Perception of Gradient in Haptic Graphs by Sighted and Visually Impaired Subjects

Beate Riedel & A Mike Burton
Department of Psychology
University of Glasgow
58 Hillhead St
Glasgow G12 8QB, Scotland
beate@psy.gla.ac.uk mike@psy.gla.ac.uk

Abstract

We report an experiment that presented visually impaired and sighted users with virtually rendered haptic two-line graphs of various orientations. Participants made a forced-choice decision on whether a stimulus was convergent, parallel, or divergent. The use of complex linear haptic graphs was investigated. Possible variations in performance patterns for overall two-line orientations of 0^o (vertical), 30^o, 60^o, and 90^o (horizontal) were explored in view of any haptic oblique effect. No difference between visually impaired and sighted participants was found. Overall orientation and degree of convergence showed an effect. The results are discussed in view of using force-feedback devices in data visualisation for the blind.

1. Introduction

The experiment we report here is part of a programme of work which aims to make complex graphical data more accessible to blind and visually impaired people. Elsewhere we report the results of experiments using advanced force–feedback technology (PHANToM) and 3D sound. In this paper we describe presentation of graphs which can be explored with a simple, and relatively cheap, force-feedback mouse. In previous work [6] we have shown that the WingMan force-feedback mouse can be used for accurate rendering of simple line graphs. Here we ask whether more complex graphs, and in particular the relationship between different lines on a graph, can be rendered accurately using this technology. Additionally, comparing performance of sighted and visually impaired participants would provide insight into any relevant differences between the two groups of users, if indeed present.

Most commonly, those visually impaired people who rely on tactile information acquisition will use raised paper or other custom-made materials for graph presentations (besides auditory presentation) [1]. However, producing such materials can be very laborious and time-consuming. Furthermore, the product itself often suffers from severe wear and tear following frequent handling, making it a less viable option for everyday use. Previous research has dealt both with usability and haptic interface issues of computerised renditions of graphic displays, which would alleviate portability and wear and tear issues of materials. The outcome of one of those studies showed that conventional techniques used for tactile graph representation cannot always be adopted completely [7, 8]. The current study takes a more psychological approach to testing the actual haptic linear graphs employed.

Gradient perception of tactile line displays has not been investigated extensively. One phenomenon that has been studied within this limited research topic, has been the "haptic oblique effect". Here, performance in oblique linear orientations of lines is degraded, when compared to vertical or horizontal ones [2, 3, 4]. The experiment described here made use of two-line graphs. The use of two-line graphs allowed the varying of the gradients of each individual line, thus allowing the presentation of different overall relationships between any given two lines within one stimulus. This also allowed the presentation of any two-line stimulus at varying overall gradients, ranging from the vertical (0^o) through oblique orientations (30^o and 60^o) to the horizontal (90^o). This permitted the exploration of any haptic oblique effects in this particular virtual reality set-up.

In order to make a decision about the relationship of the two lines making up a stimulus, participants were required to explore the whole stimulus (ie both lines). To do this, they had to move between the two lines comprising a stimulus and determine each line's orientation. Only following this were they able to make a decision about the overall layout of the stimulus (ie whether it was divergent, parallel or convergent). This way of exploring the virtual stimuli proves a major difference to traditional physical stimuli used for this type of information rendering. With physical stimuli, a whole hand can be used to feel both lines concurrently. This should instantly provide the information required to determine the overall relationship of the two lines. The single-point-of-contact display of the force-feedback mouse requires sequential processing of the same information provided instantly by real physical tactile displays. This could potentially mean decreased performance using such a device.

2. Experiment

2.1. Method

20 sighted participants were recruited from the student population of the University of Glasgow. 16 visually impaired participants were recruited from the Royal National College for the Blind in Hereford. All participants were right-handed. None had any known sensory or motor disabilities that might have affected their haptic perception. All received payment for their participation.

A set of virtual, haptic stimuli was presented using Logitech's WingMan force-feedback mouse. This mouse works on a 2D platform allowing the user to move on the horizontal plane. The force-feedback works through a single point of contact. The force itself consists of a minimal vibration which in turn is felt as a slight pressure against the user's hand that is in contact with the mouse. It is this force the user 'feels' while moving along a virtual stimulus giving an impression of an object (in this case a line). The mouse is used like a regular computer mouse. The only restriction with this particular model is that it is fixed onto a pad and cannot be lifted. The movement of the mouse is therefore restricted to a physical space which is 4cm x 3.5cm in size.

The virtual stimuli for use with this mouse were generated using the Immersion Studio Application (version 4.0.2) software. A set of virtual lines, two presented together, was created. All lines had the same dimensions. They varied in terms of the angle at which the two lines were presented overall and the angular relationship of these two lines towards each other (see Figure 1 for examples). There were four parallel presentations of two lines, presented at overall orientations of 0^o (vertical), 30^o, 60^o and 90^o (horizontal). Maintaining these four overall orientations as a baseline, keeping the right line at the given orientation of either 0^o, 30^o, 60^o and 90^o, the left line was varied in its gradient orientation relative to the right line. Thus, the left line was set at -15^o, -10^o, -5^o, 5^o, 10^o and 15^o respectively.

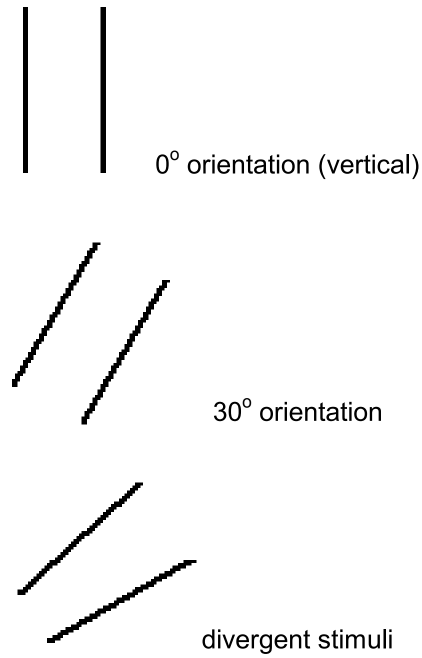

Figure 1. Examples of different overall gradient orientations of the two-line stimuli.

The lines in each two-line stimulus were positioned so that both lines remained at equal distance in regards to their centre points. This created a set of two-line stimuli which related either in a divergent (negative gradient), parallel or convergent (positive gradient) at the top or right-hand side to one another. This produced seven sets of two-line stimuli (including the parallel orientation) for each of the overall orientations. In total there were 36 different sets of two-line stimuli.

2.2. Design and Procedure

This experiment was a within-subjects design and participants were presented with four replications each of the 36 two-line virtual stimuli. Order of presentation was randomised separately for each participant. Participants' task was to explore each two-line stimulus haptically. On this occasion, the cursor of the mouse was positioned on the mid-point of the right-hand side or bottom line to start off with. Participants were asked to decide whether the two lines they had just been presented with were either convergent (at the top or right), parallel or divergent (at top or right). This was a forced-choice design and participants were informed that if they were uncertain of the orientation of the two lines towards each other, to guess. Participants were told that they could use any technique or strategy they wished to explore the stimuli and that there was no time limit involved. Sighted participants were blindfolded throughout the experiment. They were not given any feedback about their performance throughout the experiment. Participants completed the experiment in two separate sessions lasting approximately one hour each. Short breaks were provided as required throughout each session.

2.3. Results and Discussion

Figures 2 to 5 show accuracy data for judgements of convergence/divergence at the four different overall orientations. Data for the sighted and visually impaired subjects is shown separately. A 3-way mixed design ANOVA shows no main effect of subject group (sighted versus visually impaired, $F(1,34) = 2.54$, $p > 0.1$), but large effects of overall orientation ($F(3,102) = 23.9$; $p < 0.01$) and degree of convergence ($F(5,170) = 58.4$; $p < 0.01$). None of the higher-order two-way or three way interactions was significant ($F < 1.5$ in all cases).

Inspection of figures 2 to 5 shows there are no differences between visually impaired and sighted subjects, and this is confirmed in the analysis. The results of the other manipulations are equally clear. Overall performance at 15 degrees of divergence is almost at ceiling; this is the level at which most subjects are able to detect that the lines are not parallel. Performance at 5 degrees either side of parallel is essentially at chance. This provides a gauge of the sensitivity of detection of parallel lines under these conditions of haptic presentation.

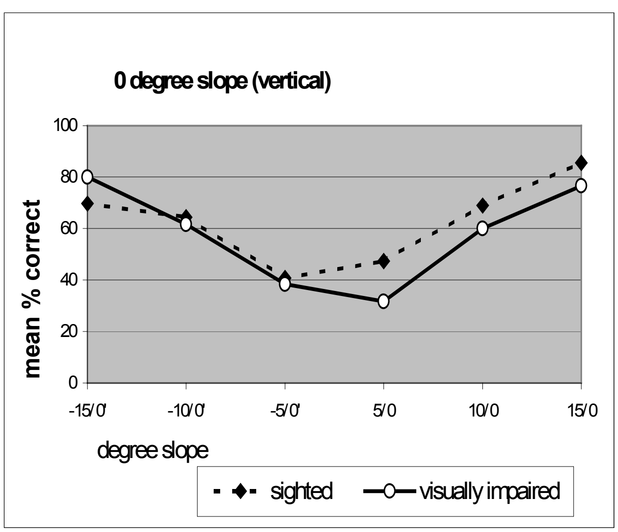

Figure 2. Results for 0° (vertical) line orientation.

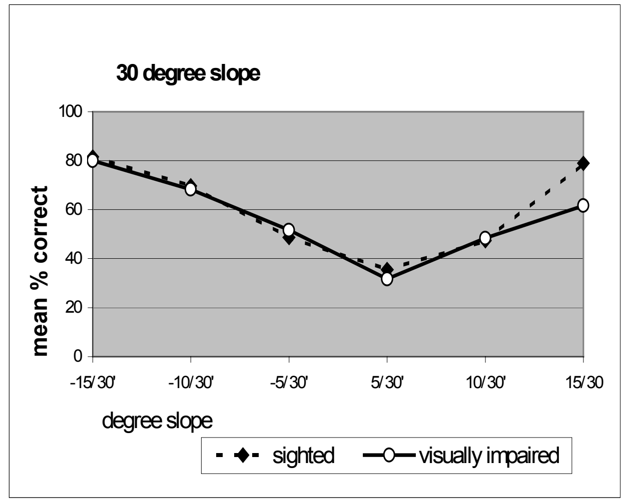

Figure 3. Results for 30° line orientation.

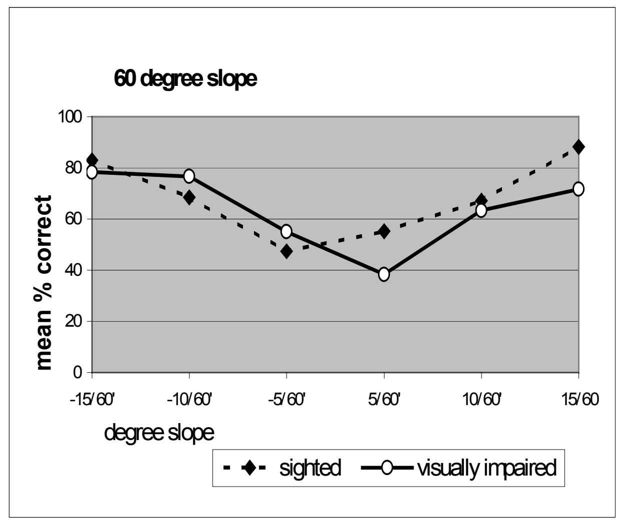

Figure 4. Results for 60° line orientation.

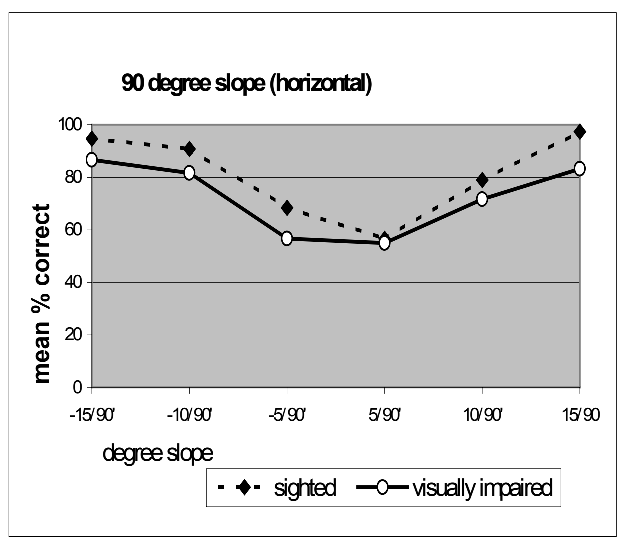

Figure 5. Results for 90° (horizontal) line orientation.

If we consider the overall effects of orientation, it is clear that subjects are progressively less accurate in performing the task as the lines range from horizontal (best performance) to vertical (worst performance). The effect of the degree of convergence is consistent across different overall orientations, meaning that the change in sensitivity to divergence is a general property of these stimuli.

The results presented here give, for the first time, a test of the sensitivity of this method of presentation. When presenting graphical data to these subjects, they are able to discriminate gradients which differ by 15 degrees, but entirely unable to discriminate divergences of 5 degrees. These limits are important for the design of computer interfaces using haptic presentation methods.

3. Conclusion

The present study shows that visually impaired and sighted users are equally good at using a virtual haptic device such as the WingMan force-feedback mouse for use with complex linear graph displays. At the same time, the results reported here provide a gauge of sensitivity for this kind of presentation: the relationship of two virtual lines and the level of relative slope participants are able to detect. A clear limitation was shown for performance at 5 degree slopes either side of parallel. Providing clear values for levels of sensitivity will help in designing computer interfaces for haptic graphs that provide the user with detectable and relevant information. The equal performance for visually impaired and sighted users does not only support the use of this type of information rendering for blind users; it supports its use for both types of users per se. Distinguishing haptic line orientation is not only important for blind users, but is relevant to virtual haptic displays in general. Thus, the findings of this study can be applied to computer interfaces that use haptic display methods in general. The use of this type of information rendering is further supported by a previous study that compared performance between physically and virtually rendered simple linear displays [6]. This found that using a force-feedback device like the WingMan mouse is a viable alternative to physically rendered stimuli for this type of information delivery.

In terms of the haptic oblique effect, performance differed from that generally found with physical stimuli. The current results show a clear advantage for horizontal line orientations overall, with the worst performance for vertical orientations. Although performance in the oblique orientations was worse than for horizontal ones, no explanation can currently be given to explain the degraded performance for vertical orientation. This will have to be investigated further to draw any clear conclusions, since the method of presentation differed greatly from studies on the haptic oblique effect that used physical stimuli.

Mostly, this study shows that visually impaired people perform equally well to sighted users. This encourages the use of such technology for information rendering for blind people in particular, as well as their use for haptic displays for the general user. Overall, the potential to make statistical information, such as contained in graphs, more accessible to blind people, is clearly given.

4. Acknowledgements

The authors would like to thank Dr Wai Yu for his help in setting up the experiment, as well as Prof Stephen Brewster for his helpful comments. Further thanks go to Shirley Evans and all the students who helped so immensely at the Royal National College for the Blind in Hereford, England. This research work is funded by EPSRC Grant GR/M44866.

5. References

[1] Edman, PK. *Tactile Graphics*, 1991. American Foundation for the Blind.

[2] Gentaz, E and Hatwell, Y. The haptic oblique effect in the perception of rod orientation by blind adults, *Perception & Psychophysics*. Grenoble France, 1998, Vol 60 (1), p 157–167.

[3] Gentaz, E and Hatwell, Y. Role of gravitational cues in the haptic perception of orientation, *Perception & Psychophysics*. Grenoble Freance, 1996, Vol 58(8), p1278-1292.

[4] Kappers, AML and Koenderink, JJ. Haptic perception of spatial relations, *Perception*. Utrecht Netherlands, 1999, Vol 28, p781-795.

[5] Oakley, I, McGee, MR, Brewster, SA and Gray, PD. Putting the feel in look and feel. In *ACM CHI 2000* (The Hague, NL), ACM Press Addison-Wesley, pp415-422.

[6] Riedel, B and Burton, AM. Perception of Gradient in Haptic Graphs: a Comparison of Virtual and hysical Stimuli, *Conference Proceedings to Eurohaptics 2001*, Birmingham, UK, pp90-92.

[7] Yu W, Ramloll R and Brewster SA. Haptic graphs for blind computer users. In *First international workshop on hapti human-computer interaction*. Glasgow UK, 2000, pp102-107.

[8] Yu, W, Ramloll, R, Brewster, SA & Riedel, B "Exploring computer-generated line graphs through virtual touch." Presented at ISSPA 2001 special s session on Enhanced User Interfaces for Non-visual Image Display. Glasgow, UK, 2001.