The Effects of Co-location of Visual and Haptic Space on Judgments of Form

Gunnar Jansson[1] and Magnus Öström[2]

[1] Department of Psychology, Uppsala University, Box 1225, SE-751 42 Uppsala, Sweden
gunnar.jansson@psyk.uu.se
[2] Department of Information Technology, Uppsala University, Box 337, SE-751 05 Uppsala, Sweden
magnus@ostrom.com

Abstract. The problem studied was the effects on perceived object form of co-location of visual and haptic information under both Stereo and Not stereo visual conditions. The participants' task was to judge the distortion of the form of a sphere by comparing its Y and Z dimensions in turn with its X dimension. The difference limen (DL) in each case was measured and the Weber fraction (DL/Standard) determined. The result was that Co-location had a significant effect on the Z dimension under Stereo conditions. This demonstrates that Co-location has positive effects on the perception of object form in depth.

1 Introduction

In the real world objects are normally perceived in the same location whether the sense involved is vision or haptics, but in the virtual world the perceived locations may differ with sense. It can be expected to be advantageous to make the virtual conditions as similar as possible to the real conditions, that is, to co-locate visual and haptic information. An alternative point of view is that the senses are highly adaptable, and therefore, at least after some training, may function well also in non-natural conditions. Thus, the importance of co-location is not self-evident.

In the context of visuo-haptic displays, where both visual and haptic virtual information are presented, it is most common that the two kinds of information are not co-located. Further, the 3D information is presented on a 2D screen with varying quality of the 3D aspects. However, there are efforts to render stereoscopic visual information that produces a clearly 3D perception and haptic information that is co-located with the visual information. For the ReachIn device such a co-location is a basic idea. However, the expected advantage of co-location has been tested in only a few experimental studies, concerning either performance or perception.

Wall, Paynter, Shillito, Wright and Scali [1] investigated the effects of co-location and stereoscopic information on performance in a targeting task. They obtained significant effects on accuracy for both factors, as well as a significant interaction such that, when stereo information is available, the benefit from haptic information is significantly less. Concerning time to reach target there was an advantage to have stereoscopic information, but haptic information had no effect. There were large individual differences in both dependent variables. As the participants in this experiment were beginners in using a haptic device, Wall et al. [1] recommend caution in generalizing the results to other levels of expertise.

The topic for Bouguila, Ishii and Sato [2] was not performance, but depth perception. They found that the perception of the location of objects in depth was improved when haptic information was added to stereoscopic information.

The present study focuses on perception. The context is a project aiming to develop a haptic device allowing simultaneous rendering of visual and haptic representations of works of art at museums, PURE-FORM [3]. The problem to be studied here is the effects of co-locating visual and haptic information, as well as of stereoscopic information on the precision in the perception of object form.

2 Visual versus Haptic Perception

In contrast to haptic perception visual perception provides immediately an overview of an object and its global shape. This is especially true of its extension in the X and Y dimensions, but it is often the case also in the Z dimension, if sufficiently efficient information, such as texture gradients and motion, is available. Visual information about the shape of virtual objects is often presented on a 2D screen, which may be sufficient in many cases, but it is sometimes enhanced with stereoscopic information.

Vision is a highly efficient sense if high quality visual information about object shape is presented. Adding haptic information can hardly be expected to improve perception of shape in the X and Y dimensions when full visual information is available, but possibly in the Z dimension, under such conditions. In order to make a reasonable comparison between conditions, the task must not be too easy for vision.

3 Experiment

There were four experimental conditions, in which all participants (n = 12, nine men and three women, Mdn age = 26 years) took part:

(1) Stereoscopic visual information co-located with haptic information (Stereo/Co-location).

(2) Stereoscopic visual information not co-located with haptic information (Stereo/Not co-location)

(3) Not stereoscopic visual information co-located with haptic information (Not stereo/Co-location)

(4) Not stereoscopic visual information not co-located with haptic information (Not stereo/Not co-location)

The aspect of shape studied was curvature, for haptics investigated by, e.g., Christou and Wing [4], Kappers, Koenderink and Lichtenegger [5] and Vogels [6]. The experimental problem was the following. Is there any difference in precision of judging the distortion of a spherical object, when the information is presented in the form of exploratory motion paths, if (1) the visual information is presented stereoscopically or non-stereoscopically and (2) the visual and the haptic information is co-located or not? In other words, is there any benefit of presenting the visual information stereoscopically and co-locating visual and haptic information?

A Reachin device co-locating visual and haptic space and a Phantom 1.5A with the thimble option were used, the Phantom placed either under a horizontal mirror providing visual information from a computer screen or to the right of the Reachin device behind a vertical screen. Via shutter glasses either different (stereoscopic) or identical information to the two eyes was presented. In neither case visual information from the exploring hand was obtained. The software based on the Reachin API was described by Öström [7].

The perceptual sensibility of the participants in the different experimental conditions was measured with the method of just noticeable differences providing the Difference Limen (DL). According to Weber's law the fraction DL/Standard is a constant, and the results are presented in terms of this fraction.

The participants' task was, in separate series of trials, to judge (1) if there was any difference in size between the X and Y dimensions and (2) the X and Z dimensions, respectively, of the virtual object indicated by the exploratory motion paths around it. The standard property (X) of the object was the same in all trials (85 mm) and the comparison properties (Y or Z) varied in five steps of .85 mm on each side of this value. The motion paths were visually presented by a circular avatar, corresponding to the thimble. The amount of visual and haptic information was similar; except for the size of the avatar that varied with its position in the Z dimension.

4 Results and Discussion

The Weber fractions are presented in Fig. 1. An ANOVA demonstrated no significant differences for the Y Weber fractions, which is in agreement with the expectations. For the Z Weber fractions there were larger differences, the one between Co-location and Not Co-location in the Stereo conditions being significant ($p < .05$ according to an LSD test). The Stereo/Co-location result for the Z dimension is closely similar to all the Y dimension results. This significant result is in agreement with the Bouguila et al. [2] results concerning depth perception. The Wall et al. [1] results concerning performance are partly different.

An additional advantage of co-location was indicated by informal observations that finding the buttons and the virtual sphere, when contact was lost (performance tasks), was more difficult in the Not Co-location conditions. This may be still more important for more complex shape perception tasks.

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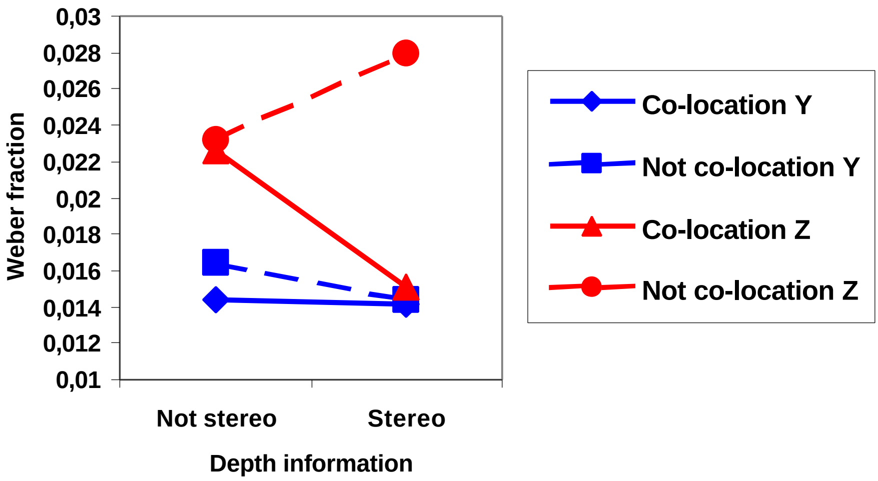

Fig. 1. Weber fractions (DL/Standard) for the Y and Z dimensions, respectively, in the four experimental conditions.

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