Psychophysical Size Discrimination using Multi-fingered Haptic Interfaces

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Abstract. The use of multi-fingered haptic devices can potentially provide users much more realistic interactions in virtual environments compared to single-point contact devices. The usability of multi-fingered devices necessitates the need for an understanding of their performance characteristics. Multiple Phantoms devices were used in psychophysical size discrimination experiments using two and three fingered grasps. The results of these perceptual experiments were found to be comparable to those of single-finger size discrimination studies as well as results obtained via finger-span methods. The findings imply that multi-fingered haptics can accurately replicate reality for tasks such as these. Additionally our findings indicate that a three-fingered haptic grasp can provide better discrimination than a two fingered grasp.

1. Introduction

Most haptic devices have utilised a single-point interaction paradigm, and although this approach has been generally convincing it does impose certain limits on what a user can feel and do. The ability to interact with objects in virtual environments using multi-fingered haptic devices would seem to offer a number of advantages over single contact devices. For example, they can be used to simulate more natural interactions found in grasping and manipulating objects as well as being more applicable to simulation of real world physics. Furthermore, additional information gained from multi-point contacts may be a useful aid to object identification, such as by blind or visually impaired users [1].

As part of a program of research investigating multi-modal haptic interactions using multi-fingered haptics this paper outlines our initial experimentations on human haptic performance for size discrimination using multiple Phantom haptic devices. Performance comparisons of size discrimination using single-point interface devices provide comparable results between real and virtual environments [2]. However, data for size discrimination using multi-fingered haptics is lacking.

2. Methods

2.1 Design. In order to assess users ability to determine size differences a two-alternative forced-choice methodology was implemented. Participants were required to judge, using touch alone, which of two haptically rendered spheres was the larger. Two studies were carried out utilising a two-fingered grasp and a three-fingered grasp condition. Spheres were chosen since it was felt that they would be more in keeping with the natural characteristics of the grasp position. The spheres were presented within the same time interval in two spatial locations – side by side with 5 cm between them. One of the haptically rendered spheres (the reference or standard stimulus) was 5 cm in diameter, the other sphere varied in 0.5 mm increments, from 4.7 cm to 5.3 cm diameter. There were a total of 132 stimulus trials (six size differences twenty-two times each). The choice of sphere diameters was a result of earlier pilot studies. To counteract any affects that the presentation order may have both sphere position (left/right) and presentation order was randomly assigned.

A visual aid was used to help subjects in locating the haptic spheres. This took the form of graphical spheres displayed via computer monitor (see figure 1). The graphical spheres were positioned to fully enclose the haptically rendered spheres. Thus, not allowing any visual aids to affect judgment. Thumb and fingertip positions were represented by two/three yellow dots.

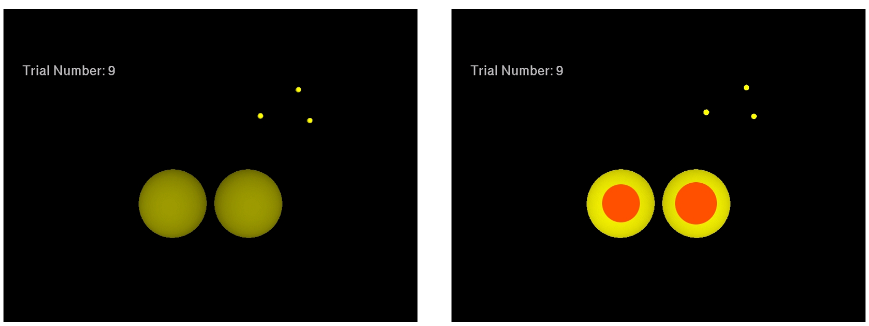

Figure 1. The left image shows the visual aid displayed to the subject and the right image shows the location of the haptically rendered spheres.

2.2 Haptic Devices. Phantom 1.5 haptic interfaces were used running rt-linux version 2.4. The Phantoms are being updated internally at 1000Hz while the phantom positions and forces are calculated at 700Hz. The graphic environment was updated at 25Hz. The Phantoms provided a total virtual workspace of approximate dimensions 27x25x19 cm. Haptic rendering was implemented using the friction cone algorithm where friction coefficients are set to zero i.e. the spheres are frictionless [3]. To enable finger and thumb grasps to be made the Phantoms were fitted with thimbles. Pre-trial investigations highlighted the necessity for accurate calibration of the Phantoms, where precise alignment of the two workspaces was vital. It was found that there were two main components of calibration error - horizontal and vertical displacement errors and rotational displacement errors.

The horizontal and vertical displacement error is due to compliance in the system and sensor resolution of the encoders. This leads to increasing alignment errors from the calibration centre towards the edges of the common workspace. In order to reduce the effect of this calibration error, calibration of the workspace was confined directly within the experimental workspace 20x10x10cm.

The rotational displacement error is due to the fact that the calibration methods calibrate both Phantoms in one point, whereas they should be calibrated taking into account the thicknesses of the thimbles. In order to minimise this error an offset is required to counteract the change in distance between the transformed endpoints when the thimbles are rotated. Inaccurate offset displacements leads to increasing positional errors upon rotation. A finger thickness offset of 1.6cm was used in addition to participants being requested to maintain the orientation of the thimbles for the two-fingered grasp. For the three-fingered size discrimination task, constrained alignment of the thimbles is unnatural and consequently rotations need to be allowed. However, this leads to an increase in rotational displacement error.

Figure 2, shows an error map of the experimental workspace. The average error for the two-fingered grasp was 0.51 mm, whereas, for the three-fingered grasp the average error was 0.56 mm. However, these error values are based upon the full range of possible hand movements and rotations. Since the highest errors are recorded when the fingers are fully rotated and the movements used within the experiment was nominally <90° around each of the axes, the actual average error could be considerably less.

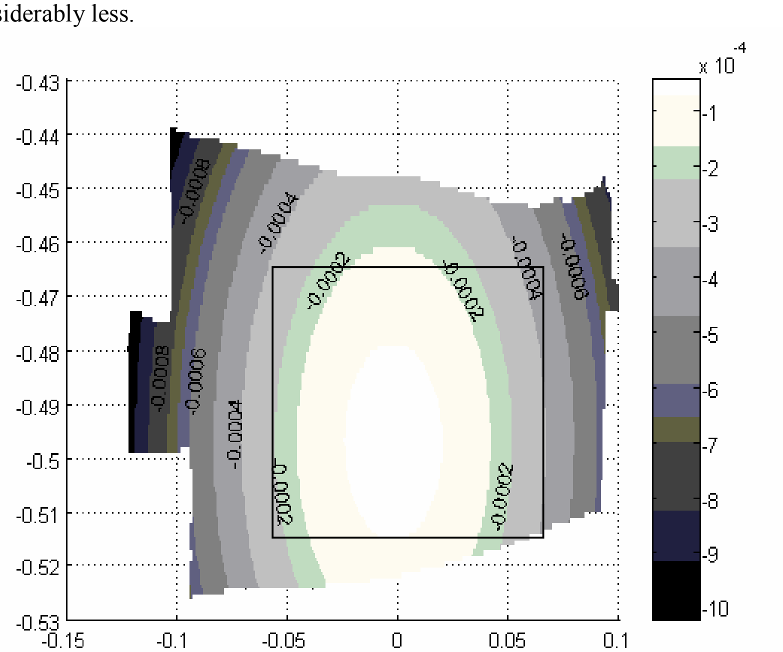

Figure 2. Error map showing the experimental workspace through the xz plane. Error contours are labelled in metres.

2.3 Participants. Thirteen subjects took part in the two-fingered condition (11 male and 2 female); the participants were students studying at Reading University. All were right-handed with a mean age of 29 years (standard deviation = 2.7). Participants reported no conditions that might affect their ability in making haptic size judgements. For the three-fingered condition ten subjects were used (8 male and 2 female) with a mean age of 25 (standard deviation = 4.6).

2.4 Procedure. Participants were initially requested to read a summary of the experiment, which detailed their task. Once subjects had familiarised themselves with the set-up they were encouraged to acquaint themselves with two practice spheres within the virtual/haptic space. This served a dual purpose, firstly, learning the location of the spheres accurately using the visual feedback provided by the monitor, secondly, acquainting them with the sense of touch provided by the haptic device.

In the two-fingered condition subjects were instructed to use the thumb and index finger of their dominant hand. The middle finger was added in the three-fingered condition. Care was taken to ensure that subjects knew how to correctly insert their fingers (and thumbs) into the thimbles so as to avoid possible gimbal collisions. Figure 3, below shows the arrangement for the three-fingered condition.

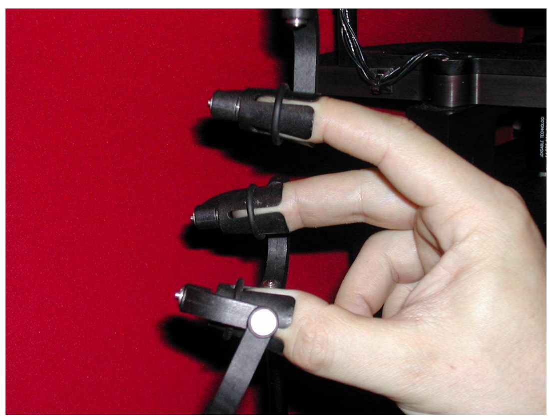

Figure 3. Three fingered grasp

In order to prevent participants from gaining additional visual information, obtained by looking at their finger positions, a partitioning screen was used to block the view of their hand. Furthermore, it was suggested that whilst making their size judgements participants might want to close their eyes in order to block out any other possible distraction.

After a period of familiarisation subjects started the experiment proper. They were exposed to a total of 132 stimulus pairs with their choices being recorded by the computer via keyboard input. Participants could take as long as they wanted in making their judgements. After each choice was made participants were given feedback, via the computer, as to whether they were correct or not. It was felt this would help them to concentrate better. Experimental sessions took between 45 minutes to 1¼ hours. Participants were encouraged to take frequent rests whenever they felt their hand tiring or when finding it hard to concentrate on the task.

3 Results

3.1 Two-Finger Grasp. Figure 4, shows a sigmoid function fitted (in a least squares sense) to the averaged data for the two-fingered condition. To provide a more meaningful fit to the data a fixed value of 50% at 0 mm has been included. The Just Noticeable Difference 75% correct response corresponds to a size difference of 1.29 mm. It can be seen that at the 0.5 mm size difference, subjects performed barely better than random guesswork.

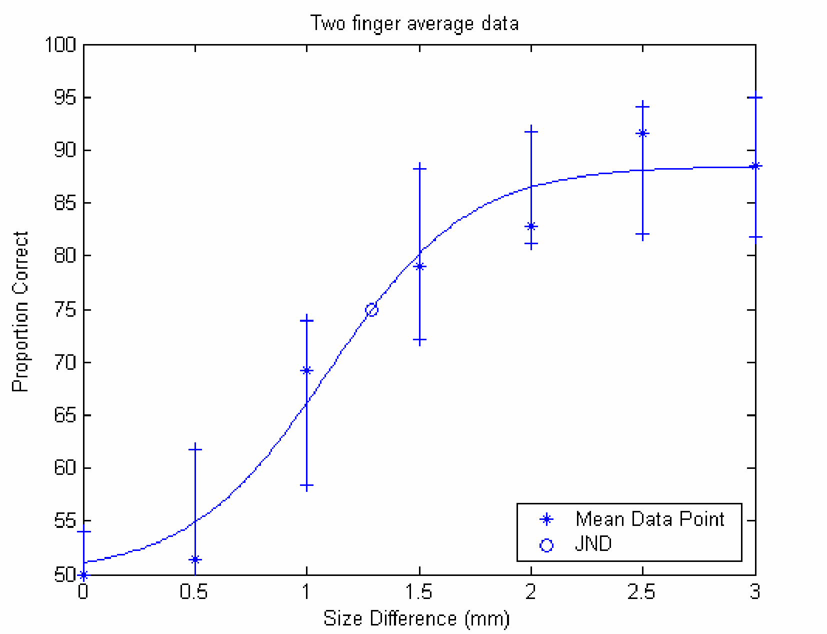

Figure 4. Summary of two-fingered grasp data with 95% confidence intervals plotted as error bars.

Based upon pilot studies we expected performance accuracy at the maximum 3 mm size difference to be higher, however, the extended demands under experimental conditions can become vary fatiguing both mentally and physically. This leads us to suggest that it is possible that these aberrations in performance may be fatigue based. Moreover, the method of exploration, relying on two finite points of contact, makes it difficult to judge the true circumference, and as the size increases it may be potentially more difficult to judge where the actual circumference lies. In three-fingered grasps the object is being enclosed by the fingers. As such, greater shape information is available and one might expect greater accuracy in judgements of the true circumference. The results of the three-fingered condition appears to bear out this assumption.

3.2 Three-Finger Grasp. Figure 5, shows a sigmoid fitted to the averaged data for the three-fingered condition. Again a fixed value of 50% at 0 mm has been included. The 75% correct response gives a value of 1.26 mm. It seems clear from comparisons of figures 4 and 5 that the subjects in the three-fingered condition seem to be on average more accurate in their judgments justifying further investigation.

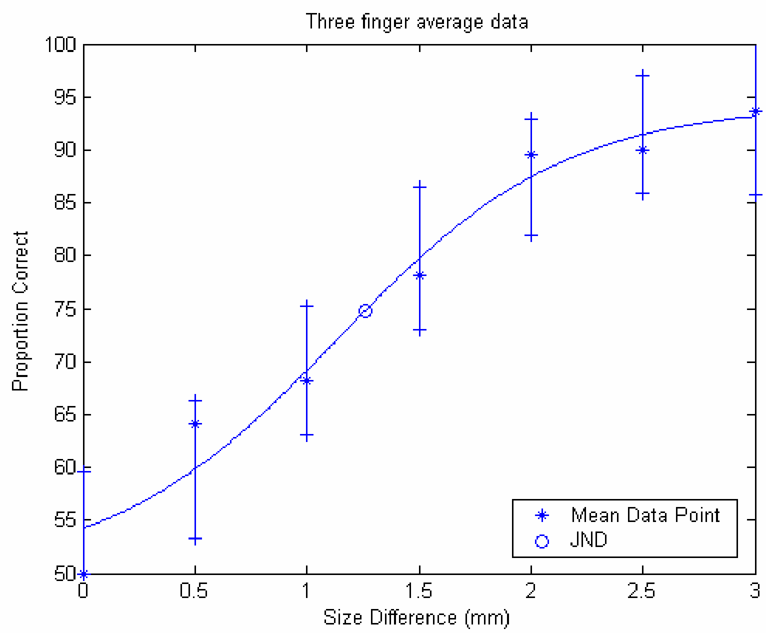

Figure 5. Summary of three-fingered grasp data with 95% confidence interval plotted as error bars.

In addition to the added shape information made available with a third finger, another contributing factor for the enhanced performance could be time taken to locate the haptic spheres. It was observed that many subjects in the two-finger condition had difficulty in accurately locating the haptic spheres. In the three-fingered condition, subjects were noticeably more adroit taking less time locating and forming size judgements and hence, less time to get fatigued.

Observations of the exploratory procedures used in the three-finger grasp were also of interest. Of note some subjects developed exploratory procedures not possible in the real world. One subject moved between the spheres as if on an imaginary cylinder between them, allowing their palm to pass through the furthest object.

4 Discussions

Determination of length via finger span methods provides a Weber fraction of 0.02 at 30 and 50 mm [4]. More recently, Durlach et al. found a just noticeable difference of 1 mm for reference lengths of 10 to 20 mm [5]. Using the Weber fraction 0.02 for a length of 50 mm would give a just noticeable difference of 1 mm, which is comparable with the results obtained in this experiment. Thus, we can say that size comparison judgements using multi-fingered haptics can be on a par with real object size perception, implying that the haptic device does a good job of simulating reality in this case. Furthermore, the results imply that high-fidelity multi-fingered haptics can be used in making experimental comparisons between real and virtual haptics for object extent.

It should be noted that the use of multiple Phantoms provides a much more natural method of size determination (via the use of a finger and thumb grasp) than would be gained by the use of a single Phantom. Studies using a single Phantom fitted with a stylus have shown that size discrimination, though not as accurate as in a real environment, is comparable. In O'Malley's experiment [2], cross-sectional ridges were used in a comparative study to determine size discrimination. Subjects correctly identified a size difference of 1.25mm approximately 80% of the time in virtual environment, compared to approximately 85% of the time in the real environment. Differences between the stylus and multi-fingered results are most likely due to additional calibration errors when using more than one Phantom.

5. Conclusions

Overall the results are encouraging for the use of multi-fingered haptics in accurately simulating the extent of real objects. The findings indicate that using three fingers provides greater accuracy over two fingers. The ability to accurately discriminate object extent may be important in possible future applications, for example, surgical training simulators, here an understanding of the human performance characteristics is essential to the design of efficient interfaces.

6. Acknowledgements

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7. References

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