The effect of stereoscopic viewing in a word-search task with a layered background

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Abstract — The benefits of stereoscopic viewing were explored in searching in words superimposed over a background. In the first experiment, eight participants searched for text in a normal 2-D display, a 3-D display using a parallax barrier, and a darkened 2-D display of equivalent brightness to the 3-D display. Word-search performance was significantly faster for the bright 2-D display *vs.* the 3-D display, but when brightness was controlled, performance on the 3-D display was better relative to the 2-D (dim) display. In a second experiment, the effect of floating text *vs.* sinking background disparity was assessed across four background conditions. Twenty participants saw only the floating-text (FT) condition and 20 participants saw only the sinking-background (SB) condition. Performance of the SB group was significantly better than that of FT group, and the advantage of SB disparity was greater with the more-complex backgrounds. Thus, when a parallax-barrier 3-D display is used to view text or other figural information overlaid on a background, it is proposed that the layer of primary interest (foreground) should be displayed with zero disparity (on the physical display surface) with the secondary layer (background) appearing to be sunk beneath that surface.

Keywords — *Steroscopic viewing, parallax barrier display, handheld devices, text legibility, text superimposed on background textures, transparent user interface, 3-D display.*

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1 Introduction

1.1 Motivation

In 2003, mass-produced cellular phones with stereoscopic displays showing three-dimensional (3-D) views on a 2-D surface reached the market in Japan.[a] The technologies were expected to offer the possibility of richer visual expression, greater information throughput, and richer multimedia experience by allowing designers to turn display spaces into display volumes (Fig. 1).

However, stereoscopic displays did not enter the main stream of mobile user interfaces and have subsequently disappeared from the market. One of the reasons seems to be the lack of "killer applications" which utilize the technology effectively.

The availability of the third (*z*) dimension raises a number of design issues. One fundamental question is whether the new *z*-direction should be continuous or layered (composed of discrete steps or planes). Designers can represent objects in a *x*–*y*–*z* space or can use several layers in depth. In the research reported below, we examine the properties of a two-layered 3-D display focusing on the common situation where symbolic information (*e.g.*, text) is overlaid on a background.

FIGURE 1 — The concept: Layering application information on a handheld device.

Multiple layers of information within a fixed area theoretically multiply that area by the number of layers. However, problems such as visual parallax and limited visual attention for simultaneous multi-level viewing mean that the measurable benefit of layered 3-D interaction is likely to be much less than might be predicted by simply summing the areas of the multiple layers in the display. Perception of information in layered displays is likely to be influenced by

[a]Sharp SH251iS and SH505, for NTT DoCoMo.

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perceptual factors such as occlusion and figure-ground relationships.[1]

Consistent with a tendency for closer objects to be perceived as more meaningful, information on the front-higher-closer layers is more likely to be perceived as "figure" while information in lower layers is more likely to be perceived as "ground." Based on well-established principles of visual perception, we anticipate that appropriately designed 3-D displays may increase the discriminability of information units that are competing for visual attention, by separating those units into different layers on the display and physically dissociating figure from ground. In challenging tasks such as reading text on a small display, the resulting increased discriminability of text from background should enhance performance. Consider, for instance, the problem of reading information shown on a map. Users often want to read city names, highway numbers, and other textual information situated within the surrounding context of the map. In such cases, other information such as color, and geographical features, is distracting when reading text.

Map reading is an example of a reading task where the text is overlaid on a background. In a standard map, there is no vertical (z-dimensional) separation between text and background, but this is generally manageable because of the high resolution and large display size of maps (which handle the size-portability tradeoff by being foldable). On small, handheld displays, creating separate layers of information for applications such as 3-D maps may facilitate selective attention to, and discrimination of, contrasting information (such as highways, geographic features, and place names in the case of map applications).

In considering the design opportunities afforded by multi-layered displays, a number of questions arise, such as

- How should depth and layering be used?
- Should the information appear to float above ("floating") or sink beneath ("sinking") the physical display surface?
- How much disparity (depth) should be used?
- Does the type of background affect text legibility and if so, how?
- Is there an interaction between background type and depth?

In the research study reported below, we addressed these questions, focusing on the problem of reading text that is overlaid on a background texture. We sought to demonstrate that the use of a 3-D display with text overlaid on a background (in a separate layer) does confer the expected benefit on text-reading performance. In addition we collected behavioral data to address the question of whether or not the type of disparity (positive or negative) also has an impact on performance.

1.2 Stereoscopic-display technology

There are several technologies for stereoscopic display (see technology overviews in Refs. 2 and 3).

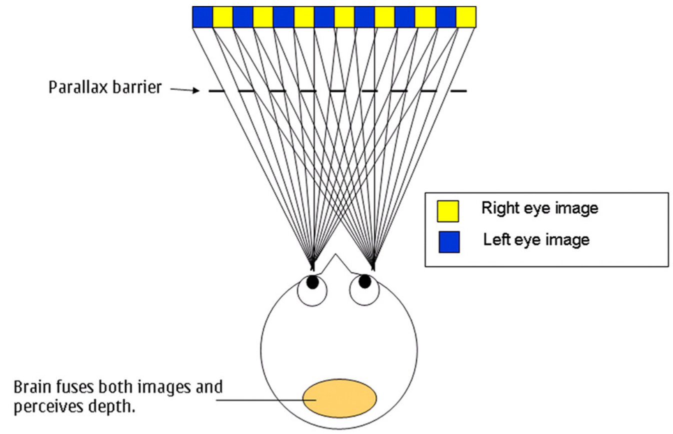

FIGURE 2 — Mechanism of the parallax-barrier display.

The anaglyph method uses spectacles with separate red and blue filters for the right and left eye. *The polarizer method* uses spectacles with filters that have orthogonally oriented linear polarizers. The display then shows the right and left images with polarization states matching the two filters. Two projectors with orthogonal polarizers may also be used in this approach or a direct-view display can be used, where every other pixel has a polarization filter that is orthogonally polarized. *The field-sequential method* shows alternating right and left images with orthogonal polarizations. Shutter glasses can also be used with polarization, provided that the left and right images are sequenced in synchrony with the shutter.

The methods listed in the preceding paragraph all require users to either wear glasses or to use other encumbering viewing aids. Autostereographic displays (*i.e.*, displays that can be viewed without aids such as specialized spectacles) are more suitable for mobile devices than other methods because they do not require users to wear or use equipment that interferes with mobility, or with perception of the surrounding environment. The *parallax barrier method* (shown in Fig. 2 and used in the 3-D displays evaluated in the research reported in this paper) is an autostereographic display that has been used in mass-marketed mobile phones because of advantages it has in terms of low cost, compatibility with high-resolution displays, and ease of switching between 2-D and 3-D modes. Using the parallax-barrier method, the contents of an ordinary 2-D display are arranged in such a way that different views (two or more) are interlaced with each other, either horizontally or in a slanted fashion. A parallax barrier is then combined with the display so that light from pixels showing right and left image data enters only the right and left eyes, respectively.

2 Previous research

2.1 Multiple-layer user interface

Human-factors research on depth/layers in displays has been carried out for a number of years. Head-up displays (HUDs), which project information directly into a human's visual field, were pioneered in aviation. Using HUDs, pilots could look at text and other information while allowing their eyes to remain pointed at the world outside the cockpit window. In these displays the HUD was a transparent and intervening layer between the pilot and the outside world.[4]

In theory, a HUD allows the user to receive multiple sources of information without changing his/her viewing direction or focus (which takes several tenths of a second to re-establish). However, eye accommodation in HUDs can be problematic.[5] In addition, multilayered information viewing in HUDs is complicated by a psychological phenomenon known as *inattentional blindness*, where there is a failure to see unattended items.[6] Haines[7] reported on a particularly dangerous example of inattentional blindness when using an HUD. In this example, experienced pilots used an HUD on an aircraft simulator. A large aircraft was placed on the runway in front of the pilots just before their simulated landing. The pilots often failed to detect the aircraft directly in front of them (in a real landing they would have crashed into it). Thus, simply placing information in a multilevel display does not guarantee that it will be seen or read.

Changing the transparency/opaqueness of a foreground layer in relation to a background layer allows the designer to manipulate the tradeoff between seeing all the information on both layers and accurately discriminating what is on the closest layer. Harrison[8] evaluated semi-transparent layered user interfaces. They examined how two overlapped layers interfered with each other through experiments based on the Stroop effect,[9] varying the transparency of the top layer. They demonstrated that there is a tradeoff between focused attention (reading one layer and ignoring the other) and divided attention (looking at information on both layers), and that this tradeoff can be manipulated by varying the amount of transparency used.

More recently, Aboelsaadat and Balakrishnan[10] compared transparency on one- and two-layered displays. They examined if physical separation of information between two (versus one) layers changes the amount of interference between foreground and background spatial stimuli. Like Harrison *et al.*, [8] they used a Stroop-like interference task. Their results showed that, for spatially overlapping stimuli, interference from the background stimuli on the perception of foreground stimuli was similar for both one- and two-layered displays, whereas interference from the foreground stimuli on the perception of the background stimuli was higher with the two-layered displays. Thus, for spatially non-overlapping stimuli, perception appears to be degraded on a two-layered display if the distracting object is placed on the front layer.

In addition to studies that have examined interference between layers in a display, there have been studies that have focused on the particular task of reading text that is superimposed on a background texture. Scharff and Ahumada[11] examined overlapped text shown as if in an HUD or shown in a see-through liquid-crystal (virtual-reality) display. They found that the amount of contrast between foreground and background was a good predictor of search times for a particular keyword embedded in text that was overlaid on background texture.

In summary, review of the prior research literature suggests that while multilayered displays may sometimes allow users to process information more efficiently by shifting visual attention quickly between layers, the displays and their content should be carefully designed to avoid problems such as inattentional blindness and interference effects between layers. Research is needed to determine how multiple-layered user interfaces should be implemented on stereoscopic displays and to examine the effectiveness of small multilayered displays when used on handheld devices.

2.2 Text legibility on 2-D and 3-D displays

Many studies have been done related to text legibility on 2-D displays. For example, Gordon *et al.* showed that lower contrast leads to reduced reading speed. Kubota[12] investigated required brightness and contrast for transmissive LCDs.

However, there has been little research on the impact of different 3-D viewing technologies on text legibility in 3-D displays. 3-D display using the parallax-barrier method generally reduces the brightness of an image by 50% or more due to the presence of the light-shielding barrier, leading to a much dimmer image being displayed. Thus, it is predicted that the benefit to text legibility of separating figure from ground in a 3-D display will be counteracted to some extent by the effect of reduced display brightness on text legibility.

In the following sections, we describe two experiments that were carried out to investigate the effect of stereoscopic viewing on text reading, using a handheld device with a parallax-barrier display. In the first experiment, we examined the effect of a parallax-barrier-enabled 3-D view as compared to both a normal 2-D view and a dimmed 2-D view. The second experiment then examined the effect of two different 3-D disparity types (floating text and sinking background) on text-search performance in 3-D.

3 Experiment 1

In this experiment, we examined the effect of relativeness brightness of the display on 2-D and 3-D visualizations of text overlaid on a background.

3.1 Purpose

The purpose of this experiment was to check if there was any advantage of stereoscopic viewing (using a parallax-barrier display) in terms of word-finding performance, relative to 2-D displays at two levels of brightness (one normal 2-D display, and one 2-D display where the brightness level was

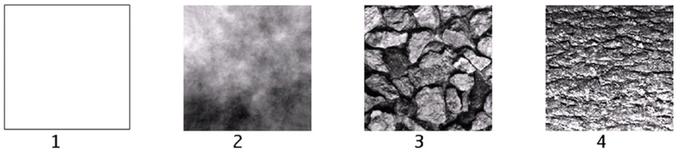

FIGURE 3 — Background images.

		Display mode	
		Normal (bright) 2D	3D
Background image	2	107.4	38.42
	3	96.9	44.45
	4	89.39	40.95

(cd/m²)

FIGURE 5 — The brightness of the display surface with different background images.

reduced so as to be comparable with a 3-D display that was dimmer due to the use of a parallax barrier).

3.2 Method

3.2.1 Participants

Eight Finnish adults (four males and four females aged from 22 to 29 years' old; mean age = 24.0 years, SD = 2.9 years) participated in the experiment with type of display and type of background being the two factors in a within-subjectss design. All participants saw both variants (bright and dim) of the 2-D display.

3.2.2 Apparatus

A Sharp SH505i device, with a parallax-barrier stereoscopic display, was used for the experiment. (The display resolution was 240 × 320, and the pixel pitch was 0.31 mm.) The text to be read was taken from the Finnish novel "Rautatie [Railway]." [b] Participants read eight screens of the extract, with the screens (pages) containing 45 words per page on average. Text was displayed in 14-point arial font, with a viewing angle of 0.62°.

Three different background images (Fig. 3) were downloaded from the Psychological Image Collection at Stirling (PICS), provided by the University of Stirling Psychology Department,[c] and were converted into a 50% level of transparency. The fourth of the backgrounds used in this experiment was a plain white background.

[b]A best-selling classic novel written by Juhani Aho, published in 1884.

[b]http://pics.psych.stir.ac.uk/.

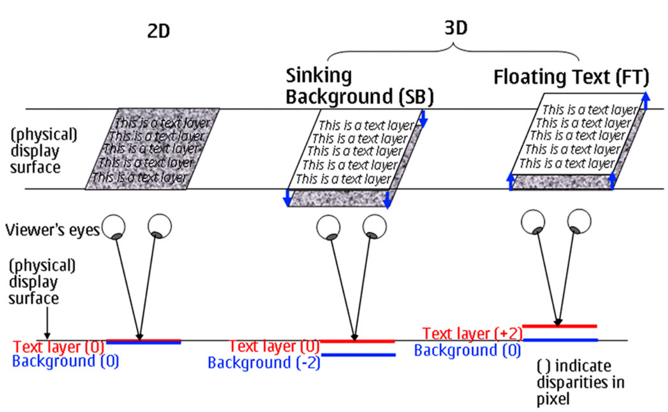

FIGURE 4 — Disparity conditions.

Three different display conditions were used in this experiment; bright 2-D, dim 2-D, and 3-D. Half the participants used an SB display in the 3-D condition and the other half used a FT display (Fig. 4). Assignment of 3-D display condition to participants was randomized.

In the bright 2-D condition, the text layer and the background layer was displayed on the same surface without disparity. The brightness of the display surface (measured by photometer) of the 3-D condition was almost half that of the normal (in this experiment, bright) 2-D condition (Fig. 5). For the dim 2-D condition, the brightness was adjusted downwards to be roughly comparable to the level of brightness of the parallax-barrier displays used in this experiment.

In the SB condition, the text layer was displayed without disparity, *i.e.*, it was shown as if on the same level as the physical display surface, and the background layer was displayed with a negative disparity of two pixels so that it appeared to be sunk under the text layer. (For an interocular distance of 65 mm, it appeared to be roughly 3.8 mm below the display surface.)

In the FT condition, the background layer was displayed on the physical display surface and the text layer was displayed with a positive disparity of two pixels so that it appeared to float over the surface of the background layer. (For an interocular distance of 65 mm, it appeared to be roughly 3.8 mm above the display surface.)

3.2.3 Task

The task was similar to that used by Scharff and Ahumada.[11] Participants read text with different backgrounds in the different disparity conditions.

There was one target word, from a list of three [ympyrä (circle)/neliö (square)/kolmio (triangle)], on each page. Participants were instructed to press the corresponding key (1, 2, or 3) to indicate which target they had seen (Fig. 6).

The target word was shown randomly in different positions in the text. Participants were instructed to find the word as quickly as possible, without guessing. Participants read eight pages of text with the order of pages viewed varying randomly between the participants. The next page was shown only after the correct key was pressed in response to viewing the previous page.

The test sessions were held in a laboratory at Helsinki University. Windows in the experiment room were shaded and the room had normal office-type fluorescent lighting (color temperature, 6500K) and the illuminance was 397 lux in the area in which the experiment was conducted. The

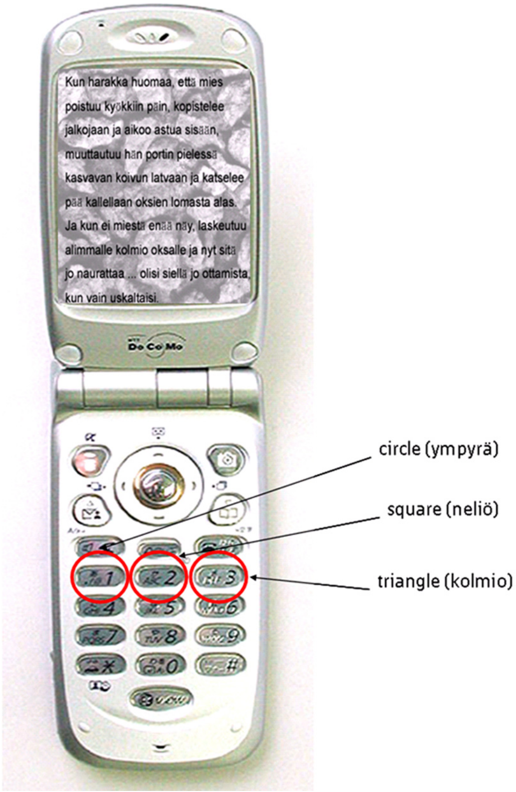

FIGURE 6 — Example image of sample text and keys.

angle and distance between the display and the participants' eyes was fixed using a chin rest. Participants sat on a chair and rested their chin on the rest, so that there was a fixed viewing distance (40 cm) and angle (25° between the line of vision and horizontal, 90° between the line of vision and the display, as shown in Fig. 7).

3.2.4 Data analysis

The search times were transformed using a natural logarithmic transformation in order to correct for the positive skew that typically occurs in reaction time data. The log transformed data were analyzed using repeated measures analysis of variance. In all the repeated measures analyses reported in this paper, degrees of freedom were adjusted

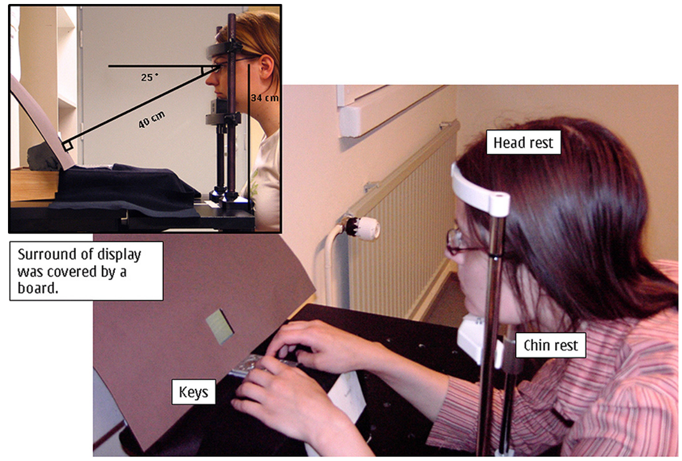

FIGURE 7 — Test setting.

using the Huyn–Feldt criterion if the Mauchly test of sphericity was significant for a given effect.

3.3 Results

There was a main effect of the display. Simple contrasts showed that on average performance on both the 3-D and the bright 2-D condition were significant faster than the dim 2-D condition ($p < 0.05$ in both cases). There was also a significant interaction between display mode and background [$F(3,21) = 3.5$, $p < 0.05$]. Since there appeared to be large individual differences in performance for the dim 2-D condition, the data for all participants and display and background conditions is plotted in Fig. 8 with one panel for each of the three display conditions. It can be seen that performance is generally worse in the dim 2-D condition for the complex backgrounds, but that individual differences are large. Performance is particularly variable for background three with half of the participants (in the dim 2-D condition) in this case having response times that are very long in the context of this experiment while the other four participants were about as fast as people were in the other conditions (bright 2-D or 3-D). As can be seen in Fig. 8, performanc in the 3-D condition was roughly comparable to the bright 2-D condition.

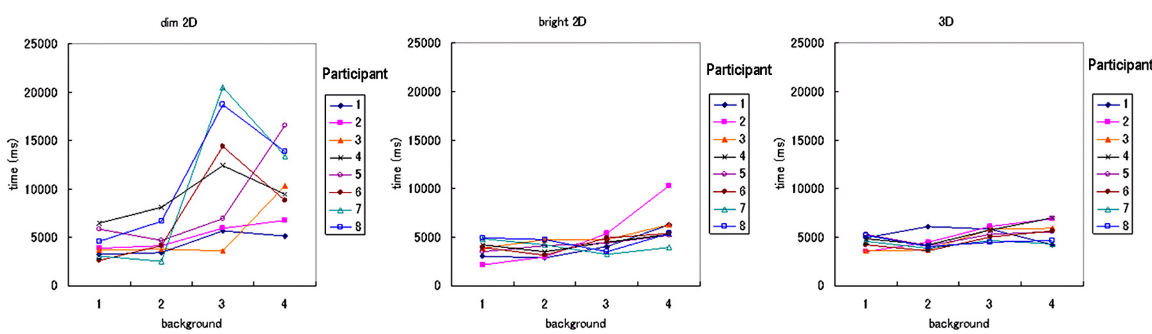

FIGURE 8 — Word-search time by individual paricipant.

4 Experiment 2

In this experiment, the effect of type of disparity (floating text *vs.* sinking background) was examined when using a parallax-barrier 3-D display for a word-search task.

4.1 Purpose

The following questions were tested in the experiment:

- Is text-reading performance better when the background appears to be in the plane of the screen with the text floating above it or when the text is in the plane of the screen with the background sunk beneath it?
- Does the effect of disparity on reading performance with overlaid text change depending on the complexity of the background?

4.2 Method

4.2.1 Participants

Forty Finnish people (20 males and 20 females, aged from 17 to 32 years old; mean age = 24.3 years, SD = 3.8 years) participated in the experiments. They were randomly divided into two groups (of 20 participants each), both of which carried out word search using a 3-D parallax barrier display. One group viewed the SB version of the display and the other group used the FT version. The participants were screened with vision tests and health questionnaires prior to the word-search task. None of the participants had severe vision impairment or any known health problems The vision tests conducted on the participants included stereo acuity, near visual acuity, far visual acuity (at a distance of 4 m), near phoria (vertical and horizontal), accommodation, convergence, and pupillary distance.

4.2.2 Apparatus, task, and procedure

The task and apparatus used were the same as for Experiment 1.

4.2.3 Design and variables

A mixed ANOVA design was used. The independent variables were disparity type (SB *vs.* FT, a between-subjects variable), and background (three textured backgrounds and a plain-white background, a within-subjects variable).

The main dependent measure in this experiment was word-search time. In addition, subjective ratings of ease of search were collected. Participants were asked how difficult it was to find target words in this condition. Participants responded to this question using a seven-point rating scale (1: very easy – 7: very difficult with 4 being neither easy nor difficult).

4.2.4 Data analysis

All search times were subjected to a natural logarithmic transformation and the transformed data were submitted to mixed-design ANOVA.

4.3 Results: Effect of disparity

4.3.1 Searching time

Figure 9 shows the mean search time for the SB and FT groups, by background.

There were significant main effects of background [$F(3,114) = 25.25$, $p < 0.001$], and disparity [$F(1,38) = 13.35$, $p < 0.001$]. There was also a significant interaction between background and disparity [$F(3,114) = 8.73$, $p < 0.01$].

The results of post-hoc t-tests showed that search times for the sinking background group were significantly shorter than those of the floating-text group for background 3 [$t(19) = –4.93$, $p < 0.001$] and for background 4 [$t(19) = –5.16$, $p < 0.001$].

4.3.2 Subjective difficulty

Figure 10 shows the mean subjective difficulty scores by SB and ST groups across the four different backgrounds. It can be seen that the general shape of the figure is similar to the previous one, with increased subjective difficulty for backgrounds 3 and 4.

There was a significant main effect of background [$F(3,114) = 47.48$, $p < 0.001$] on subjectively reported difficulty and a borderline interaction between background and disparity [$F(3,114) = 2.60$, $p = 0.056$]. The results of a post-hoc t-test showed a corresponding borderline-significant difference between SB and FT for background 4 [$t(19) = 2.03$, $p = 0.056$].

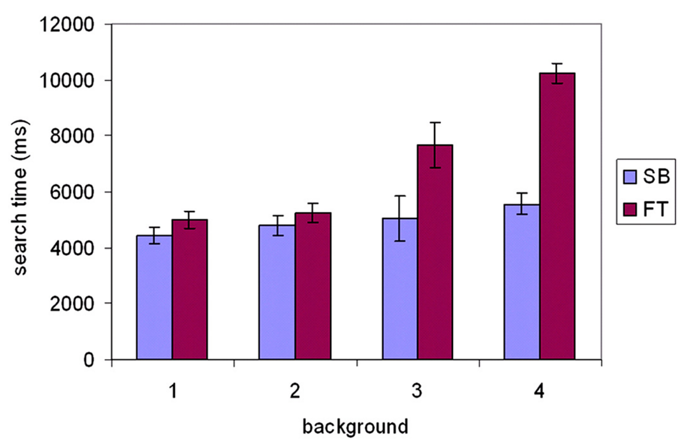

FIGURE 9 — Search time by disparity condition and background.

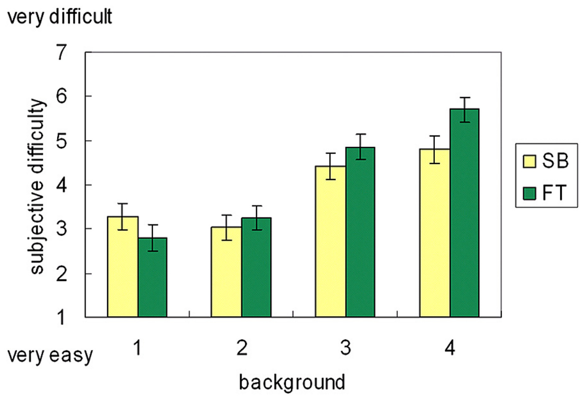

FIGURE 10 — Subjective difficulty by disparity condition and background.

4.4 Results from the post-test questionnaire

The responses to the post-test questionnaire indicated that participants generally liked the 3-D display when a suitable background was used. Eight of the participants mentioned that the 3-D view helped to bring out selected details and made it easier to read the text.

Three of the participants commented that the backgrounds looked better in the 3-D view. However, in an example of how subjective evaluation sometimes diverges from performance results, 11 of the participants stated that text reading was not a suitable application for a 3-D display, arguing that the use of the layered 3-D display was not useful in this case.

5 Discussion

5.1 Did the 3-D view improve performance?

Since the 3-D display was dimmer it was compared with two versions of the 2-D display in Experiment 1 (one with normal brightness and another with a level of brightness equivalent to that of the relatively dim 3-D display). The effect of using the dimmer 2-D display was to greatly increase the impact of individual differences in working with complex backgrounds, with some people showing relatively little slow down in word search for the dim 2-D display, while others showed considerable slowdown in word-search time when complex backgrounds were used. Post-hoc analysis revealed that the benefit of the 3-D condition was seen only for backgrounds 3 and 4, *i.e.*, with the more-complex textures.

The results of Experiment 2 showed an advantage for the SB condition, where the primary layer (*i.e.*, text layer) is on the same level as the physical display surface while the background appeared to be sunk under that layer. Since the participant's primary focus during the word-search task was presumably on the text layer, the SB condition might have been more natural because the focus was on the real display surface. In contrast, the focus was on the virtual surface in the FT condition. Based on the present results, we recommend that sinking backgrounds be used in preference to floating text for parallax barrier displays. However, further research would be needed to see if a distracting foreground floating over a figure target would lead to similar results where SB is better. If the real issue is in fact locating the target material on the surface of the screen, then a SB condition might work better if the figure being looked for was in front of the background, while an FT condition might work better if a distracting foreground was placed in front of the target material.

5.2 Reduction of brightness

Some participants noticed that the display in 3-D mode was darker than the normal 2-D mode. The effect of reduced brightness had a bigger impact on a 2-D display than it did on a 3-D display (Experiment 1).

Some recent research has proposed new techniques for improving the brightness of parallax-barrier displays (Chien *et al.*,[13]). Thus, it is possible that the brightness disadvantage may diminish in future displays with improvements in display resolution and luminance, leading to use of disparity in multilayered displays without loss in legibility due to reduction in display brightness.

5.3 What applications are suitable for stereoscopic viewing?

As mentioned by many participants, reading long and plain text might not be the best application for demonstrating an advantage of 3-D viewing. Information which becomes more valuable by being overlaid should be of interest in future studies. For example, map reading or showing a contextual menu may be well suited for stereoscopic viewing. Another application would be maintenance workers viewing annotated images of power-plant piping and valve systems on a mobile display that provided them with guidance and documentation as they performed maintenance work. While the benefits of 3-D prssentation are likely to vary from one task to another, the present studies demonstrate that reading performance for overlaid text is in fact a task that is sensitive enough to detect significant differences in display properties of the type considered here.

6 Conclusions and recommendations

We conducted two experiments to examine the time taken to find specific target words in text superimposed on background textures.

Experiment 1 was first carried out to compare the performance between the 3-D view and normal 2-D view, which is brighter than stereoscopic view. Despite of the loss of brightness, there were no large differences in word-searching time in both conditions. However, subjective difficulty was higher in the stereoscopic condition than in the 2-D condition.

Experiment 2 was carried out to assess the impact of using two different disparities in the 3-D condition. The results showed significantly better performance in both with-disparity (SB and FT) conditions versus a no-disparity (dim 2-D) control condition, especially when a relatively complex background texture was used. In addition, the SB disparity condition yielded better performance overall than the FT condition.

Based on these results, we propose the following recommendations for designing overlaid content. When a parallax-barrier 3-D display is used to view text or other figural information overlaid on a background, then the layer of primary interest (foreground) should be displayed with zero disparity (on the physical display surface) and the secondary layer (background) should be displayed with negative disparity (appearing to be sunk beneath/behind the surface of the display).

One limitation of this research is that only a small number of background displays were used. It is possible that unique properties of the particular backgrounds used may have interacted with the effects of brightness and stereoscopic viewing.

Further research is needed to clarify which levels of negative disparity work better for different participants and tasks and to examine other factors such as variations in display brightness, number of layers, and type of background. Future research should also investigate whether the recommendations concerning the use of disparity in 3-D displays need to change depending on whether the key figural information for a particular task is to be found in the foreground or the background.

Acknowledgments

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