Selection Using a One-Eyed Cursor in a Fish Tank VR Environment

Colin Ware and Kathy Lowther

Faculty of Computer Science
University of New Brunswick
Box 4400, Fredericton, New Brunswick
CANADA E3B 5A3

phone: (506) 453-4566
fax: (506) 453-3566

email: cware@unb.ca

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Abstract

This study investigates the use of a 2D cursor presented to one eye for target selection in Fish Tank VR and other stereo environments. It is argued that 2D selection of 3D objects should be less difficult than 3D selection. Vision research concerning binocular rivalry and the tendency we have to project images onto surfaces suggests that this mode of viewing will not seem particularly unnatural. A Fitts' Law experiment was done to directly compare target acquisition with a one-eyed 2D cursor and target acquisition using a 3D cursor. In both cases we used the same input device (Polhemus Fastrak) so that the device lag and gain parameters were exactly matched. The results show a large improvement in target acquisition time using the 2D cursor. The practical implications of this is that the 2D selection method using a one-eyed cursor is preferable to the 3D selection method. Theoretical implications relate to methods for extending Fitts' Law from the one dimensional task for which it was designed to 2D and 3D tasks. We conclude that the existing approaches to this problem are not adequate.

1. INTRODUCTION

It is often assumed that it is necessary to use a 3D cursor to do target selection in 3D stereo graphic environments. A number of studies have been performed to evaluate various 3D pointing interfaces (Drasic and Milgram, 1992, Zhai et al, 1994, Ware and Balakrishnan, 1994). However, even though we live in a 3D world, in most cases the problem of target selection can be accomplished with a 2D operation. This is possible because we normally wish to select objects that we can see and not those hidden from direct sight. The main exception for this is when transparent or semi-transparent objects exist and we want to select an object visible through another, but these instances are relatively rare.

There would appear to be advantages to using a two dimensional cursor: 1) a simpler input device can be used, such as a conventional mouse, and 2) the task would appear to be less difficult from the user's perspective. Thus, we hypothesize that selection times will be faster using 2D selection than using 3D selection.

Fish Tank VR provides an excellent environment for studying issues in reaching and target selection. In Fish Tank, a local virtual scene is created in the vicinity of the monitor by tracking the observer's head position and using this information to estimate the actual viewpoints for both eyes. With this information, it is possible to create a set of virtual objects in the vicinity of the monitor screen such that moving around them is like moving around real 3D objects (Deering, 1992, Ware, Arthur and Booth, 1993). The apparatus we use is illustrated in Figure 1. A position tracker is mounted on the stereo glasses and this tracking information is used to estimate the positions of the user's two eyes. This is then used to construct two perspective views, one for each eye. A hand held positioning device =4can be used to control a 3D cursor so that the cursor moves in 3D as the hand moves. We call this device a "Bat" (Ware and Jessome, 1988) because it is like a mouse that flies. The Bat has three buttons corresponding to a three button mouse. We can also use the Bat to control a 2D cursor by mapping movement in the vertical plane to movement on the screen.

If a screen cursor is presented in a stereo environment then the two eyes may see the cursor on top of two different objects or simply hanging in space. One solution, used in gunsights, is to close one eye. Although this solution might be applied to stereo graphic systems and Virtual Reality environments it complicates the interface since users must be told which eye to close and must learn to consistently close the same eye. Another solution is to present the cursor to only one eye and this is what we have chosen to investigate.

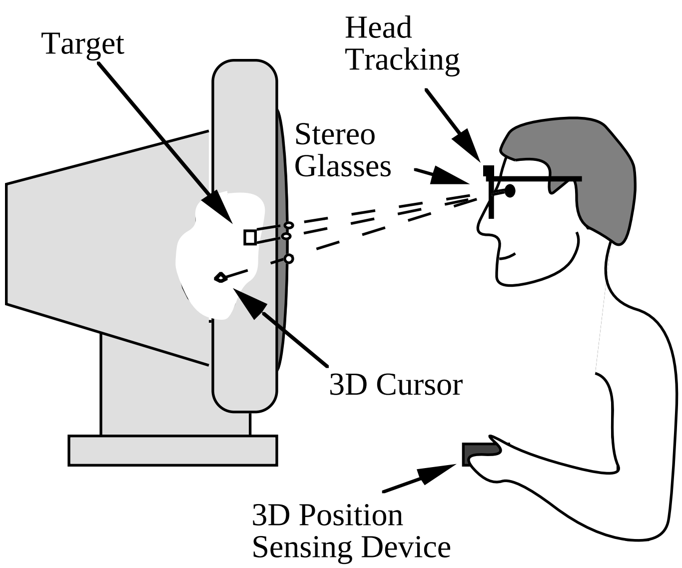

Figure 1. A Fish Tank VR system with 3D positioning using a hand held tracker. The use of a 2D cursor presents a problem if the scene is viewed in stereo.

It is possible to anticipate potential problems with a one-eyed cursor in 3D stereo environments. When radically different images are viewed by the two eyes, part of the conflicting information is suppressed. This phenomenon is called binocular rivalry. Thus, the cursor might disappear from sight because of rivalry with information presented to the other eye. However, research shows that small, high contrast moving objects are not likely to be suppressed (Blake and Overton, 1981) and so a high contrast cursor can be expected to remain visible. Moreover, binocular rivalry does not interfere with stereo depth perception because stereopsis and rivalry appear to be controlled by different processing channels (Wolfe, 1986). Therefore, a one-eyed cursor should not affect the spatial perception of objects in its vicinity.

Reaching in 3D for 3D targets is a basic activity in everyday life and it is reasonable to suppose that we have evolved to optimize it; the use of a 2D cursor might cause problems in user eye-hand coordination since 3D motion may be more natural for the selection of a 3D target. Although the one-eyed cursor should have no apparent depth, we can expect that it will become perceptually attached to the background object. This follows from the fact that after-images from flashes of light tend to be perceptually projected onto their background (Furedy and Stanley, 1970). Our informal observations suggest that this is indeed the case. The one-eyed cursor does not hover at an indeterminate depth, it is perceived on the object behind it and as such, it makes a natural pointing device.

We have been using one-eyed cursors for the stereo viewing mode in our network visualization environment for some time and we have found it to be very satisfactory. Our realization that this seems to be not merely a shortcut, but possibly a better solution to the problem, prompted the present study.

There is a standard experimental paradigm for measuring performance in one-handed positioning and selection tasks known as the Fitts' Law study. Fitts' Law describes mean movement time (MT) to select a target as a function of target distance and width. This law has been found to hold for a large number of different devices and different experimental paradigms.

We choose to use a variant on Fitts' Law that provides the closest match to the underlying information theory (MacKenzie, 1992) .

$$MT = a + b \log_2(A/W + 1.0) \qquad (1)$$

A is the distance from the initial cursor position to the center of the target, W is the target width, a and b are empirical constants and the expression $\log_2(A/W + 1.0)$ is known as the index of difficulty (ID). This analysis is based on a loose analogy with information processing, whereby the number of choices involved in the task is related to A/W (Fitts, 1954). Once the empirical constant b has been determined, the index of performance, IP = 1/b, can be derived. This value estimates the information processing rate in bits/second.

Mackenzie (1992) also provides a method for factoring different error rates into the IP estimate. When errors are high people are in effect processing less information. The method involves using the distribution of hits on the target to compute a virtual target width. This changes the ID and IP measures to take target width into account.

1.1 Fitts' Law in 2D and 3D

Aside from the purely pragmatic concern with finding the fastest selection method, there is a more theoretical reason why this study should be considered interesting. It relates to the issue of how to extend Fitts' Law to a three dimensional task. As originally conceived, Fitts' Law applies only to one dimensional movement. Time to select a target is measured as a function of the target width and target distance in the direction of movement. The early experimental studies required horizontal movement to tall vertical targets so that precise positioning is required in only one direction; essentially making it a one degree of freedom task. However, in practical interfaces, targets can have a variety of shapes and sizes and they can be two or three dimensional. Recently, there have been some attempts to extend Fitts'

Law to higher dimensional tasks. In the most extensive study, MacKenzie and Buxton (1992) show that two formulations work well for rectangular targets of various shapes and sizes.

In the first formulation, the index of difficulty is specified by the following expression:

$$ID = \log_2(A/W' + 1.0) \qquad (2)$$

where A is the distance to the target and W' is the width of the target in the direction of motion. Essentially, this reduces to a one dimensional task performed along a line from the starting point through the center of the target.

In the second formulation:

$$ID = \log_2(A/(\min(w,h)) + 1.0) \qquad (3)$$

where w and h are the width and the height of the target. In this case, the target is treated as a two dimensional object but the distance A is still a one dimensional scalar.

It is important to note that both of these formulations suggest that a two dimensional task is no more difficult than a one dimensional one. To make this point explicit, we consider making a horizontal movement to select either a tall narrow bar or a square with the same width (as illustrated in Figure 2). Both estimates of ID (2) and (3) are the same, suggesting that the time to select the target should be the same. However, a common sense prediction is that task B should be more difficult because the subject has to be precise in both horizontal and vertical directions. We give this example to suggest that there may be shortcomings in both of MacKenzie and Buxton's extensions to Fitts' Law, although we do not have any better formula to offer.

Both of MacKenzie and Buxtons formulae can be simply extended to 3D. For example (3) can be extended to

$$ID = \log_2(A/(\min(w,h,d)) + 1) \qquad (4)$$

where w,h and d represent the three dimensions of the box shaped target. For the sake of conciseness we confine ourselves to considering formulae (3) and (4) in the remainder of this paper. However, the same set of arguments and conclusions can be developed from formula (2).

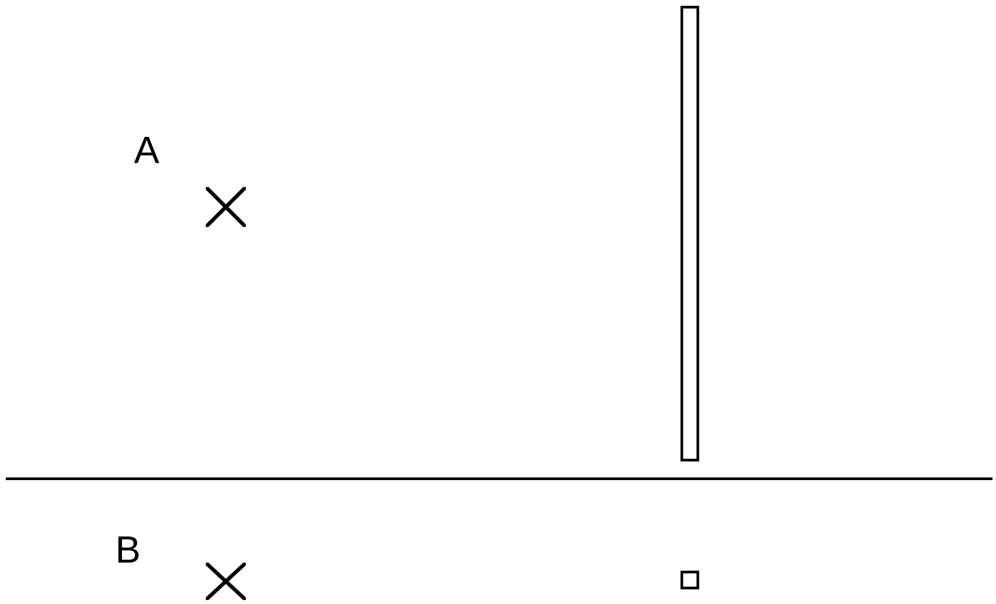

Figure 2. In task A the cursor must be moved to select a tall narrow bar. In task B the cursor must be moved to select a square of the same width. Some theories of target selection suggest that these tasks are equally difficult.

Most virtual reality systems have significant lag between the time the user makes a movement and the time the result appears on the screen. Even small amounts of lag affect performance in reaching tasks. Ware and Balakrishnan (1994) developed a theory of how system lag impedes performance in reaching tasks. They designed a new variation on Fitts' Law that makes it possible to factor out system lag in assessing task performance.

$$MT = a + b(HumanProcessing + MachineLag)\ ID \qquad (5)$$

In this variation, human processing and machine processing are assumed to occur in series. The machine determines the user's hand position and displays the new cursor position before the user assesses the need for a new corrective movement and makes the correction. This cycle continues until the target is acquired. The human processing time is found to be about 200 msec. If the machine lag value is removed from this study, the index of performance measured becomes:

$$IP = 1/(b*HumanProcessing) \qquad (6)$$

IP values measured in a 3D selection task by Ware and Balakrishnan, were found to be low, about 2.5-3.0 bits/sec, although not outside of the range of one dimensional Fitts' Law studies (values of 2.6 and 10.4 bits/sec are cited in MacKenzie, 1992). This suggests that reaching in 3D may be harder than reaching in 2D or 1D. However, in order to convincingly determine if this is the case a direct comparison between 2D selection and 3D selection is required using a carefully designed experiment.

For completeness we note that a study by Johnsgard (1994) directly compares 2D and 3D object selection. The results showed 2D selection to be better than 3D selection. Unfortunately the results are confounded by the fact that the 2D task was carried out with an accurate, low lag mouse, while the 3D task was carried out with a high lag, low accuracy Nintendo Power Glove.

In the present study, we use the setup illustrated in Figure 1 to explicitly compare the use of a one-eyed 2D cursor with the use of a 3D cursor for 3D target acquisition. We can expect that 2D selection will be faster than 3D selection for two reasons. The first is that if the movement required is into the screen, then the ID values will be lower simply because the 2D screen distance is shorter than the 3D distance (see Figure 3). The second reason is that even when the distances are the same, the task will be harder in 3D because precision is required in three dimensions rather than two.

Stating these arguments formally in two hypotheses:

Hypothesis 1: We predict that target acquisition times are shorter for 2D selection using a one-eyed cursor because the 2D screen movements areshorter than the 3D movement (directions (Z) and (XZ) in Figure 3). Therefore, our null hypothesis is that 2D and 3D MTs are the same.

Hypothesis 2: We predict that target selection times are shorter with the 2D selection even where the distance is the same. That is, selecting a 2D target is faster than selecting a 3D target because the tasks requires precision in fewer dimensions. Our null hypothesis is that a model based on formula (4) for 3D and formula (3) for 2D will yield the same IP values. If this were the case, the selection of a square and a cube should be equally difficult for a lateral movement (direction (X) in Figure 3) because the index of difficulty is almost the same for both. We expect to reject this hypothesis.

Note that if we use a 2D cursor to select any part of the cube, as opposed to the front face, then the task is slightly easier because the perspective projection of a cube is larger than a single square face. However, we correct for this in our data analysis.

2. METHOD

The general Fish Tank VR setup was the same as that used by Ware and Balakrishnan (1994) and is illustrated in Figure 1. A within subjects design was used. For each trial the task required the selection of a cube shaped target. The selection method in half the trials was two dimensional and in the other half was three dimensional. For 2D selection it was only necessary to position the one-eyed cursor over the screen image of the target; for 3D selection it was necessary to place the cursor inside the target. In both cases the cursor was activated by pressing the Bat button and selection was by releasing the button. The cursor always started in a fixed position and pressing the button locked the current hand position to the cursor. The C:D ratio was always 1.0. So, a hand movement in a particular direction resulted in an equal cursor movement in the same direction. In the 2D cursor trials, hand movements towards and away from the screen had no effect.

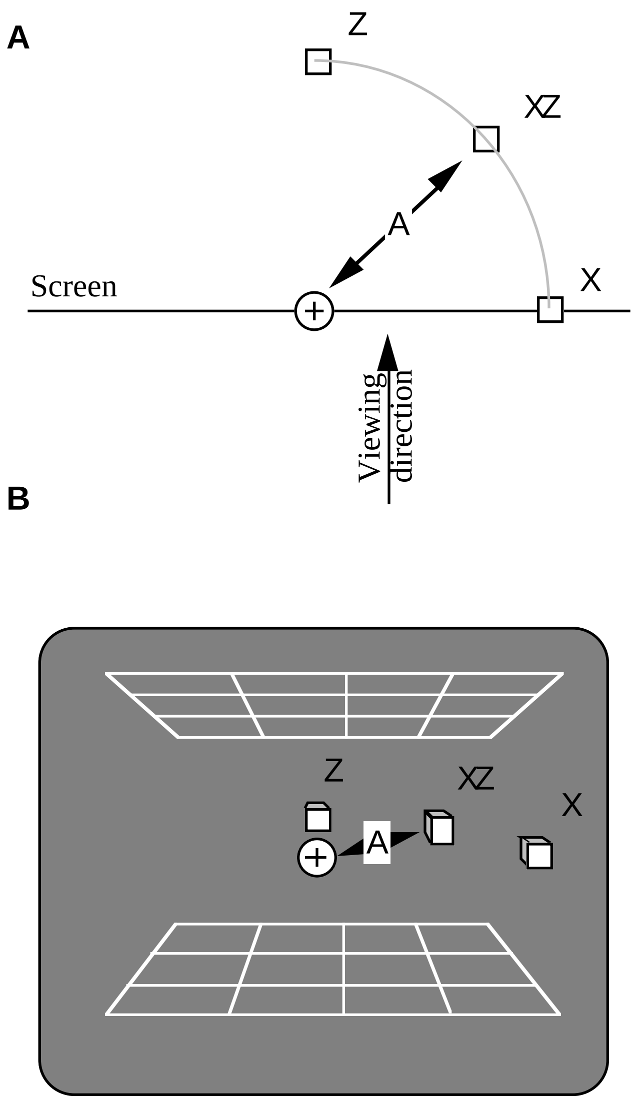

Figure 3a is plan view of the three different directions of movement. The ⊕ marks the initial cursor position and the three squares mark the three different target locations. In Figure 3b, we see the three targets from the viewpoint of a subject looking from a horizontal position slightly above the targets. Notice that target positions in directions (Z) and (XZ) are closer to the starting position for 2D selection than for 3D, while (X) is at the same distance for both. Also notice that the 2D size of the target is dependent on the viewing position because of perspective effects.

2.1 Apparatus

The visual stimuli were generated using a Silicon Graphics ™ IRIS Crimson with VGX graphics and a 19-inch stereo capable monitor (120Hz, 60 Hz to each eye),with a resolution of 1280 by 492 pixels in stereo mode (approximately 37 pixels per cm horizontally and 18 per cm vertically). Stereoscopy and tracking of the head position was achieved using the StereoGraphics CrystalEyes ™ shutter glasses with an integrated Logitech head tracker. The experiment was conducted entirely in stereo and the subject's head position was continually tracked in order to provide a correct perspective view. This system was capable of maintaining an update rate of 60Hz (for each eye) under all experimental conditions. A Polhemus Isotrak ™ is used to track hand position.

2.2 Stimuli

The screen background was set to a dark gray color. Two light gray wire mesh grids were drawn in the horizontal plane at the top and bottom of the screen (as shown in Figure 3b). The purpose of these grids was to enhance the perception of depth in our VR display. The cursors were shades of purple with different shapes to remind subjects of selection type. The 2D cursor was a pyramid shape while the 3D cursor was a red diamond shape (like a radar reflector). Both were coupled to the user's hand via the Bat. The target was a purplish cube with solid borders (1 pixel wide antialiased lines) and translucent faces. The back face of the cube, respective to the direction of movement, was made more opaque than the other five faces. This served as an aid in determining when the cursor had penetrated the back face and was no longer inside the target. The reason for the avoidance of green in the cursor and target colors was due to the slow decay of the green phosphor on the monitor which results in ghosting effects with stereo viewing.

The three directions of motion for target acquisition are illustrated in Figure 3:

(Z) a distance A into the screen,
(XZ) a distance A at a 45 deg angle, and
(X) a distance A across the screen.

The distance is always relative to the initial cursor position.

There were two target distances (6cm, 12cm) and two target sizes (1cm, 3cm) in each of the three directions.

To estimate the 2D sizes of the targets and the 2D distances we took two subjects of average height, one male and one female, and measured the distances on the screen display for each of the experimental conditions. The average values are given in Tables 1 and 2.

Dist A	(Z)	(XZ)	(X)
6 cm	0.71	4.56	5.90
12 cm	1.55	8.80	11.80

Table 1: The 2D screen distances between cursor and target for the different directions (values in centimeters).

Dist A	Cube Size	(Z)	(XZ)	(X)
	1 cm	1.09	1.08	1.05
6 cm	3 cm	3.26	3.24	3.05
	1 cm	1.05	1.02	1.00
12 cm	3 cm	3.09	2.99	2.90

Table 2: The estimated 2D screen sizes (min(width,height)) for the differenttarget sizes, distances and directions (values in centimeters).

We measured the head lag and the hand lag in the tracking systems and found head lag to be 114 msec and hand lag to be 87 msec (see Ware and Balakrishnan 1994 for details).

The subjects were instructed to press down the Bat button to start each trial, drag the cursor to the target and then release the button when the cursor is in place. In 2D selection, they were told that they only needed to put the center of the cursor over the target box. In 3D selection, they were told to get the center of the cursor inside the cube. The experimenter demonstrated to subjects that the target box had transparent front and back faces to make it possible to see when the cursor was inside the target. Subjects were also instructed to work as fast and accurately as possible.

2.3 Conditions

The trials were grouped into blocks. In a single block there was a fixed selection method, a fixed direction and all 4 distance-size combinations repeated 8 times for a total of 32 trials. The trials in a block were given in a random order.

A complete session consisted of nine 2D blocks and nine 3D blocks interspersed in a balanced design. This yielded a total of 24 trials per individual condition (a particular distance/size/direction/selection method). In addition to these experimental trials, there were 72 practice trials at the start of the experiment and 2 practice trials added at the start of each block. A subject could take a break before any block began.

2.4 Subjects

There were 12 subjects, consisting of graduate and undergraduate students. Each subject was tested using stereograms to ensure that they could see in stereo. Subjects were paid for participating.

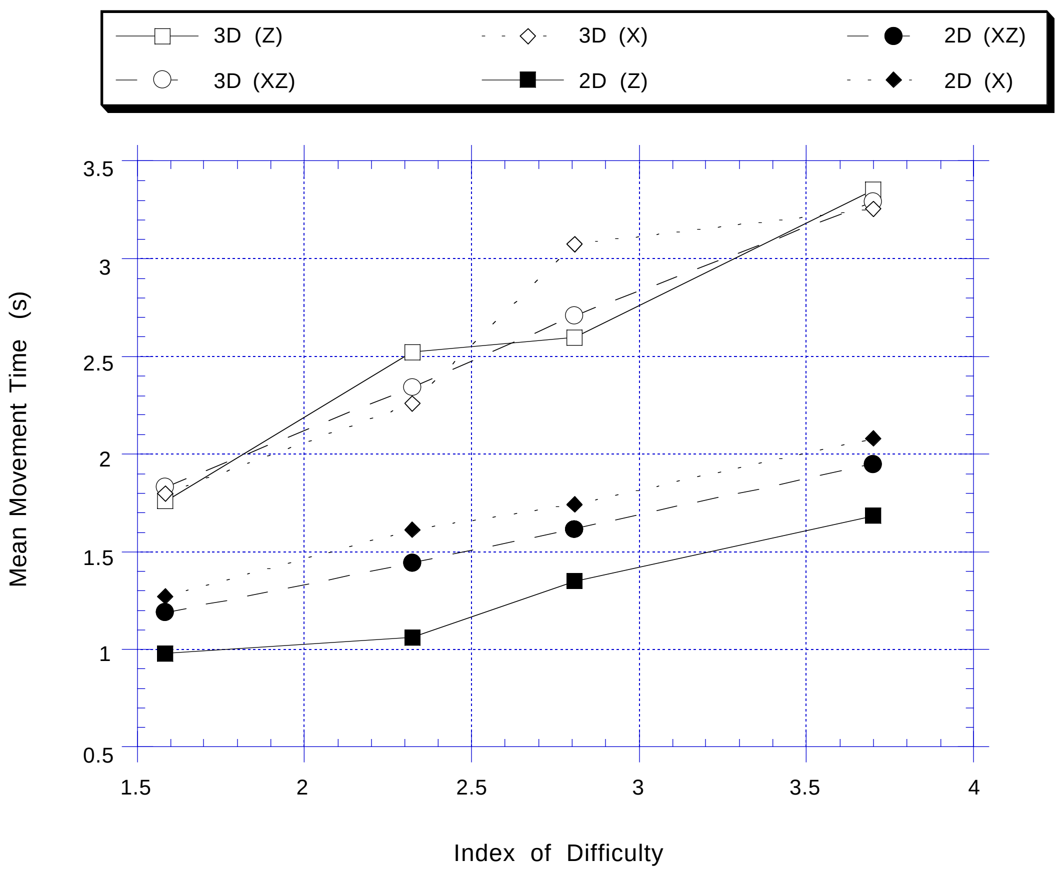

Figure 4. Mean movement time is plotted against the index of difficulty. Points for the 2D selection with the one-eyed cursor are shown with filled black symbols while points for the 3D task with the 3D cursor are shown as outlined symbols.

3. RESULTS

Figure 4 shows movement time plotted against index of difficulty. In order to make a direct comparison between the 12 conditions of the 2D and the 3D selection methods the plot uses the ID defined for the 3D conditions (equation 4). While this is not correct for the 2D conditions (because the 2D distances are shorter), it does allow a direct comparison between 3D and 2D selection for the purpose of testing hypothesis 1. We find that 2D selection using the one-eyed cursor is considerably faster than 3D selection for all 12 conditions. A binomial test is sufficient to reject Null hypothesis 1 ($p < 0.01$).

The errors in target selection are also lower for the 2D selection method. The percentage errors for the conditions shown in Table 4. Since 2D selection resulted in lower error rates than 3D selection for all 12 subjects, this difference is highly significant ($p < 0.01$, binomial test).

Conditions	**(Z)**	**(XZ)**	**(X)**
2D	0.3	1.2	1.1
3D	4.8	3.3	3.6

Table 4. Summary of errors given as percentages.

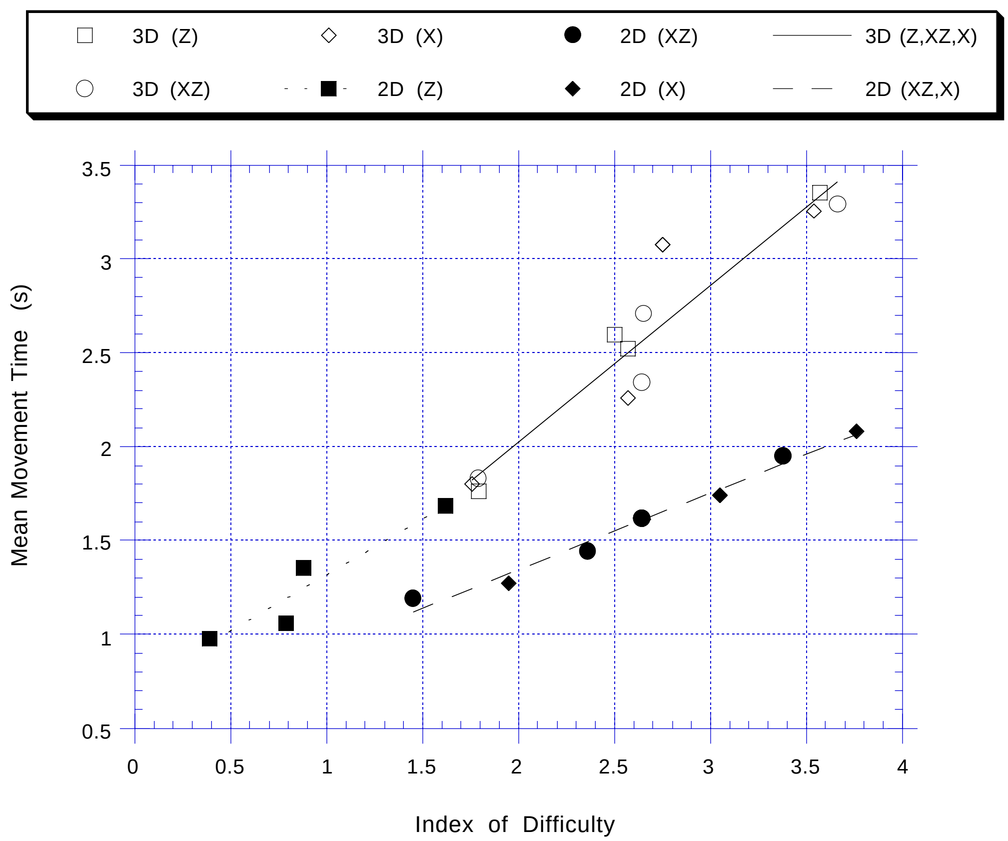

Figure 5. Mean movement time is plotted against the corrected index of difficulty. Points for the 2D selection with the one-eyed cursor are shown with filled black

symbols while points for the 3D selection with the 3D cursor are shown as outlined symbols.

To address the more theoretical issues relating to Fitts' Law, we must be more careful in defining the index of difficulty for the 2D conditions. We use equation (3) with values for w and h that are the width and the height of the *screen image* of the target cubes as shown in Figure 3b and A is the *screen distance* to the center of the target. The effect of this re-definition is to reduce the index of difficulty because the target sizes are increased and the target distances are decreased. We also apply MacKenzie's (1992) technique for factoring errors into the index of difficulty calculation.

Figure 5 shows the data replotted with the corrected index of difficulty values. The major change comes from the fact that the 2D distances are shorter. The data for directions (XZ) and (X) have now become approximately co-linear, and the data for direction (Z) has been shifted so far to the left that it no longer appears to belong to the same family of curves. The regression gradients for 2D selection (directions (XZ) and (X) are lower than those for 3D selection (directions (Z), (XZ) and (X)) *for all 12 subjects* and this is highly significant ($p < 0.01$). Thus we can reject null hypothesis 2, but only for directions (X) and (XZ). For direction (Z) the 2D data have a gradient that is closer to the 3D gradient than that of the other two 2D directions.

The three regression lines illustrated in Figure 5 are:

3D (all points) MT = 0.355 + 0.835 ID $r^2 = 0.952$

2D (XZ) and (X) MT = 0.526 + 0.410 ID $r^2 = 0.990$

2D (Z) MT = 0.722 + 0.594 ID $r^2 = 0.950$

To determinine the index of performance it is necessary to factor out the effects of lag. To do this we use equations (5) and (6). If g represents the single regression gradient from (5) we get:

g = b(HumanProcessing + MachineLag)

and so
b = g/(HumanProcessing + MachineLag)

then from (6) we get

IP = (HumanProcessing + MachineLag)/g(HumanProcessing)

Using a value of 0.087 sec. for MachineLag and 0.2 sec. for HumanProcessing results in an estimate the estimated IP values given in Table 3.

	3D	**2D (X),(XZ)**	**2D (Z)**
IP	1.72	3.50	2.41

Table 3. IP values for different selection modes

4. DISCUSSION

The fact that 2D selection with a one-eyed cursor is faster than 3D selection does not surprise us. We have used this method extensively in the lab for a number of practical tasks and believe that for stereo applications it is clearly superior to the 3D method. We have also been using one-eyed menus and dialog boxes and found them to be usable, although not as advantageous as the one-eyed cursor. These menus and dialog boxes look semi-transparent and as Harrison et al (1995) have shown there is interference between a transparent layer and its background. As well, the large speed advantage of the one-eyed cursor does not apply to menus since they are are already two dimensional.

A complication with the one-eyed cursor relates to the fact that some people have a pronounced ocular dominance. One of our subjects was aware the cursor was in his non-dominant eye and found this to be uncomfortable. Clearly, for these cases some simple dominance test should be provided so the cursor can be presented to the dominant eye.

From a theoretical perspective, the results are not as clear as we would have liked. For two of the directions of motion (laterally and at 45 degrees) the 2D and 3D data clearly belong to different families of curves. For the (Z) direction 2D picking is much faster than 3D picking, but it should be co-linear with the other 2D conditions and it is not. The reason may have to do with the direction of movement. Directions (XZ) and (X) required predominantly lateral movement of the hand in order to acquire the target, whereas direction (Z) required a short upward movement. Whisenand and Emurion (1995) found considerably longer movement times for upward movements in a Fitts' Law task, although they used a conventional mouse for input.

The index of performance values that we obtained are on the low side even for 2D picking (although well within the range of previous studies). A possible explanation for this is that subjects were required to do the task with an unsupported hand: The availability of hand support when using a conventional mouse may make the task easier.

Using a one-eyed cursor is not the only way of turning the selection of a three dimensional target into a two dimensional task. Another method that has been used is a kind of virtual pointer consisting of a line in 3D space controlled by a hand held pointing device, capable of sensing both position and orientation. If the hand is held still and simply rotated then only two degrees of freedom of rotation are necessary to ensure that the line will pass through any object in the 3D scene (Liang and Green, 1994; Bolter et al, 1995) . Because of this, the index of difficulty will usually be reduced, much as it is in the task described in this paper. The empirical evaluation of these interfaces has yet to be done to find out if the result obtained here generalizes to such designs. This is an area for future research.

There are many other issues related to the use of a one eyed cursor, such as, how natural it is to switch from a truly 3D task, 3D object placement, to a task that can be done in 2D like 3D target selection. We are currenlty building a new environment to explore the issues of manipulating and navigating through 3D environments. We plan to use the 2D one-eyed cursor for selection of 3D targets then determine how well this integrates with other common operations.

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