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The effects of functional binocular disparity on route memory in stereoscopic images

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Abstract

In this study, the effects of functional binocular disparity on route memory were experimentally verified in the context of learning of evacuation routes in disaster prevention and mitigation training. Functional binocular disparity in 3D images using cognitive characteristics such as the perspective of a specific location correlated memory in this paper. Depth maps were manipulated with the objective of assisting memorization and intuitive understanding of evacuation routes. In particular, with respect to deciding the advancing direction of the evacuation route in buildings without explicit signs, for a specific building, depth maps that could work as guide marks for the advancing route direction were manipulated to augment functional binocular parallax. In the experimental stimuli, eight locations within the building were selected to form the evacuation route, and recording was conducted using a 3D camera. The four conditions simulated in the experiment were 3D conditions using 3D images, 2D conditions using only the left image of the 3D images, adding depth map manipulation and functional binocular disparity to 2D, and placing guide marks at locations in directions that are different from the actual advancing direction to create distracted 3D conditions. 32 participants were given the route recognition task two times, once immediately after the interference task and once more after an interval of one week. The results suggest that, the participants who observed the evacuation route images modified into functional binocular disparity, remembered the correct path more easily after an interval of one week and were able to better focus their eye-gaze onto the parallax augmented locations.

1. Introduction

Reflecting the recent trends in 3D content, the International 3D Society was founded in the United States in 2011, and an affiliated committee was established in Japan in the same year. This organization, in cooperation with major companies, organizations, and universities in Japan, aims to promote healthy dissemination and development in the 3D contents market [1]. From 2015, the organization, renamed "Advanced Imaging Society", expanded its target to include content representation utilizing advanced imaging techniques such as Ultra High Definition (UHD) including 4K and 8K, VR, and HDR, in addition to 3D images technology, and started activities to disseminate and develop the market through education, training, commendation, and research. One of the commendation activities of the Japan Committee is presenting the Advanced Imaging Society Lumiere Japan Award (Lumiere Japan Award). This activity was started in 2011 with the aim to promote usage of high-quality content and encourage quality improvement, by awarding the prize to contents, produced and published in Japan using 3D or UHD technology, and adjudged to be excellent according to the society standard evaluation model devised by the Japan Committee. In particular, the attributes unique to 3D and used in evaluating 3D contents are: function, value, safety, comfort, opportunity and marketability [2].

Among them, in the "function" category, since the Great East Japan Earthquake, regarding attributes unique to 3D such as, visual effects or challenge in applying technology for new ways of expression, earthquake damage or other disaster-related contents are being highly considered and evaluated. The Great East Japan Earthquake occurred in 2011, and a documentary on damage due to tsunamis won a special award that year [3]. Further, in 2014, contents regarding protection from the threat of natural disasters such as earthquakes and landslides, or contents with disaster prevention educational elements in them, have been produced and have won awards [4]. Immediately after the earthquake, a large volume of 3D content was related to reporting on damages due to earthquake and tsunami in 3D movies, but with passage of time, the focus shifted to functional utilization of the 3D content, where more and more of the contents are now being produced on educational themes of disaster prevention or disaster risk mitigation for public viewing in natural museums or disaster-related theme parks. With increasing attention being given to the functional use of 3D movies, studies on the production methods and their effects remain insufficient, resulting in inadequate knowledge in this area. In recent years, disaster prevention education in Japan has changed considerably after the Great Hanshin-Awaji Earthquake and the Great East Japan Earthquake. Before the recent great earthquakes, focus was mainly on "once only type training" based on evacuation drills. After the great earthquake, the need to protect one's own life or help each other at the time of a disaster, has been recognized anew, and this has resulted in more emphasis being placed on practical "comprehensive survey" focusing on self help, public and mutual assistance in the community, rather than just disaster knowledge [5]-[6]. Moreover, in recent years, an earthquake with its epicenter under the Tokyo metropolitan area has been predicted, and it is becoming more important every year to remember how one should act depending on the surrounding environment in the event of a disaster. Against this background, in this study, with the aim to garner basic knowledge about functional utilization of production and presentation of 3D images, focusing on cognitive effects of functional binocular disparity, we have developed a learning tool to assist intuitive understanding of evacuation routes in the event of a disaster, and experimentally verified its effects.

2. Functional binocular disparity

Using distinctive manipulation of depth maps, the authors have been studying the effects on attraction, educational applications, attention, and memorization. In this study, based on findings thus far, functional binocular disparity in 3D images to produce specific cognitive effects, named as functional 3D in this paper, has been applied in assisting intuitive understanding and memorization of evacuation routes. Functional 3D is generated

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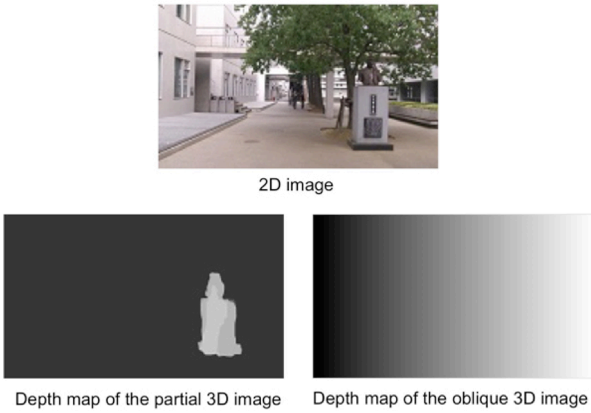

Figure 1. Depth maps of the functional 3D image were manipulated manually from 2D image

using 2D3D conversion technology, wherein the monocular depth cue in 2D images is analyzed to create depth maps, and then augmented with binocular depth cue. Depth maps are images in which depth is expressed in a gray-scale of 256 shades, and are recently being used to design depth perception of in 3D films productions. Using the size and distance at the time of viewing, the parallax angle can be calculated, and by generating a histogram of the parallax distribution in a depth map, the middle of the 3D space and the maximum value can be calculated. The parallax angle refers to the difference in the convergence angle at the point of intersection between 3D images and the display screen, and the convergence angle of an object perceived through stereoscopic viewing of images, and it is used as a parameter to evaluate the safety of 3D images [7]. Adding cross parallax to an object on the screen results in negative parallax angle, making the object appear closer to the viewer than the actual screen, whereas adding non-cross parallax results in positive parallax angle making the object appear further from the viewer than the actual screen.

To date, regarding functionality parallax, we have evaluated the cognitive effects using partial or oblique 3D. Partial 3D refers to an image converted to 3D by augmenting cross parallax to a specific area of the 2D image. To eliminate any undesired parallax at the other areas, a fixed level of non-cross parallax is augmented. Regarding the visual characteristics of the partial 3D, analysis of the measurements of a visual search task and eye movement, suggests that visual attention and the eye-gaze concentrated on the parallax augmented targets [8]. In addition, the results from the experiments on change blindness task suggest that partial 3D affects memorization [9]. Such findings suggest that in images with partial conversion to partial 3D, attention is focused on the target objects and improved retention in memory. In particular, the results show that, compared to the 2D image or normal parallax augmented 3D image, images with partial 3D conversion exhibit visual characteristics wherein attention concentrates on the target objects improving their visibility. On the other hand, oblique 3D refers to an image in which the monocular information and the tilt of the screen are represented together, by augmenting gradient type binocular parallax (oblique parallax) to the image as a whole. The results from the previous studies showed that that the participants found it easier to decide right or left turns based on the tilt direction of the direction instruction screen [10]. In this study, employing the enhancing effects of partial 3D on drawing attention, and oblique 3D on directional indication, experiments were conducted with contents to facilitate easier memorization of the evacuation route in the event of a disaster.

3. Experimental method

In the experiments, images recorded inside a building were first converted to functional 3D, and these were then used as evacuation route images to evaluate and verify the effectiveness of the contents in disaster prevention education. The participants in the experiment were shown images of the evacuation route with different parallax conditions, and under varying conditions and level of memory retention related to the correct evacuation route, locations where line of sight was concentrated, and the time difference to recognize the evacuation route, were evaluated and verified.

3.1 Presentation stimuli and conditions

In the experimental stimuli, the evacuation route adopted was not overly simple, and the School of Science and Engineering building of the University was used as the location where effectiveness of the disaster prevention contents could be evaluated and examined. Inside the building, on each floor from the first to the third, the branching points on the route were filmed using camcorders (AG-3DP1, Panasonic Corp.), and from this video recording eight 3D still images were extracted and used for stimulating 3D conditions. In 2D conditions, only the images for the left eye were selected from the 3D stimulus conditions. In functional 3D conditions, at the branching points on the routes in the 2D conditions, depth maps were manipulated and augmented at the correct advancing direction or locations of the route. In addition, distracted 3D conditions were set, by placing guide marks augmented with binocular parallax, at locations different from the correct advancing direction of the route. Figure 2 shows 2D image and three depth maps on conditions. For video stimulation in all four conditions, images obtained by 50% compression in the transverse direction were displayed by placing the right and left images in side by side format (resolution: 1920 pixel x 1080 pixel). In the experiment regarding easy memory task, participants themselves were asked to add arrow markers on stimuli images in selecting the direction of advance for the route. Table 1 shows 2D images with arrows denoting the advancing directions to right or left and depth maps on functional 3D conditions.

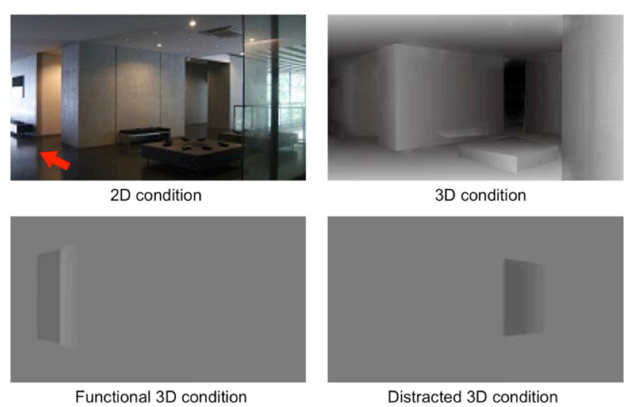

Figure 2. Depth maps of the experimental stimulus (No. 6). Evacuation route was left side of the images with a red arrow. Depth maps were manipulated and augmented left side of the image as the correct advancing direction of the route on the functional 3D condition. Depth maps were augmented right side of the image on the distracted 3D condition.

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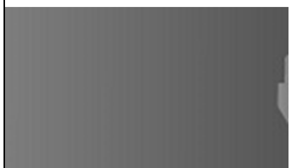
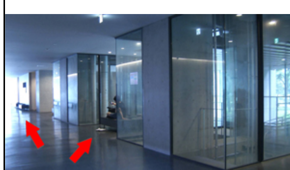
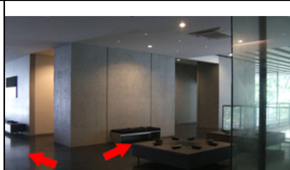
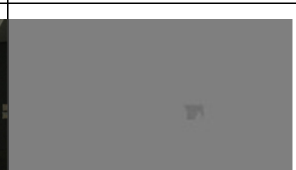
Table 1. 2D images with arrows denoting the advancing directions and depth maps of functional 3D conditions

No.	2D images	Depth maps
1		
2		
3		
4		
5		
6		
7		
8		

3.2 Procedure

The participants were asked to observe only one of the 2D/3D/functional 3D/distracted 3D conditions. The participants were allowed to choose the path they want to take by using the controller while observing the images with arrows denoting the advancing direction to right or left. The challenge was to memorize the correct route from the eight images after gaining knowledge on the correct routes. The participants observed the images without any time limit, and after they were able to memorize one, they switched to the next image using the controller buttons.

After completing the route recognition task, as an interference task, the participants were asked to perform ten multiplications of two-by-two digit numbers on a sheet of paper. The participants were informed that there was no time limit for completing the multiplication task. This was done to present the participants with a higher order interference compared to visual searching task. After that, the participants were given the first route recognition task regarding the correct route they memorized in the route. Each stimulus was presented without any arrow being shown on the images with each presentation lasting 5 seconds, after which the image automatically switched to the next one. The correct answer rate for each condition was analyzed by asking the participants to use the controller to select the correct route from memory. After completing the task, a questionnaire on the stimulation and experiment was conducted. The second route recognition task was then conducted after an interval of one week, to examine the effect on long-term memory. Considering applicability on various devices, the correct answer rate for each condition was analyzed, by checking the route on paper prints of the experimental stimuli (Figure 3).

The experiments were conducted in a dark room, and the eye-gaze measurements were performed using an eye movement measuring apparatus (PowerRef3, PlusoptiX GmbH) employing corneal reflection method. For consistency of the starting point of the eye-gaze, a white cross mark was shown on the center of the screen before presenting each stimulus image, and the participants were asked to hold their gaze on the mark at the center. The stimuli were presented on a 27 inches 3D LCD monitor (D2743P-BN, LG Electronics), with the viewing distance set to one meter. The experimental setting is shown in Figure 4.

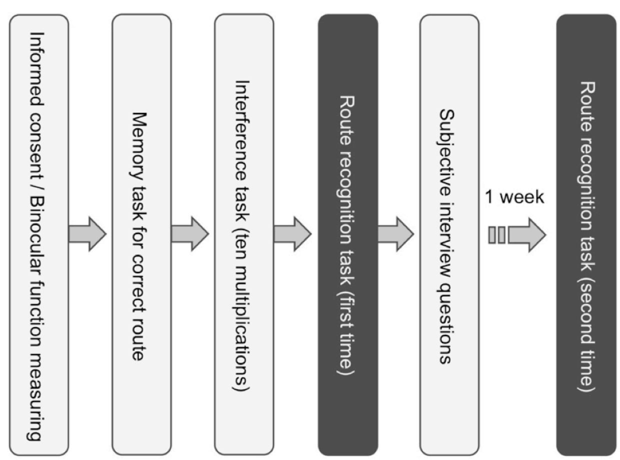


Figure 3. Experimental procedure

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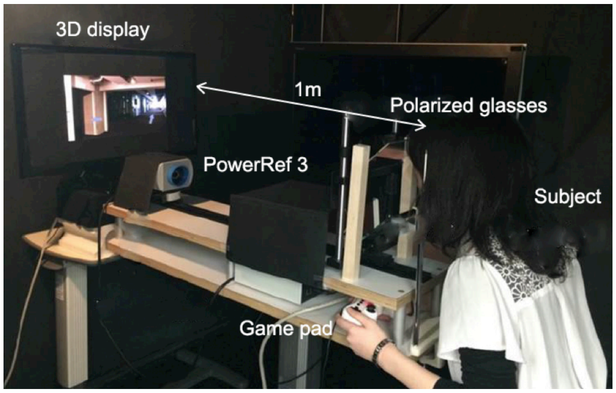


Figure 4. Experimental setting

3.3 Participants

There were healthy 32 students in total, 16 of them belonged to the School of Science and Engineering and the rest belonged to other schools (age 20.96±1 year). This was done so that the percentage of correct route selection can be analyzed in two different groups, one quite familiar with the building that the stimulus images represented (familiar group), and the other that has never been inside the building (unfamiliar group). Informed consent was obtained from the participants after explaining to them the purpose of the experiment. Prior to the experiment, stereoscopic vision of the participants was examined and all of them were found to be normal.

4. Results and Discussions

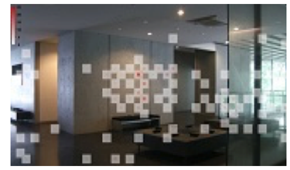
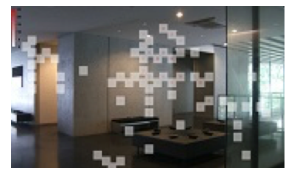
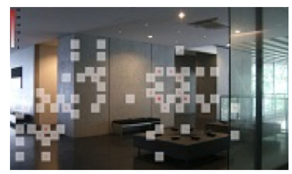
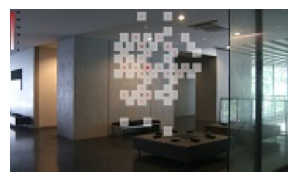
Using the data on eye movement measured by PowerRef3, the locations that the participants were gazing at were identified, and image markers were placed on the corresponding stimulus image for each condition, to compare the characteristics between different conditions. In addition, using the selection data from the controller, the correct answer rate under different conditions of route selection was evaluated and analyzed. To verify the amount of parallax in functional 3D, parallax analysis using the stereo matching method was conducted, and the percentile value of the parallax angle was derived.

4.1 Image gaze range

Among the experiment participants, using the data of eye movement for 24 participants for whom PowerRef3 measurements were possible, gaze fixation of the participants in the second experiment was recorded as the horizontal and vertical gaze angle under different conditions. The results of the analysis of the gaze location and duration were displayed as a heat map. Table 2 shows a part of the results.

As shown in Table 2, under 2D conditions the whole image was gazed at, but under 3D conditions, only locations with parallax were gazed at, and the eye fixation was focused along the route. Under functional 3D conditions or distracted 3D conditions, a tendency to gaze at an extent with augmented parallax was observed. It has also been observed that, at the time of route selection, the participants gazed at locations with augmented parallax. In the questionnaire, the participants observing functional 3D or distracted 3D conditions reported that although they were aware of the parallax, they were not consciously observing the parallax augmented locations. However, analysis of the heat map image composed from the eye movement data reveals that many of the participants gazed at extents with augmented parallax, and this suggests that functional 3D induces attraction of the eye fixation without the participants being conscious about it. The results also suggest that, in deciding the direction of the route, it is likely that the eye fixation can be induced to focus on parallax augmented locations.

Table 2. Heat map with fixation marks on the experimental stimuli (No. 6). Fixation marks turn red color from white to increasing lengths of gaze fixation.

Conditions	Heatmaps
2D	
3D	
Functional 3D	
Distracted 3D	

4.2 Parallax analysis

Percentile values were estimated from the parallax analysis of the eight images converted to functional 3D for use in the experimental stimuli. The results are shown in Table 3. Since the amount of parallax was increased in the first, fourth, and fifth images, higher percentile values for the amount of parallax for these images were obtained from the parallax analysis. For the sixth and the subsequent images, very little difference in percentile values was observed. Although, for the first, second, sixth, and seventh images very little difference in parallax percentile values was found, for the fourth and fifth images where oblique parallax was augmented, an increase in the parallax amount in the longitudinal (depth) direction was estimated.

It is thought that the parallax amount of the sixth and subsequent images was small because, as opposed to oblique 3D where the parallax is augmented to the whole image, in functional 3D parallax was augmented at specific locations in the form of partial 3D, resulting in a lower percentile value for the whole

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Table 3. Parallax angle in functional 3D conditions (degree)

No.	10%ile	50%ile	90%ile
1	0.84	0.54	0.15
2	0	0.03	-0.12
3	0	0.03	-0.27
4	1.26	0.75	0.18
5	1.02	0.6	0.12
6	0	0.03	0
7	0	0.03	0
8	0	0.03	0

image in the parallax analysis. Moreover, it was found, that as a general trend, the images with higher percentile value were the ones in which oblique parallax was augmented. It was also found that, for functional 3D conditions, more of non-cross parallax than cross-parallax was augmented. This may be due to the fact that there were fewer things inside the building, and the routes extended from near to far along the front direction. Under functional 3D conditions, where parallax was augmented to prompt selection of route direction, cross parallax was usually augmented with guide marks such as stairs and walls, but in most of the images used in this study, oblique parallax was augmented to the routes in the direction of advance, resulting in more of non-cross parallax being augmented to the images.

4.3 Correct answer rate

In this experiment, the participants were given the route recognition task two times, once immediately after the interference task and once more after an interval of one week, and from the results the correct answer rates under different conditions were calculated. The correct answer rates based on the time interval for the presentation conditions are shown in figure 5. A two-way analysis of variance was conducted for the correct answer rates by taking times and the presentation conditions as factors of consideration. As a result, the main effects of the presentation condition were recognized, and a significant difference was observed in their interaction ($p < 0.05$).

Figure 6 shows the correct answer rates under different conditions from the first route recognition task. Based on the results of analysis of variance and hypothesis tests, no significant difference between the different conditions was found, but for functional 3D condition, the correct answer rate was the highest. Based on this, we think that it is likely that functional 3D route memory is influenced by visual memory. Regarding the correct answer rate for the 2D condition being the second highest, it is likely that this is due to the experimental stimuli used in the memory task for correct route. Since in this memory task, arrows were added to the routes, but no parallax was augmented, it is likely that the participants gazed at and memorized these arrows. It was also found that for familiar group, there was no significant difference between the conditions, the correct answer rate for the 2D conditions being the highest. This may be due to the fact that, since the familiar group was very familiar with the locations where the experimental stimuli were filmed, they were able to memorize the routes irrespective of the different stimulus conditions. In contrast, for the unfamiliar group, a significant trend was observed between functional 3D and distracted 3D conditions. It is thought that this is due to the fact that, when viewing the images, the unfamiliar group, had never been to the shooting locations before and observed them for the first time in the experiment, whereas the familiar group instantly recognized the locations. When memorizing the routes, the participants, who were looking for features including minor ones, gazed at the parallax augmented locations, enabling memorization. As a result, functional 3D conditions that prompted route selection produced the highest correct answer rate, whereas distracted 3D conditions that interfered with route selection produced the lowest correct answer rate.

Figure 7 shows the correct answer rates under different conditions of the second recognition task conducted one week after the first one. Based on the results of analysis of variance and hypothesis tests, it was found that, a significant difference ($p < 0.05$) between 2D and functional 3D conditions was present, whereas a significant trend ($p < 0.10$) between 3D and functional 3D conditions was present. These results suggest that, functional 3D, in addition to prompting better route selection, enables long-term memory retention. Moreover, compared to the correct answer rate in the first route recognition task, the correct answer rate for

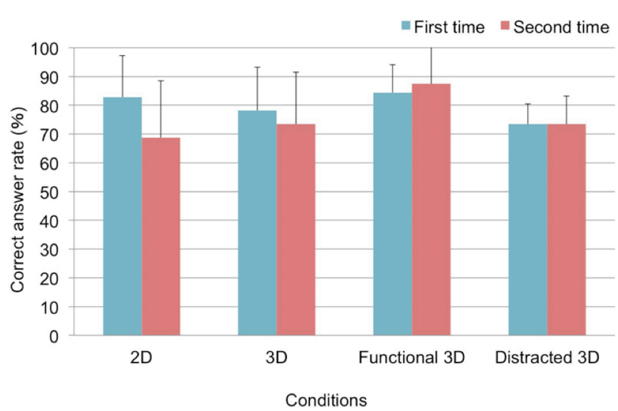

Figure 5. Correct answer rates under four conditions in the route recognition task during the time interval

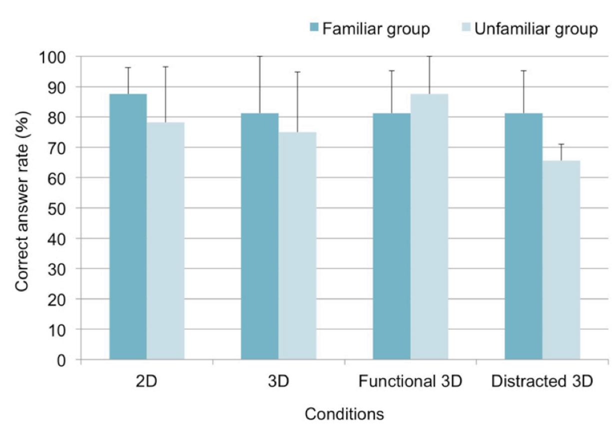

Figure 6. Correct answer rates under four conditions in the route recognition task (first time)

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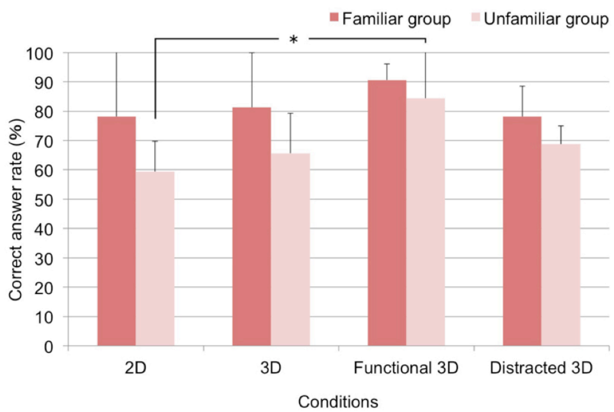

Figure 7. Correct answer rates under different conditions in the route recognition task (second time)

the 2D condition dropped significantly in the second task, most likely because binocular parallax plays an important role as a clue to retain the memory of the evacuation route over a period of one week, but since the 2D conditions had no parallax augmented, the participants could not memorize the correct evacuation route, leading to a lower correct answer rate. In contrast, regarding distracted 3D conditions, no change was observed in the correct answer rate between the first and second tasks. This suggests that it is likely that, the parallax augmented in distracted 3D conditions, was not effective in interfering with correct route selection.

No significant difference was observed between the different conditions for the participants from the School of Science and Engineering, the correct answer rate being the highest for functional 3D conditions, and the lowest for the 2D and distracted 3D conditions. We think this is due to the influence of the way of response on route selection as mentioned earlier. It may also be likely, that under 2D conditions, the participants who did not memorize the routes inadvertently selected the ones that they used almost daily. However, for unfamiliar group, significant difference was present between 2D and functional 3D conditions, and a significant trend was present between 3D and functional 3D conditions. In addition, the highest correct answer rate was obtained for functional 3D conditions. We think that this is due to the fact that the participants who gazed at the routes as correct ones retained the visual memory of these routes even after a period of one week.

5. Summary

In this experimental study, the effectiveness of disaster prevention content containing evacuation route images converted to functional 3D was evaluated and verified. For verifying the validity of the content, we conducted route recognition tasks, compared the correct answer rates, and analyzed eye movements. The results of the experiment suggest that functional 3D content is effective in increasing the attraction and improving memory retention, especially after a time interval. It is thought that this phenomenon can be attributed to the fact that organizing and augmenting of the complex configuration of parallax information found in normal 3D conditions through manipulation of the depth maps, contributed to the reduction of perception cost for attracting attention and memorization. This also suggests that this may likely be a new expression technology for making spatial information easier to remember but difficult to forget. Hereafter, applying the knowledge garnered in this study, we would like to develop functional 3D content for disaster prevention and mitigation education, with respect to evacuation guidance or mutual aid techniques in the event of a disaster. To that end, issues such as, replay of the actual route by walking along it, and the effect of multiple persons taking part at the same time, need to be studied.

Reference Preparation

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