccades [21]. An eye-tracking system can record three kinds of information, fixation frequency, fixation duration, and fixation sequence. Fixation frequency is the total number of fixations on a specific visual area. Fixation duration is calculated by summing the total length of fixations on a certain area of the visual field. Fixation sequence is the hierarchical order of a viewer's eye movements [7]. Fixations are usually dense in an area where high semantic or visual information is placed, and generally reflect one's cognitive strategy in perceiving visual information [22].

An eye-tracking system has been used in the studies of education and human engineering, such as a study on the visual verification of the existence and disappearance of an object [23], and on the strategies in the process of text reading [24]. In media studies, eye-tracking is also used in the studies of the information search process of the readers of advertisements [25-30], newspapers, or web pages [31-32]. In these studies, the focuses are on the readers' eye movement locations and the orders in which the readers' eyes travel according to targets of interest. Similarly, this study focuses on the relationships between the vectors of visual stimuli and visual attention. Visual vectors are one of the principles of screen composition, and this study attempts to show how they operate on visual attention by tracking eye movements.

3. HYPOTHESES AND METHODS

3.1 Hypotheses

This experiment used four types of screen vectors, independent vectors, continuing vectors, converging vectors, and diverging vectors. An independent vector consists of one single vector. A continuing vector is made of two or more independent vectors in the same direction. A converging vector operates when vectors face each other. A diverging vector is formed when vectors are in the opposite direction. Based on these conceptualizations, this study tests if any patterns exist between vector types and visual attention. In addition, the question remains that what kind of vector has a greater impact on eye movements

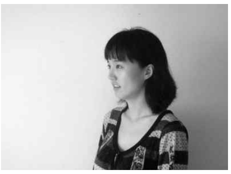


Fig. 1. S1

Fig. 2. S2.

Fig. 3. S3

Fig. 4. S4

Fig. 5. S5

Fig. 6. S6

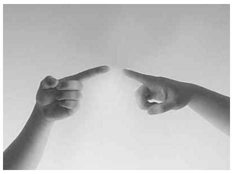


Fig. 7. S7

Fig. 8. S8

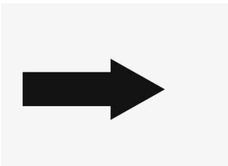
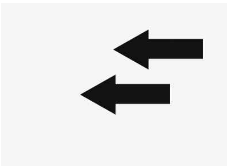


Fig. 9. S9



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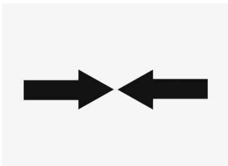

Fig. 11. S11

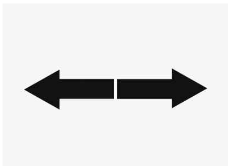

Fig. 12. S12

than the others. To investigate these questions, hypotheses are posited as follows:

H1: A participant's eyes will fix at the direction of independent vectors.

H2: A participant's eyes will fix at the direction of continuing vectors.

H3: A participant's eyes will fix at the direction of converging vectors.

H4: A participant's eyes will diversify to the directions of diverging vectors.

3.2 Participants

This study used a convenience sample. Twenty eight students were recruited from a large university in South Korea. They were aged between 19-29 (11 males and 17 females). They participated for extra credit.

3.3 Experimental Design and Materials

It was a 4 (Vectors) × 3 (Objects) within-subject design so that each participant saw 12 pictures in a row. Considering the distance between the monitor and the participants (50cm), 400×300 pixel sized stimuli were used. This is for avoiding eye fatigue from full size stimulus. Twelve pictures were taken in black and white to control other interventions like color. Each group of vectors was composed of three pictures: human sights (S1-S4), pointing fingers (S5-S8), and graphic arrows (S9-S12). The Latin-square design was employed for the stimuli.

3.4 Apparatus

Eye movements were recorded using the Tobii Eyegaze system. During data collection, the participants positioned themselves 50 cm from the screen. Small and unobtrusively hidden cameras were mounted around the computer monitor. Participants viewed the output on the computer screen after a short calibration. After suitable calibration, specific to the individual, this equipment returned the x and y screen coordinates of the screen pixel to which the participant's gaze is directed. The equipment uses cameras mounted directly below the screen to identify the relative positions of the retinal and corneal reflections of an infra-red light mounted co-axially with the optical axis of the camera. The angle of gaze was computed directly from the disparity between these two positions. Eye fixations were recorded as dots and eye movements were recorded as lines. The measuring unit of eye fixation was in milliseconds.

3.5 Procedure

Upon arrival, participants were greeted and consented to participate in this experiment. Only one subject was allowed to participate at a time. Twelve visual stimuli were presented to each participant. Each picture was presented for 7 seconds, and the slide show of all 12 pictures took 98 seconds with 2 second intervals between pictures. After watching all stimuli, the participants filled in a demographic questionnaire. They were thanked and dismissed.

3.6 Data Analysis

Although all fixation data were recorded as a text, an image, and a video file in a computer, only the particular areas of interest were determined and selected for analysis. The area of interest (AOI) was selected for two spots per stimulus, in front of the vector and behind the vector. In this study, only fixation durations were used for the analysis as the total number of milliseconds spent on the AOIs. Data were analyzed by paired-sample t-tests.

4. RESULTS

4.1 Independent vectors

Hypothesis 1 predicted that a participant's eyes would fix at the direction of the independent vec-

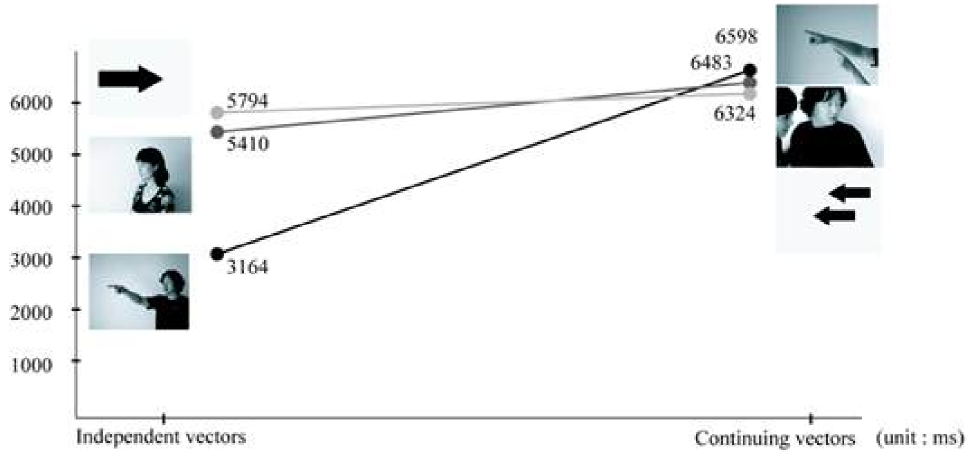

Fig. 13. Independent vectors vs Continuing vectors.

tors (e.g., a person's sight, a pointing finger, and a graphic arrow) as shown in Fig. 13. The main effect of the independent vectors showed significant results for the three types. First, the fixation duration at the location to which the human sight fixated (M= 5410.54, SD=3335.08) was much longer than on the other side (M=444.48, SD =194.36, t =11.04 , p<.001). Similarly, eye fixation was longer at the spot where a human finger (t= 5.98, p< .001) and a graphic arrow (t= 7.64, p< .001) pointed than on the other side. Three stimuli of an independent vector (human sight, a human finger, a graphic arrow) showed the same patterns. Thus, hypothesis 1 was supported.

4.2 Continuing vectors

The result of this experiment verified the hypothesis that a participant's eyes would fix at the direction of two persons' sight, fingers, and two graphic arrows (Fig. 13). A participant's eyes dwelled significantly longer at the direction of the couple's eyes (M= 6324.54, SD=2758.98) than on the other side (M=1165.21, SD=1139.74), t=9.50, p<.001. In the same way, two people' fingers (S6) and two graphical arrows (S10) also supported the continuing vectors' power, t=11.78 and t=10.06, p<.001.

4.3 Converging vectors

As predicted, the point where the couple's sight met (M=6742.50, SD=3612.49) captured visual attention longer than the other point (M=1171.31, SD=923.46), t=7.70, p<.001. The different visual stimuli (S7 and S11) had the similar results, t=10.36 and t=9.58, p<.001. People looked at the point where two forces are met. Examples are shown in fig. 14.

4.4 Diverging vectors

The mean of the directions at which each person looked (M=2653.30, SD=1173.77) was longer than the mean of the residual parts (M=1838.00, SD= 1171.31, t=3.01, p<.001). Also, both of other stimuli (S8 and S12) had the same patterns, t=6.98 and t=1.74, p<.001. However, the difference of fixation time was relatively smaller compared to the other vectors because visual attention had to be split to two directions. Stimuli are shown in Fig. 15.

5. DISCUSSION

As Figures show, the fixation duration time of two persons' sight, fingers, and graphic arrows exceeded a single person's sight, finger, and arrow. In other word, the visual vector of two objects is more powerful than that of one object. We adopted and tested Zettle's four categories of graphic

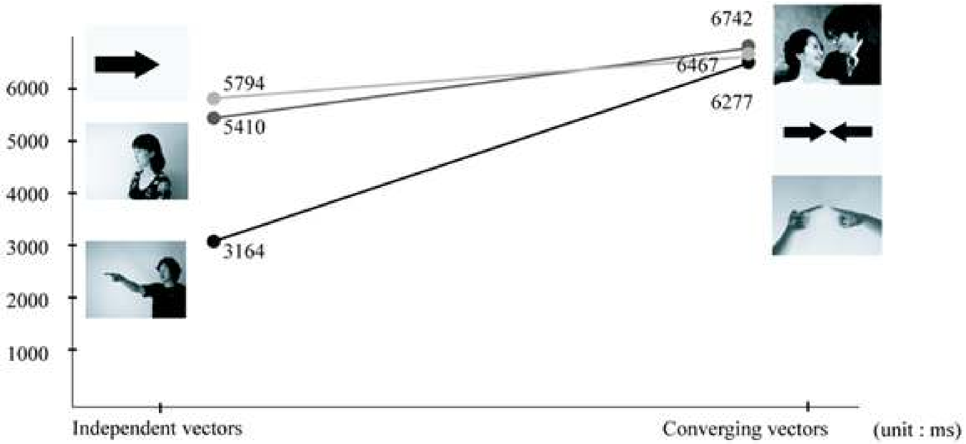

Fig. 14. Independent vectors vs Converging vectors.

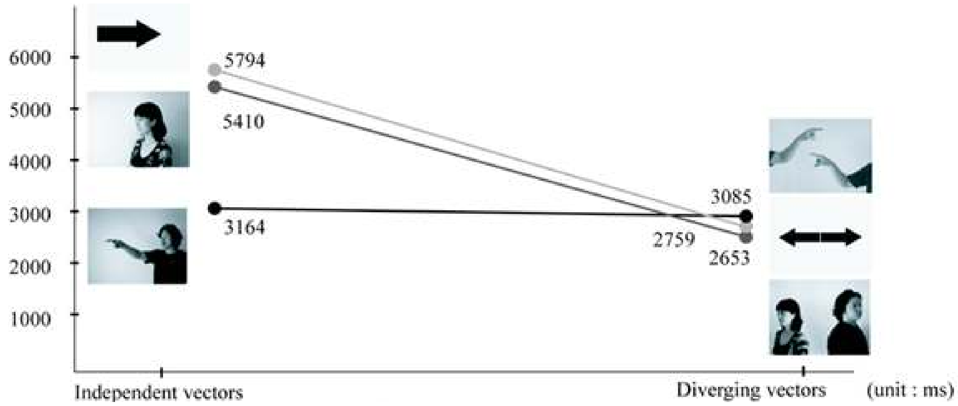

Fig. 15. Independent vectors vs Diverging verctors.

vectors. Our experiment results said that the converging vector power of two objects showed similar results. If the visual vectors of two objects converge together, they become stronger than one object. Inversely, the diverging vectors' case revealed that the vector of two distracted objects had a tendency to lose power as compared with a single object.

These findings are meaningful because to the authors' knowledge, it is the first attempt to test screen vectors. Through measuring and evaluating the audience's attention using an eye movement tracker, it revealed that vector power of the screen exists between visual objects on the screen. More importantly, this experiment found that there is a strong causality between the direction of the screen vectors and viewers' eye movements. Various screen vectors induced the viewers' eye movements to the vector object by the directivity of the visual stimuli. This research also implies that the addition and multiplication of screen vector power is possible mathematically, if we change the visual objects' directions and distance. This research can provide a scientific approach for verifying how we can set up the distance between visual objects, how we arrange the directions of the objects, and how much lead room or nose room would efficient or aesthetically seen on the screen. In this era of the prevalent wide screen, it will contribute to designing visual layouts practically.

Although this study is meant for the reasons discussed above, it has limitations. First, it would be better if there were more participants for this study even though the results were all significant. Next, the stimuli had to be as simplified as possible in order to control potential confounding variables. Thus, only still pictures were used. It will be interesting to design a study with moving pictures in the future, which will also enable the testing of motion vectors. Third, it is recommended to extend the area of vector content. Vectors can be found in music, color, and emotion [6]. It would be interesting if future research seeks to discover how audio vectors would work. With that, the vectors of both video and audio could be assessed, which will be more useful for realistic media production.

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