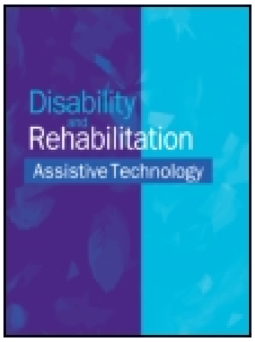

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Disability and Rehabilitation: Assistive Technology

ISSN: 1748-3107 (Print) 1748-3115 (Online) Journal homepage: http://www.tandfonline.com/loi/iidt20

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Disability and Rehabilitation: Assistive Technology, July 2008; 3(4): 221–235

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DEVICES AND PRODUCTS

Toward automatic adjustment of pointing device configuration to accommodate physical impairment

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Received 17 July 2007; revised 22 January 2008; accepted 6 February 2008

Abstract

Purpose. Software was developed which makes recommendations regarding configuration of a computer pointing device, such as a mouse, to accommodate a person's physical impairment. Specifically, a software agent automatically recommends a setting for the computer's control-display gain based on observations of a user's performance in a target selection task.
Method. The software agent makes its recommendations based on available adjustment settings in the existing operating system. The agent was evaluated in studies with 12 participants who have motor impairments.
Results. The agent-selected gain was not associated with significant improvements in selection time or error-free performance compared with the operating system's default gain. Across participants and trials, gain did not have a significant effect on selection time except at the lowest gain settings tested. However, two participants did have notable and consistent improvement in selection time and error-free performance using the agent-selected gain; gain across trials had a significant effect on number of target entries and number of submovements; and a post-hoc analysis indicated improved target selection time when varying both target size and control-display gain.
Conclusion. These observations provide possible avenues for future work, although the current study indicates that changes to control-display gain, alone, are unlikely to offer improvements in speed or accuracy for the general population of people with motor impairments.

Keywords: *Computer access, mouse, adaptive, motor impairment*

Background

Computer technology is increasingly important for vocational, recreational, and educational activities. In order for people with disabilities to take advantage of this technology, they need computer systems which are closely matched to their needs and abilities. Most user interfaces provide a number of settings which can be adjusted; but it is not always clear what settings are available, or how they can best be tuned for an individual user [1,2]. Typical parameters for pointing device configuration include those shown in Table I. Other settings may be available, depending on the specific device and device driver being used. For example, Logitech trackballs (Logitech, Fremont, CA, USA) allow the user to program the buttons to perform different functions. The trackpads common on laptop computers include settings related to cursor speed and whether the user can click by pressing on the trackpad or whether he or she must use the buttons.

Proper adjustment of these settings can be critical to efficient use of the pointing device for people with disabilities [3]. For someone with impaired motor control, the default pointer speed on the pointing device may cause the cursor to move much too quickly, making it difficult or impossible to select small targets such as toolbar buttons. Other difficult tasks include dragging the pointer with the mouse button depressed and clicking and double-clicking the mouse button while keeping the pointer still. Trewin and Pain reported target acquisition error rates of greater than 10% for 14 of 20 users with physical disabilities, and observed that 55% of the dragging tasks made by these users were unsuccessful [1]. An average of 28% of clicks in this study

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ISSN 1748-3107 print/ISSN 1748-3115 online
DOI: 10.1080/17483100801972975

Table I. Typical configuration options for pointing devices.

Parameter	Description
Button-handedness	Controls the functions assigned to the left and right mouse buttons.
Click method	Whether the user performs a single or double-click to select icons.
Double-click speed	Controls the allowable time between two clicks in a double-click.
Pointer speed (Gain)	How quickly the cursor moves across the screen in response to mouse movements.
Enhanced pointer precision	The Enhance Pointer Precision (EPP) setting enables a complex algorithm controlling the velocity and acceleration of the mouse cursor.
Snap-to-default	If this option is active, when a dialog box appears on the screen, the cursor will immediately move to the default button (e.g., 'OK').
Object size	It is possible to change the size (in pixels) of icons, menu bars, and other objects in the user interface. Increasing the size of these objects may make them easier to select, at the cost of reduced space on the screen. There may be many separate settings which could be adjusted to make different classes of objects larger.

included a mouse movement, which is a potential source of error, and 40% of multiple click attempts were unsuccessful [1].

Ideally, configuration is performed in consultation with a clinician who has expertise in computer access for people with disabilities. However, a trained clinician may not always be available. For example, Trewin and Pain [2] found that only 35% of 30 computer users with physical disabilities had a 'computer teacher'. Even when a clinician or other advisor with relevant expertise is available, input device configuration often requires considerable trial and error.

If computer support is not available, a person may use the default values for the device. Moderately inappropriate values may result in difficulty selecting targets, decreasing user performance and satisfaction. In a more extreme case, the system may be virtually unusable under the default values. Alternatively, the user may make his or her own adjustments. This requires that the user know that these parameters are available for adjustment and what to do to adjust them. This alone is a complex task. For example, performing all possible adjustments for keyboard and mouse within Windows XP requires accessing three separate Control Panel applications and nine different tabbed panels; not counting the possibility of making objects larger for easier selection, which would require accessing a number of additional Control Panel applications. Knowing the most appropriate values for all applicable settings may be even more difficult. Users may not understand how the parameter settings relate to the interface problems they are having, or if they do, the best choice of specific values may be unclear. Recent versions of the Windows operating system include an accessory program called the Accessibility Wizard, which provides some help in reducing the complexity of configuration. However, it does not include all available settings, nor does it give specific suggestions about how to appropriately set parameter values based on user performance.

Another challenge is that a given configuration may not remain appropriate for a user across time [4,5]. A user's needs may change due to a change in abilities (due to fatigue, progression of the disability, recovery of function, or other factors) or desired tasks (e.g., some computer activities may require greater precision than others). Even if a clinician is available to make an initial configuration recommendation, he or she will generally not be available every time adjustments to the configuration are desirable. If the user is responsible for his or her own adjustments, he or she may not notice a gradual decline in performance, or may not wish to take time to reconfigure the system. Interface configuration is secondary to the user's primary computer tasks; even if it can be done effectively, it takes time, physical effort, and cognitive focus away from more central tasks.

For these reasons, input devices are often not appropriately configured to meet users' needs, with consequent negative effects on user productivity and comfort. An automated software assistant (agent) on the user's computer could help ensure that input devices are properly configured for the individual, and reconfigured as the user's needs change. Such a software agent would need a means to observe the user's performance, and also to predict appropriate input device configuration settings based on performance.

Definition of gain

This paper is particularly concerned with configuration of a pointing device, such as a mouse, trackball, trackpad, or head-operated pointing device. One setting which is available for pointing devices is the control-display gain. Gain determines how far the cursor moves on the screen for a given movement of the pointing device. For the mouse, this is typically measured in pixels (on the screen) per inch (of physical movement of the mouse). The Windows control panel refers to control-display gain as 'pointer speed', and allows 11 possible settings.

These settings are assigned values in the range of 1 to 20 in the Windows registry. The default setting is assigned a value of '10', and corresponds to 400 pixels of cursor movement per inch of mouse movement. Lower gains (i.e., less cursor movement for a given pointing device movement) are assigned values of 1, 2, 4, 6, and 8. Higher gains (i.e., more cursor movement for a given pointing device movement) are assigned values of 12, 14, 16, 18, and 20. In this paper, the 'pointer speed' setting will be referred to as 'gain' for consistency with previous research.

Effect of gain on performance

For mouse users without physical impairments, gain does not appear to have a large effect on pointing performance within a moderate range of the default setting [6]. However, for people who do have physical impairments (from spinal cord injury, neuromuscular disease, cerebral palsy, or other conditions), gain may affect performance, and the 'just right' setting may be quite different from the default value. For example, someone with cerebral palsy may have some spastic movements that make it difficult to precisely control their pointing device. For this individual, a lower gain might better accommodate their spasticity. Someone with multiple sclerosis, on the other hand, may have good fine motor control but significantly reduced range of motion. For that individual, a higher gain might be a better fit.

In addition to differences between users' physical abilities, there are many pointing devices besides the mouse (trackballs, joysticks, headpointers, mousekeys, etc.). There are also different movement patterns that can be used with various pointing devices. A typical target selection movement with the mouse involved a single large, 'ballistic' movement which covers most of the distance to the target, followed by a number of smaller, 'homing' movements to correct for the error between the cursor position after the ballistic movement and the desired cursor position on the target [7]. While this is a stereotypical movement pattern with a mouse for people without disabilities, Zhai has described pointer movements that follow a constrained path as *steering* [8], and MacKenzie has referred to *throwing* the cursor across the screen using a single ballistic movement with a trackball [7]. Input methods like MouseKeys and (some) joysticks, on the other hand, allow the user to *drive* the cursor to the target with little or no actual hand movement. Finally, in informal observations we observed several users *crawling* towards the target using numerous small ballistic inputs.

The effect of gain on performance might be more important for one or more combinations of device, control method, and user characteristics. The limited literature that addresses this suggests that this might be the case. For example, Radwin and colleagues found that gain did have an effect on movement time for able-bodied individuals using a head pointer [9].

Another study compared subjects' throughput using a head-controlled pointing device for three levels of gain [10]. Throughput is a measure of speed corrected for distance traveled [7,10]. For subjects without disabilities, there was a moderate but consistent effect of gain. Throughput decreased and overshoot increased as gain increased. However, subjects who had difficulty reaching the targets were better able to do so with increased gain. Among the three subjects with disabilities, the gain resulting in best performance was different for each subject. Bayes' Theorem was used to calculate a decision boundary between those subjects who performed best with the standard interface and those who performed best with the decreased gain. This decision boundary indicated that subjects who had throughput less than 1.7 bits per second or overshoot greater than 10% with the medium gain would experience improved throughput with a decreased gain. On the other hand, subjects who were able to reach less than 90% of the targets would benefit from increased gain.

Adapting pointing devices to users' needs

If a relationship can be found between an individual's movement patterns and his or her optimal configuration settings, a software agent could customize the settings in response to the user's needs. This concept has been explored with a force-sensing joystick which adapted to hand tremor using measurements of the user's tracking ability and tremor [11]. A preliminary study with three subjects who had Friedrich's ataxia indicated that the adaptive joystick provided some improvement in performance for tracking tasks. Tracey and Winters developed a system to configure mouse settings in the Windows operating system based on subject performance on computer tracking exercises as well as direct questions directed toward an assistive technology clinician who had observed the user [12].

Work has also been done on enhancing pointing performance for people without disabilities. Balakrishnan reviewed a number of techniques for dynamically adapting the pointing device gain or target size based on cursor speed or position; for example, acceleration (higher gain for faster cursor speeds), semantic pointing (lower gain when the cursor is inside targets), and increased target size when the cursor is near targets [6]. While each of these techniques may have some isolated benefits, they may not generalize well to real-world interface use. For example, Balakrishnan identifies object pointing [13] as one of the most promising techniques, allowing pointing performance that averaged 74% faster in controlled experiments. In object pointing, the cursor skips over blank space on the screen; when the cursor leaves a selectable object and its velocity exceeds a threshold, it jumps to the next available target in the direction of the cursor's current movement [6,13]. While this works well for selecting individual targets, the speed improvement compared to standard pointing decreases as the user interface becomes more densely populated, with standard pointing being preferably in very densely populated interfaces [13]. Furthermore, object pointing does not allow for situations where the user might want to select arbitrary locations on the screen (e.g., in a word processor) or select a 'blank' location (e.g., to initiate selecting multiple objects); and may have perceptual drawbacks in real-world use [6,13].

In another approach [14], software attempts to predict a desired amplitude of cursor movement by determining the peak velocity of the movement. The software first learns a particular user's movement patterns, and the movement distances associated with different peak velocities. Once the software is calibrated, it monitors cursor movements and, when it has identified the peak velocity of a movement, 'jumps' the cursor to the predicted end location. The software was associated with a significant decrease in movement time for long movements (greater than 800 pixels) among 16 participants without disabilities.

For movements requiring unusual precision, a cascade neural network with Kalman filtering has been developed which can decrease movement error by an average of 39.5% based on data for microsurgeons [15]. Filtering was also explored in a mouse adapter for people with hand tremor, which filtered mouse movements and also provided support for people who have difficulty performing double-clicks [16].

These studies show the potential of pointing device configuration agents for use by people with disabilities. However, they have some limitations:

(1) The system developed by Tracey and Winter [12] assumed the presence of an assistive technology expert; in some cases, users may need or want to configure their systems independently;

(2) The system developed by McGill [11] was specialized for a particular group (people with Friedrich's ataxia) and a particular impairment (tremor); similarly, the systems developed by Ang and Riviere [15] and Levine and Schappert [16] were specialized for people with tremor;

(3) The systems described by McGill [11], Balakrishnan [6], Asano et al. [14], Ang and Riviere [15], and Levine and Schappert [16] make use of pointing methods that are not available with standard device drivers.

Preliminary work

To begin addressing these limitations, LoPresti developed and evaluated a system that automatically adjusted the gain for users of head-controlled pointing devices [17]. For 16 subjects with physical disabilities, the system was able to select settings that were appropriate for most subjects and provided a modest but significant improvement in performance ($p < 0.05$). This study provides the foundation for successfully developing a configuration agent for pointing device configuration. However, additional work is needed to apply this work to hand-controlled pointing devices and to provide a greater improvement in performance.

In a more recent study, 12 individuals received recommendations from an earlier prototype of the software described here, which we call an Input Device Agent (IDA) [18]. Each participant had a physical impairment which affected his or her ability to use a mouse. During a recommendation phase, IDA selected a gain for each subject. This was followed by an evaluation phase in which each subject's performance was measured under three conditions: (i) 'IDA', using the gain recommended by the agent, (ii) 'Default', using the default gain in the Windows operating system, and (iii) 'User', using the subject's own gain (which may or may not differ from the default). The IDA gain agent made recommendations that seemed reasonable and were readily usable by participants. However, the agent's recommendations did not provide large performance benefits, and paired *t*-tests showed no statistically significant differences. Gain effects may have been limited due to the specific choice of target sizes and distances. It is likely that IDA gain changes benefited certain types of targets and harmed others, thus resulting in relatively small net changes in performance across 32 mixed trials.

In a follow-up study to better understand the effects of pointing device settings and target size, seventeen subjects with upper extremity physical impairments performed four or more target acquisition trials [19]. Each trial included 32 targets: Four targets at each combination of four different sizes (18, 24, 40, and 100 pixels) and two different distances (50 and 512 pixels). Each trial with a given input device used one of four combinations of gain (low or default) and enhanced pointer precision (on or off) settings. After completion of all four combinations, the protocol was repeated with a second input device. Across all subjects, the low setting (where Gain = 6) with enhanced pointer precision active was the fastest condition. Looking only at each subject's best performing device, target acquisition time was about 14% faster with G = 6 compared to the default of G = 10. However, this significant main effect masks the fact that gain had different effects for different subjects. Across all subjects, there was a significant main effect of target size, with larger sizes requiring less acquisition time. There were also main effects of enhanced pointer precision ($p < 0.001$) and input device ($p < 0.001$). Performance averaged 23% faster with enhanced pointer precision on for the participant's best input device. Target acquisition times averaged 122% faster for each subject's best-performing input device compared to their second-best input device, using Windows default values for Gain/EPP settings. The results of this exploratory study cannot be definitive, but they strongly suggest the following:

(1) The gain setting for a pointing device often makes a difference, but that difference needs to be assessed for each individual;
(2) The Enhanced Pointer Precision setting should be on for most people;
(3) Increased target size may have a role as a further enhancement to pointing performance;
(4) The combination of appropriate pointer settings and increased target size can yield a definite improvement in target acquisition time and cursor control, supporting the value of an agent that can help establish the appropriate combination for each unique individual;
(5) Choosing the right input device hardware is at least as important as correct software configuration.

The results of this follow-up study suggested that revisions to the IDA pointing agent have the potential to enhance pointing performance.

Hypotheses

One goal of the current study was to determine whether a revised IDA pointing device agent can select an appropriate gain for individual users. In pursuit of this goal, the following hypotheses were tested:

1. The agent-selected gain will be associated with better performance than the default setting; specifically, the agent-selected gain will yield significantly more error-free selections and significantly faster target selection times compared to the default.
2. Participants will rate the agent-selected gain as providing easier target selection, a more acceptable speed of cursor movement, and a more desirable level of performance overall.
3. Performance with the agent-selected gain will be similar to the best performance achieved across all gain settings, specifically:
   a) The number of error-free selections with the agent-selected gain will not be significantly lower than with the 'best' gain, where the 'best' gain is associated with the highest accuracy and fastest target selection time across all available gain settings.
   b) Target selection time with the agent-selected gain will not be significantly longer than the target selection time associated with the 'best' gain.

Note that the agent will select a gain based on a non-exhaustive review of the available gain settings, guided by the agent's algorithm. In addition, this study investigated the perceived usefulness of an agent such as this; with a hypothesis:

4. Participants will rate the concept of a software agent for pointing device gain selection as useful.

Finally, this study investigated the effect of target size on pointing performance, in order to investigate possible agent-recommended changes in icon size and related parameters to improve pointing performance. To this end, two hypotheses were tested.

5. Increased target size will lead to significantly faster target selection times across subjects.
6. Application of agent-recommended gain settings in combination with increased target size will have a larger effect than either modification on its own.

If the IDA pointing agent can give appropriate guidance about a user's gain, this could help improve a user's initial and ongoing performance and satisfaction with their pointing device. A pointing agent which is able to provide such assistance would be combined with the IDA keyboard and scanning agents [20–22] to provide computer access assistance across input device modalities.

Methods

Software agent

The software agent described above [18,19] was modified based on the results of preliminary trials. The revised agent observes a user's performance over the course of four pointing trials. In each trial, the user is asked to select 33 targets (square icons on the computer screen). The initial target is intended to orient the user to the task, and is always located at the center of the screen. The 32 subsequent targets appear at one of two distances from the previous target (102 pixels or 512 pixels), in a randomly selected direction relative to the previous target, and with one of four sizes (16, 24, 32, or 48 pixels). For any given target, size and distance were randomly selected with the constraint that any set of 32 targets would include four targets from each size/distance combination (not counting the initial, orientation target). For each target, the user has 20 sec after the target appears to move the cursor into the target and select by pressing the pointing device button. When the target is selected (or after 20 sec if the target is not selected), the target disappears, the agent records whether the target was successfully selected, and the agent presents a new target.

Trial 1

Following the first target selection trial, IDA recommends a new mouse gain based on the number of target entries and the deceleration time. This decision is made according to a 'Y-metric' derived from preliminary data:

$$Y = 0.894 - (1.628 * \text{Decel}) + (0.244 * \text{Entries}).$$

'Entries' is the average number of times the cursor entered a target (e.g., one if the target was selected on the first attempt, greater than one if the cursor went in and out of target at least once and had to re-enter the target to select it, potentially zero if the cursor never entered the target). 'Decel' is the deceleration time (e.g., the proportion of target selection time which is spent decelerating the cursor) as illustrated in Figure 1. If this Y value is greater than or equal to 0.5, the agent recommends a decrease in pointer gain for the next trial; if $Y < 0.5$, the agent recommends an increase in pointing gain. The agent always recommends a change in the gain, rather than test the same gain twice during the recommendation process. Conceptually, a large number of target entries indicates difficulty controlling the cursor, and therefore that the cursor might be too sensitive. A high proportion of time spent in deceleration indicates that the cursor was still far from the target when the peak velocity was reached, and that a long deceleration time or multiple subsequent acceleration cycles were needed before the cursor reached its maximum distance from the starting position. In this situation, a higher gain might allow the user to move the cursor further during the initial acceleration cycle.

Trials 2–3

Prior to the second trial, the cursor gain is changed according to the Y metric. During the 2nd and 3rd target selection trials, accuracy (i.e., number of targets selected) and selection time (i.e., time from target appearance to target selection) are the primary measures used by the agent. If either measure is improved (higher accuracy or shorter selection time) without evidence of poorer performance on the other measure, then the previous change in gain is repeated (i.e., if gain was increased before, it is increased again; if decreased before, it is decreased again). If either accuracy or selection time show poorer performance, without improvement in the other measure, the previous change is reversed (i.e., if gain was increased, it is now decreased below the original value; if decreased before, it is now increased above the original value). If one measure is improved and the other is worse, or if both are about the same, then the gain is set halfway between the previous and current gain values; if this is not a valid gain setting, a decision is made based on the Y metric as in the first trial.

The agent is constrained to select a valid mouse gain for the Windows operating system (e.g., 1,2,4,6,8,10,12,14,16,18,20); and to try each setting only once. If a selected setting is not valid or has already been tried, the agent will select the closest valid setting in the selected direction (e.g., if increasing the gain, will try the next higher setting). If all valid settings have been tried in the selected direction, the agent will try the closest available setting in the other direction.

Trial 4

After the 4th and final trial, the agent compares performance across all four trials. The agent's final recommendation is the gain which was associated with the highest accuracy across all five trials. If two or more trials exhibited similar accuracy, the agent recommends the gain associated with the shortest mean selection time among trials with similar accuracy scores. If two or more trials exhibited similar accuracy and selection times, the agent selects the gain associated with the Y value closest to 0.5 from among those trials. Sample results for a series of trials, with associated recommendations, are given in Table II.

Participants

This agent was evaluated by 12 individuals with physical impairments. All subjects were current computer users, and 10 out of 12 subjects reported using a computer for 21 or more hours per week.

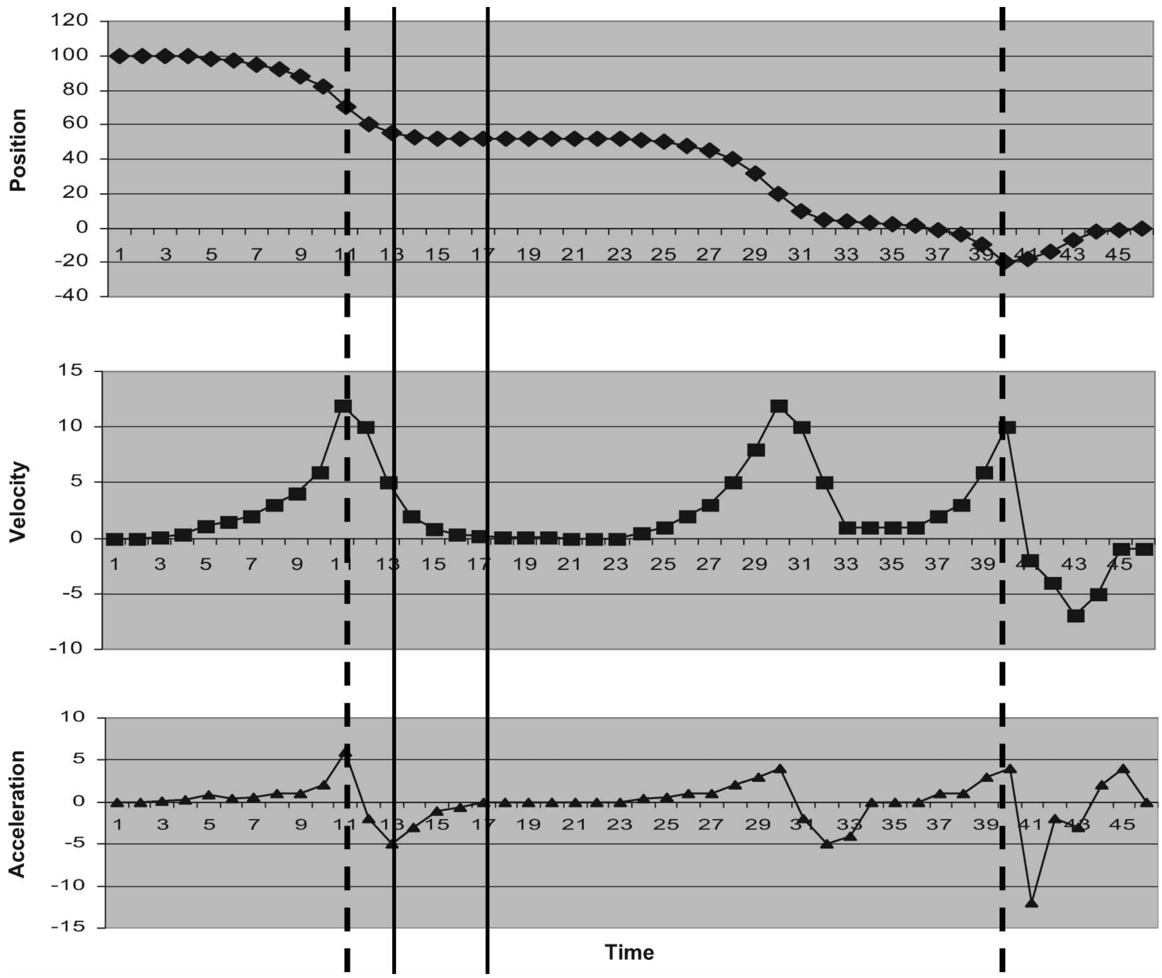

Figure 1. Deceleration time. Deceleration time is calculated as the difference between the time when the cursor reaches its maximum velocity during the first acceleration cycle (left dashed vertical line) and the time when the cursor reached its greatest distance from the starting position (right dashed vertical line). An acceleration cycle is defined as starting when the cursor begins to accelerate (time zero above for the first acceleration cycle), and ending when either the cursor has accelerated, decelerated, and is beginning to accelerate again (solid vertical line at time 17) or when the cursor velocity has decreased to half the peak velocity (solid vertical line at time 13), whichever occurs first. The first acceleration cycle is defined as being the first movement toward the target (e.g., an initial movement away from the target is not considered to be the first acceleration cycle). For the example illustrated, the first acceleration cycle is from time 0 to 13, and the deceleration time is from time 11 to 40 (decal = 29).

Participants were recruited from the local Center for Independent Living and United Cerebral Palsy center, and written informed consent was obtained. Table III provides some basic characteristics of the participant group.

Protocol

Data were collected in a single session. At the beginning of the session, the participant completed a questionnaire which requested demographic information such as education, employment status, diagnosis, and age. The questionnaire also asked for details about the participant's current pointing device and general computer use.

Once the questionnaire was complete, the participant performed a series of computer trials. Each participant performed between 10 and 14 trials across three blocks (Table IV). The first block of four trials constituted a *recommendation phase*, in which the agent evaluated the user's performance in order to recommend a gain setting. This recommendation was based on the process described above and summarized in Table II. The initial gain during the first trial was the Windows default gain of '10' (400 pixels per inch of mouse movement).

The second block of trials constituted an *exhaustive search phase*, in which the participant performed trials at available gain levels not attempted during the recommendation phase. The order of presentation was determined according to the same method used by the agent in trials 2 and 3 of the recommendation phase. Trials continue until the participant has attempted all gain settings from 4 – 16. The participant could also be assigned trials at gain settings 1, 2, 18, and/or 20, but only if recommended by the

Table II. Summary of agent decision-making with sample performance.

Trials	Agent action following this trial	Sample performance: Gain, start of trial	Relevant performance measures	Decision
1	Select the gain for the next trial based on the Y metric.	10 (Windows default)	Target entries = 1 Deceleration = 0.5 Y = 0.324 Accuracy = 0.97 Selection Time = 3.5	Y < 0.5, therefore increase gain to next valid level (which is 12)
2	Select the gain for the next trial based on the change in performance between the previous and current trials.	12	Accuracy = 0.97 Selection Time = 4.1	Improvement in selection time with no change in accuracy; repeat previous change (i.e., increase gain to 14)
3	Same as 2	14	Accuracy = 0.91 Selection Time = 3.6	Decrease in accuracy and selection time; therefore, reverse previous change. Initially recommend changing gain to 12, but since 12 and 10 have already been tried, change to next lowest new value (which is 8)
4	Make a final gain recommendation based on which gain was associated with the highest accuracy, or the fastest performance among those with similar (high) accuracy.	8	Accuracy = 0.97 Selection Time = 2.9	Accuracy is best for gains 10, 12, and 8; of these, selection time is best for gain 12
Final gain				12

Table III. Basic characteristics of the participant group.

Subj ID	Sex	Age	Diagnosis	Education	Pointing device	How long participant has used current device
4	F	69	MS	HS	Trackball	5 years
7	M	39	SCI (cervical)	Some college	Trackball	<1 year
10	F	28	SCI (C7)	MS	Mouse	2 years
15	M	24	MD	HS	Mouse	Not reported
16	F	44	CP	Associates	Touchpad	6 years
18	M	42	TBI	Some college	Mouse	5 years
20	M	48	SCI (C5)	MS	Trackball	10 years
21	M	42	SCI (C4/C5)	Some college	Mouse	1 year
25	M	29	CP	HS	Mouse	13 years
28	F	24	Freidrich's Ataxia	BS	Mouse	Not reported
30	M	24	SCI (C4/C5)	BS	Trackball	1 year
31	M	40	SCI (C5/6)	BS	Trackball	7 years

Table IV. Overview of computer trials. 'n' is the total number of cursor gains attempted, and can be between 7 and 11 since presentation of gains 1, 2, 18, and 20 is dependent on performance at gains 4 and 16.

Phase	Trial	Setting gain for next trial	Other recommendations
Recommendation	1	As per trial 1, Table II	
Recommendation	2 to 3	As per trials 2–3, Table II	
Recommendation	4	As per trials 2–3, Table II	As per trial 4, Table II
Exhaustive search	5 to $(n-1)$	As per trials 2–3, Table II	
Exhaustive search	n	N/A	As described in text.
Evaluation	$(n+1)$ to $(n+3)$	N/A	

testing software. Therefore, this phase includes at least three trials and as many as seven, to attempt all necessary gain settings. At the end of this phase, a 'best' gain condition is selected based on all trials in the recommendation phase and exhaustive search phase. The 'best' setting is the gain which was associated with the highest accuracy across all trials; if two or more trials exhibited similar accuracy, the best setting is the gain associated with the shortest mean selection time among trials with similar accuracy scores. The decision method for the 'best' setting is therefore similar to the final agent decision, except that it does not consider the Y score and has a larger range of gain settings from which to choose. It is possible (and in fact ideal) for the 'best' gain to be identical to the agent-selected gain, indicating that the agent selected the best setting during the first four trials.

The final block of trials for each participant constituted an *evaluation phase*, in which the participant performed three final trials at three gain settings: (i) The gain selected by the agent after the evaluation phase, (ii) the Windows default gain of 10, and (iii) the 'best' setting across the evaluation and exhaustive search phases. The order of these three conditions was counterbalanced, with two subjects assigned to each of six possible condition orders.

Before each trial in each phase, the participant performed a practice set of nine targets. Therefore, for each gain in the first two phases and each condition in the evaluation phase, the participant had the opportunity to select 42 targets (nine practice targets, one orientation target, and 32 final targets). Data is reported below based on the 32 final targets in each set.

For all trials and all participants, the computer display was set to a resolution of 1024 × 768 pixels, and Enhanced Pointer Precision was activated.

After each trial, the participant answered three questions about the trial:

1. Accurate pointing refers to how easily you were able to control the cursor and accurately select targets during this test.
   During this test, accurate pointing was:
   Difficult Easy
   1 2 3 4 5

2. How quickly did the mouse cursor seem to move around the screen?
   During this test, mouse cursor speed was:
   Too fast Too slow
   1 2 3 4 5

3. Use of this setting on a daily basis would be:
   Undesirable Desirable
   1 2 3 4 5

After completing all trials, participants were asked for additional information about the pointing device settings which they typically use, including how often the settings are adjusted, whether they know how to set them independently, and whether their pointing ability changes with time. Finally, they were asked, 'How useful would it be if your computer helped adjust your mouse speed at times to better match your abilities?' Answers ranged from 1 to 7, with 1 = 'Not at all useful' and 7 = 'Extremely useful'.

The following dependent variables were collected by the software:

- Accuracy: Percentage of targets successfully selected;
- Error-free targets: Percentage of targets selected with a single attempt (e.g., one mouse click event);
- Selection time: Time from target appearance to target selection (mean across targets);
- Target entries: The number of times the cursor entered a target (mean across targets);
- Deceleration time: The proportion of target selection time which is spent decelerating the cursor (Figure 1);
- Overshoot: Maximum distance traveled beyond the icon as a percentage of the distance to the icon from the starting position (mean across targets);
- Number of submovements: For which each submovement begins when the cursor begins to accelerate, includes cursor acceleration and deceleration, and ends when the cursor stops or just before it begins accelerating again (e.g., four submovements are shown in Figure 1; from times 0 – 17, times 17 – 34, times 34 – 44, and times 44 – 46).

In addition, participants' subjective ratings of software ease of use, speed, desirability, and potential value were collected using the survey questions described above.

These data were analyzed using *t*-tests between conditions (agent-selected, default, and 'best') and gain-target size combinations. Mixed model analyses were performed to evaluate effect of gain alone, and also the combination of gain, target size, and inter-target distance. To evaluate the stability of performance, selection time was compared between recommendation and evaluation trials for the same gain for the agent-selected and default gains. As another measure of stability, each trial of 32 targets was divided into four blocks of eight targets, and one-way analysis of variance was performed across participants and block order to look for a main effect of block order on selection time.

Results

Effect of IDA-selected gain

The gains selected by the agent for each participant are shown in Table V. 'Agent' gain refers to the gain selected based on accuracy, selection time, and Y-value after the recommendation phase (trial 4), while 'Best' gain refers to the gain selected based on accuracy and selection time after the exhaustive search phase. For two participants, the agent-selected gain was identical to the default; for four participants, the agent-selected gain was lower, and for the remaining six participants, the agent-selected gain was higher than default. Participants all had high accuracy, and accuracy was identical between the agent-selected and default gain conditions in each case. The number of error-free target selections during the evaluation phase was higher in the agent condition for four participants, higher in the default condition for two participants, and identical for the remaining five participants. Compared to the default condition, selection time during the evaluation phase was shorter (e.g., faster) with the agent-selected gain for seven participants and longer (e.g., slower) with the agent-selected gain for five participants, with no significant difference across participants. There were no significant differences between the agent-selected and default conditions for number of target entries, deceleration time, overshoot, or number of submovements.

The agent-selected gain was identical to the 'best' gain for four subjects, higher than the 'best' gain for two subjects, and lower than the 'best' gain for six subjects. There was no significant difference in selection time, accuracy, or error-free targets. The 'best' condition did have significantly lower time spent in the deceleration phase of movement and higher overshoot. This reflects the fact that the 'Best' gain was typically higher than the agent-selected gain, and therefore the cursor may have moved faster but been more difficult to control.

A mixed model analysis was used to evaluate the overall effect of gain on pointing performance, with a random effect of participant number and a fixed effect of gain. Data across participants and across trials were used for this analysis. There was a significant main effect of gain on selection time ($p < 0.001$). Post-hoc analyses showed that the source of this effect was the significantly slower selection time at gains of 4 and 6 (Figure 2). In fact, there was no significant difference across gains 8 through 20, which have mean selection times within 10% of each other.

Differences among gains between 8 and 20 are present for other performance measures. Gain had a significant effect on the number of target entries ($p < 0.001$). Specifically, a gain of 4 was associated with significantly fewer target entries compared to a gain of 10; while all gains above ten were associated with significantly more target entries compared to a gain of 10 (Figure 3). Gain also had a significant effect on the number of submovements required to reach the target ($p < 0.001$). As shown in Figure 4, the number of submovements decreases as gain increases from 4 to 8, and is fairly consistent at higher gains.

Participant ratings

Tables VI and VII summarize the participants' ratings of the default, agent-selected, and 'best' gain settings based on the post-test questionnaires.

Table V. Agent-selected gain and 'best' gain for each subject, with comparison of selection time and percentage of error-free targets between the three gain settings. Default gain is 10 for each subject. For each measure, 95% confidence interval and mean are shown across subjects. Data are for trials during the evaluation phase.

	Gain		Target selection time (sec)			Error-free targets (%)		
Subj ID	Agent	Best	Agent	Best	Default	Agent	Best	Default
4	12	10	6.03	6.63	6.64	100	100	100
7	8	14	4.60	4.26	4.33	100	100	96.9
10	8	8	1.19	1.22	1.15	100	100	100
15	10	14	2.84	2.36	3.00	96.9	96.9	96.9
16	16	16	5.57	4.29	4.19	93.8	96.9	87.5
18	12	16	3.6	3.7	4.43	90.6	87.5	84.4
20	10	18	2.25	2.05	1.99	100	100	100
21	14	14	4.58	4.36	3.24	100	96.9	100
25	16	16	3.41	3.64	4.07	87.5	90.6	84.4
28	16	10	6.02	5.77	6.16	100	93.8	100
30	8	16	1.42	1.66	1.53	100	96.9	100
31	8	16	1.56	1.55	1.7	100	100	100
Mean			3.59	3.46	3.54	97.4	96.6	95.8
95% Confidence Interval			(2.46, 4.72)	(2.36, 4.55)	(2.41, 4.66)	(99.2, 100.3)	(94.0, 99.2)	(91.8, 99.9)

Table VI shows mean ratings across subjects for the ease of accurate pointing and desirability of each setting on a daily basis. Table VII shows mean ratings of cursor speed, both in terms of raw scores and in comparison to a score of 3, which corresponded to a speed which is 'about right'. For all participant ratings, there were no significant differences between conditions.

In response to the question 'How useful would it be if your computer helped adjust your mouse speed at times to better match your abilities?' (1 = 'Not at all useful', 7 = 'Extremely useful'), participants gave responses between four and seven (mean 5.9, standard deviation 1.2). While four participants had neutral opinions (scores of 4 or 5) and one did not respond to the question at all, seven participants saw the concept as potentially useful (scores of 6 or 7).

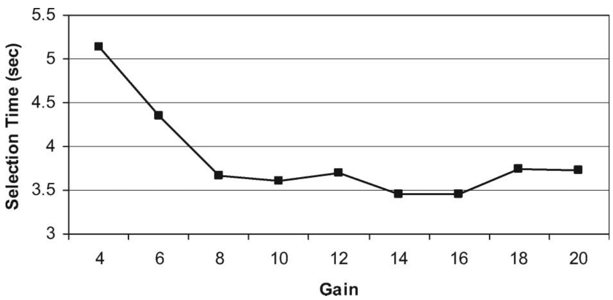

Figure 2. Effect of gain on selection time, across participants and trials.

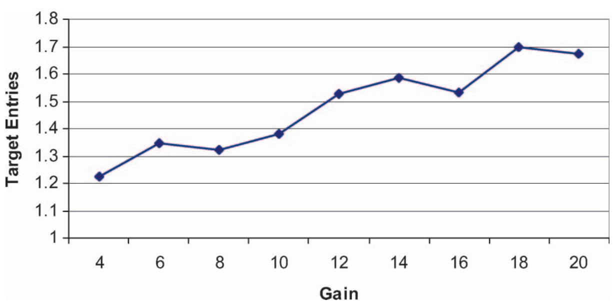

Figure 3. Effect of gain on number of target entries, across participants and trials.

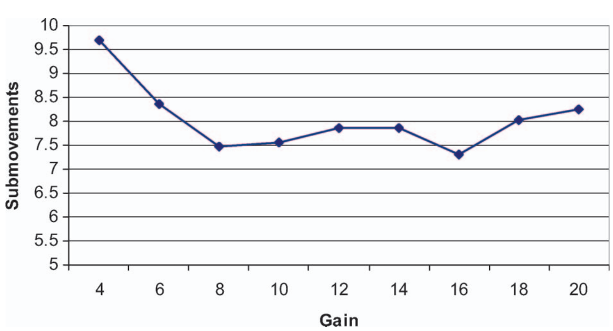

Figure 4. Effect of gain on number of submovements, across participants and trials.

Table VI. Participant ratings for ease of accurate pointing and overall desirability for each condition (mean and standard deviation across subjects).

	Ease of use (Mean)	Ease of use (SD)	Desirability (Mean)	Desirability (SD)
Default	4.1	0.9	3.9	0.7
Agent-selected	4.0	0.8	3.6	1.3
'Best'	4.1	1.1	3.8	1.1

Effect of target size

Mixed model analyses were performed for the dependent variables to evaluate effects of gain, target size, and inter-target distance. There were significant main effects of gain for reasons discussed above. There was a significant main effect of target size on selection time ($p < 0.001$), with larger targets selected more quickly (Table VIII). There were also significant main effects of target size on the number of target entries ($p < 0.001$) and number of submovements ($p < 0.001$), but no significant affect on overshoot (Table VIII). Considering inter-target distance, targets that required a larger distance to travel required longer selection times ($p < 0.001$) and a larger number of submovements ($p < 0.001$), while shorter inter-target distances were associated

Table VII. Participant ratings for cursor speed for each condition. Columns 2–3 give the mean and standard deviation of participant ratings, where ratings were from 1–5 where 1 = too slow, 3 = about right, and 5 = too fast. Columns 4–5 give the mean and standard deviation for the absolute value between the participant's rating and the 'about right' value of 3.

	Rating of speed (Mean)	Rating of speed (SD)	Difference from 'about right' (Mean)	Difference from 'about right' (SD)
Default	3.2	0.6	0.3	0.5
Agent-selected	3.4	0.7	0.4	0.7
'Best'	3.0	0.8	0.5	0.7

Table VIII. Effect of target size on selection time, number of target entries, number of submovements, and overshoot.

Target size (pixels)	Selection time (sec.)*	Number of target entries*	Number of submovements*	Overshoot (%)
16	4.7	1.7	8.8	11.1
24	3.9	1.4	8.1	10.8
32	3.6	1.4	7.7	10.1
48	3.4	1.3	7.6	9.5

*indicate significant main effects.

with more overshoot ($p < 0.001$; Table IX). There was no significant effect of inter-target distance on number of target entries. The mixed model analysis also indicated a crossover effect of gain and size ($p = 0.04$).

Discussion

Across participants, the automated adaptation agent was not associated with faster performance, more accurate performance, or higher participant ratings compared with the default. Therefore, our hypotheses 1 and 2 were not supported. However, two participants (P18 and P25) did have a consistent improvement in speed (19% and 16%, respectively) with the agent-selected gain. These two participants' target selection times were shorter for each of the three trials using this gain, compared to both of the trials using the default gain. Therefore, although the agent-selected gain provided no significant benefit across all participants, there may be a subset of people who would experience a consistent and functional benefit from automated recommendations. Further work is needed to identify whether participants P18 and P25 truly benefited from the agent-selected gain or whether the apparent effect was due to chance. If there is a real benefit, further work will be needed to characterize the benefit and either adjust the software to extend this benefit to others, or identify characteristics of participants P18 and P25 that allowed them to benefit, and test the software further for other people with the same characteristics.

The limited effect of gain was further shown by a mixed model analysis, in which there was a significant effect of gain on selection time but only due to significantly slower performance for the lowest gains tested (Windows sensitivity levels 4 and 6, 100 pixels/inch and 200 pixels/inch respectively). Across participants, there were no significant differences in selection time for gains between 8 and 20 (300 – 1400 pixels/inch). However, there were significant differences in other performance metrics. The number of target entries per selection attempt increased with increasing gain, indicating that participants had more difficulty controlling the cursor at higher gains. Also, the number of submovements tends to increase for gains lower than or higher than the default value (Windows setting 10,400 pixels/inch). At higher gains, the increased number of submovements may due to increased difficulty controlling the cursor, as evidenced by the increased number of target entries. At lower gains, the increased number of submovements may result from an inability to travel the distance to the target in a single movement. Further work is needed to determine whether these gain effects on movement patterns have implications for user comfort. If so, it might be possible an agent-selected gain to improve long term comfort and reduce frustration, even for users who are able to achieve similar accuracy and speed across gain levels.

Table IX. Effect of inter-target distance on selection time, number of target entries, number of submovements, and overshoot.

Inter-target distance (pixels)	Selection time (sec.)*	Number of target entries	Number of submovements*	Overshoot*
100	3.3	1.5	6.0	14.4%
512	4.4	1.5	10.1	6.3%

*indicate significant main effects.

There was no significant difference in selection time, accuracy, or error-free targets between the agent-selected gain and 'best' gain; supporting hypothesis 3. The agent-selected and 'best' gain were identical in four cases; including participants P18 and P25, a third participant (P31) for whom the agent-selected gain was consistently associated with faster performance, but with a small magnitude of improvement; and a participant (P4) for whom the agent-selected and 'best' gains were both the default gain. For the other eight participants, there were only two cases in which the 'best' gain was one of the gain values tested after the agent had made its decision. In the other six cases, the 'best' gain was different from the agent decision due to the difference in their decision algorithms. This indicates that for these participants, both accuracy and selection time were so similar for at least two gain values that the Y value was used by the agent to make its final decision. This indicates that four trials may be sufficient for the agent to make its decision; but also provides a further indication that small changes in gain provide little change in terms of accuracy or selection time.

The majority of participants rated the concept of automated adaptation as potentially useful, even if this particular prototype did not appear to improve the usability of the computer. Thus hypothesis 4 was supported.

Mixed model analysis indicated that target size has a significant effect on selection time. It might therefore be desirable for an automated agent to make recommendations related to the size of onscreen objects, as well as cursor gain. In particular, a drawback of varying the cursor gain is that it varies both the effective distance between targets, and also the effective size of targets. At a higher gain, the effective distance to a target is smaller because the smaller movement of the pointing device will cover the same on-screen distance in pixels. However, a higher gain also reduces the effective size of all targets, since a smaller movement of the pointing device will move the cursor past the target. Therefore, it might be desirable for an automated agent to recommend an increase in actual target size (in number of pixels) to offset any decrease in effective target size (due to recommending an increased gain).

To evaluate this option, a post-hoc analysis was performed to study the effect if the agent had recommended increased target size along with increased cursor gain. This analysis was performed for the six participants who had an agent-selected gain greater than the default gain, thus reducing effective target size. For these participants, performance data were analyzed to approximate performance if target size (in pixels) had increased in rough proportion to the reduction in effective target size. For example, participants P10 and P28 had agent-selected gains of 12 (corresponding to 600 pixels per inch), which is 150% of the default gain of 10 (corresponding to 400 pixels per inch). Therefore, performance at the default gain for targets of width 16 pixels were compared to performance at the agent-select gain for targets of 24 pixels (150% larger), and performance at the default gain for 32-pixel wide targets was compared to performance at the agent-selected gain for 48-pixel wide targets. Other participants had 200% or 250% increases in gain (800 pixels per inch or 1000 pixels per inch, respectively, compared to 400 pixels per inch). For these participants, performance at the default gain for 16- and 24-pixel wide targets were compared to performance at the agent-selected gain for 32- and 48-pixel wide targets, respectively (e.g., 200% increases in target size). Below, 'size-matched' refers to these proportional matches (as shown under 'Size Comparisons' in Table X), not to equal sizes (e.g., 16-pixel wide targets in the default condition were not matched to 16-pixel wide targets in the agent-selected condition, but rather to 24-pixel wide targets for participants P10 and P28 and 32 pixel-wide targets for other participants).

For each participant, the overall effect of size was first determined by comparing the mean selection time for small targets versus large targets. The mean selection time was calculated for all 'small' targets in both the agent-selected and default conditions, and the mean selection time was calculated for all 'large' targets in both conditions. The percent differences in mean selection times are shown in Table X as the 'Overall size effect'. Next, mean selection times were calculated for size-matched groups in each condition as described above (and as indicated under 'Size comparisons' in Table X). The percent difference in these mean selection times are shown in Table X as 'Size + Agent effect.' In addition, *t*-tests were performed between selection times for targets in the default condition and selection times for size-matched targets in the agent-selected condition. For participants P10 and P28, paired *t*-tests were performed (with times for target size 16 paired with times for target size 24, and times for target size 32 paired with times for target size 48). For other participants, unpaired t-tests were performed. The *p*-values are shown in the right-most column of Table X.

Varying both target size and gain led to improved target selection time for all six participants, and led to a larger improvement in selection time, compared to just increasing target size, for five of six

Table X. Column 2 provides the percent difference between the agent-selected gain for a participant and the default gain of 400 pixels/inch. Column 3 indicates the target sizes matched to offset changes in effective target width resulting from the agent-selected gain. Column 4 provides the percent difference in mean selection time between 'small' targets and 'large' targets (large targets consistently have shorter selection times). Column 5 provides the percent difference in mean selection times between targets at the default gain and size-matched targets at the agent-selected gain. Column 6 provides *p*-values for *t*-tests comparing selection times between targets at the default gain and size-matched targets at the agent-selected gain.

Participant	Percent difference in gain	Size comparisons (for default vs. agent gains)	Overall size effect	Size + Agent effect	Significance (*p*-value)
P10	150%	16 vs. 24 32 vs. 48	12%	8%	0.06
P18	250%	16 vs. 24 24 vs. 48	8%	24%	0.13
P25	250%	16 vs. 32 24 vs. 48	21%	35%	0.005
P28	150%	16 vs. 24 32 vs. 48	17%	18%	0.08
P30	200%	16 vs. 32 24 vs. 48	13%	18%	0.02
P31	250%	16 vs. 32 24 vs. 48	14%	21%	0.005

participants. The difference between selection times for small targets with the default gain, compared to large targets with the agent-selected gain, was significant ($p < 0.1$) for five of six participants. Further work will be needed to determine whether this is a promising avenue for automated user interface adaptation. In particular, this analysis was limited because it was a post-hoc analysis and required selectively analyzing subsets of data from different trials. A future evaluation protocol might look at separate trials between which gain and target size are changed in a consistent manner.

If it is desirable for a software agent to make recommendations regarding target size, it will be important for the agent to make recommendations that are truly relevant to target size, and not simply to screen resolution. Decreasing the screen resolution is the easiest way to increase the size of onscreen objects. However, like changing the gain, changes in resolution effect both the effective size of targets and the effective distance between targets. Windows (and other operating systems) have other options which can affect only the size of onscreen objects. In Windows, there are a number of such options on different control panels. Therefore, an automated agent would be particularly useful in making changes to these varied options in a concerted way, and in such a way as to not increase the effective distance between targets. A limitation to this approach (as with other automated recommendations of existing Windows options) is that the agent would not be able to make arbitrary recommendations (e.g., vary target sizes by 150% at one time and 200% another) but would only be able to choose from the available settings in the existing operating system software.

Conclusion

An agent was developed which makes recommendations regarding control-display gain based on observations of a user's performance in a target selection task. The agent makes its recommendations based on available adjustment settings in the existing operating system, allowing the agent to work with existing device drivers. The agent was evaluated in studies with 12 participants who have motor impairments. The agent-selected gain was not associated with significant improvements in selection time or error-free performance compared with the operating system's default gain. Across participants and trials, gain did not have a significant effect on selection time except at the lowest gain settings tested. Therefore, the results indicate that changes to control-display gain, alone, are unlikely to offer improvements in speed or accuracy for the general population of people with motor impairments. However, two participants did have notable and consistent improvement in selection time and error-free performance using the agent-selected gain. Also, gain across trials had a significant effect on number of target entries and number of submovements. This could indicate that certain gains make the cursor more difficult to control, although the sample population for this study may have been sufficiently adept with the pointing device as to adapt to these changes and maintain consistent accuracy and speed. Also, varying both target size and control-display gain may offer opportunities for improved performance. These observations provide possible avenues for future work.

One avenue for future work is to recruit a larger sample of participants in order to identify other individuals who, like two of the participants in this study, benefit from changes in control-display gain. If a significant number of such individuals are identified, analysis of participants' demographic characteristics and movement patterns could be conducted to attempt defining a pre-test for which individuals might profit from such adjustments. Further trials with the subgroup of participants who show an initial benefit could be conducted to determine whether this benefit is consistent over time.

A second avenue for future work is to determine whether changes in control-display gain can have a positive effect on long-term user comfort, as opposed to performance measures such as speed or accuracy. Such a study will require an objective measure of user comfort, as well as trials conducted over a longer timeframe.

A third avenue for future work is to explore the value of varying gain and target size in tandem. The current study included a post-hoc analysis of possible size effects. A future study could include pre-defined conditions representing a variety of gain-size combinations, in order to study this effect in a more controlled fashion.

Acknowledgements

We thank the participants for their generous contributions of time and effort. This work is funded by a Phase I SBIR grant from the National Institutes of Health, #1 R43 HD045015-01.

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