An Isometric Joystick as a Pointing Device for Handheld Information Terminals

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Abstract

Meeting the increasing demand for desktop-like applications on mobile products requires powerful interaction techniques. One candidate is GUI-style point-and-click interaction using an integrated pointing device that supports handheld use. We tested an isometric joystick for this purpose. Two prototypes were built. They were designed for thumb operation and included a separate selection button. Twelve participants performed point-and-select tasks. We tested both one-handed and two-handed interaction, and selection using the separate selection button and the joystick's integrated press-to-select feature. A notebook configuration served as a reference. Results for the handheld conditions, both one-handed and two-handed, were just slightly off those for the notebook condition, suggesting that an isometric joystick is suitable as a pointing device for handheld terminals. Inadvertent selection while moving the pointer yielded high error rates for all conditions using press-to-select. A separate select button is therefore needed to ensure accurate selection.

Key words: Isometric joystick, pointing devices, handheld devices, ISO 9241, Fitts' law.

1 Introduction

During the past few decades the size of computers has shrunk drastically, from room-size, to desktop, to notebook, to palm-size. Coincident with the reduction in size is a growth in mobility. With form factors shrinking even further the transition from "semi-mobility" to "real mobility" seems complete. Now, truly mobile, wireless, lightweight, handheld devices can be used standing up, walking about, or even cycling or driving!

The GUI paradigm, based on a mouse and point-and-click interaction, is ubiquitous for the desktop environment. The mouse is entrenched as *the* desktop pointing device; however, the rise of mobile computing (viz. notebooks) motivated the development of alternative devices, such as miniature joysticks and touchpads.

As handheld information terminals begin to offer the same applications as desktop computers (e.g., email or web browsing), there is an increased need to support GUI-style interaction. Thus, there is need for a small embedded pointing device that is suitable for handheld use. This work studies the applicability of the isometric joystick to handheld usage.

1.1 Isometric Joystick

A joystick is a good candidate for handheld pointing. Since it is mounted in the device chassis, it cannot be lost, unlike a stylus. It is small and can be manipulated potentially with the same hand that holds the device.

The device studied herein is an isometric joystick. The pointer is moved by applying force to the stick. The stick itself doesn't move, or moves very little – hence the name "isometric". The most common input-output mapping is known as “velocity-control”, whereby the applied force controls the velocity of the pointer.

In computing technology, isometric joysticks are usually associated with notebook computers. Examples include the IBM *ThinkPad*, using the *TrackPoint* joystick, or the Toshiba *SatellitePro*, using the *AccuPoint* joystick. Both use strain gauge technology. The joystick is placed on the keyboard between the “G” and “H” keys.

The traditional left and right mouse buttons are usually positioned in front of the notebook keyboard. The joystick is manipulated with the index finger while the buttons are actuated by the thumb or the index finger of the opposite hand. Recent versions of the *TrackPoint* incorporate a *press-to-select* feature allowing the user to "click" by pressing on the joystick.

1.2 Handheld Aspects of Pointing

Many studies comparing isometric joysticks and other pointing devices exist, however the domain is typically desktop computing (e.g., [1-5, 7, 9, 15-17, 19]). Non-desktop evaluations, to date, are limited to remote pointing, such as in presentation or home entertainment systems [6, 18]. A handheld implementation of an isometric joystick called *NaviPoint* is described by Kawachiya and Ishikawa [12], however only scrolling was tested. To our knowledge, the present study is the first evaluation of an isometric joystick as a general-purpose pointing device for handheld devices.

Previous joystick studies for pointing tasks have all used the index finger as the input means. We believe that in small handheld devices it is also reasonable to consider the thumb for input control.

The small size of handheld devices affords considerable leeway in their physical design, and, so, products with various form factors can be created. Devices operated manually can be classified by interaction technique as either *one-handed* or *two-handed*. One-handed devices could be, for example, smart phones or remote controllers. PDAs, web pads, and game controllers are examples of two-handed devices. In this study, both form factors are considered.

Another new initiative in this study is the empirical evaluation of the *TrackPoint*'s press-to-select feature. It is a potentially useful feature for handheld devices, since it allows one-handed operation. Also, the size of the device could be reduced by removing the selection button. In this study, the joystick is tested both with and without the press-to-select feature.

2 ISO Testing of Pointing Devices

In recent years, evaluations of computer pointing devices increasingly adopt the methodology in ISO 9241-9 [4, 10, 14]. The full standard is "Ergonomic design for office work with visual display terminals (VDTs)"; part 9 is "Requirements for non-keyboard input devices".

ISO 9241-9 describes, among other things, quantitative tests to evaluate pointing devices. The accepted test is a point-select task. The user manipulates the on-screen pointer using the pointing device, moving it from a starting position to a target, and selects the target by pressing a button on the device. There are many variations, including a simple 1D “back-and-forth” selection task, and a 2D “around-the-clock” selection task.

As the task is carried out, the test software gathers low-level data on the speed and accuracy of user actions. The following three dependent measures form the basis of the quantitative evaluation:

Movement Time. Movement time (*MT*) is the mean time in seconds for each trial in a block of trials.

Error Rate. Error rate is the percentage of targets selected while the pointer is outside the target.

Throughput. Throughput, in bits per second, is a composite measure based on both the speed and accuracy of performance. The measure was introduced in 1954 by Fitts [8], and has been widely used in human factors and experimental psychology ever since.[1] See [13] for details. Throughput, as specified in the ISO standard, is calculated as follows:

$$Throughput = \frac{ID_e}{MT} \tag{1}$$

where

$$ID_e = \log_2\left(\frac{D}{W_e}+1\right) \tag{2}$$

The term ID_e is the effective index of difficulty, in "bits". It is calculated from *D*, the distance to the target, and W_e, the effective width of the target.

The use of the "effective" width (W_e) is important. W_e is the width of the distribution of selection coordinates computed over a block of trials. Specifically,

$$W_e = 4.133 \times SD_x \tag{3}$$

where SD_x is the standard deviation in the selection coordinates measured along the axis of approach to the target. W_e reflects the spatial variability or accuracy in the block of trials. As a result, throughput captures *both* speed and accuracy in user performance. In some sense, throughput reflects the overall efficiency with which the user accomplished the task given the constraints of the device or other aspects of the interface.

It is important to test the device on difficult tasks as well as easy tasks; so, different target distances and/or sizes are used.

ISO 9241-9 also provides a questionnaire to assess the comfort and effort in using the device.

3 Method

3.1 Participants

Twelve volunteers (9 male, 3 female) participated in the study. All were employees of [omitted for blind review]. Ages ranged from 21 to 37 years, with an average of 24.5 years. All participants were right handed and had prior experience using an isometric joystick as a pointing device. Experience ranged from 1 month to almost 7 years, the average being 12.6 months.

[1] Fitts used the term "index of performance" instead of throughput. The term "bandwidth" is also used.

3.2 Apparatus

Handheld Prototypes

Upon request, IBM provided us with engineering samples of the *TrackPoint* joystick (see Figure 1). This device is found in many models of their *ThinkPad* line of notebook computers. The joysticks were mounted in two prototypes, a *one-handed prototype* and a *two-handed prototype* (see Figure 2).

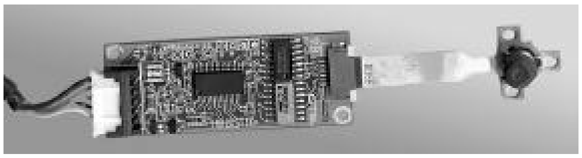
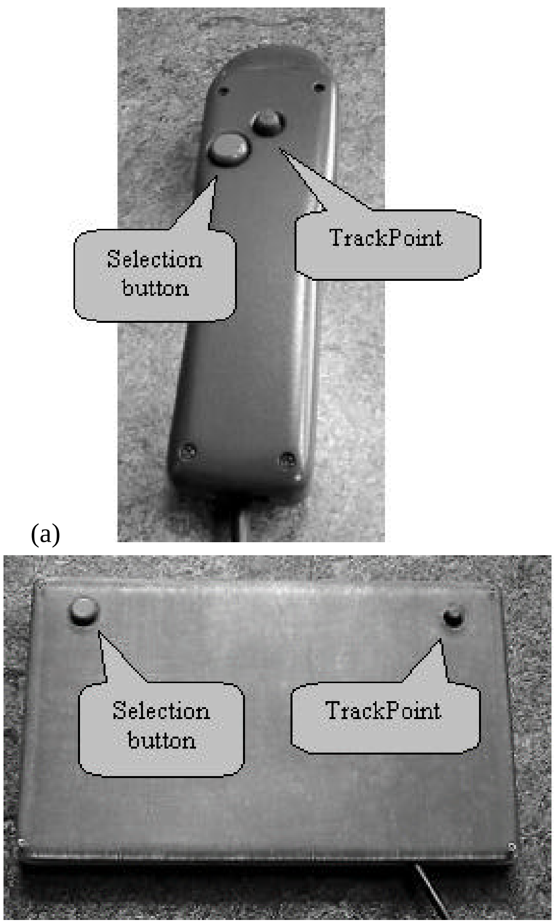


Figure 1. Engineering sample of the IBM *TrackPoint* IV



(a)

(b)

Figure 2. Prototypes (a) one-handed (b) two-handed

Both prototypes also had a separate selection button (equivalent to left mouse button). In the two-handed prototype, the selection button was located on the left side of the prototype, in a convenient place to be activated with the left thumb, while the joystick was operated with the right thumb.

In the one-handed prototype, the selection button was located just to the left of, and slightly below, the joystick. Participants operated both the joystick and the selection button with the thumb of their right hand (the left hand was idle).

(a) (b)

Figure 3. Participant using (a) the two-hand prototype, and (b) the one-handed prototype

Both prototypes had a hidden on/off switch used by the test moderator to disable the selection button when not used. Similarly, the press-to-select feature could be disabled via software. This ensured use of the intended selection method.

The prototypes had no display or processor. This would have made them too heavy for a prolonged test. (Weight is easier to control in production devices because of the high level of integration, but prototypes easily become bulky.) Instead, the joystick attached to the PS/2 port of a Pentium-class desktop PC running *Windows NT*. The output was presented on a 17” CRT screen placed in front of the user. The screen was 87 cm above the floor, tilted back about 45° to provide a convenient viewing position and angle (see Figure 3).

Notebook Reference

Notebook use was included as a reference. For the notebook condition, we used an IBM *ThinkPad 600E*, containing the same joystick technology mounted in the keyboard between the “G” and “H” keys. To minimize uncontrolled effects, we strove to make the notebook condition as similar as possible to the handheld conditions. The notebook was positioned on a table in front of the screen. The notebook’s display was tilted under the CRT.

The participants operated the joystick with the index finger of their right hand. The installed selection button (left mouse button of the notebook) was operated either with the right hand thumb or with the left-hand index finger, based on individual preferences. The press-to-select feature was disabled for the separate selection condition to prevent accidental activation.

Experimental Software

The experimental software was developed with *Borland Delphi* (version 5). The program presented the tasks to participants and logged pointing coordinates and movement times in a text file. Each pointing trial began when the participant clicked a 7 × 7 mm green "home square" appearing in the centre of the screen. When the home square was clicked, it disappeared and a red "target circle" appeared varying in diameter, distance, and angle:

- Target diameter: 3 mm, 6 mm, 12 mm
- Target distance: 25 mm, 50 mm, 100 mm
- Target angle: 0º, 45º, 90º, 135º, 180º, 225º, 270º, 315º

Figure 4 shows a sample trial. The participant is selecting the red target after moving at a 45º angle from the home square.

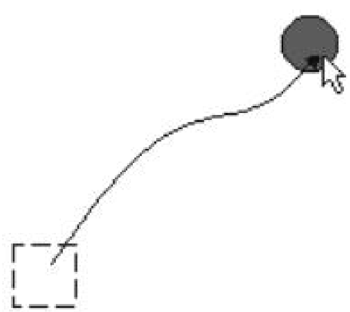


Figure 4. Sample trial

When the target circle was clicked it disappeared. This ended a trial. The trial was also ended if the participant clicked outside the target circle; this was recorded as an error. At the end of a trial, the mouse cursor also disappeared. After a one second delay, the mouse cursor reappeared in the centre of the screen together with the home square. This started the next trial.

One test block consisted of all 72 combinations (3 sizes × 3 distances × 8 angles). These correspond to Fitts' law *ID*s between 1.6 and 5.1 bits. The order of target diameters, distances, and angles was randomized.

4 Design

Three form factors were included: the one-handed prototype (1), the two-handed prototype (2), and the notebook computer (N). All form factors were tested using two selection methods: separate selection button (SS) and pressing on the joystick (press-to-select, PtS). These resulted in six conditions in a 2 × 3 within-subjects factorial design experiment (see Figure 5).

		Selection method	
		Separate selection	Press-to-select
Form factor	1-handed	*1 SS*	*1 PtS*
	2-handed	*2 SS*	*2 PtS*
	Notebook	*N SS*	*N PtS*

Figure 5. The six test conditions

Each participant ran two test blocks (2 × 72 = 144 trials) for each of the six conditions, totaling 12 test blocks per participant (12 × 72 = 864 trials per user). With twelve users the total number of trials was 10,368.

4.1 Procedure

Participants were standing during the testing of the handheld prototypes. This was done to imitate typical mobile usage. During the notebook conditions, participants were sitting.

The tests were conducted in three sessions, with one form factor in each. When possible, sessions were run on different days. The minimum gap between sessions was about five hours.

The order of form factors was counterbalanced between users to minimize learning effects. Participants were first allowed to try pointing on their own for about 1 minute. Then the test task was explained and demonstrated. The participants were instructed to work as fast as possible while maintaining a high accuracy. Errors, once made, could not be corrected as the software automatically proceeded to the next trial when selection occurred. Participants were allowed to sit and rest at any time between trials.

Two test blocks were run for each selection method. The order of selection methods was counterbalanced between users and form factors. The selection method was explained to the participant before the first test block. After completing the trials for a selection method and form factor, the participants were given a questionnaire on their experience using the device assessment questionnaire in ISO 9241-9 [10].

After completing the test with one form factor, participants returned for another two sessions with the other form factors. The total time was in a range of 20 to 30 minutes per session.

5 Results and Discussion

5.1 Adjustment of Data

With the press-to-select condition, participants sometimes pressed the joystick too hard while moving the pointer, thus inadvertently activating the select feature. The result was a selection far away from the target, causing gross outliers, and, hence, a distorted distribution of the press-to-select data. Since the calculation of W_e assumes a normal distribution, it was important to remove the accidental activations of press-to-select from the analysis of W_e, and thus throughput.

We did this by classifying the errors in two categories: *far errors* and *near errors*. A trial was classified as a far error if the distance from the click coordinate to the centre of the target was larger than twice the target radius. Far errors were included in the calculation of error rate as a specific type of error, but they were discarded from the calculation of W_e and throughput. All other errors — those within twice the target radius from the target centre — were classified as near errors, and were included in all analyses.

5.2 Throughput

Throughput results are shown in Figure 6. The throughputs for separate selection are consistently higher than for press-to-select. There is also a difference between form factors; the values are highest for notebook, lowest for one-handed. The difference between one-handed interaction and two-handed interaction with the handheld prototypes is quite small, however.

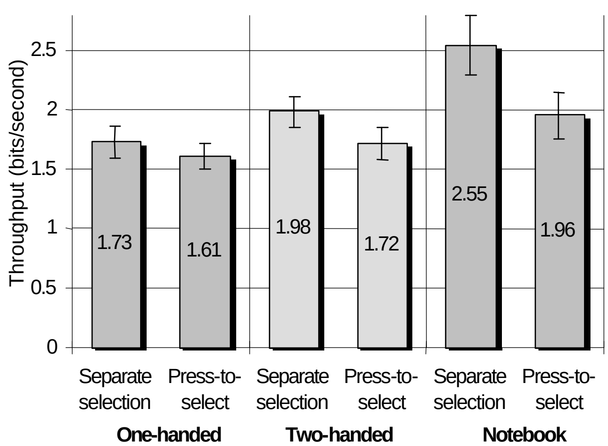


Figure 6. Throughput by condition with 95% confidence intervals

A three-way analysis of variance showed clear main effects for form factor ($F_{2,132} = 46.5$, $p < .001$) and selection method ($F_{1,132} = 41.6$, $p < .001$). However, the effect of block was not significant ($F_{1,132} = 1.5$, $p > .05$); this is in line with expectations, as most participants had prior joystick experience and therefore were quite far along the learning curve in joystick usage. Block effects, therefore, will not be discussed further.

The form factor × selection method interaction was highly significant ($F_{2,132} = 7.7$, $p < .001$).

Our notebook reference condition produced a throughput of 2.55 bits/s for the separate selection condition. This is remarkably close to the figure of 2.33 bits/s reported by Douglas et al. [4]. Their study also used IBM *TrackPoint* technology and their task also conformed to the 2D point-and-click task in ISO 9241-9. This illustrates the value of testing pointing devices in conformance with the ISO standard. The inability to undertake between-study comparisons due to variations in experimental tasks and procedures is a long-standing problem in pointing device research (see [13] for a detailed discussion). However, the use of a reference condition along with a standard test protocol allows researchers to “keep one foot on the ground” when investigating new interaction techniques or technology.

5.3 Movement Time

The average movement time was calculated for each form factor, and selection method (see Figure 7). Values are consistently lower with separate selection than with press-to-select. The notebook was clearly fastest of the form factors. Second fastest was the two-handed form factor, one-handed being slowest.

	Separate selection	Press-to-select
1-handed	2209	2301
2-handed	1922	2122
Notebook	1547	2039

Figure 7. Movement time (ms) by form factor and selection method

A two-way analysis of variance on movement time showed clear main effects for form factor ($F_{2,66} = 13.0$, $p < .001$) and selection method ($F_{1,66} = 12.4$, $p < .001$). The form factor × selection method interaction was not significant, however ($F_{2,66} = 2.58$, $p > .05$).

5.4 Pointing Errors

As noted previously, many errors occurred very far from the target centre, sometimes at the onset of pointer movement. These errors were mostly due to inadvertent activation of press-to-select. As Figure 8 shows, there was substantial variation between participants in the frequency of far errors. P12, in particular, had a very high far-error frequency (29%) compared to the other participants (average 4.4%). This indicates that while press-to-select is useful for some users, it is not suitable for all users. The far-error results were so deviant, that P12's data were removed from subsequent analyses.

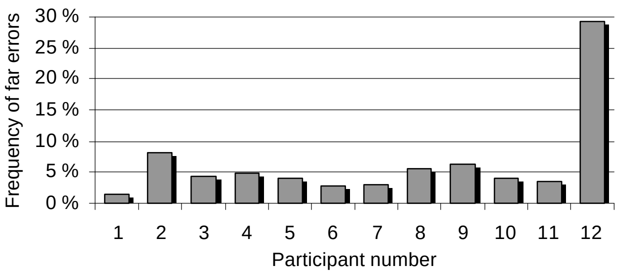


Figure 8: Frequency of far errors by participant

Figure 9 shows the frequency of near and far errors across test conditions. A very distinct difference is evident between near and far errors. Near errors were of the same magnitude for all form factors and selection methods, although the notebook condition revealed slightly less near errors. Clearly, far errors are endemic to the press-to-select condition. It seems that far errors are indeed related to the inadvertent activation of press-to-select.

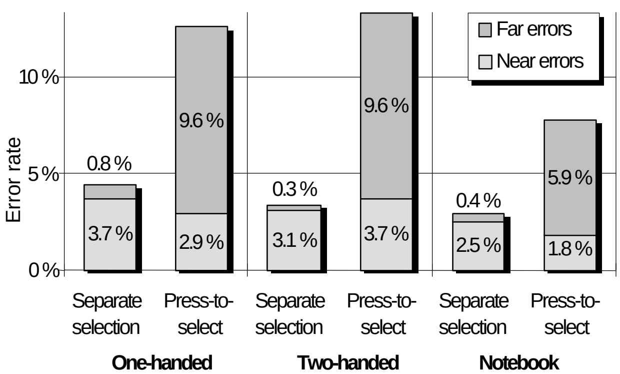


Figure 9. Near and far errors by form factor and selection method. (P12 excluded)

Two-way analyses of variance (form factor × selection method) were performed on near and far errors separately. For near errors, none of the effects was significant (Form factor: $F_{2,60}$ = .44, p > .05; Selection method: $F_{1,60}$ = .08, p > .05; Form factor × selection method: $F_{2,60}$ = .13, p > .05). For far errors, however, the effect of selection method was highly significant ($F_{1,60}$ = 73.9, p < .001), while the other effects were not significant (Form factor: $F_{2,60}$ = 1.9, p > .05; Form factor × selection method: $F_{2,60}$ = 1.7, p > .05).

To summarize, errors near the target occur with about the same frequency regardless of the form factor and selection method. However, errors far from the target clearly increase when using press-to-select. This effect is evident in all tested form factors.

There may be several explanations, such as differences between the thumb and index finger; wrist, forearm, upper arm support strategies; sitting vs. standing; or experience with the press-to-select technique. However, there is no previous research known to the authors on the press-to-select technique with isometric joysticks.

5.5 Device Assessment Questionnaire

Factor analysis was performed for the questionnaire data. Maximum likelihood extraction with varimax rotation was used. The number of factors was determined using the Kaiser rule [11], retaining only those with eigenvalues larger than 1. This resulted in two factors. Five of the eleven questions in the ISO questionnaire relate to "fatigue" [10], and, coincidentally, these all loaded to the same factor. The remaining six questions loaded to the other factor. We averaged the responses within each group of questions, and called them the *fatigue* scale and *general comfort* scale. The reliabilities of these scales were Cronbach á = .80 and Cronbach á = .94, respectively.

The results of the two scales are shown in Figure 10. Two two-way analyses of variance were performed, one for each scale. Of the six F-statistics, only one was significant: users preferred separate selection over press-to-select on general comfort ($F_{1,60}$ = 22.3, p < .001).

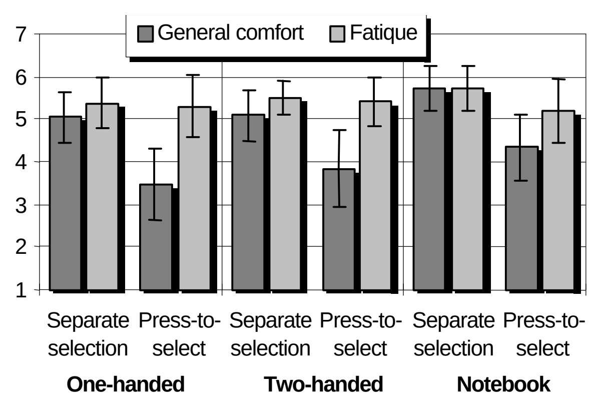


Figure 10. General comfort and fatigue with 95% confidence intervals. (Note that high values are better.)

5.6 Detailed Comparisons

Our goal was to study the use of an isometric joystick in handheld usage. With this background, some specific questions arise:

- *Increased mobility*. In a mobile context, if the device is held in the hand (not on the table) and the joystick is manipulated by the thumb (not the index finger), how do these affect usability?

- *Two-handed vs. one-handed*. What is the performance difference between these two interaction techniques?
- *Press-to-select*. Should handheld devices have a separate selection button, or is it adequate to provide only press-to-select?
- *Location of selection button*. Should a separate selection button be operated with the same hand or a different hand than the joystick?

These questions will be examined individually by comparing the throughput in individual test conditions using pair-wise *t*-tests. Errors and device assessment scales are omitted, because no significant differences were found (except between the two selection methods).

Increased Mobility

There are several issues for handheld usage, as noted earlier (see "Handheld Aspects of Pointing"). The combined effect is best analyzed by comparing the results of the notebook and two-handed conditions.

Based on our data, it seems clear that increased mobility has some negative impact on usability. The throughput in the two-handed condition was below the notebook condition, regardless of selection method (separate selection: $t_{11} = 4.78$, $p < .001$; press-to-select: $t_{11} = 2.18$, $p < .05$). The difference is moderate, however. Throughputs for the two-handed condition were 22% and 12% below the notebook condition in the separate selection and press-to-select condition, respectively. The difference could be further reduced by optimizing the joystick to handheld thumb-operated use. All in all, the joystick clearly has potential as a pointing device for handheld terminals.

Two-handed vs. One-handed Usage

In ergonomic terms, the one and two-handed press-to-select conditions are almost identical. In both conditions, participants operated the joystick with just one hand. The only difference was that in two-handed usage, the other hand assisted in stabilizing the device, whereas in one-handed usage, the other hand was held idle. However, this did not bear significant improvement in throughput ($t_{11} = 1.62$, $p > .05$). This implies that the joystick is equally suitable for one-handed and two-handed mobile interaction, at least when using press-to-select. Again, this bodes well for joystick usage in handheld devices.

Press-to-Select

The press-to-select feature had a clear negative effect on throughput, far errors, and general comfort. These differences were significant in analyses of variance, being most apparent in far errors.

This strongly implies that a separate selection button should always be provided in devices utilizing an isometric joystick, regardless of the form factor of the device. Press-to-select can indeed be useful for some users, and some contexts, but a separate selection button is needed to ensure accurate selection overall.

Location of Select Button

In the industrial design of a joystick-operated handheld product, there are several possible places for the selection button. We have covered two possibilities, either beside the joystick (one-handed prototype) or on the left-hand side of the device (two-handed prototype). Other placements for the selection button, not covered in this study, could be, for example, below the joystick or on the side or back of the device.

The individual effect of button location can be estimated by comparing one-handed and two-handed form factors in separate-selection conditions. For throughput, a highly significant difference was found between these two ($t_{11} = 5.23$, $p < .001$; see Figure 6). This means use of the left hand for selection gives more efficient pointing performance. The difference most likely comes from the extra time needed in the one-handed condition for moving the thumb between the joystick and the selection button.

6 Conclusions

We tested the applicability of an isometric joystick as a general-purpose pointing device for handheld information terminals. Previous evaluations tested the device in notebook computer keyboards, where the index finger operates the joystick, and the forearm and wrist are supported. The present study tested an isometric joystick in a very different context: using thumb control in a handheld form factor. We obtained reasonably similar performance measures to those cited in studies of notebook usage. Our conclusion is that, yes, an isometric joystick has potential as a pointing device for handheld information terminals.

We tested both one-handed and two-handed operation and found that both are feasible and yield about the same level of performance. Also, other handheld form factors are possible and merit further study. For example, the joystick could be positioned on the side or back of the case and operated by the index finger.

Selection was tested two ways, using a separate button and using an integrated press-to-select feature. Press-to-select yields slightly slower operation, although less so for handheld usage than for notebook usage. Eliminating the select button is particularly desirable for handheld devices because of cost and size constraints imposed in production. However, error rates were much higher overall for press-to-select. We conclude, therefore, that a separate selection button is needed, at least for the time being. Press-to-select is a new technique and with further research and development, particularly with optimization for handheld usage, it may be possible to use it exclusively and eliminate the select button altogether.

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