An Exploratory Investigation of Handheld Computer Interaction for Older Adults with Visual Impairments

V. Kathlene Leonard
Wallace H. Coulter Department of Biomedical Engineering & School of Industrial and Systems Engineering
Georgia Institute of Technology
Atlanta, Georgia, USA
vkemery@isye.gatech.edu

Julie A. Jacko
Wallace H. Coulter Department of Biomedical Engineering & School of Industrial and Systems Engineering
Georgia Institute of Technology
Atlanta, Georgia, USA
jacko@isye.gatech.edu

Joseph J. Pizzimenti
College of Optometry
Nova Southeastern University
Fort Lauderdale, Florida, USA
pizzimen@nova.edu

ABSTRACT
This study explores factors affecting handheld computer interaction for older adults with Age-related Macular Degeneration (AMD). This is largely uncharted territory, as empirical investigations of human-computer interaction (HCI) concerning users with visual dysfunction and/or older adults have focused primarily on desktop computers. For this study, participants with AMD and visually-healthy controls used a handheld computer to search, select and manipulate familiar playing card icons under varied icon set sizes, inter-icon spacing and auditory feedback conditions. While all participants demonstrated a high rate of task completion, linear regression revealed several relationships between task efficiency and the interface, user characteristics and ocular factors. Two ocular measures, severity of AMD and contrast sensitivity, were found to be highly predictive of efficiency. The outcomes of this work reveal that users with visual impairments can effectively interact with GUIs on small displays in the presence of low-cost, easily implemented design interventions. This study presents a rich data set and is intended to inspire future work exploring the interactions of individuals with visual impairments with non-traditional information technology platforms, such as handheld computers.

Categories and Subject Descriptors
H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Graphical User Interfaces (GUI), Auditory (non-speech) feedback, Screen design*

General Terms
Measurement, Design, Experimentation, Human Factors

Keywords
Older Adults, Visual Impairment, Macular Degeneration, Icons, Drag and Drop, Spacing, Auditory Feedback, Mobile Computing

1. INTRODUCTION
Over the past 10 years, a growing body of research has focused on understanding and improving access to Information Technology (IT) for individuals who experience some level of visual dysfunction. This is largely motivated by an expanding population of older adults, as it is estimated that 1 in 3 baby boomers will experience a vision reducing eye disease by the age of 65. By the year 2030, the population of Americans 65 and older will number 70 million [10], generating an urgency for advancements in accessible technology for this population.

Previous work has demonstrated that interactions are strongly influenced by the nature and amount of residual vision a user possesses in combination with the computer interface characteristics (summarized in [8]). This underlying concept has spawned several theories of IT interaction for individuals with visual impairments:

- IT solutions for individuals who are blind are typically inappropriate for individuals maintaining useful residual vision possessed by the user.
- The efficacy of design interventions depends on the nature and amount of a user's residual vision.
- Increasing text size and image size can be more problematic than assistive, especially considering the nature of the visual impairment.
- The emphasis of direct manipulation tasks in graphical user interfaces (GUIs) on visual interaction paradigms places users with visual impairments at a quantifiable disadvantage.

The present study aims to further expand the understanding of interactions for older adults with visual impairments, through an appraisal of influential factors of direct manipulation on a handheld computer.

1.1 Icon Manipulation & Visual Impairment
Fraser and Gutwin [5] identified barriers to direct manipulation and GUI use for individuals with visual impairments to be influenced by the fine details of iconic screen targets and the small and dynamic nature of the pointer used to manipulate these icons. The difficulty with object manipulation using the pointer is primarily attributed to reduced visual acuity and constrained visual field. This work introduced four dimensions of GUI interaction bearing influence on the efficacy of designs for this population, including: 1) the mode or sensory channel through which assistance is provided to the user; 2) the phases of iconic manipulation, such as locating the icon, its acquisition with a given input device (mouse or stylus) and movement of the icon to a final position; 3) how the input device, interface, and the onscreen pointer are interconnected; and 4) the pervasiveness of

interaction tools, balancing between the availability of the assistance and its intrusiveness on the goals of the task.

Jacko and colleagues have completed several empirically-based studies demonstrating how measures of visual function influence direct manipulation (see [8] for a review). These studies have addressed the relative performance of a cohort of users with visual impairments due to ocular disease and a cohort of age-matched controls without ocular dysfunction on several desktop computer tasks. In the examination of iconic visual search (such as file, print, save, etc.) in the presence of distracters, visual acuity, contrast sensitivity and color perception were found to be significant predictors of performance on this search task for users with AMD (contrast sensitivity was the most sensitive indicator) [13]. That is, aspects of visual function affected the performance of various task components differently. In addition, icon size, set size, and background color significantly influenced interaction as a function of ocular diagnosis.

A later study of GUI iconic manipulation again considered a population with AMD [8, 9]. Working on a desktop, participants with AMD were tasked with selecting, dragging, and dropping a single Microsoft Word Windows® file into a single Microsoft Office Windows® folder icon. This study measured the efficacy of supplemental multimodal feedback (haptic, auditory and visual) for participants possessing different visual acuities. Unlike previous studies, this experimental task did not have a substantial visual search component, but instead focused on the physical manipulation of the icons on the display. Results demonstrated significant differences in performance between groups of people with different visual acuities on task time, feedback exposure times, and the frequency of errors. Performance improvements were realized for both visually healthy and AMD participants when provided with non-visual and multimodal feedback. Effects were greater in magnitude for participants with the most severe vision loss and AMD.

Findings from these and other studies have established a baseline understanding of HCI for users with visual impairments. However, the research has yet to fully explore critical GUI interactions and dimensions of GUI effectiveness outside the context of desktop computing. Lacking are investigations focusing on the enabling and disabling facets of mobile devices.

1.2 Mobile Computing & Visual Impairment

Researchers have only recently started to ask questions concerning the use of mobile, wireless technologies by users with limited abilities such as visual impairment. Mobile computing introduces new challenges by providing powerful computing behind suboptimal interfaces: small visual displays, poor audio facilities and limited input techniques. Interactions with mobile computers are also susceptible to the effects of context: varying tasks, environments and users. Users with visual impairments who wish to use mobile computing technologies, such as cell phones and handheld computers, are likely to encounter these contextual challenges in addition to barriers of interaction imposed by their functional vision, or disability-induced impairments [11]. Tasks such as way-finding, memory recall and communication can be enhanced for this population with mobile devices, but only if the effects of context and visual ability are adequately accounted for.

As a starting point, this study applies the research methodologies proven successful in the assessment of the impact of impairment on GUI interaction in a desktop environment to direct manipulations using a mobile device, specifically a handheld computer. This study aims to reveal, for older adults with visual impairments, the personal, ocular and interface factors that are influential on different components of the handheld computer interactions.

1.3 Age-related Macular Degeneration

This study considers the interactions of users diagnosed with AMD, the leading cause of vision loss in adults 65 years and older. AMD is a disease that affects the center of the retina, or macula, the area primarily responsible for central, fine detail and color vision. Individuals diagnosed with AMD often experience measurable distortion or deficits to their central visual field, while the vision in their periphery remains intact. This intact vision is referred to as residual vision.

Accurate diagnosis of this disease is achieved via ophthalmic examination of the posterior of the eye. Visible features on the retina facilitate the diagnosis and classification of AMD. Experts scan the retina for the presence of drusen – discrete yellowish-white spots on the image. In addition they examine the state of the retinal pigment epithelium (RPE), a single layer of cells between the retina and the underlying blood vessels.

Several classification systems have been used to grade the severity of AMD. The current study employed a method introduced in 1989 [1], grading severity level on a scale from 0 (no disease) to 4 (most severe) based on the amount of drusen, their distribution on the macula and the observed condition of the RPE. Grade 4, the most severe or final stage, is assigned to those cases in which the RPE is deteriorating or leaking.

The progression of AMD involves deficits in central and high-resolution vision, which over time reduces the sharp vision necessary to resolve objects and perform near vision tasks. AMD seldom causes complete vision loss, leading these individuals to adaptively rely on their useful residual vision. As their vision diminishes, people with AMD learn to integrate non-visual cues with the residual vision. The HCI needs of this user group are significant because those who acquire AMD are likely to experience increases in severity level and associated declines in visual function over time. There is no known cure for AMD. Those with the condition manage the impact of this disease on activities of daily living by developing strategic coping skills; altering behaviors and making use of assistive devices to maintain independence.

2. STUDY OBJECTIVES

The objective of this study is to identify indicators, which predict successful iconic search and manipulation using a handheld computer for older adult users with AMD. This investigation considers demographic characteristics of the user, clinically acquired ocular measures and features of the interface and task. This paper reports on three time-based measures (trial time, visual search time, and movement time) and one distance-based measure (icon drag distance). Three design interventions were considered as well as statistical interactions between each intervention and the severity level of AMD for each. The interventions included two factors related to screen real estate: the set size (number of icons on the screen) and inter-icon spacing. The third factor is the presence (or absence) of auditory feedback.

3. METHODOLOGY

Thirteen volunteers from the Nova Southeastern University (NSU) College of Optometry patient pool and associates of NSU staff participated in the study. Ten participants were diagnosed with some level of AMD, while the remaining three were visually healthy, age-matched controls. Criteria for inclusion in the study were computer experience (frequency of use and application familiarity) and age (over 50 years). Controls were included based on the absence of ocular pathologies, while the AMD participants were screened to confirm the diagnosis of AMD and absence of other ocular pathologies. As incentive, participants were provided with comprehensive ophthalmic exams and given $50 US. When necessary, participants were provided with temporary frames outfitted with corrective lenses to enable use of their best-corrected vision for the handheld experimental task.

Participants' self-perceived assessment of health was measured using the SF-12, which generates scores for both mental and physical health [14]. The manual dexterity of participants' dominant hand (used to control the stylus handheld input) was measured with the Purdue Pegboard test of manual dexterity [12]. While none of the participants had previous experience with handheld computers, 9 owned cell phones for at least two years.

Participants interacted with a Dell Axim™ X30 Pocket PC. The handheld display was a touch-sensitive LCD, measuring 3.5 inches diagonal, with the resolution was set to 240x320 at 16-bit color. The device was secured to an inclined platform during the task to accommodate the collection of eye movement data (reported in a subsequent paper), shown in Figure 1. Participants were seated a comfortable viewing distance from the handheld and allowed to adjust the seating for their own comfort.

The experimental task was designed to assess a range of iconic manipulations and the associated difficulties imposed on this population's interactions with handheld computers. The task required visual search for a target icon among distracters, selection of the icon with the stylus, and finally the drag and drop of the icon to a new target location. In contrast to the Microsoft Word® icons used in previous studies [8, 13], this study used icons of playing cards as the target icons (shown in Figure 1).

Figure 1. Handheld experimental configuration including screen shot of the task (not actual size)

While participants were screened for computer experience, the majority of their experience was derived from Internet use, email and games. The use of the file and folder icons may cause individuals with greater amounts of computer experience or experience with certain applications to interact at higher rates of efficiency due to their familiarity and comfort with the images. The playing cards were more likely to be highly familiar images for a greater number of participants, because a large number of older adults play card games on a regular basis (as it has been shown to mitigate effects of aging and dementia). The design of the card icons embodies the criteria for simple icons of good quality. That is, icons discriminated by as few features as possible, using simple shapes and colors [4]. Decreasing icon quality has been shown to cause inefficient, longer visual search strategies for the visually healthy population, particularly as the number of distracters competing with the target icon increase. The use of playing cards provides some control over the factors of icon quality and familiarity while isolating factors affecting visual search and icon manipulation.

A custom software application was written for this experiment using Visual C. The playing card icons used in the study were numbered 2 through 9, to enable consistency in visual search (no aces, queens, kings or jacks, to exclude cards with letters instead of numbers, and those with detailed face card illustrations). All four suits were represented: hearts, diamonds, clubs and spades (e.g.♥♦♣♠), in their traditional red and black colors. The icons were consistent in size with the standard Microsoft Windows Mobile 2003® icon size, 32x32 pixels or 7x7 mm on this display.

Participants were verbally instructed to locate a target card amongst a grid of several distracter card icons of different numbers/suits, select the target using the stylus, then drag it to the card pile on the left-hand side of the display which matched its suit and drop the card into this pile. Participants were directed to work as quickly and accurately as possible. Before commencing the trials, participants were trained on the task, informed of the upcoming changes to the interface and introduced to the auditory feedback for the task (volume levels adjusted for adequate detection).

Three independent variables were controlled during this task: Set Size (SS), Inter-Icon Spacing (ISp), and Auditory Feedback (AF):

Set Size (SS) was defined in this study as the number of icons in the playing card grid, or the target icon plus the number of distracter icons. For the present study, the SS levels were considered purely on the basis of the screen real estate available on the Pocket PC. Three levels were considered: 4, 8, and 12. The card icons were always distributed four per column, for one, two and three columns in the respective conditions.

Inter-Icon Spacing (ISp) was the distance or white space between the card icons and drop piles measured relative to icon size. While ISp has not been considered before in assessments of interactions for users with visual impairments, it has been shown to be influential in visual search and icon manipulation for a visually healthy population [6]; objects near the target were observed to impact affect search and selection of the object. ISp had three levels in this study, also based on the limits of screen real estate. The levels include ¼ icon width (1.75 mm), ½ icon width (3.5 mm) and 1 icon width (7.0 mm).

Auditory Feedback (AF) was an auditory cue indicating a card icon was in position for a successful drop into the pile. The auditory cue conveyed to the user that at that moment, the card was in place for an effective drop into the pile; if the stylus were lifted at that time, the trial would be complete (note: AF is not an indication of whether or not the location is correct or not, given the identity of the card). Levels of AF were present and absent.

Previous work with non-visual auditory cues and drag and drop employed an auditory icon, a 'sucking' noise to signify accurate placement for releasing the file into a folder icon [8]. The present study employed the same auditory icon as employed by Jacko and colleagues, but considers its efficacy in the context of distracter target icons on the handheld.

The factorial design generated for the present study (3x3x2) resulted in 18 total interface conditions with nine repetitions. Twelve participants completed all 162 trials, and one completed 93 trials. The order of exposure for 18 the interface conditions were divided into two sets: AF present and AF absent. The conditions within AF present and AF absent were completely randomized and the order of exposure to the AF sets was random across participants.

The arrangement of the card icons, drop piles and the collection of distracter card icons were randomly assigned for each trial across participants. The target card for each trial was consistent between participants for simplification of the experimental protocol. While participants searched for the same target cards at trial 1, 2, and so on, the conditions under which they sought that icon differed to mitigate any specific impact of card number or suit.

The dependent variables profiled the overall efficiency and effectiveness of interaction and accounted for several subcomponents of the task. This paper reports four continuous measures of performance: three time-based (measured in msec), and a fourth measure, which was the distance (pixels) travelled with the icon, prior to the final release into the pile.

Trial Time (TT): A measure of the total time from first exposure of the task screen until a card icon (not necessarily correct) is dropped into one of the card piles (not necessarily correct).

Visual Search Time (VST): A measure of the time between when the task screen first appears, until the stylus touches the active area of the icon ultimately dropped into a pile.

Movement Time (MT): Based on the icon that is ultimately dropped into a pile, this is the time between when the user first selects the card using the stylus and when it was lifted from the screen to successfully drop a card into a pile.

Drag Distance (DD): The number of pixels over which the stylus dragged the card icon before its successful drop into a pile. A greater DD can indicate a lack of efficiency in the card movement to the pile.

4. RESULTS

Overall, participants demonstrated a high rate of accuracy in task completion (97%). A linear regression analysis was completed to ascertain which factors are most influential on handheld interaction for this population. The utility of regression in explaining interactions was demonstrated by Edwards and colleagues [2], in an assessment of sources of performance variability for users with Diabetic Retinopathy with a drop-down menu task. The sources of variability considered in the present study are summarized in Table 1, classified according to interface, participant and ocular characteristics (ocular health and function). In addition to those variables listed in Table 1, statistical interactions between the AMD severity score and the independent factors were introduced into the models. The collection of predictor variables entered into each regression was consistent, enabling comparisons of the relative effects of the predictors within and between the models.

Table 1. Predictor variables considered

Predictor	Description	Observed Levels
Interface Related Characteristics		
Set Size (SS)	The number of card icons presented for each trial	1 = 4 card icons 2 = 8 icons 3 = 12 icons
Inter-Icon Spacing (ISp)	The number space between the card icons and drop piles (above and below)	1 = ¼ icon 2 = ½ icon 3 = 1 icon
Auditory Feedback (AF)	Supplemental auditory feedback to communicate the position of the card for an accurate drop	0 = AF absent 1 = AF present
Column	The column where the target card icon is located for each trial	1 = leftmost 2 = middle 3 = rightmost
Row	The row where the target card icon is located for each trial	1 = top 2 = 2^{nd} from top 3 = 2^{nd} from bottom 4 = bottom
Drop Location	The row number of where the correct drop pile for each trial was located	1 = top 2 = 2^{nd} from top 3 = 2^{nd} from bottom 4 = bottom
Trial Number	Sequential position of the trial within a participant's overall experimental session	Range: 0 -161
Age	Age of the participant	53–82 years Mean = 68.69 Median = 70
General Participant Related Characteristics		
Predictor	**Description**	**Observed Levels**
Physical Health (PCS)	Self reported physical health at the time of the experiment, from 1 (worst) to 100 (best)	Range: 28.64-60.46 Mean = 46.15 Median = 45.22
Mental Health (MCS)	Self-reported mental health at the time of the experiment, from 1 (worst) to 100 (best)	Range: 26.39-60.79 Mean = 46.74 Mean = 48.61
Manual Dexterity	The average number of pins inserted into small holes in a board over three, 30 second trials, from 0 (worst) to 30 (best).	Range: 4.67-16.33 Mean = 11.49 Median = 12.33
Ocular Related Characteristics		
Predictor	**Description**	**Observed Levels**
LogMar Near Visual Acuity† (NVA)	Ability to focus on fine details at a distance of 40 cm, translated from Snellen acuity (e.g. 20/20) from .1 (best) to 1(worst)	Range:0.19-1.00 Mean = .71 Median = .80
Contrast Sensitivity†	Measure image visibility is before it is indistinguishable from a uniform field, from 0 (low) to 60 (high)	Range: 26.00-40.50 Mean = 33.50 Median = 34.50
AMD Severity Score†	A diagnosis of severity of disease from no disease (0) to severe (4)	Range: 0-4.00 Mean = 1.17 Median = 1.00

†For NVA CS & AMD Score, weighted average of the best and worst eye (.75 * best + .25 * worst) approximated binocular visual field.

For each model, stepwise regression was applied to analyze the contributions of the identified predictors to the overall variance of the each dependent measures and identify a linear model that best fit the data. In order to meet the assumptions of regression analysis, transformations were applied to each measure of efficiency and outlying cases were removed to strengthen each model. Considering the high variability in human performance data, particularly for older adults, the emergent models were all good fits of the data, accounting for between 47 to 58% of the variability (see Table 2).

Table 2. Model summary, all models significant at p < .001

	1/√TT	1/√VST	ln MT	ln DD
N	2011	2011	1990	2004
R^2	.580	.518	.487	.473
R^2-adj	.578	.515	.485	.470

Table 3 provides a detailed synopsis of each model, including the significant variables, coefficients and standardized coefficients. While the coefficients and constants are beneficial to constructing predictive equations for each variable, the practical interpretation of coefficients is less straightforward, due to the discrepancy in the scales used to measure each predictor variable. The standardized coefficient (B-std) proves extremely beneficial in the understanding of the models. It provides the means by which to quantitatively compare the relative impact of each predictor the efficiency measures within and between models

Although the values in Table 3 are rich with information useful in predictive modeling of task efficiency, it is difficult glean the most salient trends to emerge from this exploratory research effort from this table. To this end, Figures 2a-d, provide a more practically applicable summary. For each model, a bar graph plots B-std for the variables included. By plotting the standardized B-std, relative comparisons can be made in term of 'how much more' a predicator influences a given efficiency measure, and also draw comparisons between models.

The following should be considered with respect to Figures 2a-d:

- *Bars extending to the left of the origin:* An increase in the value of that predictor in the model imposes a decrease on the efficiency measure;
- *Bars extending to the right of the origin:* An increase in the value of that predictor imposes an increase in the value of the dependent efficiency measure;
- *Increased 1/√TT and 1/√VST:* Faster times, improved efficiency;
- *Increased ln MT:* Longer icon movement times, degraded efficiency; and
- *Increased ln DD* equates to longer distances travelled with the icon for declines in efficiency.

For example, in Figure 2a, the AMD Score bar extends far to the left. This means that as AMD severity score increases (the severity worsens) the anticipated value of 1/√TT decreases substantially more than it would in the influence of any other predictor variable. This suggests that AMD interferes with the timely completion of GUI interactions on a handheld computer far beyond the interaction of older individuals without ocular pathology.

Table 3. Summary of predictors and coefficients included

Interface Related Characteristics					
Variable		**1/√TT**	**1/√VST**	**ln MT**	**ln DD**
Set Size (SS)	*B*	-.0016	-.0029		
	SE	.00010	.00020	*****	*****
	B-std	-.32	-.34		
Inter-Icon Spacing (ISp)	*B*				.244
	SE	*****	*****	*****	.011
	B-std				.374
Column	*B*		-.00081		
	SE	*****	.0000095	*****	*****
	B-std		-.13		
Row	*B*			.12	0.45
	SE	*****	*****	.012	.013
	B-std			.18	.53
Drop Location	*B*			-.057	-.027
	SE	*****	*****	.007	.0079
	B-std			-.140	-.055
Trial #	*B*	.000017		-.002	
	SE	.0000013	*****	.00016	*****
	B-std	.134		-.17	
General Participant Related Characteristics					
Variable		**1/√TT**	**1/√VST**	**ln MT**	**ln DD**
Age	*B*	.000093	.00012	-.008	
	SE	.0000086	.000015	.001	*****
	B-std	.213	.17	-.18	
Mental Health (MCS)	*B*	.00010	.00019	-.010	
	SE	.0000093	.000017	.001	*****
	B-std	.25	.27	-.24	
Physical Health (PCS)	*B*	-.000037	-.00012		
	SE	.0000081	.000015	*****	*****
	B-std	-.085	-.16		
Dexterity	*B*	.00036	.00056		-.031
	SE	.000035	.000064	*****	.0035
	B-std	.26	.24		-.17
Ocular Related Characteristics					
Variable		**1/√TT**	**1/√VST**	**ln MT**	**ln DD**
Near Visual Acuity (NVA)	*B*	-.0033		.89	-.18
	SE	.00033	*****	.040	.048
	B-std	-.22		.53	-.088
Contrast Sensitivity (CS)	*B*	.00038	.00031	-0.081	.018
	SE	.000027	.000039	.003	.0037
	B-std	.37	.18	-.72	.13
AMD Score	*B*	-.0028	-.0049	.17	.078
	SE	.00016	.00028	.017	.011
	B-std	-.72	-.75	.38	.15
Interaction Terms					
Variable		**1/√TT**	**1/√VST**	**ln MT**	**ln DD**
AMD* SetSize (AMD*SS)	*B*	.00027	.00057	.017	
	SE	.000069	.00013	.007	*****
	B-std	.16	.21	.090	
AMD* Auditory (AMD*AF)	*B*			-.13	-.059
	SE	*****	*****	.010	.012
	B-std			-.23	-.088
Constant		**1/√TT**	**1/√VST**	**ln MT**	**ln DD**
	B	-.0012	.0067	10.26	3.81
	SE	.0013	.0023	.15	0.099
	p	.38	.004	<.001	<.001

The terms, AF and AMD *ISP were not included as predictors in any of the models, and thus not included in this table.

[*****] designates terms not included in a given model.

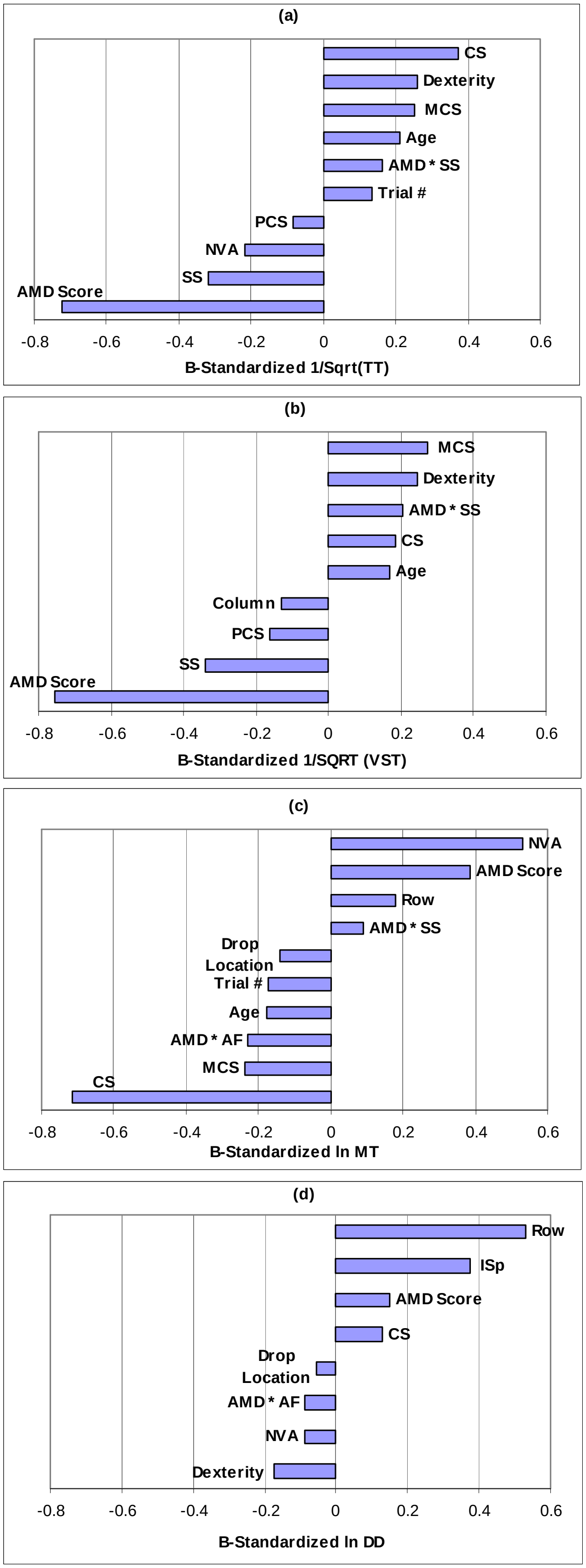

Figure 2a-d Relative impact of predictor variables, B-std

5. DISCUSSION

The results from the regression, and the emergent patterns depicted in Figures 2a-2d, provide insight into some of the most influential factors affecting handheld computer use for individuals with AMD. The results from this study serve as a baseline for future empirical research, and effectively set priorities for further investigations.

This discussion emphasizes the ways in which results involving interactions with handheld computers are consistent with previous research involving desktop systems, while also emphasizing new, emergent interaction models unique to handheld devices for this population of users.

5.1 Ocular Health and Function

Outcome #1: *The persistent impact of clinically ocular measures on performance validates several previous studies [2, 8, 13] and effectively extends the theory to new interaction platforms with small visual displays.*

Based on the standardized coefficients, measures of visual function dominated performance in the different phases. AMD Score and Contrast Sensitivity (CS) were reliable predictors for the models of all four measures (the only two predictors to be included in all four). This reaffirms the importance of investigations that focus on the sizable impact of visual dysfunction on GUI-based tasks across platforms. More specifically, these models enable the assessment of productivity costs incurred by this population with the handheld computer.

Outcome #2: *Design efforts and strategies aimed at assisting visual search are an appropriate starting point for the development of accessibility solutions for handheld interactions.*

As the severity of disease (measured by AMD score), worsened (the value increased) all the models reflected performance decrements. The performance differential imposed by AMD score is consistent with the findings of Jacko and colleagues [8], who observed a similar effect of disease on performance on a single drag and drop between a cohort with AMD and visual healthy controls. AMD score had its most notable influence on TT and VST, and was the third most influential factor on MT. The importance of TT conveys the measurable performance differential incurred due to visual dysfunction on overall task completion, while the magnitude of influence on VST suggests that visual search is an essential component in the quest for accessible design.

Outcome #3*: The role of contrast sensitivity as an essential determinant of task performance for people with visual impairments extends from traditional desktop environments to mobile device use.*

Changes to contrast sensitivity (CS) systematically impacted the efficiency of the task. Improvement (increase) in contrast sensitivity scores emerged as a predictor of faster TT, VST and MT. In previous studies, contrast sensitivity has been found to be influential across several desktop computer tasks; the observed influence in this model extends this phenomenon across novel interaction platforms [2, 3, 7].

Near visual acuity (NVA), while not influential on the prediction of VST, was included as a predictor in the models of TT, MT and DD. As *NVA* degraded, or increased in value, both TT and MT were slower which confirms the role of the quality of residual vision on task efficiency.

Outcome #4: *The path taken during the drag operation is not as strongly influenced by visual factors as it is by features of the interface itself.*

The impact of the visual factors on *DD* was small in magnitude as compared to their more substantial influence on the other three efficiency models. Features of the interface, such as the location of the target (drop location) and the Inter Icon Spacing (ISp) pose a greater influence than the ocular measures on DD.

The influence of both contrast sensitivity (CS) and near visual activity (NVA) on DD was neither expected nor straightforward. The model indicated that improvements (increases) in contrast sensitivity resulted in an increased DD; while declines in near visual acuity function (increased value) triggered shorter distances. This result is not wholly intuitive and is a clear departure from the efficacy in icon manipulation previously observed on the desktop for the AMD population. The small display of the handheld is suspect in these surprising effects, as the nature of the visual stimulus poses demands on the visual sensory function much different than those associated with the desktop, primarily with respect to the area within which a user performs visual scanning and tracks icon movement.

5.2 Personal Traits

Outcome #5: *Personal characteristics such as age (and thus indirectly task familiarity), dexterity, and learning are all influential factors in handheld device use and should be considered in empirical studies involving older adults with visual impairments who are tasked with using handheld devices.*

A handful of personal characteristics proved influential on the models across the different task phases. Increases in *age* were included as predictors of faster TT, VST and MT, which is contrary to observations obtained in previous studies, where older age was a significant predictor of longer task completion times [2]. This result can be attributed to the choice of playing cards as the visual icons in the interface. Older participants may have more experience playing cards than the younger participants, and likely had more spare time for such activities (the majority of young-old participants were not yet retired). The use of familiar icons can increase users' comfort levels and proficiency with new technologies; this should be explored in future studies. Also, it should be noted that the Edwards et al., study focused on Diabetic Retinopathy, a disease affecting a greater range in age. That said, our results provide explicit insight into the older adult population, and how "young-old" (50-65) individuals differ from those considered part of the "old-old" segment.

Dexterity was found to be influential in models of TT, VST and DD. As dexterity improved (or the score increased) TT and VST were faster, and DD was shorter, indicating amore efficient interaction. Over time, additional fatigue could amplify the impact of dexterity, especially for older adults. Also, the selection of input device is a feature of the interface that is easily altered to accommodate a range of individual needs. The implications of input device on a small interactive display are critical to the successful interaction and thus the small relative magnitude of this effect should not be overlooked. This result also suggests that dexterity is linked to visual search, and implies the use of the stylus as a pointing mechanism to direct visual search.

The impact of trial # indicated that participants demonstrated faster MT and TT during later trials, a small learning effect. Interestingly, this effect was not realized for VST, suggesting that for this task and set of participants, practice improved control of the stylus, but not the ability to locate the icon over time. The lack of a practice effect on efficient visual scan is again likely linked to the small size of the display. Most of the display was observable through a small percentage of visual field, without significant eye or head movement. This suggests that participants were able to improve their interactions with the stylus over time, while their times for searching for the icon did not incrementally improve.

5.3 Interface Characteristics

Outcome #6: *Older adults with visual impairments are able to use a stylus for input on a handheld device and the ease with which the stylus is operated influences several key aspects of interaction.*

Column impacted VST, while the Row impacted the MT and DD. Columns further to the right realized increased VST, consistent with the nature of visual scan for Western users, who work from left to right to locate an icon. The impact of rows lower on the display also increased DD and MT, suggesting that participants had more difficulty making use of the stylus to move icons from lower sections of the display. In addition, as the location of the drop pile moved lower on the display, the predicted MT and DD also increased. This is likely related to the ease with which the participants operated the stylus. It is surprising that, even though the display on the handheld spanned the visual field, there is still measurable complexity in the identification and tracking of the icons across the display.

Outcome # 7: *Supplemental non-visual cues may prove valuable in making handheld devices accessible to individuals with visual impairments.*

Main effects of Auditory Feedback (AF) were not included in any predictive models. However, the *AF*AMD* interaction was influential in decreasing MT and DD. This is especially important in light of the considerable negative impact ocular disease and functional impairment imposed on the performance models, as discussed previously. The performance gains realized from the inclusion of auditory feedback increased as AMD severity level worsened. The effect on DD suggests that participants with AMD spent more time 'chasing' the drop pile, in the absence of auditory cues. This implies that supplemental non-visual cues may valuable in facilitating accessibility to these devices. However, based on comparisons of the standardized coefficients for *AMD score* and *AMD*AF*, there remains much room for improvement to more fully counteract the impact of disease on this interaction phase.

Outcome #8: *Auditory feedback possesses utility as a universal solution to improved access.*

These conclusions about AF are consistent with the findings of Jacko and colleagues in their examination of the drag and drop [8]. They found that individuals with the most severe visual dysfunction experienced the most significant gains in performance with the inclusion of supplemental non-visual cues.

Also consistent is the fact that the presence of auditory feedback did not degrade the performance of those without ocular pathology, supporting its utility as a universal solution to improved access.

Outcome #9: *Consistent with traditional desktop displays, older adults with visual impairments using handheld devices also experience difficulties tracking target icons amongst distracters present on the display.*

It is intuitive that *SS* was found to be influential on VST in that it sufficiently imposed predicted increases in TT, slowing the rate of task completion. In addition, the *SS*AMD* interaction was found to have a significant influence on TT, VST, and MT. There was a predicted increase in MT as a result of the *SS*AMD* interaction, indicative of participants' difficulties with tracking an icon amongst a growing number of distracters across the display.

Outcome #10: *Design theories for traditional desktop environments should not automatically be applied to alternative platforms such as handhelds.*

Design guidelines and foundations for desktop design were not wholly reflected in the models of desktop interaction for this population. Specifically, the effects of diminished spacing did not influence longer search and selection times (as in [10]). This could likely be a function of the spacing size relative to the physical display size of the handheld, or because the effects of visual health were more prevalent. Most importantly, this indicates that existing computational models of HCI need to be reassessed prior to their application to alternative GUI platforms, such handheld computers.

6. CONCLUSIONS

The most compelling outcome from this study is that older adults, both with and without visual impairments, are capable of the successful interaction required to interface with non-traditional IT platforms, such as handheld computers. All participants demonstrated high levels of task accuracy, while task efficiency was compromised largely in the presence of diminished visual function and health. The regression models demonstrate the potential for low-cost, easily implemented design interventions, (e.g., auditory feedback) to enhance task efficiency for individuals with visual impairments to levels equivalent to those of users without ocular pathology. This study presents a strong argument in favor of continued research in the area of mobile computing for these population segments, as the interactions and strategies can deviate from those traditionally observed in the context of desktop computers. Future directions should include empirically based work that considers not only the fundamental interactions and design interventions, but also ethnographic studies that delve into the potential for mobile devices to provide support in daily activities

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