The Effects of Encumbrance on Mobile Gesture Interactions

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Abstract

We examine mobile gesture interaction while the user is encumbered by holding bags and boxes. This is a frequent situation in everyday life and one that can cause problems when using mobile devices. A Fitts' Law study was conducted to examine wrist rotation, a 'hands free' interaction method, to assess the effects of carrying objects on interaction performance. The aim was to understand if, and how, different types of objects affected usability. Users were tested standing and walking and while carrying a bag or box. Results suggested different forms of encumbrance led to significantly different levels of interaction performance, with holding the bag causing more problems than the box. The results suggest that designers should test their new interaction techniques with a range of different encumbrances to ensure that they are useful in real-world contexts.

Keywords

'Hands free', encumbered, Fitts' Law, wrist-rotation.

ACM Classification Keywords

H.5.3 [User Interfaces]: Input devices and strategies.

General Terms

Human Factors

$$MT = a + b * ID,$$

$$\text{where } ID = \log_2(A/W + 1)$$

figure 1. Shannon formulation where ***MT*** is the movement time, ***A*** is the target separation, ***W*** is the target width, ***ID*** is the index of difficulty. The values of ***a*** and ***b*** can be seen as the user's reaction time and task difficulty respectively.

$$TP = eIDmean / MTmean$$

figure 2. Throughput calculation where ***eIDmean*** is the mean effective Index of Difficulty which is calculated using effective target width. ***MTmean*** is the mean movement time.

figure 3. Visual interface for the experiment running on a Nokia N95 phone.

Introduction

There are many everyday situations where the user's hands are occupied while interacting with mobile devices, such as carrying shopping bags. Such encumbrances make it difficult to interact and reduce the kinds of applications and services that can be used on the move. Researchers are investigating new 'hands free' mobile interactions [2,6] and it is important to see if usability is compromised when users are encumbered. Here, we examine wrist rotation interaction with users carrying a bag or a box, in both standing and walking situations to assess the effects on interaction. If we can find an interaction technique that works well in such settings then it will make mobile devices more useful for more applications and services in wider range of real usage contexts.

Background

Wrist rotation has been shown to be a useful 'hands free' gesture method [2] as it is discreet and acceptable to do in public and can be used when the fingers are occupied. Balakrishnan and MacKenzie [1] studied the performance of finger input control and found that the wrist and forearm outperformed finger for certain pointing tasks. Feldman *et al.* [3] describe a socially acceptable setup to provide seamless access to information about everyday objects by making small wrist gestures using a wireless sensor wristband. Rahman *et al.* [6] proposed a framework to examine the limitations of tilt-based wrist interaction. They report that using a quadratic mapping function for discretization of tilt angle could greatly improve user performance.

The study described here uses a standard Fitts' Law task to characterize pointing performance for wrist rotation [2, 4]. The formula used in this paper (figure 1) follows Shannon formulation proposed by MacKenzie [4]. The formula assumes an error rate of ~4%; when this is not the case the effective width of the target is calculated based on the standard deviation of errors as proposed by MacKenzie [4]. We also calculate throughput which is a measure of the bandwidth of the communication channel and allows us to compare the performance of different pointing devices. Throughput (***TP***) [5], measured in bits per second, is calculated as shown in figure 2.

Experiment

We repeated the wrist rotation study of Crossan *et al.* [2] but enhanced it in two ways. Firstly, to assess the effects of two typical forms of encumbrance: holding a bag in the hand and carrying a box under an arm.

Secondly, we improved the sensing used to detect wrist rotation gestures. We used a SHAKE7 (a matchbox sized-sensor pack, code.google.com/p/shake-drivers) which has a built-in sensor fusion algorithm to enable it to output heading data in real time over Bluetooth to a mobile phone. The main advantage was that reliable and accurate orientation data could be collected with the user's arm in any position.

A SHAKE7 was attached to the participant's right wrist to detect wrist rotations. The other hand held a Nokia N95 phone that was used as a display for the Fitts' Law task (figure 3). The user controlled the movement of a cursor on the N95's screen, with a direct mapping between wrist rotation and cursor movement. The rotation angle was limited to 90^{o} to reduce fatigue on the wrist. Once the cursor was in the target area, the user pressed the centre button on the N95's D-pad to

figure 4. Participant performing wrist gestures while standing and holding nothing (top), holding a bag (middle) , and holding a box (bottom).

select it. As in [2], a visual display was used as we wanted to create as simple and standard a Fitts' study as possible without the issues introduced by non-visual targeting. This is a little unrealistic for a real task but allowed us to maintain a good experimental protocol and would let us to compare our results with those of others.

Eighteen participants took part in the study, all right-handed and aged between 20 to 50 years. There were six conditions: standing holding nothing (S_{NO}), standing holding a bag (S_{BAG}), standing holding a box (S_{BOX}), walking holding nothing (W_{NO}), walking and holding a bag (W_{BAG}), and walking holding a box (W_{BOX}). For the three walking conditions, participants walked a pre-set route in a large and quiet room. Each condition, which had 96 target selections, was split into 16 target width/separation combinations. The target separations were 70, 100, 150 and 200 pixels giving ~19°, 25°, 37° and 50° rotation respectively. The target widths were 20, 30, 40 and 50 pixels (~5°, 7°, 10° and 12° rotation respectively). The participants were asked to click each target as quickly and accurately as possible. Figure 4 shows a participant performing wrist rotation gestures while holding nothing and being encumbered.

The bag and box (dimensions: 30 x 28 x 15cm) weighed 0.6 kg and 0.3 kg respectively. These two objects do not cover everything a user might hold but they would show the effects of different ways of holding items and some effects of different weights of objects.

The hypotheses were:

H1 – Participants would be quicker and more accurate at selecting targets when unencumbered;

H2 – There would be no differences in performance between the two forms of encumbrance.

Results

A two-factor repeated-measures ANOVA was calculated with Stance (standing or walking) and Encumbrance (holding nothing, bag or box) as factors and Index of Difficulty as the grouping variable. For movement time, there was a significant main effect of Stance ($F(1,40)= 31.73$, $p<0.001$). The mean movement times for standing and walking were 1.52s and 1.96s. Movement time was significantly higher when walking than when standing. There was no significant main effect of Encumbrance $F(2,40)=0.73$, $p=0.48$ or any interaction between the factors.

For target accuracy, there was a significant main effect for Stance ($F(1,40)=54.36$, $p<0.001$). The means for standing still and walking were 93.52% and 80.40% respectively. Target accuracy was significantly higher when standing still than when walking. There was a significant main effect for Encumbrance ($F(2,80)=5.93$, $p<0.005$). Pairwise comparisons with Bonferroni correction showed that the target accuracy when holding a bag was significantly lower than when holding a box or holding nothing ($p<0.05$), but holding nothing and holding a box showed no significant difference.

Table 1 shows the overall means and standard deviations for movement time and target accuracy for each condition. The target accuracy of the walking conditions was much lower than the standing conditions, with walking and holding a bag producing the worst performance. However, comparing the performance between W_{NO} and W_{BOX} suggests that

	Mean Movement Time (s)	Mean Target Accuracy (%)
S_{NO}	1.502 (SD = 0.363)	94.8 (SD = 9.8)
S_{BAG}	1.587 (SD = 0.441)	89.9 (SD = 14.8)
S_{BOX}	1.502 (SD = 0.517)	93.8 (SD = 11.5)
W_{NO}	1.877 (SD = 0.672)	77.4 (SD = 22.1)
W_{BAG}	2.043 (SD = 0.869)	69.4 (SD = 22.9)
W_{BOX}	1.789 (SD = 0.577	79.9 (SD = 20.2)

table 1. The overall means and standard deviations for movement time and target accuracy for each condition.

target selection while holding our box did not affect accuracy when compared to holding nothing.

Based on these findings, hypothesis H1 is rejected because there were no real differences in movement time between the encumbered and unencumbered conditions. In addition, holding the box and holding nothing conditions exhibited very similar performance. H2 is also rejected as there was a significant difference between holding a bag and holding a box in terms of target accuracy but not movement time.

The throughput (bits/sec) for each condition was: S_{NO} = 2.035, S_{BAG} = 1.847, S_{BOX} = 1.979, W_{NO} = 1.298, W_{BAG} = 1.149 and W_{BOX} = 1.431. The W_{BOX} condition is interesting as performance is very similar to W_{NO}; it seems like holding the box we chose for this experiment did not cause the users many problems. For comparison, the throughputs from Crossan *et al.*'s wrist rotation study [2] were 1.64 bits/sec for the standing condition and 0.97 bits/sec for the walking condition. The throughputs of our encumbered conditions were greater than those of Crossan's in both standing and walking, even though his participants were unencumbered. This is due to the improved orientation sensing in the SHAKE7.

Discussion and Conclusions

The results suggest encumbrance has an effect on interaction and different types of encumbrances differentially affect performance. Further study is needed to investigate the effects of a wider range of objects. One significant issue that came out of the study was the importance of high quality sensing. Our results showed that adding better orientation estimation could greatly improve wrist rotation performance; users were able to perform wrist rotation gestures more reliably and at a wider range of arm positions.

In conclusion, our study suggests that designers should consider the effects of encumbrance on their new interaction techniques. Although there has been much research into 'hands free' mobile interaction, none has quantified the effects of users carrying or holding other objects while interacting. This is a very common occurrence in everyday life and it is important to know if new interaction techniques perform well under these more difficult but realistic conditions.

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