TwistMouse for Simultaneous Translation and Rotation

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ABSTRACT
We propose a mouse input device, the TwistMouse, with three degrees of freedom: horizontal (x), vertical (y) and rotational (z) for simultaneous translation and rotation of on-screen objects. We describe the construction of a prototype device and present a usability evaluation to investigate the appropriateness of the twist mode for positioning 2D objects on screen.

Categories and Subject Descriptors
H.5.2 User interfaces – Input devices and strategies

General Terms
Design, Performance, Experimentation, Human Factors

Keywords
H.5.2 - Input devices and strategies and Prototyping; 3DOF, Mouse, usability

1. INTRODUCTION
The computer mouse was conceived in the 1960's as an input device that could be used in a "natural way" to indicate position on a display screen [1]. Since its release the mouse has gained wide acceptance as an input device. It has also undergone many transformations but its core functionality has remained largely unchanged.

The mouse is essentially a device that can sense motion in the horizontal and vertical directions and translate this to a pointer on a computer screen. But when we move physical objects in the real world we translate and rotate them simultaneously. Object manipulation is an integral task [2] and it follows that the application of the natural structure of human object manipulation to the computer interface (matching the perceptual structure of the task to the control structure of the input device) should improve the efficiency of positioning tasks [3].

The study is based on an unpublished University of Otago Intellectual Property Description for "TwistMouse – a computer mouse system providing three degrees of freedom" by the second author. The main problem to be solved with this description was the lack of a reliable and usable support of 3D navigation using a desktop device. It turned out that there are many more opportunities for such an approach.

The importance of this study lies in the possible applications of such a TwistMouse device should it be found to be effective, efficient, and satisfactory. Some possible applications identified so far are arranging graphical elements on screen (2D), 3D navigation support, 2D and 3D manipulations in CAD systems or direct manipulation of GUI elements like turning knobs.

Because the TwistMouse offers simultaneous rotation and translation in positioning tasks but acts like a regular mouse most of the time it mitigates the need to change devices for certain tasks. Taking a very optimistic view, if the TwistMouse shows significant gains over other devices in usability studies it could replace the contemporary computer mouse as the standard input device for the desktop computer.

The paper is based on a dissertation work of the first author under supervision of the second author. It highlights related work in the field, describes the design and implementation of the prototype device and presents a usability study to test the twist mode against two other (standard) positioning modes. As a first (incremental) step the support for a standard 2D task was chosen, to be improved by the introduction of a third degree of freedom: the rotation The usability results are reported in relation to the hypotheses, arguing that a twist mode is advantageous over other standard modes of operation in terms of all three components of usability.

2. TWISTMOUSE
2.1 Related Work
According to the theory of processing of perceptual structure the attributes of objects in multidimensional spaces can have different dominant perceptual structures, integral or separable [2]. Jacob, Sibert, McFarlane and Mullen [2] took this theory and hypothesized that the distinction between perceptual structures would be a key to performance of multidimensional input devices on multidimensional tasks. In this seminal work they concluded performance is improved when the perceptual structure of the task matches the control structure of the device.

This theory was studied in the context of object transportation and orientation by the human hand [3] and it was to conclude object transportation and orientation by the human hand have a parallel and interdependent structure. It was also empirically determined that the total object manipulation time is less than the sum of the object translation time and the rotation time.

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People have proposed some form of mouse-based rotation for about the last 20 years. From the literature two main schools of thought have emerged. The first uses two computer mice to accomplish orientation and began with seminal research of Myers and Buxton and Myers [6]. [7] claims two devices are faster than one. However the single-mouse techniques used in their study were not simultaneous. A few of the devices which have been proposed over the years are:

A Two-Ball Mouse [4] uses the x-y displacement data of two mechanical ball mechanisms coupled inside the chassis of a standard mouse to get the angular motion of the mouse through a simple calculation. However, the performance of this device has not been formally assessed.

The Rockin' Mouse [13] with four degrees of freedom, senses relative x-y position and tilting along both axes. A 30% performance gain over a regular mouse for 3D positioning tasks has been reported. A 2D study was not performed.

The Mushaca [11] was originally described in one and two sensor embodiments (Poston & Srikanth, unpublished). The two sensor device has been prototyped but no empirical study has been performed to evaluate its relative performance and usability.

The Yawing Mouse [8] offering a 3 DoF interaction technique based on a device made from two cordless laptop mice glued together on their lateral side showed a performance gain in a pilot study. While a good study it was noted the results were not statistically significant. Problems identified in the study include a small number of subjects, physically different devices for the modes and no measure of effectiveness.

Without sound empirical evidence it cannot be stated with any certainty that a 3DoF input device such as the Twistmouse proposed in this study is more appropriate for 2D positioning tasks on screen. Appropriate in this context is defined in ISO 9241 as more effective, efficient and/or satisfying to use.

2.2 Scope
This study is constrained to the prototype device developed by the researchers. The device can be used in three modes:

- As a standard mouse with 2DoF that uses a click and drag method on a rotate handle to rotate an object (as in Microsoft Office applications Word and PowerPoint).
- As a wheel mouse – a standard mouse that senses rotation through the scroll wheel: 2+1DoF [4]
- As a "TwistMouse" – a standard mouse with an additional (second) optical sensor that can be used to translate and rotate on-screen objects simultaneously.

The task used to assess usability in this study is an abstraction of a real world positioning task such as that encountered in applications like Microsoft Office or Open Office.

2.3 Hypotheses
This review of related literature has provided support and method for testing the following three hypotheses that collectively contend the TwistMouse is an appropriate device for positioning 2D objects on a computer screen:

Hypothesis 1: The effectiveness of the computer mice for positioning 2D objects on screen increases in the order standard mouse, wheel mouse, TwistMouse.

Hypothesis 2: The efficiency of the computer mice for positioning 2D objects on a screen increases in the order standard mouse, wheel mouse, TwistMouse.

Hypothesis 3: The TwistMouse will be at least as satisfactory to users for positioning 2D objects on a screen as the wheel mouse and both will be more satisfactory to users than the standard mouse.

3. DESIGN AND IMPLEMENTATION
3.1 Prototype Construction
The design for the prototype mouse combines ideas from the researchers with a prototype design outlined in [11].

The prototype TwistMouse is constructed from two "Genius NetScroll+ Mini Traveler" laptop mice with 800dpi optical sensors. The shortened mice are glued together nose to tail and connected through an internal USB hub. The buttons and scroll wheel of the front mouse in the combination are retained while it is shortened by removing a small section of the rear chassis. The scroll wheel and buttons of the rear mouse were able to be removed by excising a portion of the circuit board. The chassis of the rear mouse is shortened so as to be just large enough to accommodate the shortened board (Figure 1).

A "Targus micro travel USB 2.0 4-port hub" is used inside the combined chassis to connect the two modified devices. A two port hub would have been sufficient for the task but the choice was dictated by the availability of a device small enough to fit inside the case of the prototype. The USB connectors were removed from the hub to reduce its size and the connecting wires from the mouse circuit boards and the wire with a USB connection for the computer were soldered directly onto the pins of the hub (Figure 1).

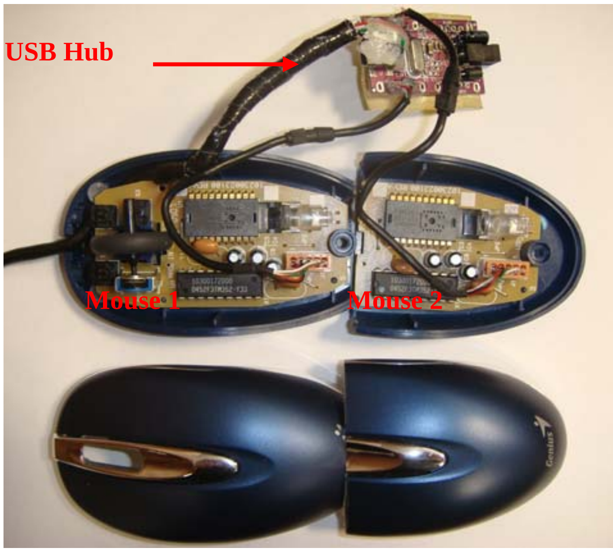

Figure 1. Prototype mouse used in study

3.2 Prototype Drivers and Settings
The software drivers for Mushaca: MouSim9 [12] and CPNMouse [7] were used to implement the prototype.

Informal pilot studies determined optimal mouse settings. However, a significant problem was encountered in Twist mode with pointer speed and its conflicting effect on the translation and rotation components of the pointer movement. Reducing the pointer speed improved rotational accuracy in all three mouse modes tested but in Twist mode this adversely affected translation performance.

A pointer speed of 3/10 was chosen for the study and the "enhance pointer precision" checkbox of the mouse item in the Microsoft Windows XP control panel was unchecked disabling the mouse acceleration algorithm. There is a 1:1 mapping of mouse to pointer movement in standard mode and a rotation of 10 degrees per scroll wheel click was chosen as optimal in wheel mode. In twist mode a mouse rotation of 45 degrees yields an on-screen rotation of 90 degrees; a 2:1 mapping of mouse to pointer movement. This mapping was chosen after several observations during the pilot testing revealed, that a full 360 degrees control would be hard to achieve otherwise. Because clicking mouse button works like a "clutch" here, the mappings were picked up easily by the pilot users. All the mappings are applied in the test application for the standard and wheel modes and the Twist mode also requires MouSim9 [12] to implement the mapping.

4. USABILITY EVALUATION

A usability study is conducted to evaluate the acceptability of the twist mode for on-screen 2D positioning tasks. This is done by comparing effectiveness, efficiency and user satisfaction of the twist mode with two more conventional techniques: the standard mode and wheel mode.

4.1 Study Variables

The independent variable in this study is the mouse mode. It is a nominal scale variable with values of:

- Standard Mouse (Standard): A mouse with 2DoF (horizontal x and vertical y) that uses a separate click and drag method on a rotate handle to rotate an object on screen. The standard mouse rotation method used in this study is similar to that used in the Microsoft Office applications Word, PowerPoint and Publisher.
- Wheel Mouse (Wheel): A standard mouse which senses rotation through the scroll wheel. The two positional degrees of freedom (horizontal x and vertical y) are controlled as usual, and the third, but separate, rotational (z) degree of freedom is controlled rotating the mouse wheel with a finger. However, it is also possible to perform translation and rotation simultaneously with the wheel mouse configuration used in this study.
- TwistMouse (Twist): a standard mouse with an additional (second) optical sensor. The change in the angle of rotation is calculated from the two sets of x-y positional data reported by the sensors. Movement of the mouse across a flat surface can simultaneously translate and rotate an object on screen.

The dependent variables in this study are efficiency, effectiveness and satisfaction. These variables are defined as follows:

- Efficiency: is measured as the time it takes to complete the 2D object positioning task used in this study with a particular mouse mode. The most efficient mouse mode is the one with which the least time is taken to perform the task.
- Effectiveness: is the accuracy and completeness of the task. In this study it is measured as the number of objects placed correctly (within the test limits) relative to the total number of objects for placement in the test. The most effective mouse mode is the one with an accuracy and completeness score closest to 100%.
- Satisfaction: the user's subjective rating of freedom from discomfort while using a particular mode in the test and their positive attitudes towards that mouse mode. In this study satisfaction is measured with questionnaires. Questionnaire items include physical operation, appeal and fatigue.

Several potentially confounding variables have been identified in this study and steps have been taken to mitigate their effect. Training will be given in the use of mouse modes to lessen any effect from lack of familiarity. The experimental design will compensate for any learning effects and gender. The mouse hand settings will be customized to the user and any potential participants with afflictions that may unreasonably impair their performance in the tests will be excluded.

4.2 Subjects

Twenty-four subjects (12 male and 12 female) were recruited to participate in this study from staff and students of the University of Otago, School of Business. Most subjects were in the 18 - 24 (11) or 25 - 34 (8) age group, with 3 in the 35 - 44 group and 1 in each of the 45 - 54 and 55 - 64 age groups. All of the subjects were experienced mouse users and regularly positioned objects on screen using the click and drag method of Microsoft Office or OpenOffice applications. Two subjects had used a computer mouse with three or more degrees of freedom but none of the subjects had used the prototype device or tested the three mouse modes (as implemented in this study) prior to this experiment.

Although three subjects indicated they were left-handed and one claimed to be left-handed or right-handed depending on the task, all preferred to use a computer mouse in a right-handed setup. A chocolate bar or energy drink was offered as a reward upon conclusion of the testing session.

4.3 Method

The methodology used in this study was bases on ISO 9241, part 9 (2000) and the study reported in [9].

4.3.1 Task

The task used in this study is an abstraction of the type of positioning task a user might perform in the real world when composing (for example) a PowerPoint presentation. It is essentially a matching task; subjects are required to position 16 numbered squares (pieces) on top of the corresponding square in 4x4 grid in the correct orientation (Figure 2) using the prototype computer mouse in each of the test modes.

Transparent pieces which turn from a yellow to a green colour when selected (piece 1, Figure 2), are presented to the subject in a random order (the same for each subject) and in different 90 degree orientations at the top left corner of the screen. When a piece is selected during the standard mode test a rotation handle appears for the standard mode method of click and drag rotation (piece 1, Figure 2).

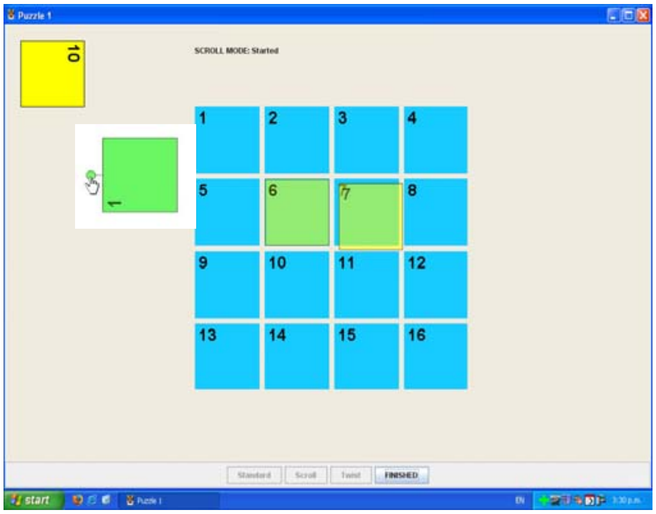

Figure 2: Test application showing puzzle pieces in different states and positions.

The squares of the grid are 5% larger than the moveable pieces that are to be positioned on top of them. The user does not receive feedback from the system when a piece was correctly positioned (piece 6, Figure 2) but a misaligned piece (piece 7, Figure 2) is visually significant in that any section of the piece that is not over the grid is yellow in colour compared to the green colour of overlapping the transparent yellow piece on the blue grid. Subjects are instructed that a correctly aligned piece is entirely inside the equally numbered grid square with the numbers in the same orientation. Although instructed to move as quickly and accurately as possible, subjects are not provided with performance feedback during the task. However, once the finished button is clicked subject performance data for the round just completed is printed to the screen.

For the efficiency evaluation the time a subject takes to complete the task using a particular mouse mode is calculated by the test application as the difference between the system time when the subject clicked the enabled mouse mode button to start the test and timer to when they clicked the finished button to stop the timer.

Effectiveness data is collected by visually analysing the test screen shots taken by the application for the accuracy and completeness of the task

4.3.2 Questionnaires

The instruments selected to measure user satisfaction of the mouse modes were an after-task and post-study questionnaire. Satisfaction describes a user's subjective response when using the product. User satisfaction is generally thought to be an important correlate of motivation to use a product and it may affect performance in some cases.

The after-task questionnaire is an independent ratings assessment of the subject's impression of each mouse mode being tested while the post-survey questionnaire is a comparative assessment of the mouse modes. A participant demographic questionnaire was also included in this study.

A demographic questionnaire is used to collect general participant information such as age group, gender, hand dominance, disabilities and computer and input device experience.

4.3.2.1 After-task Questionnaire

The after-task questionnaire used in this study is comprised of two parts. The first part: "Assessment of Comfort", consists of twelve questions on a 7-point Likert scale taken from ISO 9241, part 9 [9] and an open ended question asking the participant to describe how they physically grasped the mouse during the task. The questions cover issues of physical operation, fatigue and comfort, speed and accuracy, and overall usability. The scale is formatted in a positive direction, with the highest values being associated with the most positive impressions.

The second part of the after-task questionnaire "Assessment of Attitude" focuses more directly on user satisfaction. The eight questions on a 7-point Likert scale formatted in a negative direction, are taken are a subset of the IBM Computer System Usability Questionnaire (CSUQ) [14]. The questions cover aspects of efficiency, effectiveness, comfort, learnability, productivity and general satisfaction. A section for comments is included with each question in this part and participants are asked to elaborate on their answers.

4.3.2.2 Post-study Questionnaire

The post-study questionnaire is also composed of two parts. The first part: "User preferences", consists of seven questions adapted from the IBM Post-Study System Usability Questionnaire (PSSUQ) [14]. Subjects are asked to rank the mouse modes in order of preference for the given characteristics which are ease of use, precision, speed, comfort, learnability, productivity and general appeal.

The second part of this questionnaire is concerned with the design of the prototype device. Subjects are asked to indicate on a 7-point Likert scale how appealing they found the prototype device and whether the device influenced their assessment of the mouse mode. The scale is formatted in a negative direction. There is also open ended question asking the subject to describe any improvements they thought could be made to the prototype and why. All questions in the post-study questionnaire also invite subjects to comment further.

4.3.3 Testing Setup

In this study the experimental task was presented on a personal computer with a hyperthreaded Intel Pentium4 CPU running at 3.60GHz. The machine had 1GB of RAM. The screen, a 15" colour LCD screen was set to a resolution of 1024 x 768 pixels at 60 Hz. Even though a keyboard was not required for the test, one standard keyboard was included in the hardware setup so the configuration appeared to be that of a typical workstation. The PC was running Microsoft Windows XP SP2.

A typical office setup was used. An observer sitting behind and to the left of the subject recorded informal observations of the test.

4.3.4 Experimental Design

This study used twenty-four participants in a within-subjects experimental design. Each subject performed the 2D positioning task for each of the three mouse modes (treatments). The order in which subjects received the treatments was completely counterbalanced using six treatment plans. Four subjects were randomly assigned to each plan.

A within subjects design was chosen for this study because previous research [8] indicates the effect of the simultaneous translation and rotation on task completion times may not be strong. With a between subjects design any differences in the mouse mode results may be overshadowed by differences in the makeup of the test groups.

4.3.5 Assumptions

There are several assumptions underpinning this study. The first four relate to the tools used to test the hypotheses:

- The implementation of each mouse mode is optimised to provide the participant with the best possible experience of the positioning technique and the standard mode is comparable to mainstream implementations.
- The test application is suitable for measuring performance in 2D object positioning tasks on a screen and the task is generalisable.
- The questionnaires are a suitable measure of user satisfaction. Subjects will also be observed during the testing in this study to gather supporting information for the questionnaires.
- The prototype mouse device is sufficiently like a production mouse so as not to unduly influence a subject's performance or evaluation of a mouse mode.

For the chosen experimental design it is assumed that if present there is a symmetrical transfer of learning effect. The other assumption made in this study is the participants are representative of typical computer users.

The basis of these assumptions is that they give a close-to-the-real-world context to the study. This is important if the results from the study are to be considered as adding to the body of knowledge in the field.

4.4 Procedure

Subjects were booked into individual sessions with most lasting between 30 and 60 minutes. The purpose of the study (to investigate the usability of different mouse based methods for positioning 2D objects on screen) and the session procedure were outlined to the subject in an information sheet. Their rights and anonymity were explained in an attached consent form which they were asked to read then sign. Next subjects completed a demographic survey which provided information for customising the mouse setup (left and right button configuration) to their requirements. While these changes were made the subject was asked to read the Task Description and given an opportunity to ask questions.

Each participant received instruction and training in the use of the prototype mouse in the three mouse modes but this did not include any suggestion of how they should use the technique to accomplish a task. To facilitate keeping the information consistent for each participant the same coordinator ran each session and delivered information from a rehearsed script using a checklist of important items as a prompt. During the instruction section of the experiment the participant was also presented with a training application and encouraged to use it until they felt they had mastered each mouse mode. The time participants spent using the training application ranged from approximately 10 minutes to almost 20 minutes.

The subject was asked to work as quickly and accurately as possible in the test and to click the "FINISHED" button when they had completed the task. Three rounds of the task, one for each mouse mode, were performed. In each round the subject filled in an after-task questionnaire when the task was finished. At the end of the three rounds, when the subject had used all of the mouse modes in the test, they completed the post-study questionnaire. The coordinator recorded observations of how the subject used the device and mouse modes throughout the experiment and also noted any relevant comments made by the subject during the testing.

4.5 Results and Discussion

Data analysis was performed with SPSS version 13 and all significance testing is performed at the 95% confidence interval. Generally a one-way repeated measures analysis of variance (ANOVA) was performed to test for the significance of the effect of the independent variable (mouse mode). Where variances were indicated to be as a result of the independent variable post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. The 7-point Likert scale data obtained in this study is treated as interval data where the frequency distribution of the scores is approximately normally distributed. The data collected from all 24 participants was used in this analysis; the small number of outliers were not excluded.

4.5.1 Mouse Mode Effectiveness

Table 1 shows the task mean error results and accuracy for the three mouse modes in the 2D positioning task used in this study. All subjects completed the task for each mouse mode. There was little difference in the mean values and standard deviation between the three modes. A cumulative plot of the percent of population against the number of errors (Figure 3) reveals most subjects made less than 2 errors in the task for each mouse mode.

The assumptions for a repeated measures ANOVA did not hold so nonparametric tests (Friedman test and Wilcoxon signed-rank test) were performed to confirm there was no significant difference in the error results.

Table 1. Mouse mode effectiveness

	Standard	Wheel	Twist
Mean Completeness	100%	100%	100%
Mean Errors	.58	.67	.79
Std. Deviation	.929	.868	.932
Mean Accuracy	96%	96%	95%

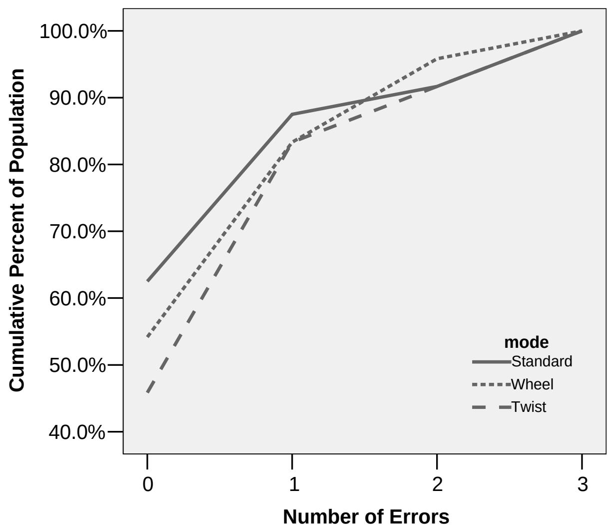

Figure 3. Cumulative plot of errors by mouse mode

Hypothesis 1: The effectiveness of the computer mice for positioning 2D objects on screen increases in the order standard mouse, wheel mouse, TwistMouse was not supported in this study as the accuracy and completeness of the tasks did not increase in the order standard mouse, wheel mouse, TwistMouse. No significant difference was found in accuracy or completeness and therefore effectiveness of the mouse modes for positioning 2D objects on screen.

4.5.2 Mouse Mode Efficiency

Table 2 shows the results for the task completion time using the three mouse modes. All but one of the twenty-four study participants was faster completing the task with the wheel mode than with either the standard or twist mode. Figure 4 shows that the distribution of the task time results for the mouse modes. The standard and wheel modes are approximately normal in distribution while the results for the twist mode are slightly skewed.

Table 2. Mouse mode efficiency

	Standard	Wheel	Twist
Mean Time (seconds)	186	113	174
Std. Deviation	51.24	37.02	48.34
Most Efficient (% trials)	0	96	4

A repeated-measures ANOVA was conducted to assess whether there was a difference between the mean test times of the three mouse modes. The assumptions of normality, homogeneity of variance and sphericity were tested and met. The results indicated the participant test times were different $F(2, 46) = 42.129$, $p < .001$.

Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. Participants were quicker completing the task using the wheel mode ($M = 113$, $SD = 37$) than they were with the standard mode ($M = 187$, $SD = 51$, $p < .001$) or twist mode ($M = 174$, $SD = 48$, $p < .001$). No significant difference was found between the task times for the standard and twist modes.

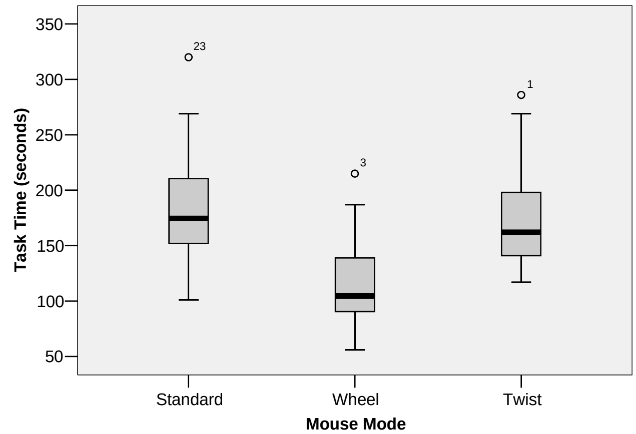

Figure 4. Box plots of task time results by mouse mode

Hypothesis 2: The efficiency of the computer mice for positioning 2D objects on a screen increases in the order standard mouse, wheel mouse, TwistMouse was not supported in this study as the task time did not increase in the order standard mouse, wheel mouse, TwistMouse. The wheel mode was found to be the most efficient of the three mouse modes for positioning 2D objects on screen; no significant difference was found in the efficiency of the standard and twist modes.

4.5.3 User Satisfaction with Mouse Mode

The after-task questionnaire used to collect data for the user satisfaction evaluation of the mouse modes in this study is divided into two parts. The first part consists of twelve items which are used to evaluate user comfort and the second part of eight items is used to evaluate attitude. The negatively worded scale items in the attitude section of the questionnaire were recoded before the data were analysed.

To assess whether the items that were summed to create the comfort and attitude scores formed reliable scales, Cronbach's alpha was computed using the questionnaires from all 24 subjects. The alpha for the twelve items that make up the comfort scale was 0.92 while the alpha of the eight items that make up the attitude scale was 0.96. Generally an alpha value above 0.70 is considered acceptable [10]. All items were retained in each scale for the subsequent analysis.

4.5.3.1 Mouse Mode Comfort

Table 3. shows the results of the comfort component of the satisfaction questionnaire for the three mouse modes. The mean composite comfort score of the wheel mode is higher than those of the standard and twist modes. Figure 5 shows that the distribution of the comfort results for the mouse modes. The standard and twist modes are approximately normal in distribution while the results for the wheel mode are slightly skewed.

Table 3. Mouse mode comfort

	Standard	Wheel	Twist
Mean Score	54.13	69.04	55.71
Std. Deviation	13.677	10.119	15.261

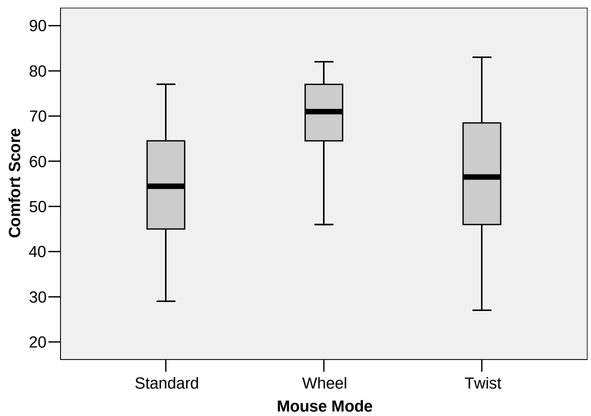

Figure 5. Box plots of comfort score results by mouse mode

A repeated-measures ANOVA was conducted to assess whether there was a difference between the mean composite comfort scores of the three mouse modes. The assumptions of normality, homogeneity of variance and sphericity were tested and met. The results indicated the participants did score the mouse modes differently in the comfort assessment $F(2, 46) = 14.806$, $p < .001$.

Post-hoc comparisons were performed using the Bonferroni adjustment for multiple comparisons. Participants scored the wheel mode ($M = 69.04$, $SD = 10.12$) more highly than either the standard mode ($M = 54.13$, $SD = 13.68$, $p < .001$) or the twist mode ($M = 55.71$, $SD = 15.26$, $p < .001$). No significant difference was found between the composite comfort scores the standard and twist modes.

4.5.3.2 Attitude towards Mouse Mode

Table 4 shows the results of the attitude component of the satisfaction questionnaire for the three mouse modes. The mean composite attitude score of the wheel mode is higher than those of the standard and twist modes. Figure 6 shows the standard and twist modes are approximately normal in distribution while the results for the wheel mode are slightly skewed.

Table 3. Attitude towards mouse mode

	Standard	Wheel	Twist
Mean Score	37.88	49.83	41.29
Minimum Score	17	34	22
Maximum Score	55	56	56
Percentiles: 25th	29.25	46.25	35.00
50th	40.50	51.00	43.50
75th	45.75	54.00	47.75

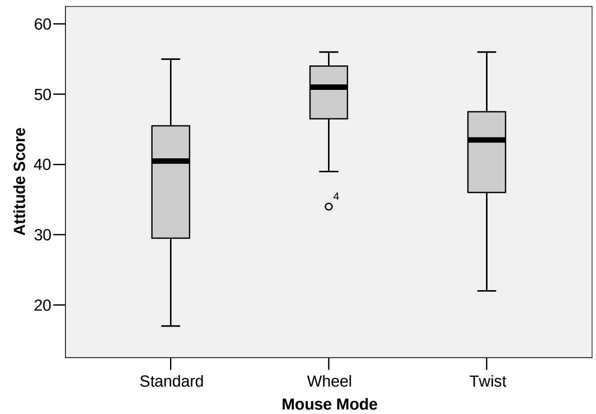

Figure 6. Box plots of attitude score results by mouse mode

The assumption of homogeneity of variance for a repeated measures ANOVA is violated for the attitude data (F-max = 3.39) so nonparametric tests were performed. A Friedman test was used to assess if there was a difference between the three mean ranks. The results indicated the participants did score the mouse modes differently in the attitude assessment X^2 $(2, N = 24) = 21.94$, $p < .001$.

Three orthogonal contrasts were performed using Wilcoxon tests with the Bonferroni correction (comparison-wise alpha = .017). The participants had a more positive attitude towards the wheel mode than either the standard mode ($z = -4.116$, $p < .001$) or the twist mode ($z = -3.164$, $p < .01$). No significant difference was found between the composite attitude scores of the standard and twist modes.

Hypothesis 3: The TwistMouse will be at least as satisfactory to users for positioning 2D objects on a screen as the wheel mouse and both will be more satisfactory to users than the standard mouse was not supported in this study as users did not find the twist mode at least as satisfactory as the wheel mode. Taking the results for comfort and attitude together as a score for user satisfaction the wheel mode was found to be more satisfying to the user for positioning 2D objects on screen than either the standard or twist modes; no difference was found between the user satisfaction of the standard and twist modes.

4.5.4 Other Findings and Limitations

The post-study questionnaire confirmed the ratings in the after-task questionnaires. The wheel mode was consistently ranked the preferred device by subjects for a range of characteristics (Figure 7.): highest rank 3; lowest 1.

More than 71% of subjects rated the prototype design as appealing. On the influence of the prototype design on their assessment, subjects were evenly split between agreeing (50%) or disagreeing (50%). to some extent. There was no strong rating and no-one gave a mid-point rating. Recommendations for the prototype device design were a wider body and shorter length. However one subject commented that they thought the longer mouse body reduced/prevented wrist fatigue.

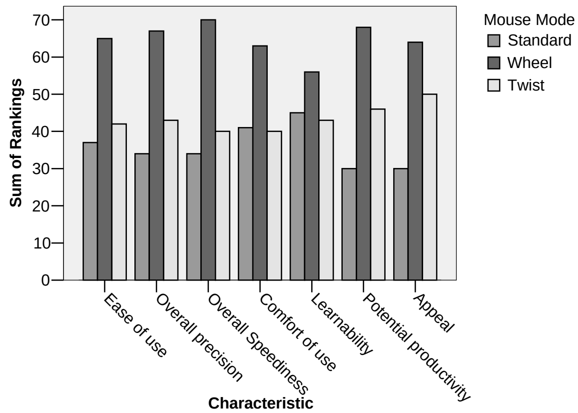

Figure 7. Bar graph of post-study results by mouse mode

Four important observations were made during testing: approximately a third of subjects appeared to have difficulty rotating pieces to align them and several commented that the implementation was not as smooth/easy as it is in commercial products like Microsoft Word. Second: at least half of the subjects experienced technical difficulties as a momentary stall while trying to translate a piece in twist mode. Third: some subjects (approximately 3) tried to prevent rotation during translation in twist mode and they found this difficult to do. Forth: only one subject out of twenty-four appeared to perform translation and rotation simultaneously in wheel mode.

5. CONCLUSION

In this study a 3DoF mouse based technique capable of integral 2D object manipulation on screen performed no better in a usability study than the standard technique similar to that available in Microsoft Office applications. However, a third technique which used the mouse wheel to perform rotation performed significantly better in most aspects of the study.

However half of the subjects experienced minor technical difficulties with the twist mode and a third thought the standard mode was not comparable to commercial products. This raises an important limitation with the study: if the assumptions do not hold then it is questionable as to whether the results will be applicable to a real-world task.

A surprising result in the user satisfaction analysis was although 5 subjects voiced concern about finger fatigue the overall results did not reflect a negative feeling. Despite this, could the awkwardness of the technique described by some account for the fact that only one subject, out of the twenty-four tested, rotated the object with the wheel while moving it across the screen?

It cannot be said with any certainty that the results of this study will be applicable to a real-world scenario. However, the wheel mode did perform better under the conditions in this study. These results are somewhat at odds with previous studies which found that positioning techniques that enabled simultaneous translation and rotation showed some performance benefits. However, it should be stated, that none of these studies were able to statistically indicate a significant difference in performance.

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