Object Manipulation in Virtual Environments: Human Bias, Consistency and Individual Differences

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ABSTRACT

This paper investigates human bias, consistency and individual differences when performing object manipulation in a virtual environment. Eight subjects were asked to manipulate a wooden cube to match a 3-D graphic target cube presented in 3 locations and 2 orientations. There were two visual conditions for the experiment: the subject performed the tasks with or without vision of the hand and the wooden cube. The constant errors of object translation and orientation suggested specific human biases. In terms of the variable errors, visual feedback appeared to be more critical for object transportation than object orientation. It was also found that individual differences were more pronounced in human bias than in consistency during object manipulation. These results suggest tolerance for human bias and variability should be accommodated in human-computer interface design.

Keywords

Interface design, object manipulation, virtual environment, human performance

INTRODUCTION

Object manipulation is an activity we perform every day. The promise of direct manipulation, one of the most important user interface styles, is to transfer object manipulation skills developed in the physical world into human-computer interaction environments. However, evidence shows that humans may make systematic and random errors in prehension movements including object manipulation under certain task conditions (Soeching and Flanders, 1993; Jacob *et al.*, 1996; Fikes, 1995). Such errors will occur in human-computer interaction as well. The purpose of this study is to examine human bias, consistency and individual differences when manipulating an object in a virtual environment, and therefore to provide useful information for future computer interface design.

EXPERIMENTAL DESIGN

Manipulation tasks were designed that required both object transportation and orientation, under different visual feedback conditions. A stereoscopic, head-coupled graphical display, and a half-silvered mirror were used to create a virtual environment (The Virtual Hand Lab). Eight students were asked to manipulate a small wooden cube so that it occupied the same position and orientation as a graphic target cube. The target cube was located on the table top, 30 mm, 100 mm or 200 mm from the starting position, and rotated by 22.5 or 45 degrees from the frontal plane of the subjects. The tasks were performed in one of two conditions: without vision (only the graphical objects were visible), or with vision (the subject's hand and the physical cube were also visible). An OPTOTRAK monitored 3-D positions of 3 infrared markers placed on the cube. Dependent measures were errors in location matching and orientation matching between the manipulated cube and the target cube. The constant error indicated human bias in object manipulation, and the variable error reflected the consistency of control on a trial-by-trial basis.

RESULTS

Constant Errors

As shown in Figure 1, there was a highly significant bias to the right of the target (positive Y direction), in both visual conditions, $p < .01$. Further, the bias differed between the two conditions ($p < .01$), 2.6 mm without vision of the hand and the wooden cube, and 12.9 mm with vision. There was a trend (6 out of 8 subjects) to overshoot the target, but the bias in the X direction was not statistically significant for either visual condition.

The subjects significantly under-rotated ($p < .05$) the angle required to match the target orientation, as shown in Figure 2. The average under-rotation was 2.5 degrees in the "with vision" condition and increased to 6.6 degrees when no visual feedback was available ($p < .01$).

Variable Errors

For both X and Y axes, subjects were less consistent without vision of the hand and the cube than with vision ($p < .01$). With vision, the average X error was 1.5 mm and the average Y error was 1.2 mm, while without vision the X error increased to 11.6 mm and the Y error increased to 5.7 mm.

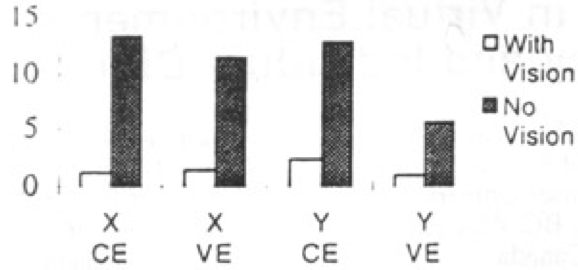

Figure 1. Displacement errors (mm) in X and Y directions. CE = Constant Error and VE = Variable Error.

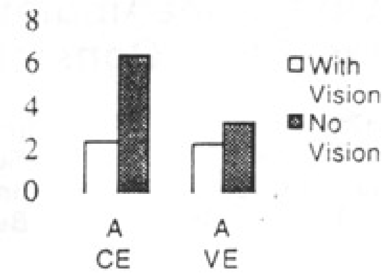

Figure 2. Angular Errors (degrees) on XYPlane.

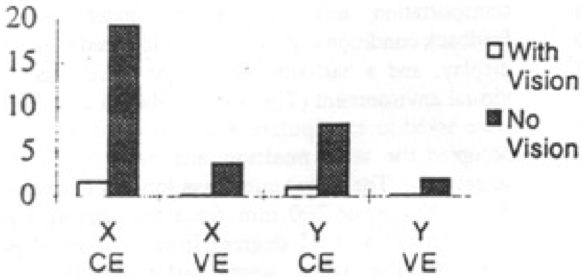

Figure 3. Between subject standard deviation of displacement errors (mm).

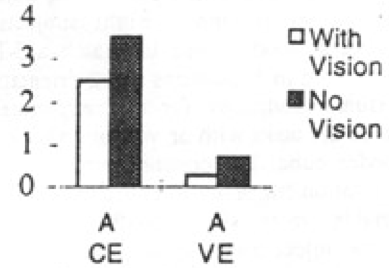

Figure 4. Between subject standard deviation of angular errors (degrees).

It is worth noting that even though the angular variable error increase from the vision to the no vision condition was statistically significant ($p < .01$), this increase was rather small, less than 1 degree (Figure 2).

Individual Differences

Figures 3 and 4 demonstrate the individual differences in bias and consistency of object manipulation, in terms of standard deviation for the eight subjects. In general, individual differences were greater in bias than in consistency during object manipulation. Deprivation of visual feedback information of the hand and the wooden cube increased the performance variation among the individuals. In the no vision condition, the individual transportation bias ranged from -15.6 mm (target was undershot) to 43.7 mm (target was overshot) along the X axis, and from -0.8 mm (cube to left of target) to 25.2 mm (cube to right of target) along the Y axis. The individual rotation bias ranged from -9.0 degrees (under-rotation) to 1.7 degrees (over-rotation).

DISCUSSIONS AND CONCLUSIONS

The magnitude of the human bias in object manipulation is larger in the no vision condition, but the trend of the bias is very consistent whether or not visual feedback of the hand and the cube are present. Users tend to overshoot the target, but under-rotate the target orientation. Consistency decreases with "impoverished" visual feedback in the virtual environment. However, the change in consistency over different visual conditions is not as dramatic for object orientation as for object transportation. When visual feedback of the manipulator (hand) and manipulated object are unavailable in a virtual environment, individual differences in bias are particularly large. This implies that direct manipulation interfaces in virtual environments will be more effective should they utilize a calibration mechanism which accounts for individual biases. The error values presented in Figure 1 and 2 may serve as rule of thumb for determining the tolerance bounds for matching or selection tasks.

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