

# Zooming Interfaces! Enhancing the Performance of Eye Controlled Pointing Devices

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## ABSTRACT

This paper quantifies the benefits and usability problems associated with eye-based pointing direct interaction on a standard graphical user interface. It shows where and how, with the addition of a second supporting modality, the typically poor performance and subjective assessment of eye-based pointing devices can be improved to match the performance of other assistive technology devices. It shows that target size is the overriding factor affecting device performance and that when target sizes are artificially increased by 'zooming in' on the interface under the control of a supporting modality then eye-based pointing becomes a viable and usable interaction methodology for people with high-level motor disabilities.

## Keywords

Eye-tracking, pointing devices, assistive technology, zoom screen, graphical user interfaces

## INTRODUCTION

Eye-based pointing devices, or eye mice, have been in existence for many years within the motor-disabled community, with a small but significant number of disabled people using these devices to access computers and communication devices. Anecdotal evidence suggests that eye-based pointing is an inefficient means of pointing in assistive technology due to the inaccuracy of eye-tracking systems, making direct interaction with standard graphical user interfaces very difficult. To overcome this difficulty, most systems in use typically interact indirectly with standard graphical interfaces via soft devices or secondary interfaces specifically designed to allow for the limitations of eye-based interaction. Although these custom interfaces allow interaction, it is indirect and often laborious and cumbersome, reducing the benefits of direct pointing and

manipulation of the interface. The aim of this paper is to investigate the performance of direct manipulation using an eye mouse on a standard graphical user interface and to show how the performance of an eye mouse can be dramatically improved by the addition of a 'zoom screen' facility.

## The Benefits of Eye-Based Pointing

Firstly, eye-gaze has the potential to be a very natural form of pointing, as people tend to look at the object they wish to interact with [11, 17]. Secondly the speed of eye-gaze to locate a target can be very fast when compared to other pointing devices [23, 18]. Thirdly, due to the specialised nature of the muscles controlling the eye, natural eye movements exhibit little detectable fatigue and offer near fatigue-free pointing [16]. Finally, eye-tracking technology can be non-encumbering, as users are not required to wear or hold any device.

## The Costs of Eye-Based Pointing

Firstly the eye is not a highly accurate pointing device as it exhibits a positional tolerance [5, 12]. The fovea of the eye, which gives clear vision, covers a visual angle of  $\approx 1^\circ$  arc of the retina, hence when fixating a target the eye only needs to be within  $\approx 1^\circ$  of the target position to clearly see the target. This gives an inaccuracy in measured gaze position. Secondly, since eye gaze position cannot easily be consciously controlled or steered, as it is driven by subconscious interest [28], the eye tends to fixate briefly on targets of interest before jumping to other points of interest. Thus it requires effort to fixate steadily on a target for any extended period of time. Thirdly the eye is being employed as both an input modality to the user, so the person can see feedback from the interface, and an output modality from the user to the interface, indicating the pointing intention of the user on the interface. This convergence of interaction point and gaze point means that, without recourse to an additional command, the pointing cursor cannot be parked or left at a position on the screen whilst the eye momentarily looks away. This results in unwanted pointing movements at the feedback point on the

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computer screen as the cursor follows the eye wherever it gazes [12, 23]. Finally, eye-trackers are not widely available, and can be expensive.

#### **A 'Zoom Screen' Facility**

There is a clear relationship between target size and the performance of eye-based pointing devices, with the smaller targets found on common graphical user interfaces presenting considerable selection difficulties [9, 23]. Target magnification, such that the user can increase the effective size of target objects by temporarily 'zooming in' on the interface during a single interaction task, has been suggested in order to overcome the difficulties with smaller targets [10, 13]. However these 'zoom' devices have been based on *indirect* interaction with the interface, which is often a poor solution due to the additional interaction overheads of indirect interaction in comparison with direct interaction. Previous work [1] has confirmed with abstract target acquisition tests that adding a transparent magnification function that allows continuous *direct* interaction, with no visible on-screen device between the user and the interface, does increase the performance of eye-based pointing devices. Hence employing such a zoom screen facility retains the benefits of direct interaction and should also increase eye-based interaction performance. To date, this approach has not been tested during direct interaction with a standard graphical user interface.

#### **TESTING EYE-BASED POINTING**

A series of comparative 'real world' experiments were conducted to assess the performance and usability of direct eye-based interaction on a standard graphical user interface with and without zoom enhancement.

#### **A Baseline for Comparison**

In order to place the performance of eye controlled pointing devices in the context of other assistive technology pointing devices, an eye mouse with and without a zoom screen facility was compared to a standard head mouse. Head mice are very commonly used by people with high-level motor disabilities and are widely accepted as 'usable' pointing devices. If the performance of an eye mouse could approach or surpass that of a head mouse then it would offer a usable alternative pointing device for disabled users, without the fatigue often associated with head pointing. A standard desktop hand mouse was also included in the tests to give a known benchmark performance.

#### **Test Apparatus**

A standard PC running Windows was used for the tests. For the eye mice a Senso-Motoric Instruments [26] infrared video-oculography eye-tracker was used to measure eye-gaze position with a software driver used to move the cursor in response to the eye-gaze of the test participants. A Polhemus Isotrack [25] electromagnetic motion tracking system was used to measure the head position of the test

participants for the head mouse and a second software driver was used to move the cursor in response to head position. Target selection was by a hand held micro-switch and text entry was via a WiViK [27] on-screen keyboard. A zoom screen facility was implemented by controlling a specially modified Dolphin Computer Access Ltd. 'Supernova' [24] commercial screen zoom application, originally designed to magnify the screen for users with low vision, via a custom driver. The zoom level was controlled by two hand-held micro-switches, one to increment the zoom level and one to decrement the zoom level. Other supporting modalities, for example a multi-state sip-puff switch, could be used equally well for users with high-level motor disabilities. Four zoom levels were possible:  $\times 1$ ,  $\times 2$ ,  $\times 4$  and  $\times 8$ . During a zoom the complete screen was magnified, with the magnified area centred on the current cursor position. Participants were seated with a head or eye to monitor screen distance of 60cm on a seat with a backrest and head support to help participants to steady their head position and to increase seating comfort.

#### **A 'Real World' Test**

A 'real world' experimental test sequence, rather than an abstract target acquisition test, was used to test the performance of the devices. The test consisted of a series of simple tasks in two domains, word-processing with Microsoft Word and web browsing with Internet Explorer, that formed a natural flow of interaction. Two different domains were used so that any performance differences caused by the different nature of interaction in each domain could be identified. A total of 150 test tasks were constructed, with approximately half of the tasks comprising a word-processing sequence and half a web browsing sequence. The proportions of object usage, target sizes and interaction techniques in the two sets of tasks mimicked as closely as possible 'real world' interaction based on previous observation of users. The 150 test task objects that comprised the test, such as a button or menu item, were then assigned one of four size categories ( $0.3^\circ$ ,  $0.6^\circ$ ,  $0.9^\circ$ ,  $1.2^\circ$ ) based on the smallest visual angle subtended by the screen object central to the task at a distance of 60cm from the screen.

#### **Measuring Performance**

The usability of the mouse systems was assessed in terms of objective device *efficiency* and subjective user *satisfaction* based on the European ESPRIT MUSiC performance metrics method [3, 15] and the recommendations outlined in the ISO 9241 Part 11 'Guidance on Usability' International Standard [19]. These metrics were defined as follows:

- *Efficiency*: the objective performance of the device, expressed in terms of the amount and quality of interaction with the device and the time taken to perform that interaction.

- *Satisfaction*: the subjective acceptability of the device, expressed in terms of the user workload and comfort when using the device and the ease of use of the device.

**Efficiency**

The efficiency of interaction with the devices was calculated by measuring the quality of interaction during the tasks and the time taken for the tasks. Quality was assessed by counting the number of incorrect commands generated (such as hitting the wrong target), the number of intended targets missed (with no command generated), and the number of cursor position corrections. A cursor position correction was defined as a path variation or unnecessary pause of cursor movement during the task [14]. These variations and pauses indicate a lack of control when compared to an idealised ‘perfect’ cursor movement. Tasks were initially given a quality rating of 5 (perfect) [20], with subsequent errors reducing the quality until the task was completed or failed, and the next task started. To reflect the consequences of generating each error type, the quality factors were weighted, giving a simple formula for quality (Figure 1). Tasks were declared failed when the quality was reduced to 1. The time taken to complete the tasks was measured from the start of a task until the task was finished or abandoned and included all activities during the task, including any time taken controlling the zoom facility. Device efficiency was calculated by a simple formula (Figure 1). The formula was constructed so that completed tasks that have the highest level of quality and take no time would give a performance of 100%, with any reduction in quality or increase in time degrading the measured efficiency.

$$\text{Quality of interaction} = 5 - (3 \times \text{count of incorrect commands} + 2 \times \text{count of target misses} + 1 \times \text{count of control corrections})$$

$$\text{Device efficiency} = \frac{\text{Quality of interaction (1-5)}}{5 + \text{Time taken for interaction (secs)}}$$

Figure 1. Calculation of Efficiency

**Satisfaction**

Device satisfaction was measured using a multidimensional device assessment questionnaire based on the ISO 9241 Part 9 ‘Non-keyboard Input Device Requirements’ International Standard [19] and the NASA task load index questionnaire [8]. The questionnaire consisted of three rating sections: workload, comfort, and ease of use, with each giving a multidimensional score comprised of ratings from the factors within each section (Table 1).

The comfort and ease of use factors were chosen specifically to examine issues related to eye and head pointing satisfaction. 7-interval fully labelled scales suitable for input device assessment were used for rating all of the individual questionnaire factors [4, 2].

Satisfaction Questionnaire Sections	Section Factors (each rated 1-7)
Workload	Physical effort Mental effort Temporal pressure Frustration Performance
Comfort	Headache Eye comfort Facial comfort Neck comfort
Ease of use	Accuracy of pointing Speed of pointing Accuracy of selection Speed of selection Ease of system control

Table 1. Satisfaction Questionnaire Factors

**Test Subjects**

Six able-bodied test participants were chosen for the experiment. The participants were selected to give a wide range of experience using the head and eye mice from very experienced users through to novice users with little previous experience of the devices. Each participant was given training and practice to become familiar with the test tasks before the tests were started. A hand held mouse was used for the practice sessions and all participants were familiar with this device. The number of test participants required to identify the usability problems of a system can be quite small [22]. From this work, only six test participants were required to determine 100% of ‘high severity’ usability problems and at this number of participants 95% of ‘medium severity’ usability problems and 60% of ‘low severity’ problems were also found.

**Data Collection**

All data was obtained by capturing the complete contents of the test computer screen, including the cursor position, at a rate of 5 frames per second. The data was analysed by stepping through the video files and recording the quality and time taken to perform each task. In addition, the time taken by any non-productive actions during the task was measured and the nature of the non-productive action was recorded. The pointing accuracy of the participants with the devices was recorded after device calibration and before each test by asking the subjects to point at 9 equally spaced targets on the screen, with the overall mean distance

of the cursor from the targets recorded. From this, tests were only conducted with calibrations exceeding 75% of the accuracy obtained by expert users with the devices. This removed the possibility that a poor calibration would affect the test results. The head mouse and standard eye mouse tests were conducted in a random order with the zoom eye mouse tests conducted after development of the device. To avoid order effects, a gap of several months was left between the head and standard eye mouse tests and the later zoom eye mouse tests, with no intermediate practice with the devices permitted. Statistical comparisons were made using Mann-Whitney two-sample rank tests, with any significant differences ( $p < 0.05$ ) shown on plots where appropriate.

## RESULTS

### Task Domains and Efficiency

Figure 2 shows box-plots of the efficiency metrics for all tasks in each domain contributed by the 6 participants. There were no differences found in device efficiencies for the head mouse and standard eye mouse between the domains, indicating that the use of these devices was not affected by the nature of the tasks

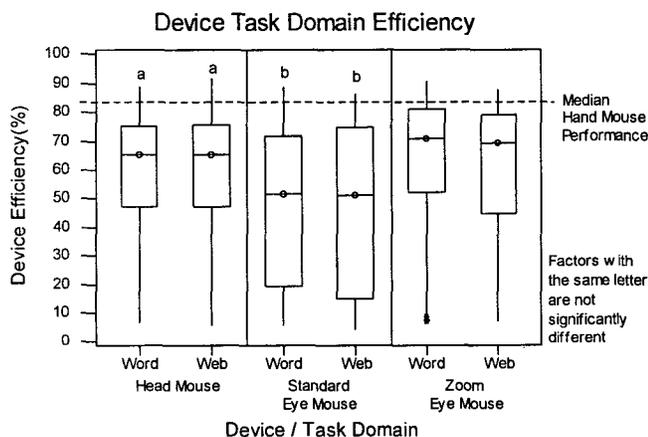


Figure 2. Device Efficiency by Domain

However, there was a small significant difference in performance between the domains for the zoom eye mouse. Pooling the efficiencies for the devices for both task domains gave an efficiency of 52% for the standard eye mouse, 65% for the head mouse and 70% for the zoom eye mouse. None of the assistive technology pointing devices rivalled the performance of the hand mouse baseline at 83%. The standard eye mouse performed poorly in comparison with the head mouse. However, the addition of zoom increased the eye mouse performance by 36% such that the performance of the enhanced eye-mouse outperformed the head mouse.

The small, 70.9% vs. 69.2%, but significant difference between the Word and Web domains for the zoom eye mouse can be attributed to the reduced time taken in

controlling the zoom facility in the word processing domain. The mean time taken for controlling the Word domain zoom level was 138ms, and for the Web domain zoom level, 236ms. It was observed that participants held the same zoom level over several tasks during typing. Participants would zoom in on the on-screen keyboard and type several characters before zooming out and observing the text generated, thus spreading the time to control the zoom facility over several tasks. The amount of text entry required for the word processing tasks was greater than that required for the web browsing tasks.

### Target Size and Efficiency

Figure 3 shows box-plots of the efficiencies for the 4 target size categories, pooled across participants and task domains. A similar pattern of efficiency increases with increasing target size exists for the head mouse and the standard eye mouse. Note that the efficiency of the standard eye mouse on the 0.3° target is very low, to the extent that it is probably unusable. This confirms the difficulty these devices have with smaller interface objects.

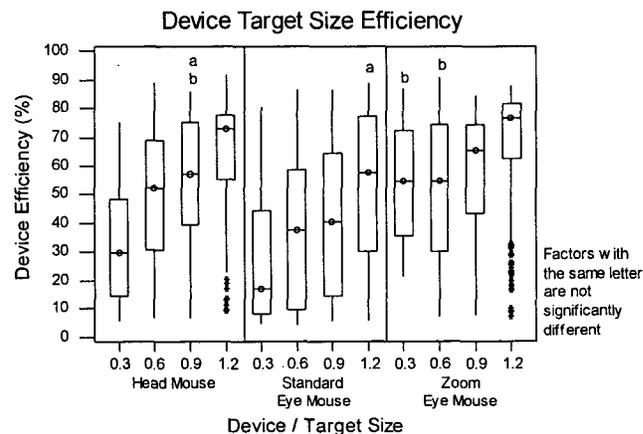


Figure 3. Device Efficiency by Target Size

Target size	Proportion of tasks in which zoom was used	Proportion of task time used to control zoom	Mean eye mouse zoom level used	Effective mean eye mouse zoomed target size
0.3°	94.4%	19.8%	5.39	1.62°
0.6°	85.9%	13.6%	2.80	1.68°
0.9°	62.7%	10.1%	2.03	1.83°
1.2°	42.7%	2.2%	1.43	1.72°

Table 2. Zoom Levels and Equivalent Target Sizes

There was a clear relationship between target size and the use of zoom, with zoom increasingly being used as target size decreased (Table 2). The use of zoom was most pronounced with the smallest target size with almost all

interactions using zoom at high levels. Translating the zoom levels into the effective zoomed target sizes used by the participants shows a consistency in effective zoomed target size for all targets, translating to an overall preferred size of 1.73° for all targets (Table 2). It is notable that the effective mean zoomed target size is just larger than the mean pre-test measured pointing accuracy of the eye mouse at 1.61°. This strongly suggests that participants magnified targets until they were just larger than the pointing accuracy of the device and hence could be selected accurately and reliably. The zoom levels used can be modelled by zoom level = 1.59 (target size)<sup>-0.89</sup>. This model is supported by a previous abstract target acquisition test using a similar direct interaction zoom method that found zoom level = 1.15 (target size)<sup>-0.99</sup> [1]. The slightly higher zoom levels found in this experiment compared to the previous abstract test are probably due to the higher consequences of error on the real interface causing participants to zoom targets to reliably acquired sizes. This again suggested that the use of the zoom enhancement with the eye mouse was affected by the nature of the tasks it was required to perform.

### Target Size and Quality

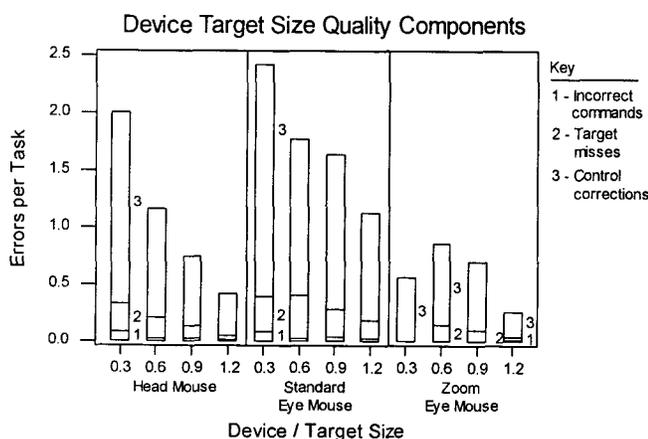


Figure 4. Device Quality by Target Size

Figure 4 shows a breakdown of the types of errors occurring for each target size, for tasks across both domains and for all participants. The task quality elements of the efficiency metric showed steady decreases in errors, and hence increases in quality, with increasing target size for the head mouse and standard eye mouse. All of the devices have low counts of incorrect commands, suggesting that the devices can be accurate when the consequences of error, such as correcting the outcome of an incorrect command, are high. The higher counts of target misses for the standard eye mouse in comparison to the head mouse indicate some difficulty in maintaining the cursor over the intended target during selection. This resulted in a ‘machine gun’ approach to selection with

multiple button presses close to the intended target but not hitting adjacent targets. The high rate of control corrections for the standard eye mouse in comparison to the head mouse indicates some considerable difficulty in manoeuvring and positioning the cursor onto a target – the rate is equivalent to more than one control correction per interaction. Of all of the quality metrics, it is clear that the number of control corrections generated by the standard eye mouse causes the most impact on the efficiency of the device.

Examining the results for the zoomed eye mouse we see the effect of the zoom facility, with a large reduction in control corrections. It is notable that the smallest target size has a disproportionately lower error rate than the larger targets, this is probably due to participants nearly always (94.4% from Table 2) zooming these targets so that errors rarely occur.

### Target Size and Task Time

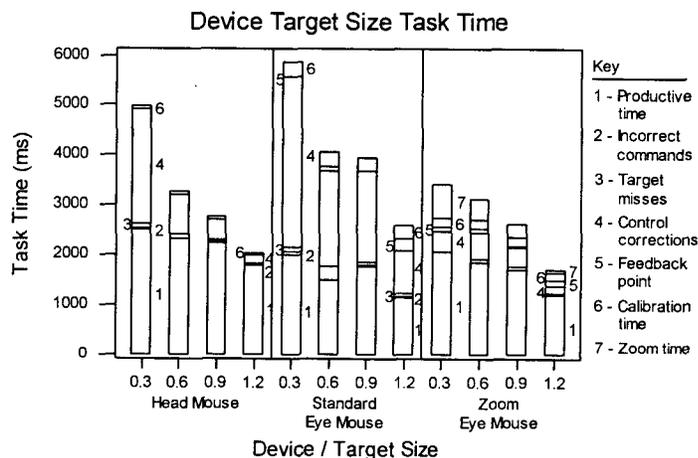


Figure 5. Device Task Time by Target Size

Task time was broken down into seven elements: productive time, the time lost generating incorrect commands, target misses and cursor control corrections, time lost whilst the eye mouse cursor was displaced looking at the feedback point on the interface, time taken for calibrations of the devices, and finally the time taken controlling the zoom facility. Looking at the individual elements of task time for the head mouse and standard eye mouse first (Figure 5), it was clear that time lost in cursor control corrections was by far the most non-productive element for these devices, indicating that considerable time was wasted correcting the cursor position onto targets. A comparison of the productive times shows that the standard eye mouse had shorter productive times (was more time efficient) than the head mouse, indicating that it has the potential to be superior to the head mouse if the non-productive elements can be reduced. The time lost in incorrect commands and misses was not significantly different between the devices.

Examining the zoom eye mouse results showed that it too had shorter productive times than the head mouse, indicating the potential to outperform this device, although it had slightly but significantly longer times than the standard eye mouse. This additional time is due to participants taking a little more time, without producing errors, during positioning of the cursor before zooming and may be due to participants planning the best cursor placement before zooming. The effect of the zoom facility on task time is marked, with a large reduction in the non-productive time due to control corrections to below that of the head mouse. The cost of controlling the zoom facility is shown in Figure 5, with the addition of a zoom non-productive time element indicating the time taken changing the zoom level. Zoom time, at an average of 8.2% of task time for all tasks, now becomes a significant non-productive time factor and approaches the time lost in cursor control corrections at 12.7%. This overhead is particularly important for smaller targets (Table 2), where zoom time becomes the largest non-productive time element. This indicates the need to find a more efficient method of controlling zoom, such as an automatic zoom based on user intent derived from gaze patterns or timings [6, 7]. In addition, based on the preference for an overall zoomed target size of 1.73°, all targets could simply be zoomed to this size using a single command, removing the need for multiple commands to step through each available zoom level. However, even with the overhead of zoom time, it is clear that the benefits of zoom outweigh the costs.

### Device Satisfaction

Figure 6 shows box-plots of the average of the individual ratings within each subjective assessment category (Table 1) to give the overall workload, comfort and ease of use ratings for the devices.

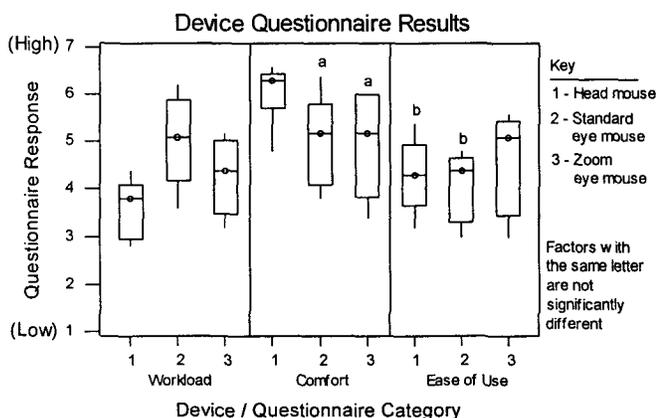


Figure 6. Device Satisfaction Questionnaire Results

### Aggregated factors

Examining the results for the head mouse first, it is clear that the device has the lowest workload and highest level of

comfort, indicating that the head mouse is probably the most sustainable to use over longer periods of time. However, its ease of use rating is no different from the standard eye mouse. The standard eye mouse had the highest workload and was less comfortable to use than the head mouse. The relatively low subjective acceptability of the standard eye mouse, together with the relatively low efficiency of the device supports the anecdotal evidence as a reason why eye-based pointing devices are not commonly used.

The addition of the zoom facility halved the difference in workload between the standard eye mouse and the head mouse, in spite of any additional workload caused by controlling the zoom facility. The zoom facility did not change the level of comfort, with the zoom eye mouse having the same comfort rating as the standard eye mouse. However, the zoom eye mouse showed the highest ease of use of all devices with a 16% improvement over the standard eye mouse.

### Individual factors

Table 3 shows the individual satisfaction ratings within the workload, comfort and ease of use categories and shows the eye mouse differences from the head mouse baseline. For all factors except pointing speed and clicking speed, the standard eye mouse was rated as poorer than the head mouse.

With addition of zoom, the eye mouse has retained superior ratings of pointing speed and has also gained superior ratings of pointing accuracy compared with the head mouse. This improved rating for pointing accuracy is supported by the reductions in the number of control corrections generated by the zoom eye mouse (Figure 4). However, the addition of the zoom facility has reduced ratings of clicking speed, as participants needed to spend time controlling the zoom level before clicking a target. This change in rating is supported by the addition of a zoom level control time to the task time (Figure 5). For the other factors, there is a small reduction in mental workload for the zoom eye mouse compared to the standard eye mouse, a potentially greater reduction is possibly offset by additional mental effort caused by operating the zoom facility. Both physical workload and frustration show marked reductions, probably due to the increased accuracy provided by the zoom facility allowing participants to relax more and feel confident of hitting targets. The addition of zoom has no effect on the comfort ratings of the eye mouse compared with the head mouse.

Overall, the addition of the zoom facility has reduced the eye mouse workload and increased the ease of use but has not affected the physical comfort experienced when using the device. Much of this discomfort seems to be due to participants being required to remain still in front of the eye-tracking camera. Eye-based interaction should be natural and fatigue-free. However, from these results, it is

clear that the eye-based devices are less comfortable to use than the head-based device. The head tracking facility of the eye tracking equipment was not used, as it was found to be ineffective for large changes in posture during trials. Consequently, participants were required to maintain a static posture whilst using the eye-mouse in both its forms. This is the probable cause of the relatively high discomfort ratings.

Factor / Device		Head Mouse	Standard Eye Mouse*	Zoom Eye Mouse*
Workload (low=good)	Physical	3.8	5.5 (+1.7)	4.5 (+0.7)
	Mental	3.8	5.7 (+1.9)	5.3 (+1.5)
	Temporal	2.7	4.3 (+1.6)	3.7 (+1.0)
	Frustration	3.7	5.0 (+1.3)	4.2 (+0.5)
	Performance (inv.)	4.2	4.7 (+0.5)	3.8 (-0.4)
Comfort (high=good)	Headache	6.5	5.5 (-1.0)	5.5 (-1.0)
	Eye	6.2	4.7 (-1.5)	4.3 (-1.9)
	Facial	6.2	5.0 (-1.2)	5.0 (-1.2)
	Neck	4.7	3.8 (-0.9)	3.7 (-1.0)
Ease of Use (high=good)	Pointing Accuracy	3.8	2.2 (-1.6)	4.7 (+0.9)
	Pointing Speed	3.5	4.5 (+1.0)	4.5 (+1.0)
	Clicking Accuracy	4.5	4.5 (0.0)	4.8 (+0.3)
	Clicking Speed	4.5	5.1 (+0.6)	4.2 (-0.3)
	System Control	5.2	4.1 (-1.1)	5.0 (-0.2)

\*Figures in brackets indicate difference from head mouse baseline

Table 3. Individual Satisfaction Factors

If, by the addition of reliable and accurate head tracking and re-calibration, the user was allowed to move more freely whilst operating the eye mouse, then it is likely the eye mouse comfort ratings would improve. It is notable that the intended users of eye-based pointing are often quite severely motor-disabled, making movement difficult. It is possible that the levels of physical discomfort experienced by these user groups would be somewhat lower than those experienced by the able-bodied participants used in these trials, making the zoom eye mouse a more attractive device.

## CONCLUSIONS

These experiments have investigated and compared the usability of a standard eye mouse and a zoom eye mouse to the baseline of a head mouse for direct interaction on a standard graphical user interface. Not surprisingly, it was found that none of the assistive technology pointing devices performed as well as a standard hand mouse when tested with able-bodied users who were all experienced users of hand mice. The performance of the standard eye mouse shows that direct interaction on a standard graphical user interface is more difficult with this device than with a head mouse. The addition of the zoom enhancement controlled by a supporting modality, however, lifts the performance of the device to the extent that its efficiency exceeds that of a head mouse. This has been achieved largely by reducing unnecessary cursor position corrections when selecting targets. The provision of the zoom enhancement reduced the high subjective workload ratings of the standard eye mouse considerably and lifted the ease of use of the mouse to higher than the head mouse. The measured performance improvement takes into account the cost of using the facility in terms of the additional time taken to use it. The provision of the zoom facility has not however resulted in a measurable improvement in the ratings of physical comfort for the eye-mouse in comparison with the head mouse. The static posture required to use the eye-tracking equipment effectively, thought to be responsible for the comfort ratings, may be much less of a problem when it is used by groups of users with severe motor impairments

The work has shown the value of measuring the various components of efficiency and showing in detail how the provision of the zoom enhancement has improved device performance. It also indicates where further improvements can be made.

Future work will investigate more efficient methods of controlling the zoom level, particularly in view of the constancy of the zoomed target size, and will also examine how the performance metrics of efficiency and satisfaction are changed when eye mice are used by high-level motor disabled users.

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