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Empirical validation of the Windows® accessibility settings and multimodal feedback for a menu selection task for users with Diabetic Retinopathy

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This study investigates the effectiveness of two design interventions, the Microsoft® Windows® accessibility settings and multimodal feedback, aimed at the enhancement of a menu selection task, for users with diabetic retinopathy (DR) with stratified levels of visual dysfunction. Several menu selection task performance measures, both time- and accuracy-based, were explored across different interface conditions and across groups of participants stratified by different degrees of vision loss. The results showed that the Windows® accessibility settings had a significant positive impact on performance for participants with DR. Moreover, multimodal feedback had a negligible effect for all participants. Strategies for applying multimodal feedback to menu selection are discussed, as well as the potential benefits and drawbacks of the Windows® accessibility settings.

1. Introduction

There is a documented, growing need to generate design-relevant data aimed at providing improved computer access to individuals with visual impairments, separate from those efforts for users who are blind. Researchers have recognised that the number of computer users with visual impairments is approximately three times larger than that of computer users who are blind (Newell and McGregor 1997). Moreover, over 1.5 million people in the US seek access to the Internet despite having a limiting visual impairment (Gerber and Kirchner 2001). An important distinction must be made between users with visual impairments and users who are blind; users with visual impairments often maintain different degrees of residual vision, which they attempt to use to the fullest extent (Bailey and Hall 1989). Thus, an important distinction must be made when discussing those tools designed to meet the needs of this population, apart from users who are blind.

This study examines the needs of computer users with diabetic retinopathy (DR). DR is a type of visual impairment that affects approximately 40–45% of the estimated 18 million people in the US who have diabetes (American Diabetes Association 2003). Since DR can affect people of all ages and covers a wide range of impairment (American Diabetes Association 2003), this study focuses on investigating potential graphical user interface (GUI) features that can enhance computer access for this unique and varied segment of the population.

Two commonly employed design interventions for improving the effectiveness of GUI interaction for users with visual impairments—the Microsoft®[1] Windows® accessibility settings and multimodal feedback—alone and in combination, were investigated in a menu selection task with users with DR of varying severity as well as with visually healthy controls. It is interesting to note, however, that while the Windows® accessibility settings are readily available, the activation of the settings can produce

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unpredictable visual screen configurations, especially for web browsing (American Foundation for the Blind 2000). Furthermore, the Windows® accessibility settings have received little attention in the way of validation of their effectiveness for users. In contrast, multimodal feedback, which has frequently been validated in the research literature (e.g. Belz and Robinson 1999, Oakley *et al.* 2000, Jacko *et al.* 2003b), is much less widely available to the general population in mainstream computing technologies.

The main goal of this study was to determine the potential benefits of these two technologies for computer users with DR stratified according to clinical assessments of visual function. A secondary goal was to conduct a first of its kind empirical validation of the Windows® accessibility settings.

2. Background

2.1 *Diabetic retinopathy*

Diabetes affects an estimated 18 million people in the US (American Diabetes Association 2003) and approximately 40–45% of them have DR (National Eye Institute 2003). Over time, most people with diabetes will develop some degree of retinopathy. DR is common in both type 1 diabetes (which usually occurs before age 30) and type 2 diabetes (which usually occurs with later onset), thus affecting people of all ages. It is the leading cause of new cases of blindness for people between the ages of 20 and 74 in the US (American Diabetes Association 2003). Three forms of DR and their effects are described as follows:

> **Background DR.** The most common form of DR, in which the blood vessels in the retina may bulge slightly or leak blood or fluid. This is also the mildest form of DR, as the macula (the central portion of the retina) remains unaffected.
>
> **Maculopathy.** This occurs when the symptoms of background DR begin to affect the macula. At this point central vision becomes affected and noticeable loss of vision begins to occur. One common effect is loss of fine detail vision, but peripheral vision remains intact.
>
> **Proliferative DR.** At this point new blood vessels form on the surface of the retina in order to compensate for the blockage of old blood vessels caused by the disease. However, these blood vessels are weak and can bleed easily as well as leave scars on the surface of the retina. This can lead to blurry and patchy central and peripheral vision and eventually to complete visual loss. Proliferative DR, both the rarest and most severe form of DR, can lead to retinal detachment and glaucoma. Figure 1 below shows an example of the effects of proliferative DR.

2.2 *Designing for users with visual impairments*

Because DR, among other ocular diseases, often leaves significant residual vision intact, design considerations for these users are not as simple as implementing a non-visual interface. A better understanding of how computer users who retain varying degrees of residual vision interact with computer interfaces is needed (Jacko and Sears 1998). As a starting point, several strategies that are typically used to address the needs of users with visual impairments are discussed.

2.2.1 Alternative presentation of screen elements. One technique that is often employed when designing computer interfaces for users with visual impairments is enhancing the visual salience of key screen elements or the overall appearance of the interface. The two properties that are most often modified are colour and size. This strategy is predicated on the assumption that making visual elements (e.g. text) larger will make them easier to see and that

Figure 1. A comparison of normal vision (left) to proliferative diabetic retinopathy (right) (images from http://www.nei.nih.gov/health/diabetic/retinopathy.asp).

increasing the colour contrast between the foreground and background will make the foreground elements more discernable and therefore more visually salient. There is abundant evidence to support these assertions (e.g. Lalomia and Happ 1987, Mills and Weldon 1987, Tullis *et al*. 1995, Hill and Scharff 1997, Cardosi and Hannon 1999, Arditi 2002, Arditi 2003). However, the nature of some visual impairments may negate the effectiveness of these techniques. For example, if text is very large, then it may become harder to read for users with significant visual field loss, as opposed to general acuity loss. Similarly, following visual design principles for judicious colour selection may benefit some users with visual impairments, but may also break down for others because of the colour deficiencies often experienced by people who have impaired vision (Fraser and Gutwin 2000).

These strategies have been employed for several generations of the Microsoft® Windows® operating system. The Windows® accessibility options (Microsoft Corporation 2003) offer high-contrast colour settings and enlarged fonts and icons in prepackaged combinations of black-on-white or white-on-black text and large or extra large fonts and icons. A sample screen of Microsoft® Word™ with one of the accessibility settings configurations is shown in figure 2.

These settings are applied to a host of screen elements, such as text, scrollbars and menu items, but do not apply to elements outside the bounds of standard Windows® controls or 'widgets'. This can become problematic because of the volume and variety of third-party applications that are written for Windows®. In addition, the Windows® accessibility settings yield mixed results when applied to an Internet browser application. A web page with the Windows® accessibility settings activated is shown in figure 3. The background and standard text have been changed to black and white, respectively. The links have been changed to a standard scheme; blue for previously unvisited links and purple for visited links, and fonts have been increased. In contrast, the images retain their original size and colour. Sometimes, font, link colours and sizes are not overridden by the accessibility settings, depending on how the page was designed.

Another obvious drawback of the Windows® accessibility settings is the decrease in screen real estate incurred by increasing the size of screen elements. Text and other items are frequently truncated in order to fit larger icons or other controls within the bounds of the screen. An example of this can be seen in figure 3, in which the names of the open documents listed in the taskbar appear truncated (as 'Docu...', 'Adob...', and 'Goo...'), which can render them confusing at best.

2.2.2 Magnification. In order to avoid inconsistencies with modifying screen elements, many solutions for users with visual impairments revolve around the use of magnification. Numerous software packages for screen magnification exist (e.g. Ai Squared Inc. 2003, ALVA Access Group 2003, Dolphin Oceanic Limited 2003, Freedom Scientific 2003) with an assortment of magnification techniques. The Macintosh® Universal Access options (shown in figure 4) (Apple Computer Inc. 2003) focus on using magnification to aid users with visual impairments, in addition to offering white-on-black colour settings and contrast enhancement. Microsoft Windows® also offers a screen magnifier, which works by designating the top portion of the screen as the magnification window.

Magnification offers flexibility in that the user can typically control the amount of magnification and can selectively zoom in and out, alternating between whole and

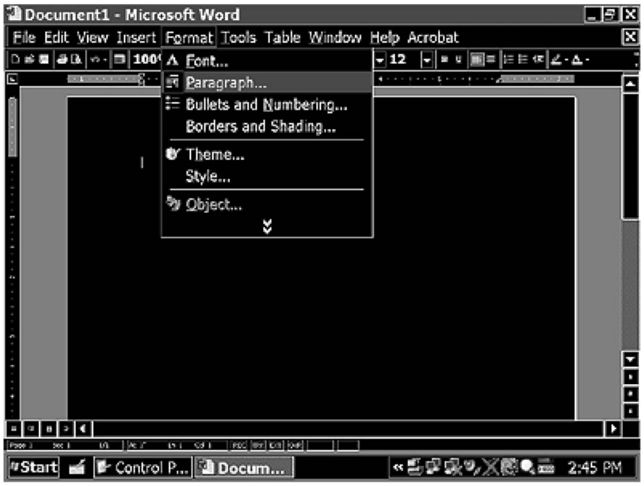

Figure 2. An example of a common Windows® accessibility setting.

Figure 3. The Google™ news web page viewed with the Windows® accessibility settings activated.

Zoom in: ⌘⌥=
Zoom out: ⌘⌥-
Turn zoom on or off: ⌘⌥8

Switch to white-on-black: ⌘⌥^8

Reduce contrast: ⌘⌥^,
Increase contrast: ⌘⌥^.

☐ Enable access for assistive devices
☑ Enable text-to-speech for Universal Access preferences

Figure 4. The Macintosh® universal access display settings.

detailed views. A significant drawback to using magnification is that enlargement of an area of the screen comes at the expense of obscuring or losing a view of the rest of the screen. Fraser and Gutwin (2000) noted that magnification offers benefits to some users with visual impairments, but not to others. The way in which the magnifier tracks the area of the screen to be enlarged also has the potential to hinder the user. This solution is also less transparent to users and can be distracting for users with normal vision.

An attempt to design a more intelligent magnification system was made for the X Windows operating system (Kline and Glinert 1995). In this system, two modes of magnification can be used depending on the type of task being performed and location of the mouse cursor. Many of the features implemented in this program have made their way into the magnification software listed above.

2.2.3 Multimodal feedback. Another technique for aiding users with visual impairments is to provide supplemental information via non-visual channels. Visual feedback is commonly used to support GUI interaction, and the same principle can be applied for non-visual feedback, particularly for computer users with visual impairments for whom visual feedback is less effective.

Two widely available forms of non-visual feedback are auditory feedback and haptic feedback. Auditory feedback typically involves the use of sound to reinforce the conveyance of information to the user. It has been successful because of its ability to provide meaningful information that is consistent with the corresponding visual information without adding to the visual processing requirements of the user. Numerous studies exist that have evaluated the beneficial use of auditory feedback in various computing contexts (e.g. Gaver 1989, Brewster *et al.* 1994, Brewster 1998a,b, Belz and Robinson 1999, Brewster and Crease 1999).

Haptic feedback (sometimes referred to as force feedback) is synonymous with tactile or vibratory feedback and is typically implemented by a vibration in a mouse or other input device. It takes advantage of the (relatively ignored) sense of touch in computing. Unlike the use of auditory feedback in potentially noisy environments, there is typically very little competition for tactile resources in computing, making haptic feedback a good candidate for delivering salient supplemental feedback. Haptic feedback has been used successfully in a variety of desktop and non-desktop environments, including: steering and targeting tasks (Dennerlein *et al.* 2000, Oakley *et al.* 2000), window manipulation (Miller and Zeleznik 1998), drag and drop interaction (Jacko *et al.* 2003b), scrolling (McGee 1999), menu interaction (Oakley *et al.* 2001), virtual environments (Stanney 2003), and automobile systems (BMW 2002). In a study by Oakley and colleagues (2000), haptic feedback was shown to reduce errors and workload for common GUI interaction tasks, but the authors cautioned that haptic feedback may not be appropriate for all aspects of GUI interaction. Also, because of its novelty and relatively high level of abstraction, users may have difficulty adapting to it, depending on various factors such as experience and age (e.g. Jacko *et al.* 2003b).

Multimodal feedback, when implemented appropriately, can improve interaction for both users who experience visual impairment as well as users who have normal vision. One benefit of multimodal feedback is that, while novel, it is less likely to be perceived as an assistive technology. Thus, it can be more transparent to users, which can improve interaction without the stigma of apparent assistive enhancements (e.g. screen readers or magnifiers) or interference with normal user behaviours. For example, previous studies have shown that the combination of auditory and haptic feedback, along with visual feedback, can be effective in improving the salience of interaction events for both users with visual impairments and normally sighted users (Jacko *et al.* 2003b, in press). Additionally, multimodal feedback can be considered a cross-disability accessible technology, where additional feedback modalities are typically redundant and can supplement or even replace information that cannot be effectively conveyed to users who possess limitations in one or more senses.

2.3 *The menu selection task*

As one of the components of the Windows, Icons, Menus, Pointers (WIMP) standard for GUI interaction, menu selection is an integral part of most everyday computer tasks. Menu selection is also viewed as one of the five primary interaction styles (along with direct manipulation, form fill-in, command language and natural language) (Shneiderman 1997). While this task is essential for GUI interaction, it can be problematic for users with normal vision (Brewster and Crease 1999) and becomes increasingly challenging for users with visual impairments (e.g. Gunderson 1994, Jacko *et al.* 2000).

2.4 *Current study objectives*

Edwards *et al.* (2004, in press) reported a series of linear and logistic regression models constructed to examine the extent to which various factors influence efficiency and accuracy in a menu selection task under the experimental conditions described in the current study. These models served as the basis for the current study's objectives as they identified user-specific and interface-specific factors, which are significant predictors of task performance. Significant user-specific factors included age, experience, visual acuity and contrast sensitivity; interface-specific factors included the Windows® accessibility settings and the location of menu items. Based on these prior outcomes, this paper aims to:

> *Further investigate alternative design interventions (Windows® accessibility settings and/or multimodal feedback), to determine how they can either independently or cooperatively enhance the performance of computer users who have been stratified according to visual function.*

The implications of addressing this aim advance the issue of universal access by investigating one-size-fits-all solutions for users with diverse visual capabilities. While many assistive technologies exist to benefit users with visual impairments, the Windows® accessibility settings are readily available and easily activated and deactivated. It is likely that their effectiveness can be improved in combination with other software or internal configurations, but it cannot be assumed that the additional features or software will be implemented. This research study is intended to investigate the default Windows® accessibility settings without supplemental assistive technologies because this is representative of a minimal effort configuration for users with visual impairments. Similarly, non-adaptive, non-dynamic multimodal feedback is used because it is easily implemented and requires little expertise to configure and use. The intent is to determine the most effective and simple methods of improving menu interaction for users stratified by their limited visual capabilities. To be clear, the goal of this study was not to determine optimal menu configurations considering such factors as breadth versus depth or the order of menu items, as these issues have been examined in previous research (see Jacko *et al.* 1995, and Jacko and Salvendy 1996, for example).

3. Methodology

3.1 *Participants and stratifications*

Twenty-nine participants volunteered for the study. Of these participants, five were excluded because they failed to meet the criteria required by the study. Four were excluded because they did not meet the acuity requirements. Another participant was excluded due to inadequate computer experience. Of the remaining participants, 15 were diagnosed as diabetic with evidence of retinopathy, and nine were selected as a control group who possessed no limiting ocular condition. The diabetic participants were recruited from the College of Optometry patient database at Nova Southeastern University (NSU) and screened for appropriate computer experience, age, visual acuity, education, fluency in English and absence of severe physical limitations. The controls were recruited by members of the College of Optometry and screened in the same manner. All participants were given a free comprehensive eye exam by licensed staff at NSU and paid US50 dollars for their participation. Participants ranged in age from 28 to 79 years (mean age = 56) and included nine females and 15 males. NSU optometrists performed visual acuity, contrast sensitivity, visual field and colour blindness tests, in addition to the diagnosis of retinopathy.

In order to more fully categorise the experience and abilities of the participants, several assessment tools were used in the study. Participants responded to the SF-12™ Health Survey (Ware *et al.* 1995), the National Eye Institute VFQ-25™ questionnaire (Mangione *et al.* 2001, Clemons *et al.* 2003), the Mini-Mental Status Exam™ (MMSE) (Folstein *et al.* 1975), and a background questionnaire that assessed computer experience and demographics. The background questionnaire generated a computer experience rating comprised of frequency of computer use, comfort with a computer, and number and type of applications used, similar to the procedure reported in Emery and colleagues (2003). Each participant also performed the Purdue Pegboard test of manual dexterity (Tiffin and Asher 1948). Additionally, because diabetes can cause decreased tactile sensitivity, the WEST-hand™ Test of tactila sensitivity (Connecticut Bioinstruments Inc. 2003) was administered. Thus, each participant's sensitivity threshold was recorded at the fingertip, base of the fingers and palm. Handedness was also recorded, but not included in the analysis because the task could be completed with either hand due to the left–right symmetry of the mouse.

Given that clinical measures of visual function like visual acuity and contrast sensitivity have been shown to be significant predictors of performance for computer users with DR performing menu selection tasks (e.g. Edwards *et al.* in press), participants were stratified according to visual function (i.e. binocular visual acuity (assessed at 40 cm) and presence or absence of diabetes with signs of retinopathy). Three groups were formed: the Control group (no presence of diabetes or signs of retinopathy with visual acuity from 20/20 up to but not including 20/30); Group 1 (presence of diabetes and evidence of retinopathy with visual acuity from 20/20 up to but not including 20/30); and Group 2 (presence of diabetes and evidence of retinopathy with visual acuity from 20/30 up to and including 20/50). Acuity scores refer to participants' best corrected (i.e. with glasses or contact lenses) acuity.

Table 1 displays the stratifications for each group and their defining characteristics. Note that the computer experience rating score was a composite score of frequency of computer use and number of applications used (for example, if a person uses a computer one to three times a month and uses three different applications, the score obtained equals six). The SF12 physical component score (SF12 PCS) and mental component score (SF12 MCS) were obtained from a survey of participant's self-reported physical and mental health at the time of the experiment (Ware *et al.* 1995). Moreover, the Snellen acuity scores (e.g. 20/20) were converted to standard logMAR (minimum angle of resolution) values, which is achieved by applying the log10 transformation to the Snellen denominator divided by its numerator (Ferris *et al.* 1982). The participants were stratified by visual function, which translates to a stratification scheme that is defined not only by visual acuity (see Emery *et al.* 2003, Jacko *et al.* 2003a, for precedence), but also by the significant clinical metrics of contrast sensitivity and colour blindness (conveyed in table 1). VFQ metrics, indicators of self-perceived visual function, very typically mirror the clinical metrics, as was the case here.

Edwards *et al.* (in press) also demonstrated that factors such as age and computer experience serve as significant predictors of performance in this context of computer use for these users. Thus, attempts were made to balance such factors across groups. Therefore, there were, by design, no significant differences across stratified groups for age, computer experience, the SF12 (PCS and MCS components), MMSE and dexterity. Analyses of Variance (ANOVA) were used to generate F-statistics for continuous variables and the Chi-Squared test was used for categorical variables in order to establish the presence or absence of statistically significant differences between the stratified groups.

3.2 *Experimental task and conditions*

Participants were seated in front of a Windows®-based desktop computer and a monitor. The monitor was an 18-inch diagonal flat panel LCD display, set at a resolution of 1280 × 1024 pixels. The mouse that was used was a Saitek™ TouchForce™ (Saitek Industries 2003) optical mouse with haptic feedback capabilities. Embedded within the mouse is a small motor that generates vibratory pulses that can be triggered by specified interface elements (e.g. scrollbars, menus, buttons and hyperlinks). Despite its haptic capabilities, the appearance and size of the mouse was consistent with a standard mouse. This mouse was used to provide tactile feedback to participants and will be discussed in more detail below.

The task was a series of menu navigation and selection actions. A custom interface written in Visual Basic was designed to resemble selected menus from the Microsoft®

Table 1. Demographic summary of participant characteristics by group.

	Groups				
	Control (n = 9)	Group 1 (n = 9)	Group 2 (n = 6)		
Diabetes	Absent	Present	Present		
Acuity	[20/20 – 20/30)	[20/20 – 20/30)	[20/30 – 20/50]	Test statistic[a]	p value
LogMAR acuity	– 0.045	0.018	0.255	20.401	< 0.001*
Contrast sensitivity[b]	1.9 (0.11)	1.70 (0.18)	1.45 (0.15)	14.647	< 0.001*
Test for colour blindness	Pass = 9, Fail = 0	Pass = 6, Fail = 3	Pass = 1, Fail = 5	$\chi^2 = 11.25$	0.004*
VFQ	93.1 (9.1)	89.7 (6.2)	68.6 (24.7)	4.880	0.021*
Age	51.2 (18.3)	55.9 (10)	64.5 (11)	1.636	0.219
Comp. Exp. Rating	8.7 (1.7)	8.0 (2.8)	7.7 (2.9)	0.335	0.719
SF12 PCS	49.1 (10.1)	42.6 (12.5)	39.6 (8.8)	1.568	0.232
SF12 MCS	42.5 (5.9)	45.9 (11.9)	43.2 (11.6)	0.287	0.754
MMSE	29.0 (1.3)	28.6 (1.8)	27.8 (2.6)	0.705	0.506
Dexterity[c]	14.3 (2.7)	12.1 (1.8)	9.6 (1.0)	2.186	0.140

Notes:
*Significant differences between groups.
Values in parentheses are standard deviations.
[a] Unless noted, test statistics are F values.
[b] Values are log10-transformed contrast sensitivity scores.
[c] Dexterity scores were adjusted for acuity in order to acount for the effect of visual loss on performance of the Purdue Pegboard test.

Word™ menu bar. There were three menus available, each with five items to select from. In this paper the term 'menu' describes a top-level menu, such as File or Edit, while the terms 'item' and 'menu item' describe items that are selectable within a menu, such as Open or Copy. The available menus and items, in the appropriate order, are shown in table 2.

Participants were instructed to use the mouse to select (via a mouse click) a specified item from a specified menu. The menus were located in the upper left corner of the screen, as in most Windows® interfaces. The names of the target menu and target item within that menu were centred in the lower portion of the screen in 36-pt Arial bold font. Within each condition, participants were instructed to select each of the items once, in a randomly selected order, resulting in 15 trials per condition.

Each participant performed 15 trials in each of four conditions. The experimental paradigm employed represented a 2 × 2 full factorial design, with two factors (Windows® Accessibility and Multimodal Feedback) with two levels each (absent and present). This design resulted in four interface design conditions, as shown in table 3.

Table 2. Menus and menu items available for the menu selection task.

Menu	File	Edit	Help
Menu Item	New	Undo	Microsoft Word Help
	Open	Copy	Show the Office Assistant
	Save	Cut	What's This?
	Print	Paste	Office on the Web
	Close	Select All	About Microsoft Word

The first condition represented a standard menu interface with no enhancements or adjustments. Each menu and item is shown in figure 5. When the mouse was placed over a menu item, a blue highlight appeared over the item and the text colour was inverted, providing visual feedback to the participant. No other feedback was provided. This condition is referred to as the Normal (N) condition throughout this paper.

The second condition was designed to emulate the Windows® accessibility settings. The same menus and menu items were available but were presented with a larger font size, white text on a black background, and a purple highlight for visual feedback, as shown in figure 6. In this study, this condition is referred to as the Windows® accessibility (WA) condition.

The third condition was visually identical to the N condition. The difference was that two types of additional feedback, auditory and haptic, were provided besides the visual feedback from the blue highlight. Auditory feedback took the form of a brief, simple, abstract sound. Before the task began, participants listened to the sound several times and adjusted the volume to an appropriate level. Haptic feedback, provided by the TouchForce™ mouse, was a short mechanical vibration. Both types of feedback were initiated when the mouse crossed the boundary between one item and another. In this experiment, this condition is referred to as the Multimodal feedback (M) condition.

Table 3. Summary of the four menu selection task conditions.

		Factor 1: Multimodal feedback	
		Visual feedback	Visual, auditory, and haptic feedback
Factor 2: Windows® accessibility	Absent	Normal (N)	Multimodal feedback (M)
	Present	Windows® accessibility (WA)	Multimodal feedback and Windows® accessibility (M + WA)

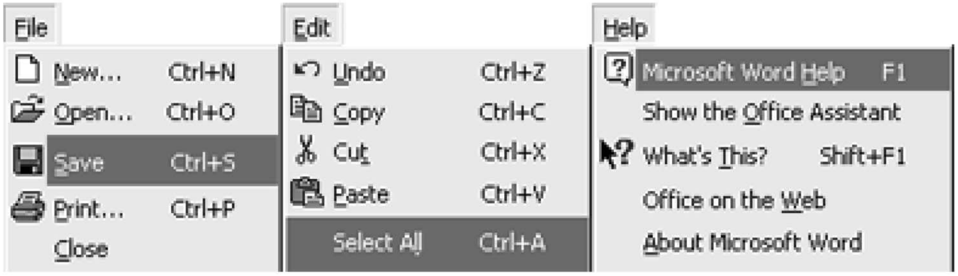

Figure 5. The Normal (N) menu interface condition. (Note that the distance between menus has been expanded to show all menu items at once. In the experiment, the three menus were immediately adjacent to each other.)

The fourth condition was visually identical to the WA condition, with the addition of the same auditory and haptic feedback as for the M condition. This fourth condition is called Multimodal feedback and Windows® accessibility (M + WA) throughout in the paper.

Participants completed all 15 trials within a condition before moving on to a new condition. The order in which participants encountered each condition was randomised.

3.3 *Procedure*

After receiving an assessment of visual health by NSU staff, participants were briefed about the computer-based task and asked to fill out an informed consent form. Participants were then administered the background questionnaire, Purdue Pegboard test of manual dexterity, Mini-Mental Status Exam™, WEST-hand™ Test of tactile sensitivity, SF-12™ and VFQ-25™ by one of the experimenters.

Upon completion of these tests, participants were seated in front of the computer and introduced to the equipment and task. Each participant was given a pair of trial frames that were fitted with lenses for their prescription, allowing them to see with their best-corrected vision. Exceptions were made when participants required no correction to their vision for computer use, in which case they were not given trial frames. Participants were given training for the menu selection task and performed practice trials for all four conditions before beginning the experimental task. The use and meaning of the auditory and haptic feedback were also demonstrated during the training. When participants stated that they felt comfortable with the task, they began the series of four sets of 15 trials. After each condition, participants answered brief questions about their opinions of the task and provided subjective feedback about the level of workload they experienced while performing the task. When all four conditions were completed, participants were asked to indicate which interface they preferred and offered an opportunity to make any additional comments about the task or conditions.

3.4 Experimental measures

In addition to the subjective measures described above, the objective measures that were recorded for each participant for each trial, along with their abbreviations used throughout in the paper, are listed in table 4.

4. Results

4.1 *Time*

A summary table listing the mean total time (TT) and navigation time (NT) per trial for each group and condition is displayed in table 5. The mean times for each condition, separated by group are shown in figure 7. Since NT is a subset of TT, both measures are plotted on the graph, with NT, which is shaded in dark grey, overlaying TT.

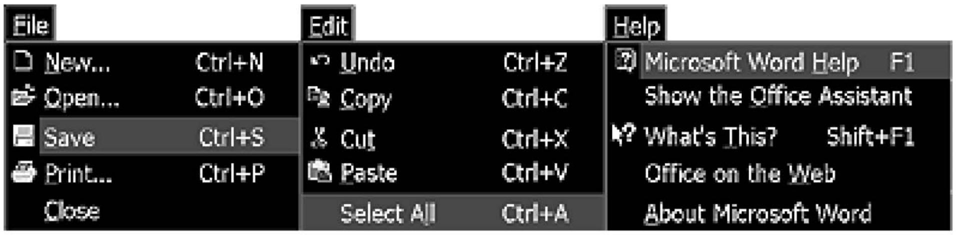

Figure 6. The Windows® accessibility (WA) interface condition. (The distance between menus has been expanded to show all menu items at once. In the experiment, the three menus were immediately adjacent to each other.)

Table 4. Objective measures collected for the menu selection task.

Measure	Description	Type
Total Time (TT)	Time in milliseconds from when the target menu and item were presented until a menu item was selected	Number
Navigation Time (NT)	Time in milliseconds from when the first menu was hovered over until a menu item was selected	Number
Items Highlighted (IH)	The total number of items that were highlighted	Number
Missed Opportunities (MO)	The number of times that the target item was highlighted without being clicked	Number
Wrong Item Selected (WIS)	Indicates whether or not the correct menu item was selected in the trial	Yes/No

Table 5. Mean Total Time (TT) and Navigation Time (NT) per trial for each group, separated by condition, in milliseconds.

Group	Condition	Mean TT (ms) (Std Dev.)	Mean NT (ms) (Std Dev.)
Control	N	4361 (2459)	3010 (2045)
	WA	4251 (2801)	2894 (2225)
	M	4342 (1806)	2927 (1460)
	M + WA	4311 (1948)	2829 (1358)
Group 1	N	5392 (4028)	4039 (3757)
	WA	4558 (1830)	3137 (1282)
	M	5453 (3230)	3904 (2544)
	M + WA	4679 (2004)	3223 (1578)
Group 2	N	9738 (6630)	6875 (5363)
	WA	6609 (3244)	4138 (2313)
	M	10 279 (7018)	7545 (6210)
	M + WA	6603 (2988)	4260 (2147)

A repeated measures ANOVA was performed to test main effects and their interactions between groups (Control, Group 1 and Group 2), Windows® accessibility [present (conditions WA and M + WA) or absent (conditions N and M)], and multimodal feedback [present (conditions M and M + WA) or absent (conditions N and WA)], on TT and NT. This analysis technique was used because a mixed experimental design was used for the experiment so that both the within (condition) and between (group) subject factors could be accounted for. In order to meet the assumption of normality required for the analysis, the authors applied the reciprocal ($= 1/x$) transformation to all time measures. The transformed time-based measures can be also interpreted as the rate of task completion. Homogeneity of variance was achieved through this transformation. The results of the ANOVA analysis for both 1/TT and 1/NT are presented in table 6.

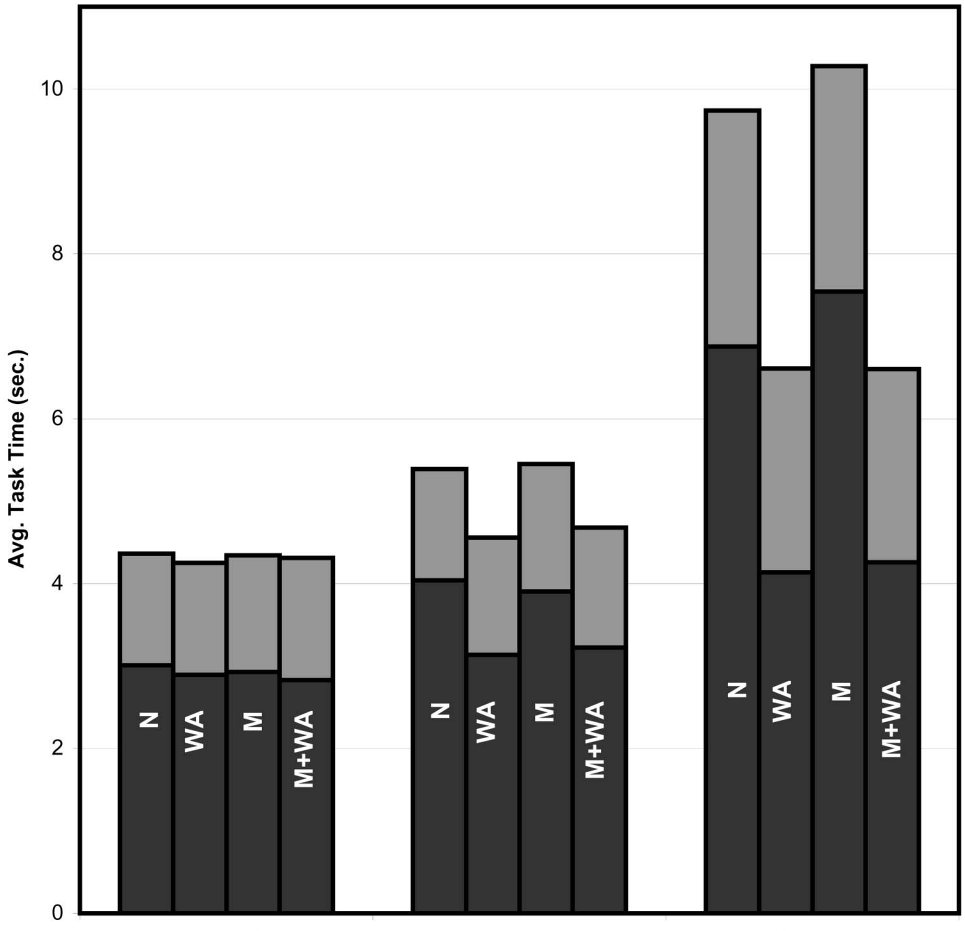

Figure 7. Navigation Time (NT) (dark grey) overlaying Total Time (TT) (grey) between conditions for each group (the conditions are as follows: N = Normal; WA = Windows® accessibility; M = Multimodal feedback; M + WA = Multimodal feedback and Windows® accessibility).

As demonstrated in table 6, there were significant main effects for group and Windows® accessibility for 1/TT and 1/NT. In addition, there was a significant Windows® accessibility × group interaction for both measures, implying that performance differences due to the presence of the Windows® accessibility interface varied by group. Non-overlapping joint confidence intervals (CIs) were used to determine significant differences for this interaction effect. Figures 8 (1/NT) and 9 (1/TT) clearly show that Group 2 had a greater variation in performance between conditions, absence and presence of Windows® accessibility settings, than the Control group and Group 1.

From figure 8, examining the 95% CIs for Group 2 shows that the rate of navigation with Windows® accessibility settings was significantly higher (faster) than that of navigation without Windows® accessibility settings for this group. The 1/NT performance for the Control group and Group 1 was not significantly different between conditions, although similar patterns emerged with respect to improvements associated with the presence of Windows® accessibility settings (see figure 8). The 95% CIs for 1/TT demonstrate the same pattern of differences, with significant performance improvements (faster TT) for Group 2 in the presence of Windows® accessibility settings. These results are shown in figure 9.

In addition to the above effects, for 1/TT, a main effect of the presence of multimodal feedback was significant. Surprisingly, it appears that the presence of multimodal feedback increased, though not significantly, both TT and NT, especially for Group 2 (see table 5 and figure 7). However, instances of these increases were quite small and not statistically significant, which makes these slightly detrimental impacts of the presence of multimodal feedback of little practice significance.

While the main effect of the groups is very intuitive given the differences in visual function between the groups, it is interesting to note that post hoc tests identified significant differences among all three groups for both time measures. These differences are clearly demonstrated in figures 7–9. As expected, Group 2 exhibited worse performance, with slower rates of task completion (1/NT and 1/TT), compared with Group 1 and the Control group. Interestingly, however, Group 1 also exhibited worse performance, with a slower rate of task completion (1/NT and 1/TT), compared with the Control group. This indicates that even though Group 1 and the Control group had similar visual acuity, the Control group is more efficient in completing the menu task.

4.2 *Errors*

As indicated in table 4, three measures of accuracy were recorded in addition to the efficiency measures of TT and NT. Each of these measures was sensitive to a different facet of participant behaviour. The first accuracy measure, Items Highlighted (IH), indicates the number of items that were highlighted for each trial. This measure provides an

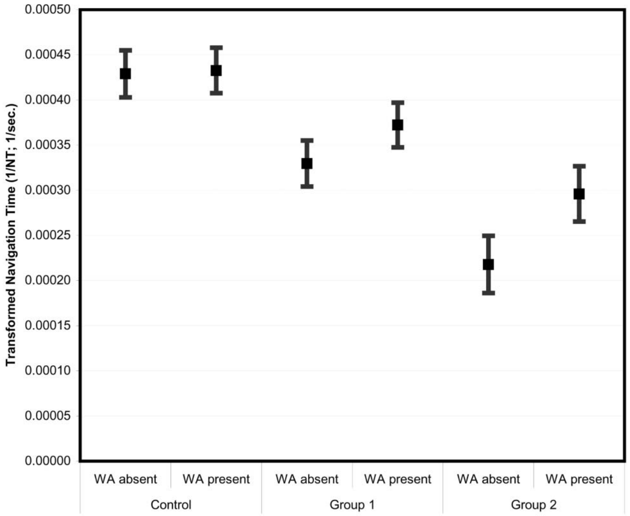

Figure 8. Mean transformed Navigation Time (1/NT) and 95% confidence intervals (CIs) between conditions for each group.

Table 6. ANOVA table for 1/TT and 1/NT.

	1/TT			1/NT		
Effect	d.f.	*F*	*p*-value	d.f.	*F*	*p*-value
Group	2	51.56	< 0.001*	2	40.47	< 0.001*
Windows® accessibility	1	50.51	< 0.001*	1	63.31	< 0.001*
Multimodal feedback	1	4.30	0.039*	1	1.36	0.245
Windows® accessibility × group	2	9.91	< 0.001*	2	16.08	< 0.001*
Multimodal feedback × group	2	0.09	0.912	2	1.33	0.265
Multimodal feedback × Windows® accessibility	1	0.35	0.554	1	0.00	1.000

* Difference is significant at level 0.05.

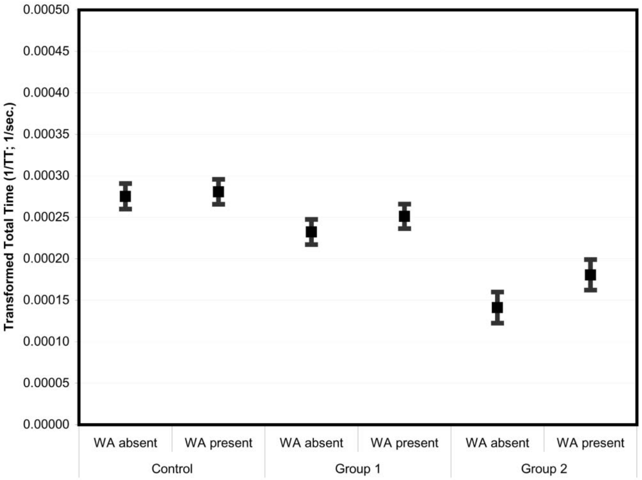

Figure 9. Mean transformed Total Time (1/TT) and 95% confidence intervals (CIs) between conditions for each group.

indication of the efficiency of participants' strategies by recording the number of items highlighted by the mouse and comparing it to an ideal, error-free value. The minimum possible value for this measure is 3 (the average distance to the target item) and thus reflects the optimum performance mark.

The second accuracy measure, Missed Opportunities (MO), indicates the number of times that the target item was highlighted without being clicked. This measure is sensitive to the salience of the cues pointing to the target item or the participant's awareness of the target item, independent of the navigational path taken to arrive there. While the occurrence of MO was relatively low overall, this measure provides an indication of how well participants knew that they had located and identified the target menu item. This is an error of omission.

The last accuracy measure, Wrong Item Selected (WIS), indicates the percentage of trials in which an incorrect item was selected instead of the target item. This is an error of commission and goes beyond MO. Whereas MO detects instances in which the target item was overlooked or missed, WIS indicates an active selection of an incorrect item. In this experiment, a time limit was not imposed on the participants' task completion. As a result, users demonstrated relatively high accuracy in making the correct menu item selection and consequently a very low incident of WIS errors.

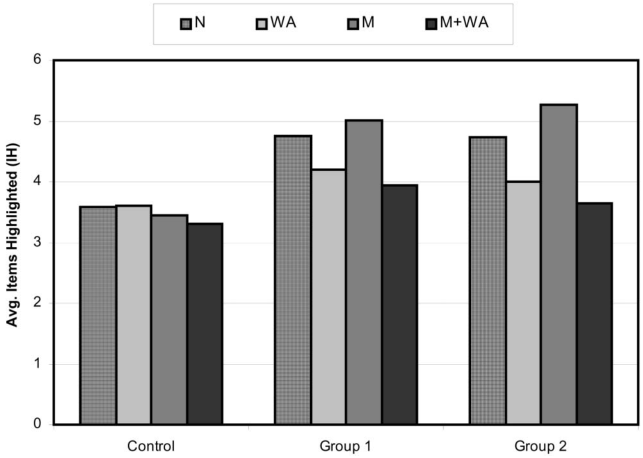

Figure 10. Average number of Items Highlighted (IH) per trial between conditions for each group (the conditions are as follows: N = Normal; WA = Windows® accessibility; M = Multimodal feedback; M + WA = Multimodal feedback and Windows® accessibility).

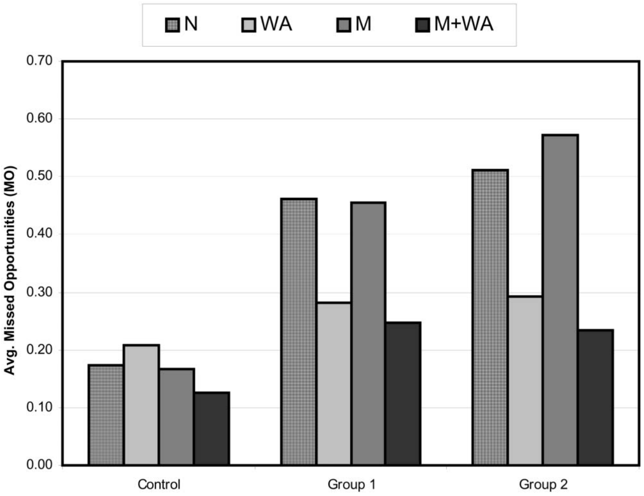

Figure 11. Average number of Missed Opportunities (MO) per trial between conditions for each group (the conditions are as follows: N = Normal; WA = Windows® accessibility; M = Multimodal feedback; M + WA = Multimodal feedback and Windows® accessibility).

The average numbers of IH and MO for each group and condition are shown in figures 10 and 11, respectively. The Wilcoxon Signed Ranks test was used to detect differences between conditions for each group. This non-parametric test was used because of the non-normal distribution of the two measures of interest and because the measures analysed were collected within subjects. Statistical tests were not run on the WIS measure because most subjects did not make any incorrect item selections. The average percentage of WIS for each group is shown in table 7 for reference.

The differences in IH and MO for each group are summarised in table 8. Similar to the time-based measures

(TT and NT), no significant differences were observed due to the presence of Windows® accessibility settings or multimodal feedback for the Control group. However, Group 1 and Group 2 performed better (fewer IH and MO) in the conditions with the presence of Windows® accessibility settings.

The Kruskal–Wallis test was used to detect differences in IH and HO between groups for each condition. This non-parametric test was used because of the non-normal distribution of the two measures of interest and because the measures analysed were collected between subjects. In instances where the Kruskal–Wallis test indicated a significant difference between groups, the Mann–Whitney test was used to complete paired comparisons between groups. The differences in IH and MO between groups for each condition are summarised in table 9. Interestingly, while the Control group performed better than the other two groups in the conditions where Windows® accessibility was absent (conditions N and M), there were no significant differences among the groups on these measures when Windows® accessibility was present (conditions WA and M + WA).

4.3 *Preferences*

In addition to the objective measures discussed above, each participant was asked to indicate the interface condition that they preferred at the conclusion of the experiment. The results of this survey are listed in table 10. The body of the table indicates response frequencies reported by group for the interface conditions. Note that not all participants indicated a distinct preference for one condition over another, represented in the no preference column of the table.

While subjective, these results are consistent with the results from the objective measures, particularly in the

Table 7. Average percentage of Wrong Items Selected (WIS) for each group, by condition.

	Average percentage of WIS for each condition			
Group	N	WA	M	M + WA
Control	0%	0%	0%	0.7%
Group 1	0%	0%	0.7%	0%
Group 2	14.7%	2.2%	14.6%	2.2%

Table 10. Preferred interface conditions for each group.

	Preferred Condition				
Group	N	WA	M	M + WA	No Pref.
Control	1	4	0	2	2
Group 1	1	5	1	0	2
Group 2	1	2	0	2	1
Total	**3**	**11**	**1**	**4**	**5**

Table 8. Summary of significant differences of IH and MO between conditions for each group. (Note that 'X < Y' indicates fewer IH or MO in condition X than in condition Y.)

	Items Highlighted (IH)		Missed Opportunities (MO)	
Group	Multimodal feedback	Windows® accessibility	Multimodal feedback	Windows® accessibility
Control	No difference	No difference	No difference	No difference
Group 1	No difference	WA present < WA absent ($Z = -3.360$; $p = 0.001$)	No difference	WA present < WA absent ($Z = -4.190$; $p < 0.001$)
Group 2	No difference	WA present < WA absent ($Z = -4.248$; $p < 0.001$)	No difference	WA present < WA absent ($Z = -3.904$; $p < 0.001$)

Table 9. Summary of significant differences of IH and MO between groups for each condition. (Note that 'X < Y' indicates that group X had significantly fewer IH or MO than group Y.)

Condition	Items Highlighted (IH)	Missed Opportunities (MO)
N	Control < Group 1 ($U = 6898$, $p = 0.002$) Control < Group 2 ($U = 4839$, $p = 0.034$)	Control < Group 1 ($U = 6970$, $p < 0.001$) Control < Group 2 ($U = 4616$, $p = 0.001$)
WA	No significant difference	No significant difference
M	Control < Group 1 ($U = 6785$, $p = 0.001$) Control < Group 2 ($U = 4172$, $p < 0.001$)	Control < Group 1 ($U = 6986$, $p < 0.001$) Control < Group 2 ($U = 4240$, $p < 0.001$)
M + WA	No significant difference	No significant difference

presence of a strong overall preference for conditions involving the Windows® accessibility settings.

5. Discussion and conclusions

5.1 *Summary*

For menu selection, a key GUI interaction component, users with DR and marginal visual functioning (Group 2) and, to a lesser degree, those with minimal loss due to DR (Group 1) were able to take advantage of the enhancements provided by the standard Windows® accessibility settings. However, both groups experienced little consistent effect from the implementation of multimodal feedback. The performance of participants with no vision loss (Control group) appeared relatively unaffected by the use of the Windows® accessibility settings and multimodal feedback. These results are consistent across measures of time (TT and NT) and efficiency/accuracy (IH and MO).

Additionally, an incremental decrease in visual abilities (i.e. from 20/20 – 20/30 to 20/30 – 20/50) between participants with DR yielded a significant negative change in performance, regardless of interface condition or feedback used. To a lesser extent, the presence of DR alone had an effect on performance (i.e. the Control group vs Group 1), leading to slower task completion and more errors in some cases. This result is similar to results found in Jacko *et al.* (in press) in which users with mild age-related macular degeneration (AMD) performed a drag-and-drop task less effectively than users without AMD, who exhibited otherwise equivalent visual and demographic profiles.

When applying the results of this study, however, it is important to consider the ways in which DR manifests itself (e.g. retinal degradation and patchy vision). Since other visual diseases and causes of visual acuity loss (e.g. ageing) may differ in terms of resulting visual dysfunction, the results observed here may not necessarily apply to all users with visual impairments.

5.2 *The Windows® accessibility settings*

The use of the Windows® accessibility settings for a basic menu selection task showed the most striking effect on performance. Group 2, representing users who typically have difficulty performing computer tasks because of their limited vision, performed consistently better in conditions involving the Windows® accessibility settings as compared to conditions without them. In fact, the effect of the Windows® accessibility settings appeared to increase between groups as participants' visual abilities declined. Although the effect is not significant for the Control group or Group 1, a clear trend can be seen in figures 8 and 9, whereby the separation between the Windows® accessibility present and Windows® accessibility absent conditions increases from left to right. It is unknown whether this trend would continue for participants with DR and visual acuity worse than 20/50, but it is certainly possible. While the Windows® accessibility settings do not appear to provide a dramatic absolute benefit for Group 2 (roughly 2 seconds per trial), when considering the number of menu interactions required for daily computing, this effect becomes potentially very large. This difference also indicates the use of a much more efficient strategy for participants in the worst visual acuity group while using the Windows® accessibility settings.

However, the benefits achieved by using the Windows® accessibility settings do not come without cost. As indicated previously, two major concerns arise when considering the use of the Windows® accessibility settings: screen real estate and incompatibility. As most screen elements increase in size, a battle for screen space ensues, usually with some important controls losing out. This becomes especially problematic because many users with visual impairments are also older users, who may be less experienced with computers and also have decreased cognitive resources available. Researchers (Chadwick-Dias *et al.* 2003) found that the benefit of increased text size for older users was commonly offset by the detrimental effect of increased scrolling (particularly horizontal scrolling) that was required as a result. This is just one example of the difficulties that can be caused by a crowded screen and a testament to the fact that larger is not necessarily better.

The Windows® accessibility settings can be fine-tuned with some precision in order to optimise the cost–benefit trade-off for a specific user with specific hardware, which may be a viable and adequate solution for experienced computer users. However, a far more ideal solution would be an adaptable interface capable of configuring and reconfiguring its appearance based on inferred or learned characteristics of its user. Otherwise, it is unreasonable to expect that the majority of users who have trouble clearly seeing all elements on a screen will be able to configure and manage the Windows® accessibility settings in order to sufficiently improve their own performance. Clearly, more work needs to be done to investigate the use of the Windows® accessibility settings, using more diverse interaction scenarios, while examining the trade-offs that result.

Other evident issues in the application of the Windows® accessibility settings includes their incompatibility with third-party software and inadequate integration of these settings within both third-party and Microsoft® software. The use of the settings for Web browsing provides a convincing instance of these issues. It is unfeasible to predict in all circumstances how a software package will respond to the Windows® accessibility settings. This uncertainty makes broad implementation of the Windows® accessibility settings disconcerting and potentially unfavourable. However, this issue may not arise in all scenarios.

Depending on the application(s) used, the Windows® accessibility settings may likely provide more benefit than detriment.

In summary, when designing software for users with diverse visual capabilities, consider applying the Windows® accessibility settings as a relatively easy solution, particularly due to the absence of other effective low-cost assistive technologies available in the mainstream consumer market. Be aware, however, of their limitations, specifically regarding integration with web browsers and other software, and effective use of screen real estate.

5.3 *Multimodal feedback*

Multimodal feedback has been shown to be beneficial in supporting basic GUI interactions for users both with and without functional limitations (e.g. Belz and Robinson 1999, Oakley *et al.* 2000, Jacko *et al.* 2003b). The most basic form of feedback—visual highlighting—is ubiquitous in all domains of computing, and adding redundant information through feedback targeted at other senses (e.g. hearing, touch) can potentially reduce noise in the task environment and aid in task completion, overcome physical limitations (e.g. vision and hearing impairments) and environmental limitations (e.g. noisy and/or hazy/dark situations). However, alternative feedback modalities can also add to the noise in the environment and direct attention away from the task if improperly implemented. Brewster and Crease (1999) discuss ways in which auditory feedback can lead to annoyance in computer tasks. Two ways this can occur are discussed: excessive intensity and using attention-grabbing sounds for frequent, non-critical events. This leads to an attempt to design intelligent auditory feedback that would differentiate between erroneous and correct menu selections and use different sounds in each case. While the technique was imperfect, it was shown to reduce subjective feelings of effort for a menu selection task. Brewster and Crease (1999) recommended the investigation of haptic feedback to be used in a similar fashion.

The feedback used in this study was not designed to distinguish different types of menu selections (e.g. correct vs incorrect), as there are no well-established standards for the implementation of complex, adaptive multimodal feedback. For example, the visual, auditory and haptic feedback used in this study represents a fairly simple, monotonic version of multimodal feedback, as this interface enhancement provided additional sensory information in the same manner (e.g. consistent auditory and haptic cues with unvarying intensity) for all menu items. The intention of the study was to investigate readily available technologies, in their default configurations, that did not require excessive expertise to use.

As configured, the multimodal feedback used in this study proved to be predominantly ineffective overall for the three participant groups involved. One potential exception occurred in the number of IH and MO for all groups, where the combined multimodal feedback and Windows® accessibility condition produced the most efficient strategies, implying that the combination of these enhancements may lead to reduced errors for menu selection tasks. The time measures, however, showed a very small, practically insignificant (e.g. actual time in milliseconds not meaningful) decrement in performance when multimodal feedback was present.

The nature of the task played a role in this result, to be sure. In a similar study involving a drag-and-drop task (Jacko *et al.* 2003a), multimodal feedback was shown to significantly improve performance for both visually healthy participants and participants with impaired vision. Drag-and-drop interactions usually occur with a limited number of possible targets present among areas of empty space. Multimodal feedback can be used to identify the presence of those targets. However, in menu selection tasks, users typically select from a large set of adjacent targets, making information about target location less relevant. The information desired by users in a menu selection task is the location of the specific target they are looking for. Microsoft® has attempted to address this concern by implementing personalised menus that show only the most-recently accessed menu items before displaying all items when hovered over, the assumption being that the next desired menu item will most likely be one that has recently been accessed.

Menu selection presents a unique challenge for multimodal feedback. The additional feedback provided must be consistent with the visual feedback and serve as redundant information, otherwise it may add to the complexity of the task by conflicting with other information that is being received. The form that this feedback should take is not at all intuitive, however. A trial-and-error approach may, in fact, be the most direct way to progress, given the nature of the problem. Judicious selection and implementation of sounds and/or vibrations, along with the possibility of intelligent menu systems (e.g. adaptive modelling and (re)configurations based on user behavioural trends) may hold the key to improving the efficiency of this problematic interaction technique. It is clear that more work in this area is needed.

Another potential reason why improvements in performance failed to materialise from the use of multimodal feedback is the degree of residual vision retained by the participants in this study. This study intentionally investigated participants with binocular visual acuity of 20/50 or better, none of whom were prevented from completing the task because of their visual limitations. Users with severely-impaired visual acuity may begin to make use of information provided through non-visual channels to a greater extent (e.g. Fraser and Gutwin

2000). In support of this idea, Jacko and colleagues (2003a) found that participants with visual acuity worse than 20/100 performed best when receiving auditory, visual and haptic feedback.

One final implication lies in the lack of benefit provided by both multimodal feedback and the Windows® accessibility settings for the Control group. The Control group in this study was used as a baseline in order to compare performance for users with visual impairments, but this should not be interpreted to indicate that the Control group performed optimally. In all conditions, the Control group had more MO and IH than the ideal, indicating that there remain opportunities and untapped potential to aid all users for this key GUI interaction.

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