Low Vision: The Role of Visual Acuity in the Efficiency of Cursor Movement

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ABSTRACT

Graphical user interfaces are one of the more prevalent interface types which exist today. The popularity of this interface type has caused problems for users with poor vision. Because usage strategies of low vision users differ from blind users, existing research focusing on blind users is not sufficient in describing the techniques employed by low vision users.

The research presented here characterizes the interaction strategies of a particular set of low vision users, those with Age-related Macular Degeneration, using an analysis of cursor movement. The low vision users have been grouped according to the severity of their vision loss and then compared to fully sighted individuals, with respect to cursor movement efficiency.

Results revealed that as the size of the icons on the computer screen increased, so did the performance of the fully sighted participants as well as the participants with AMD.

Keywords

Low vision, cursor movement, icon size, age-related macular degeneration, search strategy, graphical user interface, GUI

INTRODUCTION

In the United States alone, one in every six Americans report some type of uncorrected vision impairment by the age of 45 [20]. Among the elderly, the most common causes of vision loss are Age-related Macular Degeneration (AMD), cataract, and diabetic retinopathy [17]. AMD is the leading cause of visual impairment for those 75 years old and older. It is also the most common cause of new cases of visual impairment for those 65 years old and older [16].

AMD affects central vision while leaving peripheral vision relatively intact. As the name implies, Age-related Macular Degeneration results in a degeneration of the macula. Briefly, the macula is the central portion of the retina that is responsible for acute vision. Although degeneration of the macula is a progressive disease and often results in a loss of visual acuity, it does not always cause total blindness. Individuals with AMD tend to choose to rely on their residual vision to function within their environment [11]. This vision loss can cause these individuals to rely primarily on their peripheral vision. Instead of looking directly at an object, they must adapt their search strategies to utilize their peripheral vision. This typically manifests itself in more head and eye movement as individuals attempt to compensate for their central field loss.

Because people with low vision, specifically those with AMD, will remain an active part of society, they will need to access information via information technologies [17]. The graphical user interface (GUI) style is a standard interface style that relies heavily on users' visual perception. Due to the shear size of the growing AMD population, understanding how this clinical pathology affects the functional requirements to use GUIs is vital.

While research continues to render the interface between user and machine more transparent, a significant number of individuals who have low vision are unable to effectively access GUIs. A limited amount of information exists regarding low vision users and GUIs. We propose to identify AMD usage strategies through an analysis of cursor movement.

Characterizing Interaction

There are a number of different modes of interaction that can be employed while interacting with a computer. Common modes include pressing buttons, manipulating mice, touching screens, and speaking. Direct manipulation approaches to interaction, which emphasize eye-hand coordination and spatial references, are inherently problematic for those with low vision. Inherent in the use of GUI are pictorial representations or icons. Previous work with low vision users has focused on the use of screen readers and simple text manipulation tools. With the advent of the GUI, these tools are no longer adequate. The ability to recognize and interact with visual representations is necessary. Among members of the low vision population, icon size and background color have been found to significantly affect general performance during computer use [10]. A better understanding of the manipulation techniques and behavioral characteristics employed by low vision users will allow for more effective accessibility aids to be developed, and thus furthering the goal of universal access. Several functional capabilities and design issues to consider investigating when discussing low vision users' abilities to access computers, have been identified by Gunderson [9]. Most importantly, he found a users' ability to control their eye movements must be determined. Second, it must be determined whether contrast and color settings meet the visual capabilities of the user and provide the capability to be enlarged, both text and images on the computer display [9].

The research presented in this study examined the interaction of the user and the computer via a mouse. This interaction provides a measure of movement control. Research relating to movement control of computer input devices spans many topics, from hand dominance to age related differences [12,22]. Previous work examines the performance of a variety of input devices for different types of applications. Kline and Glinert [13] have determined that the use of a mouse pointer, or cursor, is essential in current GUI environments. For this reason, we have recorded, analyzed, and can now characterize the cursor movements of low vision AMD computer users.

Cursor Movement

Although there is considerable research on cursor movement, there is relatively little research focusing on cursor movement control for the visually impaired. Mouse-driven cursor movement has been examined in the field of Human-Computer Interaction with a number of different metrics for item selection and target acquisition tasks. Speed, accuracy, direction of movement, and user preference has been previously examined with fully sighted users. Cursor movement has also been examined with reference to the target [1,3,4,7,12,24].

Parameters for analysis of movement during the approach time have been identified in the literature as maximum velocity of movement, maximum acceleration of movement, time to maximum velocity of movement and time to maximum acceleration of movement [1,2].

In addition to these measures, cursor movement can also be characterized through Fitts' law and the visual characteristics of individual icons.

From Fitts' law, and its derivatives, large movements correspond to longer movement times. It is also known that the time required to position a mouse on a target increases with smaller targets [8]. The work presented here uses a range of target (icon) sizes to fully explore this principle.

Visual characteristics of individual icons have also been examined with respect to user performance. If icons are not viewed as meaningful or easily comprehended, users rely on the location of the icon rather than the visual characteristics. It is known that some individuals with low vision utilize location cues to identify icons on the GUI rather than to rely on direct identification [15]. There are several visual cues conveyed via a GUI that guide a user. Users must be able to recognize both the physical movement of the mouse and the corresponding movement of the cursor on the display. To better understand if these cues are being received, a user's strategy for manipulating the cursor must be identified.

RESEARCH OBJECTIVES AND HYPOTHESES

Analysis of cursor movement will lead to a characterization of a critical facet of the interaction strategies of low vision users. An examination of the cursor movement strategies of fully sighted users and those with AMD will empirically demonstrate differences in their use of a GUI.

For those with low vision, the severity of vision loss is an important factor to consider. Previous research [23] has identified categories of visual acuity. These stratifications will allow for a more meaningful discussion of the effect that degree of vision loss has on interaction strategies.

We hypothesize that the movement time and velocity of fully sighted users will be significantly faster than that of those with low vision, regardless of the degree of impairment. Further, as visual impairment becomes more pronounced, performance will be degraded.

METHOD

Participants

Twenty-five individuals volunteered to participate in the experiment. AMD participants numbered 20 (10 male, 10 female) and were recruited from the AMD patient pool at the Bascom Palmer Eye Institute. The institute is part of the University of Miami and is the largest facility of its kind in the United States, annually performing 8,000 surgeries and treating more than 130,000 patients with virtually every ophthalmic disorder. Participants with AMD ranged from 63 to 90 years of age (mean = 80.3). Five fully sighted male participants were recruited from Florida International University. Their ages ranged from 22 to 32 (mean = 26.2) years. As compensation for participating in the experiment, AMD individuals were provided with visual assessments at the Low Vision Clinic of the Bascom Palmer Eye Institute and were paid $50. The visual assessments included determination of participants' binocular, left and right eye visual acuity; right and left eye contrast sensitivity; visual field and color perception. Table 1 provides a summary of the habitual vision of the AMD participants. Habitual vision was recorded at the time the data were collected. This was done so participants could wear their existing corrective eyewear during interaction with the GUI for maximum comfort.

Table 1. Visual Profiles of Participants with AMD (CS = contrast sensitivity, R = right, L = left)

		Clinical Assessment						
Subjects	Group	Acuity			CS		Visual	Color
		Binocular	R. Eye	L. Eye	R. Eye	L. Eye	Field	
A	2	20/40	20/32	20/100	24	17	99	3
B	2	20/50	20/126	20/40	26	28	90	3
C	2	20/50	20/200	20/32	19	29	94	3
D	2	20/50	0	20/64	28	0	85	3
E	2	20/63	20/100	20/50	24	32	95	5
F	2	20/63	20/40	20/160	31	33	100	3
G	2	20/63	20/160	20/40	9	31	98	3
H	2	20/80	20/50	20/250	17	24	95	4
I	2	20/80	20/200	20/64	12	32	88	3
J	2	20/80	20/400	20/40	5	30	100	3
K	3	20/100	20/50	20/800	24	1	99	3
L	3	20/100	20/80	20/126	18	11	90	1
M	3	20/125	20/640	20/80	2	34	90	4
N	3	20/125	20/126	20/160	15	22	96	5
O	3	20/125	20/100	20/320	20	22	95	3
P	3	20/125	20/250	0	29	0	85	5
Q	4	20/160	20/100	20/800	15	2	98	4
R	4	20/200	20/160	20/400	6	20	99	3
S	4	>20/200	20/200	20/320	18	6	96	2
T	4	>20/200	20/250	20/250	6	18	89	4

Visual acuity was assessed with the Bailey-Lovie Chart, where acuity is presented with Snellen scores. Normal acuity is specified as 20/20. Binocular visual acuity ranged from 20/40 to greater than 20/200 for AMD participants. Subjects were grouped according to their binocular visual acuity, based on an evident grouping of subjects' visual profiles and the work of Webster, Cook, Tompkins, and Vanderheiden [23]. The fully sighted subjects formed one group (group 1). The remainder of the participants were divided into those having binocular vision worse than 20/20 (group 2), 20/80 (group 3), and 20/125 (group 4). Table 1 identifies low vision participants according to group. Contrast sensitivity was measured using the Pelli-Robinson Chart. Full contrast sensitivity is specified as 48. AMD participants' contrast sensitivity scores ranged from 0 to 34. Field of view was determined with the Esterman projection perimetry method for binocular field of view. The normal score for field of view is 100%. Participants with AMD scored between 85% and 100% for field of view. Finally, color perception was assessed using the Farnsworth D-15 color vision test. AMD participants demonstrated a range of color perception from full color perception (5), to general color confusion (4) and deficiencies in red (1), green (2), and blue (3) color perception.

Apparatus

The Jacko Low Vision Interaction Assessment (JLVIA) software was used during experimentation. Figure 1 illustrates the experimental setup. The software allowed manipulation of specific features of a graphical user interface such as icon size, number of icons on screen and background color while collecting specific metrics like selection time and velocity of cursor movements. The participant sat at a computer running the JLVIA software, viewing a 21" color monitor while manipulating a mouse pointer to perform the experimental task.

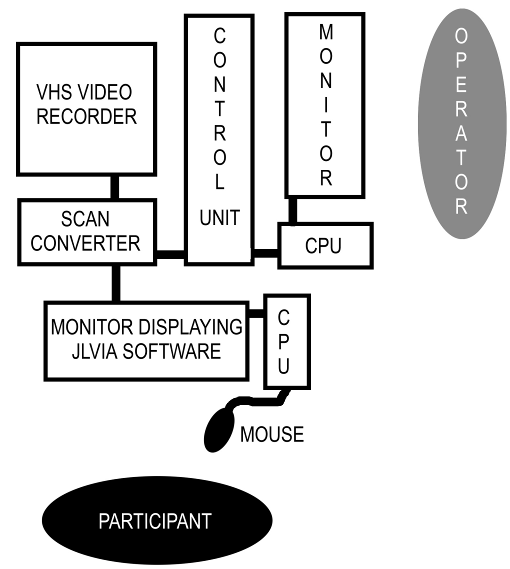

Figure 1. Schematic illustrating the experimental setup

Cursor coordinates were sampled at a rate of 60 per second (60 Hz) throughout the experimental session. A video signal was also recorded on a VHS tape to create a permanent record of the experiment.

Experimental Task and Procedure

Approval was acquired from all institutions represented on the experimental team for the use of human subjects, prior to experimentation. Informed consent was individually obtained from participants.

Data were collected while participants performed a continuous matching task. At the start of each trial a stimulus was presented. The stimulus, for example the Copy icon, measured 58.3x58.3 mm. A click with the pointer stationed on the home position of the stimulus screen generated a separate target presentation screen. The experiment was a 5x5x5 nested factorial repeated measures design. On the target presentation screen, dependent variables such as icon size, background color and set size, were manipulated. The number of icons varied from two to six icons and ranged in size from 9.2 to 58.3 mm. Icon sizes were 1 (9.2 mm), 2 (14.6 mm), 3 (23.2 mm), 4 (36.8 mm), and 5 (58.3 mm) in width. The background colors were fully saturated black, blue, green, red and white.

On the target presentation screen, participants were told to visually search for the target icon that matched the stimulus icon. Once the target icon had been identified, a click of the mouse with the pointer on the home position would activate the icon and its iconic region. Participants were told to move the pointer from the home position to the target icon. A click on the target icon ended that trial and began the next trial.

Differences in the number of icons (set size) and their size created a range of values for minimum distances required to reach a target. The distance required for the cursor to reach the closest icon, at the smallest icon size, was 8.22 cm (233 pixels). The required distance to reach the furthest icon at this icon size was 10.26 cm (291 pixels). As the size of the icons increased, the minimum distance to reach the icons increased. For the icons measuring 14.6 mm in width, the distances were: closest 8.39 cm (238 pixels) and farthest 11.71 cm (332 pixels). For the icons measuring 23.2 mm in width, the distances were: closest 7.90 cm (224 pixels) and farthest 13.97 cm (396 pixels). For the icons measuring 36.8 mm in width, the distances were: closest 8.89 cm (252 pixels) and farthest 17.64 cm (500 pixels). Finally, for the icons measuring 58.3 mm in width, the distances were: closest 9.03 cm (256 pixels) and farthest 19.47 cm (552 pixels). Participants were able to select a "Too Small" button when they believed that the icons were not distinguishable from one another. This button was located 4.00 cm (115 pixels) from the start position. Figure 2 is an example of the JLVIA interface at the 36.8 mm icon size, and a set size of six. The icons presented as stimulus in this study were some of the most identifiable icons in Microsoft® Word [18]: Print, Paste, Save, Copy, New and Open.

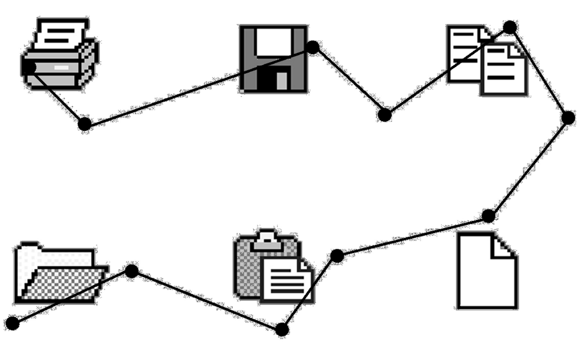

Figure 2. Sample cursor path with six icons

Analyses

Analytical techniques similar to those reported by Cakir, Cakir, Muller, and Unema [5] and Walker, Meyer, and Smelcer [21] were used to analyze the participants' search behavior. Metrics explored in the current paper are movement time and velocity, which are common for cursor movement analysis [1,2,3,4,7,12,14,19,21,24]. The following section briefly describes these two analytical techniques.

Movement Time (MT)

This performance measure is computed as the product of the total number of collected cursor positions by the inverse of the sample rate. Longer MT suggests inefficient search, while shorter MT suggests a more efficient search.

Velocity (V)

Dividing MT by movement length enables a derivation of the V of cursor movement. Card, Moran, and Newell have estimated that the maximum V for aimed mouse movements that are to hit a target region rapidly is approximately 150 cm/s [6]. The V of movement is also an indication of the efficiency of search. Lower V may imply an inefficient search.

RESULTS

Analysis of MT and V revealed significant differences between subject groups. The only significant variable among icon size, set size, and background color, was icon size (magnification). Additional analysis was performed on the participants' option to choose the "Too Small" button. Overall, performance was better with larger icon sizes than with smaller ones.

Too Small Button

Participants were given the option of choosing a "Too Small" button to indicate their inability to detect or distinguish the displayed icons. Table 2 illustrates the percentage of instances where the "Too Small" button was selected. A one-way ANOVA with repeated measures was performed on the number of times the "Too Small" button was selected. Significant differences were found for icon size across the groups ($F(12,84) = 6.943$; $p < 0.05$). Additional analysis revealed significant differences in performance for the group with the worst visual acuity (group 4) compared to the three other groups at the smallest two icon sizes (9.2 and 14.6 mm). For icon size 23.2 mm, the second and fourth groups were found to be significantly different.

Table 2. "Too Small" button responses by icon size for each subject group

	Icon Size (mm)					
	1	2	3	4	5	
Group	9.2	14.6	23.2	36.8	58.3	Average
1: 20/20	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
2: >20/20	8.8%	2.4%	0.4%	0.4%	0.4%	2.5%
3: >20/80	22.0%	6.7%	4.0%	3.3%	2.0%	7.6%
4: >20/125	70.0%	52.0%	19.0%	3.0%	1.0%	29.0%
Average	25.2%	15.3%	5.9%	1.7%	0.9%	9.8%

Movement Time

As shown is Figure 3, the one way ANOVA with repeated measures performed on movement time was significant across the stratified groups ($F(3,21) = 3.120$; $p < 0.05$) across icon size. The first group corresponds to the fully sighted users and the last group is the participant group with the most impaired vision. Tukey's pairwise comparisons for MT showed that all groups were significantly different from each other.

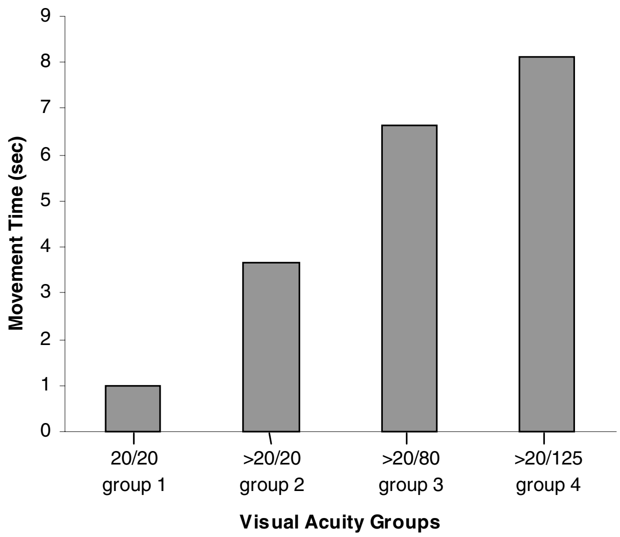

Figure 3. Movement Time by subject group

A significant interaction was observed between groups and icon size on MT ($F(12,84) = 2.051$; $p < 0.05$). Means are reported in Table 3. All subject groups were significantly different from the fully sighted group (group 1). The one exception was for icon size 1 (9.2 mm), where the fully sighted group (group 1) and the subject group with the most impaired vision (group 4) were not significantly different. At icon size 1, the performance of the most visually impaired group (group 4) was strongly coupled with their inability to detect or distinguish the icons. As a result, the MT for group 4 was mostly composed of the short time required to reach the "Too Small" button. Further comparisons indicate that at the largest icon size, 5 (58.3 mm), all subject groups perform differently. At the smallest icon size, 1, the second and third subject groups performed significantly different. Comparisons among AMD subject groups indicate a significant difference in performance at the middle icon size (23.2 mm), for the second and third subject groups with the fourth group.

Table 3. Movement Time (sec) as a function of icon size

	Icon Size (mm)				
	1	2	3	4	5
Group	9.2	14.6	23.2	36.8	58.3
1: 20/20	1.0	1.0	1.0	1.0	1.0
2: >20/20	4.2	4.1	3.3	3.6	3.0
3: >20/80	9.0	6.3	5.0	6.2	6.8
4: >20/125	2.4	6.7	9.3	11.0	11.3

Velocity

As shown is Figure 4, the one way ANOVA with repeated measures performed on velocity was significant across the stratified groups ($F(3,21) = 771.111$; $p < 0.05$). Fully sighted participants (group 4) performed with a higher V than the other participants. Tukey's pairwise comparisons for V showed that groups 2, 3, and 4 were significantly different from group 1. Group 2 was also significantly different from group 4.

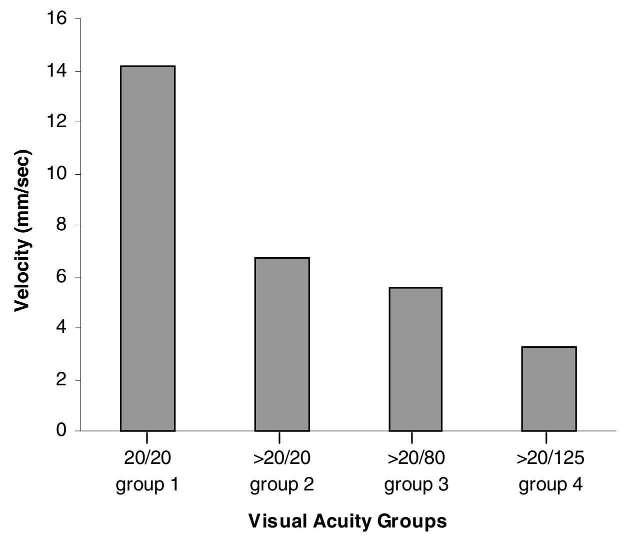

Figure 4. Velocity by subject group

A significant interaction was found between groups and icon size on V ($F(12,84) = 2.435$; $p < 0.05$). Means are reported in Table 4. Comparisons between the fully sighted group (group 1) and those with AMD show significant differences at each icon size. The AMD subject groups also proved to be significantly different with respect to performance. Each subject group performed significantly different from each other, except for icon size 4 (36.8 mm). At icon size 4, the middle two subject groups did not perform significantly differently.

Table 4. Velocity (mm/sec) as a function of icon size

	Icon Size (mm)				
	1	2	3	4	5
Group	9.2	14.6	23.2	36.8	58.3
1: 20/20	10.1	11.4	13.9	17.2	18.4
2: >20/20	4.3	5.2	6.8	7.9	9.5
3: >20/80	2.9	4.1	5.4	7.4	8.1
4: >20/125	0.9	1.7	3.2	4.6	6.0

Discussion

The research presented here characterizes the interaction style of one specific type of low vision computer user according to two metrics. Individuals with AMD were presented with the JLVIA software and asked to perform a series of target matching tasks. Using six of the most commonly identified icons, icon size, set size, and background colors were manipulated to determine performance across a range of values. Analysis of cursor movement was conducted to characterize the interaction style of the AMD participants. Icon size proved to be a significant factor. Comparisons among stratified binocular acuity groups provides empirical evidence for which only anecdotal evidence currently exists. Fully sighted users perform better in cursor V and MT. In general, participants with greater deviations from normal acuity performed worse than those with smaller deviations from the norm. Participants with the worst binocular acuity performed the worst, as judged by the performance measures.

Varying the size of the icons on the computer screen showed consistent trends in performance. As icon size increased, the performance of the participants improved. Significant results were not observed for background color and set size. These results motivate future inquiries that incorporate a broader range of background color and larger set sizes.

Too Small button

When participants were unable to detect icons on the screen or distinguish between icons on the screen, they were able to click on a button labeled "Too Small" in order to initiate the next trial. When this was done, the participant moved on to the next interface screen without having to choose a target icon. The time recorded for this participant reflected the time to click the option indicating that the icons were not distinguishable. These instances were not screened out of the experimental analysis for either MT or V.

Determining the location of the target icon when participants selected the too small button, proved to be useful. Based on findings shown in Table 2, as visual impairment increased, it also became more difficult to visually perceive the icons. Additionally, as icon size increased, the number of instances in which individuals chose the "Too Small" option decreased.

For the fourth group, the participant group with the highest degree of visual degradation, the smallest icon size (9.2 mm) proved to be extremely difficult to see. This group chose to select the "Too Small" button in this instance 70% of the time. According to this measure, beyond the fourth icon size (36.8 mm), performance between visual acuity groups was nearly equal.

Movement Time

Fully sighted users appeared to require the same amount of time for all of the icon sizes. Additionally, fully sighted participants did not benefit from increases in icon size to the same degree as the low vision participants. This result can be attributed to the fact that fully sighted participants had little difficulty recognizing the icons at various sizes. Conversely, the AMD participants encountered difficulty distinguishing the icons at small sizes thus, their interaction with the interface was hampered.

Under unique circumstances, participants with poor visual acuity chose to skip screens with small icons. For small icon sizes, this behavior would improve movement time, and hence velocity, since the distance and recognition of the "Too Small" button was far easier than finding a potential target icon. For larger and more distinguishable icon sizes, this behavior resulted in longer movement times. As icon size grew, the movement time increased, on average, and participants increasingly chose to attempt to identify the target icon.

Overall, the observed measure of MT reported in this study was longer than MT reported in previous studies [1,3,4,12,14]. This is the result of dissimilarities between our study and previous studies. Although the performance measures observed in this paper were similar to other studies, the interface screen, participant population and research goals were entirely different. In the other research, participants were presented with a single target that was closer in distance than the target available to the participants in this study. Previous studies also did not necessarily couple target selection with MT. Further, this study focused on the effect low vision had on performance. In all studies previous to this one, cursor movement, represented through MT and V, was characterized for only fully sighted users. In this study, fully sighted users were only one set of the participant sample. The difference in MT between this study and previous studies provides experimental evidence that low vision users perform differently than normally sighted users.

Velocity

As can be observed in Figure 4, fully sighted users performed with twice the V as the subject group with less than 20/20 visual acuity. Further, those with the poorest visual acuity (group 4) performed with less than a third of the movement V as the fully sighted group. As previously mentioned, V is an indication of the efficiency of search and those with AMD clearly are unable to perform as well as those with full vision for any icon size. This may be due to problems with visual tracking and issues related to other losses of central vision.

Velocity was the only measure sensitive enough to detect a difference between icon sizes for the fully sighted group. The highest V reported in this study was near the approximate maximum V for rapid movement determined by Card, Moran, and Newell [6].

The results showed that the individual participant groups were significantly different from each other for most levels of icon size. As a result, the severity of vision loss significantly altered the interaction style of the participants.

CONCLUSIONS

This paper presents empirical evidence comparing the interaction styles of AMD and fully sighted computer users. It has been previously assumed that magnification of GUI elements improves the performance of low vision users. Research presented here tested that assumption in the context of a variety of background colors and set sizes. This context allowed for a far more detailed evaluation of interaction style.

Using principles outlined by Gunderson [9], low vision subjects were found to perform significantly different from fully sighted users in both MT and V of cursor movement. Performance differences among those with AMD were also found, indicating differences in GUI interaction styles as visual acuity changed.

Using this compelling information, designers and developers must recognize that there are significant differences in the interaction styles of users with varying visual profiles. To further the objectives of universal access and GUI development according to user centered principles, more information, such as what was found in this study, must be gained about the interaction strategies of low vision users.

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