Isolating the effects of visual impairment: Exploring the effect of AMD on the utility of multimodal feedback

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ABSTRACT

This study examines the effects of multimodal feedback on the performance of older adults with an ocular disease, Age-Related Macular Degeneration (AMD), when completing a simple computer-based task. Visually healthy older users (n = 6) and older users with AMD (n = 6) performed a series of drag-and-drop tasks that incorporated a variety of different feedback modalities. The user groups were equivalent with respect to traditional visual function metrics and measured subject cofactors, aside from the presence or absence of AMD. Results indicate that users with AMD exhibited decreased performance, with respect to required feedback exposure time. Some non-visual and multimodal feedback forms show potential as solutions to enhance performance, for those with AMD as well as for visually healthy older adults.

Categories & Subject Descriptors: H.5.2 [**Information Interfaces and Presentation**]: User Interfaces – *Auditory (non-speech) feedback, Haptic I/O, User-centered Design;* H.1.2 [**Models and Principles**]: User/Machine Systems – *Human information processing*
General Terms: Design, Human Factors

Keywords: Age-related macular degeneration (AMD), multimodality, multimodal feedback, universal access, visually impaired users, visual impairment, visual feedback

INTRODUCTION

Several research studies have found that multimodal feedback, when implemented in computer interfaces, has shown some potential as a solution for enhanced performance for a variety of simple user tasks [5, 11, 18, 33]. The study reported in this paper is aimed at investigating how multimodal feedback, in the context of a common direct manipulation task, enhances the performance of users with AMD as well as visually healthy older adults. Additionally, this study reports the isolated effects of AMD on a computer-based task. This was achieved by examining the relative behaviors of two user groups that were equivalent on all subject variables, including traditional ocular health metrics, aside from the presence or absence of AMD. This paper reports on a drag-and-drop direct manipulation task. Auditory, haptic, and visual feedback forms, presented in unimodal, bimodal, and trimodal conditions, were used to investigate the relative effects of feedback on user task performance, as measured by total target highlight time (TTHT) and final target highlight time (FTHT).

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BACKGROUND

Individuals with AMD & Computer Use

AMD is a common ocular disease that causes visual impairment. As the name suggests, AMD involves the general degradation of the visual functioning of the macula and is strongly related to aging. As AMD progresses, affected individuals often experience degradation in central and high-resolution vision. This visual degradation ranges from somewhat mild to quite severe, depending on the progression of the disease.

AMD is one of the leading causes of severe visual impairment in the aging population (individuals 65 years and older), affecting more than ten million Americans [2]. Researchers have suggested that information technologies, particularly personal computers, can serve as tools for helping to maintain independence, aid in daily tasks, and maintain contact with the outside world when aging and failing health limit the mobility and abilities of this aging subset of the population [25]. In order to remain an active part of society, these individuals need to be able to effectively interact with information technologies [15]. However, many current technologies employ graphical user interfaces (GUIs), which emphasize a visual feedback paradigm, thereby placing users with visual impairments at a distinct disadvantage [10].

A loss of high-resolution foveal vision has a serious impact on an individual's ability to perform focus-intensive activities, such as reading, driving, or using a computer [31]. Despite this loss of visual acuity, individuals with AMD tend to rely on their residual peripheral vision to function within their environment [19]. Initial investigations have examined how GUIs can be changed to make the visual aspect of these interactions more accommodating for these visually impaired users [17, 19]. Studies investigating the effects of AMD on computer use have revealed performance differences, for both selection tasks [15, 28] and drag-and-drop tasks [18], between normally-sighted users and users with AMD. These studies have identified some potential performance aids for users with AMD when performing computer-based tasks.

While some insight into the effect of macular degeneration on computer use has been gained through research efforts, there remains a clear need for further investigation on the potential source of the performance differences between visually healthy users and visually impaired users with AMD. Many of the studies that have been conducted have not looked at other subject variables, which might also affect performance. Additional controlled studies need to be conducted to help isolate the effects of AMD in order to help further understand the effects of this ocular disease on computer use and to further develop predictive models of task performance.

The Drag-and-Drop Task

The aptly named 'drag-and-drop' task is common to most GUIs and current computer interfaces [5]. A drag-and-drop task that utilizes a mouse as the input device has been the focus of studies for more than a decade [12, 14, 23]. Several studies have compared the drag-and-drop paradigms to other actions, such as pointing-and-clicking, revealing both the ubiquity of this user action in the GUI environment and the relative performance effects of this particular action for different direct manipulation tasks [14, 29].

Given the intrinsic visual nature of the GUI, it becomes clear that people with visual impairments, including those with AMD, will be at a disadvantage when trying to perform tasks using this visual paradigm [10, 15]. Moreover, direct manipulation tasks (e.g. the drag-and-drop) require the successful integration of visual and motor functioning by the user. This creates another disadvantage for users with AMD, as these individuals likely also suffer from other sensory and motor detriments associated with aging, including decreases in motor control [30] and decreased manual dexterity [8]. This poses an even greater challenge for people with AMD in the use of computing technologies, as their abilities to use peripheral devices (e.g. a mouse), process visual information presented by the interface, and integrate these two processes, are greatly hindered.

Previous studies have illustrated the use of auditory feedback with common GUI interaction tasks, including the drag-and-drop, as an effective means of enhancing task performance [5, 7]. These results naturally extend themselves to the potential utility of using alternative feedback forms to augment visual feedback to help users, particularly visually impaired users, with these interaction issues. Additional studies are needed to explore these possibilities.

The Use of Non-Visual Feedback & Multimodality

Multimodal interfaces, which employ multimodal feedback, have the potential to enhance user interaction with computers via utilization of multiple perceptual processes, allowing for enhanced information processing through parallel sensory channels [7, 33]. Given the obvious sensory deficiencies experienced by visually impaired users, multimodal feedback is an ideal candidate for improving task performance when interacting with a GUI. Three forms of feedback - auditory, haptic, and visual – have shown promise in assisting users with visual impairments [11].

There have only been a limited number of studies investigating the application of multiple modalities in exploring the conflicting, redundant, and complementary interactions that occur when several sensory modalities are engaged in unison. McGee, Gray, and Brewster [24] introduced the concept of 'Integration of Information' with respect to multimodal texture perception through the integration of auditory and haptic information. This concept refers to the information processing that occurs when combining two or more sensory signals of different modalities that have been presented together to represent the same piece of information. This integration of different sensory information may lead to performance enhancement for users when performing computer-based tasks. The most common forms of auditory feedback used in multimodal research include the auditory icon and earcon [4, 6]. Much of the haptic feedback explored includes the use of kinesthetic feedback, or mouse vibration and movement, to provide users with tactile information [1, 23]. Enhanced visual feedback should be distinguished from the intrinsic visual nature of GUIs. Enhanced visual feedback is commonly employed in current computer interfaces, often in the form of a colored highlight [33].

Several research studies on the use of multimodal feedback (e.g.[4-6, 18, 33]) suggest that sensory stimuli, presented via alternative and combined modalities, have shown to contribute surprisingly mild additive effects for performance, indicating that individuals may naturally tend to rely on the most salient or effective sensory information available. This is likely a result of the complex nature by which humans integrate information from different sensory modalities, which involves the complicated selection and generation of appropriate signals as well as understanding the complex perceptual interaction between various sensory signals [35]. However, because residual vision is often so poor in individuals with visual impairments, other sensory modalities may be more effective in conveying information

[20]. This further suggests a need to design and develop technologies that incorporate accessibility and usability features for visually impaired users. Given the clear interaction needs for these users, the number of individuals comprising this user segment, and the limited access experienced by visually impaired users, it is necessary to continue investigating the interaction needs of these users, while exploring new interface design paradigms.

METHOD

Participants

Twelve older adult volunteers (seven females and five males) ranging in age from 62 to 80 years (mean age = 73.33 years) participated in this study. Compensation for participation included $50 and free comprehensive visual examinations. All participants were recruited from the patient pool of the Bascom Palmer Eye Institute. Participants were selected on the basis of several simple inclusion criteria including: 1) presence or absence of AMD; 2) visual acuity; 3) right-handedness; and 4) age. All participants were selected on the basis of having either no ocular disease present or with only AMD present. Participants were then assigned to groups based on the presence or absence of AMD, henceforth referred to as the AMD and NO AMD groups, respectively. All participants, despite the diagnosis of AMD or No AMD, were also selected based on visual acuity scores denoting normal, or near normal, vision (i.e. 20/20 – 20/40).

To ensure current knowledge of participants' visual capabilities, several visual capabilities were assessed, including: visual acuity, contrast sensitivity, and color perception. Visual acuity (normal acuity: 20/20), an individual's ability to resolve fine detail, was assessed with the ETDRS exam. Contrast sensitivity (normal score 48), an individual's ability to detect characters at increasingly lower levels of contrast, was assessed by a Pelli-Robson chart [27]. For analytical purposes, visual acuity scores for each participant were converted using the logMAR transformation [3, 28] and contrast sensitivity scores were converted to a weighted average score of 75% of the better eye score plus 25% of the worse eye score [28]. Color perception, an individual's ability to detect differences between colors, was assessed with the Farnsworth Dichotomous Test for Color Blindness [9]. Additionally, other variables of interest were also collected which included: manual dexterity, computer experience, physical health, mental health, age, and gender. Manual dexterity was assessed by the Purdue Pegboard test, resulting in a score reflecting the average number of pins placed in the board over three trials [32]. Computer experience was based on previous experience within the year prior to the study. Physical and mental health were assessed with the Short Form-12 (SF-12^{TM}) Health Survey, which yields a physical composite score (PCS) and a mental composite score (MCS) [34]. Average PCS and MCS for the general U.S. population aged 55+ have been estimated to be 38.7-46.6 and 50.1-52.1, respectively [22].

Intergroup comparisons were made for all participant profile variables. All continuous variables were compared using one-way ANOVAs, while the categorical variables were analyzed using the chi-squared test. The results (see Table 1) showed that the AMD and NO AMD groups were equivalent with respect to all profile variables except with respect to the diagnosis of AMD, which enabled isolation of the role of the variable of interest (presence/absence of AMD) on task performance. Studies have found multiple visual parameters, such as contrast sensitivity and visual acuity, to have an impact on computer-based task performance (e.g. [28]). This study aims to extend this analysis by isolating the AMD-specific effects, and examining how multimodal feedback can benefit users with or without AMD.

Variables	AMD (n = 6)	NO AMD (n = 6)	Test Statistics	P-Values
Age	73.67	73.00	F=0.035	0.856
Dexterity	12.56	12.33	F=0.036	0.852
LogMar Acuity	0.17	0.05	F=4.200	0.068
Contrast Sens.	32.92	34.83	F=1.148	0.309
PCS	49.94	52.34	F=0.294	0.600
MCS	56.34	54.82	F=0.211	0.656
Gender	M = 3, F = 3	M= 2, F= 4	$\chi^2 = 0.558$	1.000
Experience	Y = 6, N = 0	Y = 5, N = 1	$\chi^2 = 0.296$	1.000
Color Test	Pass=5, Fail=1	Pass=6, Fail=0	$\chi^2 = 0.251$	0.455

Table 1. Demographics summary demonstrating no significant differences between groups

Apparatus and Experimental Task Environment

The setting of the experimental system in this study was the same as in Jacko et al. [18]. The computer used was an IBM®-compatible machine with a 20-inch viewable CRT monitor, with an 1152 X 864 pixel resolution, set approximately 24 inches from the participant. Participants used a Logitech WingMan® Force Feedback Mouse, which provided haptic feedback in the form of a moderate frequency mechanical vibration. For the purposes of this study, the Multimodal AHV 2.0 software program was developed, which was based on key features of a previous interface used in a baseline study by Vitense et al. [33] of multimodal feedback with a general user population. This program incorporates a drag-and-drop task, using Microsoft® Windows icon bitmaps for the mouse cursor, file icon, and target folder screen elements. The file icon and target folder sizes were 36.8mm (diagonal distance), based on the previous findings by Jacko et al. [15, 16].

This study's experimental task represented a simplified version of the drag-and-drop tasks used in previous studies [5, 33]. A Microsoft® Word file icon was located bottom center in the task space, while a Microsoft® Windows target folder icon was dynamically located in one of 15 discrete locations in the task space. The feedback was provided to the user when the file icon was correctly positioned over the target folder, indicating that the file icon could be released for a successful 'drop'. Participants completed 15 repetitions of the task for each of the 7 different feedback conditions (auditory (A), haptic (H), visual (V), auditory-haptic (AH), auditory-visual (AV), haptic-visual (HV), autory-haptic-visual (AHV)). Auditory feedback consisted of a metaphorical auditory icon that imitated the sound of a suction cup. The volume level was adjusted for each participant to a level that was easily detectable. The visual feedback employed was a purple coloration that highlighted the file icon when it was correctly positioned over the target folder icon. As previously mentioned, the haptic feedback used was a mechanical vibration generated by the Logitech WingMan® mouse.

Procedure

Participants were first provided with a comprehensive visual exam, in order to obtain a clinical diagnosis and knowledge of the current visual capabilities. Participants performed the task with their best-corrected vision, employing corrective frames when needed. Participants then answered an interview-administered background questionnaire, which assessed demographic information and previous computer experience. Participants also answered the general and visual health questionnaires, as previously outlined. Participants then performed the Purdue Pegboard test of manual dexterity, with three 30-second trials. Next, participants were briefed on the experimental task and equipment and given practice on a similar drag-and-drop task based on shape matching. Finally, participants performed the sets of trials of the drag-and-drop computer task. Following the computer task, participants were asked to complete an exit survey, also interviewer-administered, that was specific to their feelings and perceptions about their experiences with the program and the study. Participants then received the remainder of the ocular examination, including examination of the retina.

Experimental Design

This study employed a 7X2 factorial design, in which there were 7 feedback modality conditions and two groups of participants. Each participant performed 15 repetitions of the drag-and-drop task under each of the 7 feedback modality conditions, resulting in a total of 105 trials per participant. Each of the 15 repetitions was generated by randomly locating the target folder at one of 15 screen locations, so that each of the 15 locations was experienced once under each modality condition. The order of the feedback conditions and the order of the folder locations was counterbalanced to avoid learning effects throughout experimentation. The dependent variables used to assess participants' performance included final target highlight time (FTHT) and total target highlight time (TTHT). FTHT represents the total amount of time, in milliseconds, that participants received feedback upon the last correct positioning of the file icon and completing the trial. TTHT represents the length of time, in milliseconds, that participants received feedback over the course of a given trial. If a participant successfully drops the file icon in the target folder icon on the first try, TTHT and FTHT are equal. FTHT is a subset of TTHT and is synonymous with the 'target highlight time' measure used in previous studies [5, 33]. FTHT and TTHT are both believed to be specific measures of feedback effectiveness, or ineffectiveness, because they both focus on the participant's response to receiving feedback [5]. Both FTHT and TTHT measures were used because observations of how users react to feedback in both successful and unsuccessful attempts is important in obtaining an entire characterization of the effectiveness and salience of the feedback.

Data Analysis

Analyses in this paper contain two parts:

Part I: To determine the significant differences in TTHT and FTHT between the AMD and NO AMD group within each feedback condition, and between feedback conditions within each group. Analyses of variance (ANOVA) were used on $\log_{10}$ transformed data. Transformation was used since the original data was not normally distributed. If significant differences were found in the within group analysis, post hoc tests (Tukey's honestly significant difference (HSD) test) were performed to highlight the specific differences between feedback conditions.

Part II: To understand how additional non-visual feedback component(s) when added to visual feedback, helped to improve performance. Three types of additive feedback were considered, as follows: a) Adding an auditory (A) component to the visual (V) unimodal condition – resulting in the auditory-visual (AV) bimodal condition; b) Adding a haptic (H) component to the visual unimodal condition – resulting in the haptic-visual (HV) bimodal condition; c) Adding both auditory and haptic components to the visual (V) unimodal condition – resulting in the auditory-haptic-visual (AHV) trimodal condition. First, the difference in each participant's performance as a result of the additional component was determined. For example, the difference in TTHT as a result of the addition of the haptic component to the visual unimodal condition can be determined by the difference of TTHT in the visual unimodal and in the haptic-visual bimodal conditions. Means of the change in performance time between the unimodal and multimodal conditions were computed. As transformations on the data were ineffective in approximating the normal distribution, Mann-Whitney U (for comparison between groups) and Friedman tests (for comparisons between feedback conditions) were used to examine the significant differences in changes in performance.

RESULTS

Part I: Figures 1-4 show the mean TTHT, FTHT and the comparisons between groups for each feedback condition (Figures 1 and 2), and within group between feedback conditions (Figures 3 and 4). The results from the ANOVA

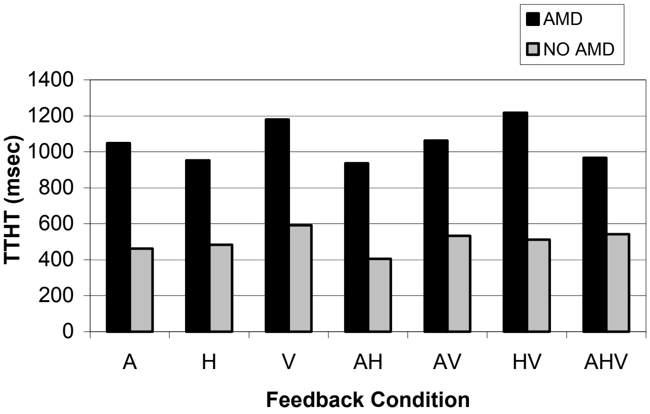


Figure 1. Comparison of mean TTHT between groups for each feedback condition

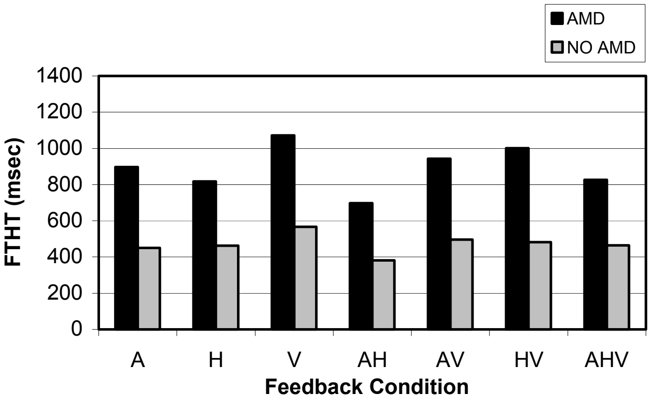


Figure 2. Comparison of mean FTHT between groups for each feedback condition

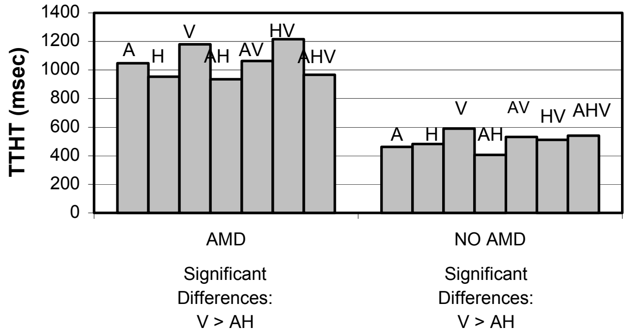


Figure 3. Comparison of mean TTHT within group between feedback conditions

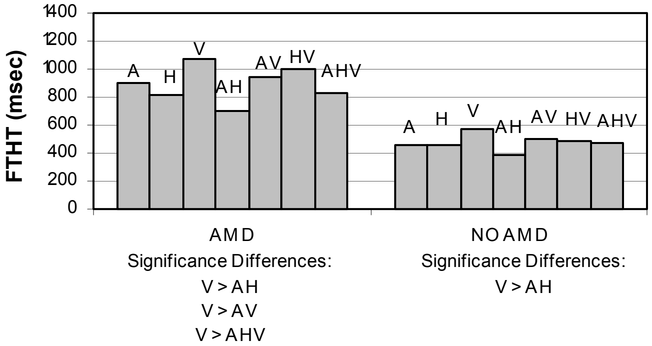
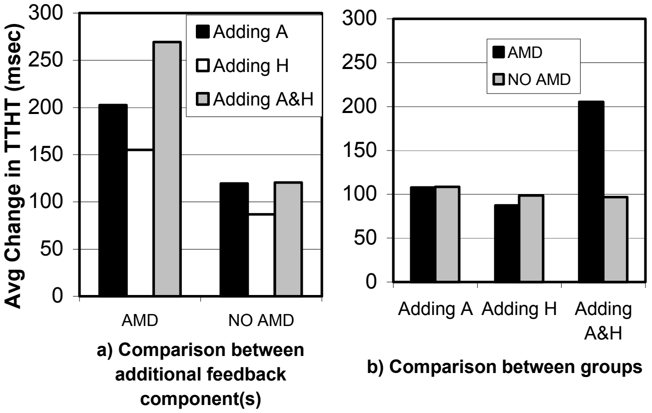


Figure 4. Comparison of mean FTHT within group between feedback conditions

show that the AMD group required significantly more time for both TTHT and FTHT than did the NO AMD group under all feedback conditions ($p<0.01$). Also, it revealed that significant differences existed between feedback conditions for both the AMD ($F_{TTHT}=3.140$; $p=0.005$; $F_{FTHT}=4.030$; $p=0.001$) and NO AMD ($F_{TTHT}=2.951$; $p=0.008$; $F_{FTHT}=3.205$; $p=0.004$) groups. The post-hoc tests revealed that both groups performed significantly worse in the visual unimodal condition, compared with several auditory-based multimodal conditions. For example, both groups performed significantly slower (both TTHT and FTHT) in the visual unimodal condition, as compared to the auditory-haptic bimodal condition ($p<0.02$). Furthermore, the AMD group was significantly slower under the visual unimodal condition compared to the auditory-visual bimodal (TTHT: $p=0.005$; FTHT: $p=0.005$) and auditory-haptic-visual trimodal (FTHT) conditions ($p=0.019$).

Part II: The results from the TTHT and FTHT within group, between-condition ANOVA (see Figures 3 and 4) showed that both the AMD and NO AMD groups performed worse in the visual unimodal condition than almost all other conditions. Additionally, bimodal and trimodal feedback conditions, containing an auditory component, (e.g. AV, AH, and AHV) were found to help augment task performance for both the AMD and NO AMD groups. Thus, it was of interest to identify those non-visual feedback component(s) that when added to visual feedback, helped to significantly improve performance for the AMD and NO AMD groups.

Figures 5 (TTHT) and 6 (FTHT) show the comparisons of average change in TTHT and FTHT, respectively, as a result of adding non-visual feedback component(s) to the visual unimodal condition. Each figure depicts differences between type(s) of additional component (5a and 6a) and between groups (5b and 6b). The results from the between-group Mann-Whitney U test showed that there were no significant differences in the improvement in TTHT and FTHT between the AMD and the NO AMD group when the auditory or haptic components alone were added to the visual unimodal condition (see Figures 5b and 6b). However, when both the auditory and haptic feedback components were added to the visual unimodal condition, the AMD group improved significantly more than NO AMD, with respect to FTHT (as shown in the far right bars of Figure 6b; $Z=-2.658$; $p=.008$), but not TTHT ($Z=-1.536$; $p=.125$). Recall that TTHT is the total amount of time the participant received feedback during the complete trial. FTHT only includes the time elapsed for feedback provided during the successful drop. As a result, TTHT has a higher variability than FTHT. So, while the average changes in TTHT and FTHT (when auditory and haptic feedback are added) are similar in scale, only the difference in FTHT



a) Comparison between additional feedback component(s)

b) Comparison between groups

Figure 5. Average change in TTHT

was statistically significant. The results from the between condition Friedman test revealed that there were no significant differences in the improvement in TTHT and FTHT between added feedback type for either the AMD or NO AMD group (see Figures 5a and 6a). Thus, with respect to both TTHT and FTHT, the degree of improvement observed when auditory or haptic, or both auditory and haptic, feedback were added, was not statistically significant. However, the greater benefit observed in the AMD group when both auditory and haptic feedback were added together is worth exploring, despite the lack of statistical significance, especially when considered in conjunction with the previously mentioned finding that the AMD group had significantly slower FTHT under the visual unimodal condition compared to the auditory-haptic-visual trimodal condition.

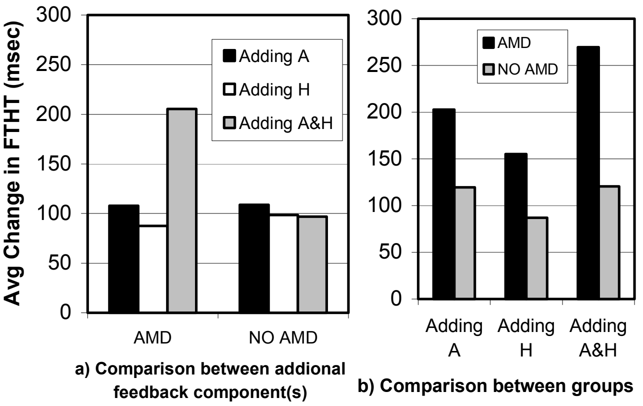
VFQ Scale	AMD (n = 6)	NO AMD (n = 6)	Test Statistics	P-Values
VFQ-GV	73.33	85.83	F=10.321	0.009
VFQ-MH	86.67	96.67	F=5.806	0.037
VFQ-RD	87.50	100.00	F=8.571	0.015

Table 2. Significant differences between groups on VFQ Scales

DISCUSSION

This study highlighted how multimodal feedback enhances computer task performance for users with AMD as well as for visually healthy older adults. Additionally, the effect of AMD, when isolated from other ocular measures (e.g. contrast sensitivity, visual acuity), was found to have a significant impact on computer task performance with respect to feedback time.

The finding that participants with AMD performed consistently worse for both time measures and for each feedback condition (as indicated in Part I of the results) strongly indicates that the presence of AMD impairs a computer user's ability to efficiently perform computer tasks, as the drag-and-drop task is highly representative of key interactions with most GUIs. This result is particularly interesting given that the participants with AMD possessed near normal visual acuity, and their scores for visual acuity, contrast sensitivity, and color perception were not significantly different from those of the participants who did not possess AMD. To further investigate the performance differences in light of the lack of differences with respect to the clinical assessments, subjective assessments of visual functioning were conducted using the National Eye Institute Visual Functioning Questionnaire (NEI VFQ-25). This questionnaire produced several subscores, each based on multiple questions concerning how a person's visual capabilities affect daily activities. Significant differences between groups were detected for the subscores of general vision (VFQ-GV), mental health (VFQ-MH), and role difficulties (VFQ-RD) (see Table 2). The between-group differences in the VFQ sub-scores are particularly interesting in that they emphasize the influence of AMD on participants' perceptions of their general vision, which are consistent with the measured performance differences. Differences related to perceived mental health, and role difficulties are also byproducts of this disease.



a) Comparison between addional feedback component(s)

b) Comparison between groups

Figure 6. Average change in FTHT

In addition, evidence from the literature indicates that users with AMD make additional gross (head) and fine (eyes) motor movements during task performance, in order to compensate for central vision deficiencies [20]. This behavioral phenomenon may explain the additional time taken by users with AMD to complete the task. Additionally, it has been shown that users with AMD utilize a less efficient search strategy than the visually healthy population [20].

Both the AMD and NO AMD groups performed worse in the visual unimodal condition compared with most other feedback conditions. One explanation for this is that information processing times for visual information can be slower than those for other forms of information. Auditory information processing occurs about 50 ms faster than visually represented information [13]. As shown by this study, auditory feedback resulted in improved performance for both the AMD and no AMD groups, in general. Additionally, auditory feedback, when combined with other forms of feedback, also resulted in improved performance. This is supported by Wickens' multiple resource theory [35], which proposes that auditory information can be processed in parallel with visual information, leading to improved perception and processing of simultaneous visual and auditory cues. On the other hand, this study shows that the addition of haptic feedback to visual feedback tended to result in less improvement in subjects' highlight times, particularly those with AMD. It is hypothesized that there is a potential interference between haptic and visual information with respect to information processing [21]. In comparison to the visual and auditory processing channels, which have shown to be efficiently integrated in human information processing, haptic and visual sensory signals may result in some interference when users try to integrate these stimuli into a meaningful sensory signal.

The use of non-visual feedback (e.g. the auditory only and haptic only conditions), while not significant compared to the visual only condition, still illustrates potential for enhancing user task performance. With respect to both FTHT and TTHT, auditory and haptic feedback both produced better user performance when compared with the visual unimodal condition. This is not surprising, as previous research has shown that both auditory [7, 12] and haptic feedback [26] can be used as effective performance enhancers for computer-based tasks. More interestingly, however, multimodal feedback conditions produced some noteworthy trends. Generally, all bimodal and trimodal feedback conditions, with the exception of the haptic-visual bimodal condition (for TTHT in the AMD group as noted above), yielded better performance than the visual unimodal condition. These results were further supported by the findings that the addition of non-visual (e.g. auditory, haptic, or both) feedback to visual feedback resulted in improved performance for both the AMD and NO AMD groups. Additionally, the AMD group benefited significantly more from this addition of non-visual feedback, compared to the NO AMD group.

The practical implications of the results from this study involve providing important insights into the relative abilities of individuals with progressive visual impairments and potential solutions (e.g. multimodal feedback) to continually support their interaction needs. The knowledge generated by this study will help guide the development of a computer-based diagnostic tool to be used by visually impaired individuals to determine their current level of visual capabilities and make appropriate adjustments to the interface in order to support their interaction. The interface used in this study represents a very simplified computer environment and task. This simplification is necessary to help develop the fundamental, empirical knowledge of the interaction needs of visually-impaired users, which can then be used to guide further research into user performance in more complex usage scenarios.

CONCLUSIONS

Overall, this study provides support for the potential use of multimodal feedback in GUIs for a common direct manipulation task (e.g. drag-and-drop) as a means to improve task performance, especially for visually impaired users. The results also show the importance of considering more non-traditional analyses of visual capabilities, aside from visual acuity, contrast sensitivity, and other traditional functional eye metrics, when trying to examine and model the performance of users with visual impairments.

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