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The Effects Of Multimodal Feedback And Age On A Mouse Pointing Task

Brian Oakley
University of Central Florida

THE EFFECTS OF MULTIMODAL FEEDBACK AND AGE ON A MOUSE POINTING TASK

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BRIAN OAKLEY
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ABSTRACT

As the beneficial aspects of computers become more apparent to the elderly population and the baby boom generation moves into later adulthood there is opportunity to increase performance for older computer users. Performance decrements that occur naturally to the motor skills of older adults have shown to have a negative effect on interactions with indirect-manipulation devices, such as computer mice (Murata & Iwase, 2005). Although, a mouse will always have the traits of an indirect-manipulation interaction, the inclusion of additional sensory feedback likely increases the saliency of the task to the real world resulting in increases in performance (Biocca et al., 2002). There is strong evidence for a bimodal advantage that is present in people of all ages; additionally there is also very strong evidence that older adults are a group that uses extra sensory information to increase their everyday interactions with the environment (Cienkowski & Carney, 2002; Thompson & Malloy, 2004).

This study examined the effects of having multimodal feedback (i.e., visual cues, auditory cues, and tactile cues) present during a target acquisition mouse task for young, middle-aged, and older experienced computer users. This research examined the performance and subjective attitudes when performing a mouse based pointing task when different combinations of the modalities were present.

The inclusion of audio or tactile cues during the task had the largest positive effect on performance, resulting in significantly quicker task completion for all of the computer users. The presence of audio or tactile cues increased performance for all of the age groups; however the performance of the older adults tended to be positively influenced more than the other age

groups due the inclusion of these modalities. Additionally, the presence of visual cues did not have as strong of an effect on overall performance in comparison to the other modalities.

Although the presence of audio and tactile feedback both increased performance there was evidence of a speed accuracy trade-off. Both the audio and tactile conditions resulted in a significantly higher number of misses in comparison to having no additional cues or visual cues present. So, while the presence of audio and tactile feedback improved the speed at which the task could be completed this occurred due to a sacrifice in accuracy. Additionally, this study shows strong evidence that audio and tactile cues are undesirable to computer users.

The findings of this research are important to consider prior to adding extra sensory modalities to any type of user interface. The idea that additional feedback is always better may not always hold true if the feedback is found to be distracting, annoying, or negatively affects accuracy, as was found in this study with audio and tactile cues.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ID	Index of Difficulty
IP	Index of Performance
THT	Total Highlight Time
TMT	Total Movement Time

CHAPTER ONE: INTRODUCTION

Our society is experiencing a shift in its growing dependence upon computer technologies, while at the same time the older demographic is becoming an ever increasing sector of the population. Our increasingly "graying nation" can be attributed to two primary factors, improvements in health care over recent years and the normal aging of the large baby boomer population. Over the next 5 to 10 years the baby boomers will be moving into older adulthood, with the early generation of baby-boomers turning 65 by 2011. By 2020 approximately 1 in 6 American will be over the age of 65 (Meyer, 2001).

Researchers have already begun examining some of the implications this large influx of older adults will have on mobility (Bladock, Mathias, McLean, & Berndt, 2006; Oxley et al., 2005), health care (Prohaski et al., 2006; Ryan, Anas, & Friedman, 2006), and product design practices (Demirbilek, & Demirkna, 2004; Koncelik, 2003), however very little of the literature has concentrated on older adults interaction with computers. With our continued reliance upon computer based technologies it is not unreasonable to assume that computers will continue to permeate different aspects of our everyday lives. People of all ages and experience levels will have to interact with these systems, including an older population that may exhibit lower levels of computer experience as well as relevant physiological and psychological declines that accompany aging.

Little consideration has been given to the natural changes in performance that people experience due to age when developing current human-computer interactions. There are, however, some accessibility features that can offset the weaknesses of older populations, such as the accessibility options available in Microsoft Windows. The built in accessibility features in

Windows aid users with hearing, visual or motor control issues, however because the features are software based solutions they are functionally limited. These accessibility options are not seamlessly integrated into the interaction of the computer system and are often used as tools for users to interpret the interaction with the computer, much in the same way a magnifying glass would be used to read small print. A solution that is directly implemented into the computer system, which does not alter the performance of regular computer users, but also increases the performance of users with compromised abilities, is preferable. Rather than a software based solution, which may be difficult to implement across the many possible computer applications, a change in our computer hardware should be examined, specifically the devices we use to communicate with a PC.

Today's computer setups primarily use two feedback modalities for relaying information to users, those being visual or auditory in nature. Auditory feedback is most often provided by three sources: the software, the keyboard and the mouse. Auditory feedback from software often alerts a user to an event, such as the tone one hears if an error has occurred. The keyboard and mouse auditory cues are used to show that a person has successfully made an input to the device, separate from what is occurring within the software. Most commonly this feedback would be the clicks one hears when pressing a mouse button or key. A user knows that he or she has successfully sent a signal to the computer because they can hear the hardware activate. Visual feedback communicates changes made to the state of the software by displaying those changes via the monitor.

A modality that has not been used frequently in computer interfaces is tactile feedback. At the most basic level tactile feedback is our sense of touch. This sensory channel is underutilized in current computer systems. Mice have been developed and marketed to provide this extra dimension; however they were often marketed for entertainment purposes. A far greater application for this additional feedback would be to help aid in the degradations that may occur with the onset of old age. Tactile feedback is a solution that will also avoid negative repercussions on other populations because it is reasonable to assume that the addition of tactile feedback may increase performance of younger computer users as well.

The current study will examine the performance changes when using a more robust computer interface, through providing tactile feedback via the mouse. The addition of this modality is believed to create more intuitive and absorbing interfaces for the general population and also provides the additional feedback capable of increasing computer usability for older audiences. The intended outcome of this study is to aid in the creation of interfaces that truly add to the experience of using computers for older adults as well as everyone else who uses computers on a regular basis.

CHAPTER TWO: LITERATURE REVIEW

Computers and Older Populations

A number of technological innovations have allowed computers to become an ever growing presence in our homes and lives; this is most evident due to the number of computers that have become integrated into our daily lives. It is difficult for the average person to avoid interacting with a computer interface at some point in their day to day lives; whether it is for communication, shopping, banking or an integral tool in their occupations. In the past 10 years the home PC has become a fixture in most American homes and workplaces. This incorporation stands to grow even larger as computers develop into convergence devices and ultimately become firmly rooted in our homes.

Aside from making the general populations lives easier, there are many aspects to computers that can improve the lives of older adults. Computers are capable of such a positive influence on older adults' lives because they can reduce the distance between family and friends, especially in cases in which travel is difficult. Older adults who communicate with family and friends by using e-mail, chat, and internet phone have already been shown to lead happier lives (White et al., 1999; White et al., 2002; WirthlinWorldwide, 2003). These results may seem trivial; however older adults experience the largest number of mobility problems, so these additional communication capabilities can have beneficial effects on mental health. Communication via computer is not the only positive influence on elderly lives. It has also been shown that computer literate elderly report higher levels of life satisfaction (Karavidas, Lim, & Katsikas, 2005; Groves & Slack, 1994). Health care has also been shown to be a catalyst for older adults to go online. Currently, connected elderly computer users utilize the internet to look up medical information more so then any other computer task (Fox, 2004). Health care information and consultations via computers (i.e. telemedicine) are likely to become common in future years due to the lower costs involved, thus the number of senior internet users is likely to increase in the coming years (Cohen, 2001).

Even with all of the inherent benefits of computers, older adults are the least computer-experienced portion of the population. Less than a fourth of Americans over the age of 65 actively use a personal computer (Fox, 2004). Compared to other age groups these numbers are incredibly low. Specific reasons why the elderly do not actively use computers are unknown, however it can be hypothesized that many different factors, such as technophobia, and cognitive, perceptual, and physiological changes may be playing a role. Older adults are however slowly amassing in the computer world, with the growing number of aging computer literate baby-boomers and the elderly becoming more proficient with computers. With the beneficial properties of computers and the ever growing elderly population the following years will produce the largest population of elderly computer users in history. Due to this "graying nation" the design of computer interactions must consider both the large number of previous users joining the ranks of the elderly as well as inexperienced older adults migrating to computers.

Developers have done minimal work to enhance computer interactions for older users. Web design is just one of the few areas in which the design implications for older computer users have even been considered (Chisnell, Lee, & Redish, 2004).   Little focus has been placed on the hardware interactions, such as mice and keyboards, necessary for adequate communication with a computer. Due to normal decreases in motor control, vision, and auditory functioning associated with aging the control of mice, keyboards, and even touch screens may become difficult for elderly users to master.

Due to heterogeneity of aging there is a large amount of variance between older individuals even of the same age. There are however physical declines that are more likely to appear among the elderly. For example, some common visual impairments that the elderly population are susceptible to include decreases in static and visual acuity, lower thresholds for contrast sensitivity, longer times necessary when adapting to dark environments, declines in color sensitivity, and difficulties with glare. Variability in contrast sensitivity, visual acuity, useful field of view and color perception have been shown to affect icon selection speed when using a touch-screen (Jacko et al., 1999). Older computer users have been shown to have higher difficulty reading text off of a computer monitor and this is believed to have affected overall performance when using a word processor (Charness, Schumann, & Boritz, 1992). Older adults have also been observed to commit more errors and experience much higher levels of difficulty when asked to select small icons with a mouse (Charness, Bossman, & Elliot, 1995). Difficulty reading text and selecting targets may be associated with difficulty detecting contrast differences dependent upon background color. Individuals with visual decrements as well as ones with healthy visual systems perform best when text and icons are displayed on a black background (Jacko et al., 1999). These findings may also be associated with older adults' general performance decrements in visual search tasks and target acquisition tasks (Kline & Schnieber, 1985). These declines in visual performance will negatively affect computer use since it largely involves performing the most basic and common tasks such as browsing the World Wide Web, writing and reading e-mails, or interacting with tool bars like those seen in Excel or Word.

User performance cannot be attributed solely to one factor. Computer interactions also require cognitive and motor abilities to work in unison along with the visual system. Cognitive abilities associated with general information processing, attention, working memory, problem solving, and long-term and short-term memory have all shown to have some declines with aging (Park, 1992; Salthouse, 1985). These cognitive declines are likely a factor in the performance decrements observed in older populations when using the internet and other computer applications. Attention and psychomotor speed were strong predictors for older computer users' performance when entering data into spreadsheets (Czaja, & Sharit, 1998). It has also been postulated that declines in cognitive abilities, such as working memory, processing speed and text comprehension, may contribute to the difficulty older adults have when attempting to gain computer skills (Morrell & Echt, 1996). These cognitive declines may also make using the Internet difficult for some populations, especially when searching the Internet, which could conceivably require the use of the different memory systems, attention, learning, and problem solving (Czaja & Lee, 2003). Accommodations can be made to limit the difficulties older adults may experience due to cognitive decrements through the use of navigation and search aids as well as including extra information to create more salient memory cues.

Although cognitive abilities are important when interacting with a PC, motor skills are a primary attribute required for most human-computer interactions. Whether it is a keyboard, mouse, or touch-screen all of these peripherals require motor coordination to successfully communicate with a system. Multiple motor skill changes have been observed in older populations including general slowing, declines in ability to perform fluid continuous movements, coordination difficulties, and lower flexibility (Rogers & Fisk, 2000).

These changes in motor skills appear to most often affect indirect-manipulation devices which represent most interaction devices employed on home and office computers. The antithesis of indirect-manipulation devices are direct-manipulation devices examples of which would be touch-screens or light pens where a user interacts directly with what is displayed on a visual screen. Indirect-manipulations however, are categorized by devices, such as mice or touch-pads which are used as intermediaries to interact with the system. Direct-manipulation has been shown to elicit superior performance in elderly populations when compared to indirect-manipulation devices (Murata & Iwase, 2005). When comparing performance between a touch-screen (direct-manipulation) and a mouse (indirect-manipulation) it has been shown that when older adults use a touch-screen for a pointing task, they perform similarly to younger computer users. While performance with a touch-screen was similar between age groups, when a mouse was employed to do the same task large differences between the old and young emerged. Older participants took a significantly longer amount of time to acquire an icon with a mouse (Murata & Iwase, 2005).

Since there is evidence that older adults' pointing performance declines when using indirect-manipulation devices, researchers have begun examining the possible mitigating effects of direct-manipulation devices for older users. In one case, task performance with a light-pen has been found to be comparable for young and old age groups during a menu navigation task that was heavily based upon target acquisition (Charness, Holley, Feddon, & Jastrzembski, 2004). These earlier findings have been corroborated by other researchers who observed higher performance levels for both young and old adults while using a touch-screen to navigate a drop down list box. Rogers, Fisk, McLaughlin, and Pak (2005) compared touch-screens and a rotary encoder, an indirect manipulation device, for drop-down boxes, however high performance for the touch-screen was only observed when scrolling was not required. Although others have found that direct-manipulation devices can reduce some of the performance degradations caused through natural aging (Rau & Hsu, 2005; Charness, Bosman, & Eliot, 1995), it can be argued that direct manipulation interfaces are very limited in actual application or require interface designs that are incompatible with current computer setups.

Even though direct input devices, such as touch-screens or light-pens, have produced higher performance in elderly samples they are not feasible for many everyday computer tasks. Most studies examining direct-manipulation devices concentrated on performance during pointing tasks (i.e. target acquisition), which although these are common in everyday computing, they only make up a small portion of computer interactions. Furthermore, direct-manipulation devices are not the perfect solution because target size will affect performance in similar ways despite whether a touch-screen or a mouse is used. Older participants or those with degradations in motor skills need a reasonably large sized object (50 x 50 pixels or greater) or error rates will dramatically increase regardless of the type of input device being used (Murata & Iwase, 2005; Casali, 1992; Jacko et al., 1999). The most common human-computer interactions seen today and in the foreseeable future rely on indirect-manipulation devices, thus research focused on older adults should follow these real world trends.

Currently, mice are the most prevalent input devices for pointer manipulation. Smith, Sharit, and Czaja (1999) set out to collect information on the effects of a multitude of age deficits on some of the most often used mouse tasks. The study examined the performance of three separate age groups (young, middle, and old) on four separate mouse tasks including pointing, clicking, double-clicking, and dragging, as well as how age related changes in motor-control, processing speed, and visuo-spatial skills affected mouse use skills.

The study employed a variety of physiological and cognitive tests that measured abstraction, spatial ability, processing speed, visuo-motor ability, perceptual speed, and motor coordination. To measure performance for each task the experimenters collected movement time, movement distance, movement speed, sub-movements, and slip errors. Movement time was defined as the period of time it took to reach the cursor target from the home position, while movement distance was the total distance the mouse traveled to reach the target. Movement distance would include the actual distance traveled, for example if a user did not take the shortest direct route to the target, that movement distance would be larger. Movement speed measured how fast the participant could reach the target. Finally slip errors were simply the number of times that the cursor left the target before successfully completing the task.

The results of the study indicated that the clicking and double-clicking tasks produced significantly worse performance for the older groups than the other age groups tested. The lower performance was related to longer movement times, more frequent errors and a higher number of movements to the cursor while the mouse button was being pressed. Of all the tasks tested, the double-clicking task was most difficult for older adults to complete efficiently. Older adults also performed less well with the dragging and pointing tasks, often committing more slip errors. Overall the older group had higher movement distances and more slip errors when using a mouse. Motor control ability was the sole predictor for mouse performance, with motor control being less precise in the older participants resulting in more errant mouse behaviors.

Even though motor control was highly predictive of mouse control performance for older adults when precise actions were a requirement, these findings have also been related to the sensitivity of the input device. Mouse gain affects how far the cursor will move corresponding to how far the mouse has been physically moved. Mouse gain therefore may play a pivotal role in the precise motor control required for mouse tasks. The use of a mouse however is not just related to motor control; it is a complex system that also involves the visual system. The motor control and visual system must work in conjunction to successfully transfer the movements made with the mouse to the visualizations displayed on the computer. Due to this complex relationship the visual demand of a mouse task is associated with the size of the objects being manipulated in the computer environment. In young computer users it has been found that target size and gain work collectively in determining performance. It has been shown that higher gains will cause lower performance if the target size is smaller, in effect the increase in gain and a decrease in target size will create situations in which fine motor control are necessary and performance decrements will be observed (Bohan, Thompson, Scarlett, & Chaparro, 2003).

Sandfeld and Jensen (2005) examined the mouse gain and target size relationships effect in older adults. Participants assigned to groups according to age (young and old) were instructed to perform a pointing and clicking task with three levels of mouse gain and target size. The levels of mouse gain were 1:2, 1:4 and 1:8. These ratios denote how far the mouse movement will move the cursor, so for example 1:4 would move the cursor four times the distance on-screen in relation to the physical movement of the mouse. The target sizes used for this study were small (8 x 8 pixels), medium (16 x 16 pixels), and large (32 x 32 pixels). Unsurprisingly it was shown that the higher mouse gains with smaller targets amounted to the largest decrement of performance for both age groups, however the older group performed significantly worse. The higher mouse gains with smaller targets lead to a situation in which precise movements are necessary and these types of movements are the ones that have previously been shown to be difficult for older adults (Smith et al., 1999). It was found that a mouse gain of 1:4 had the best performance for both age groups as long as smaller targets were avoided, if smaller targets are to be used then a lower mouse gain should be used instead.

The degraded ability of motor control affecting the mouse use performance is consistent with other research that has examined motor control in older adults. Older adults have been shown to have difficulty decelerating their movements, which could lead to some performance decrements (Siedler and Stelmach, 1995). An additional factor resulting in decreases in mouse performance could be associated with older adults' difficulty in performing discrete pointing tasks. A discrete pointing task requires a person to move a pointer, whether it be a finger, pen, or cursor, and stop within a target. Teeken et al., (1996) instrumented this type of task using a touch-pen and found that adults over the age of 60 performed 30% (425 ms) to 50% (> 500 ms) slower than adults in their twenties.

Multimodal Feedback and the Older Adult

It has been suggested (Akamatsu, MacKenzie, & Hasbroucq, 1995; Smith, Sharit & Czaja, 1999) that additional feedback, such as tactile feedback, may increase the performance of older adults when using a mouse. Currently human-computer interactions via the mouse offer limited perceptual feedback, for example if one were to compare interacting with a real world object to interacting with a computer terminal it becomes evident that they are drastically different due to the limited amount of feedback available. Gobel et al. (1995) describes these discrepancies through comparing the disparity between moving a real object versus moving the mouse pointer. When handling a real object the different sensory components are processing the characteristics that are inherent in the manipulated object (See Figure 1). For example, proprioception allows a person to know where his arm and hand are in relation to the object, as the person touches the object there is tactile feedback, such as pressure; concurrently constant visual feedback on the object is available. All of these senses are working in unison to manipulate a single object. The operation of a mouse deviates significantly from a real-world interaction because there are less salient sensory cues available. For example, the proprioception cues are providing feedback of where the mouse itself is located in relation to the body, while the visual system is providing feedback about the location of the on-screen mouse pointer. This produces a situation in which the inputs (i.e., the mouse) and outputs (i.e., the monitor) of the interaction are spatially separated (See Figure 2). Although the spatial separation of this interaction will likely be a characteristic of most visual display terminals in the foreseeable future, the addition of tactile feedback can provide a stronger link between what is occurring on-screen and the point of input. Additional sensory cues can create interactions that leverage the natural abilities that people have when interacting with objects in the real world.

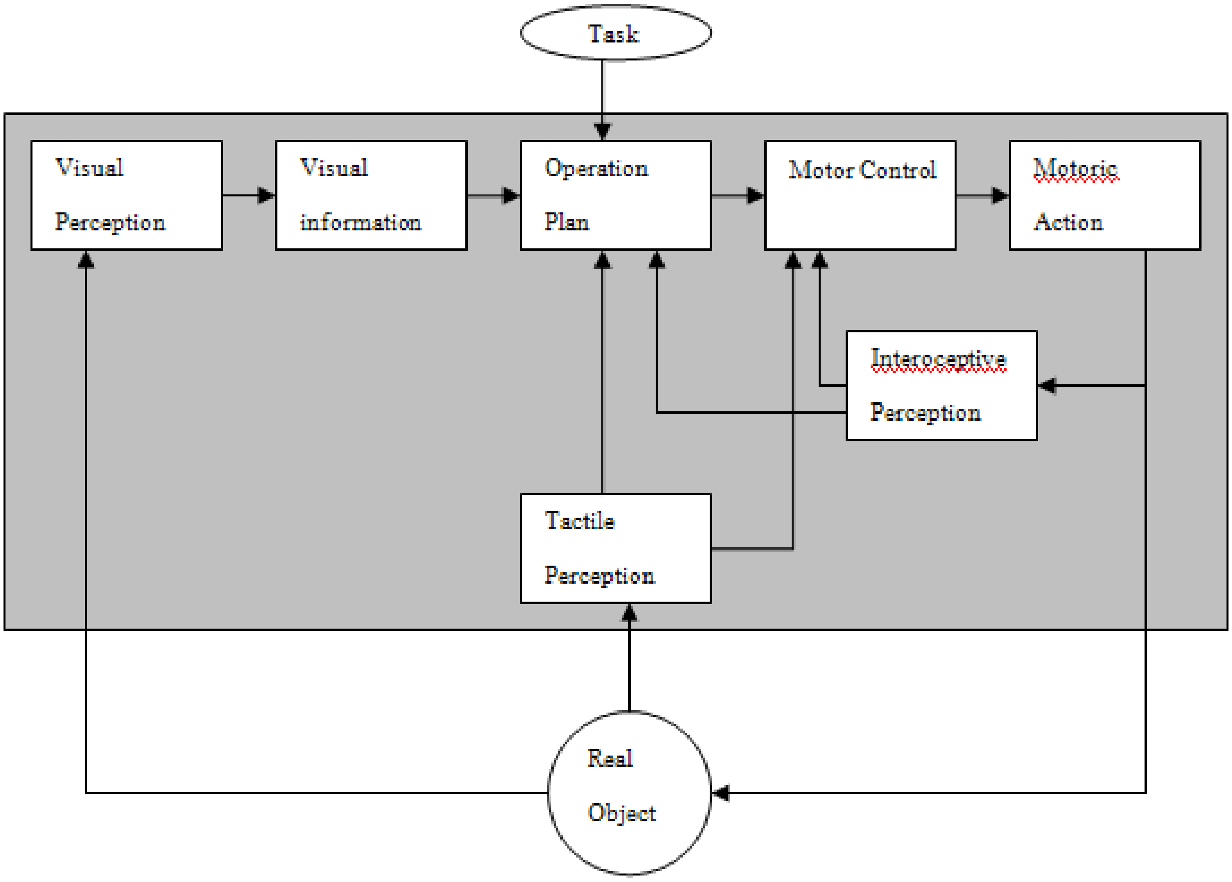

Figure 1. Direct manipulation of an object

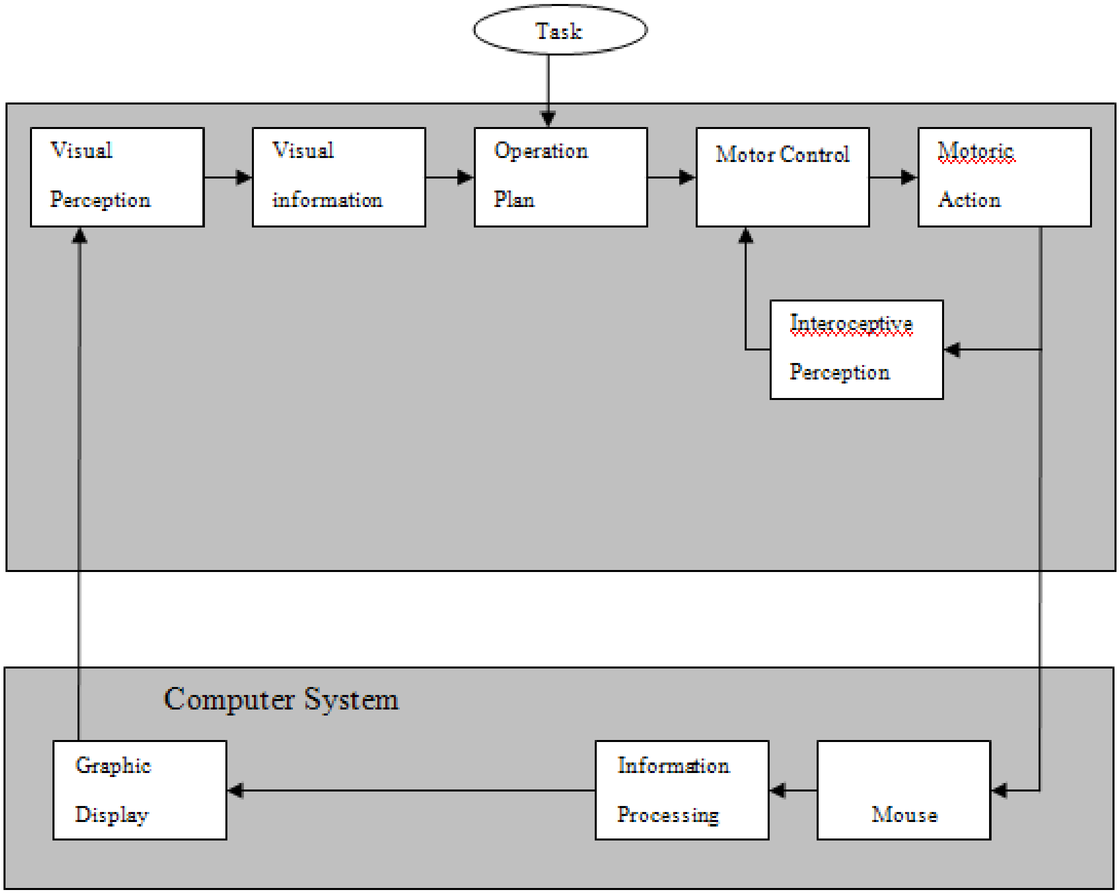

Figure 2. Indirect manipulation in a computer task

People perceive multiple streams of information and integrate them to create a perception of the world that is accurate and dynamic; however many typical computer interactions only provide visual and limited auditory cues. There is strong evidence that additional sensory information, whether it be tactile, motion, or auditory, can enhance the interaction with a system through providing more salient stimuli (Biocca et al., 2002). These enhancements are likely to occur because individuals do not interpret the environment as separate pieces of sensory information in isolation; rather our sensori-motor system takes the different sensory inputs, such as vision, hearing, and touch, and creates one cohesive picture of the world around us (Driver &

Spence, 2000). People will create a picture of the environment that combines all of the separate sensory modalities in a way in which things make sense as evidenced by the “ventriloquist effect”. This effect can be observed when people naturally associate a ventriloquist’s voice to the location of the mouth movements of a dummy, thusly causing one to sense the dummy is speaking (Alais & Burr, 2004). The McGurk Effect further emphasizes this cross-modal integration by showing that the vocal phoneme a person perceives is dependent upon the lip-movements that are viewed (McGurk & MacDonald, 1976). These well documented effects are important because they show that sensory information creates a unified perception of the environment through communication between the senses or higher level processing. The addition of extra sensory modalities to a computer interaction will change the overall environment by providing a larger number of sensations needed to create a unified perception of the environment.

The underlying principles and benefits concerning multiple modes of sensory information have resulted in countless studies and theories. Two contrasting theories of how an individual processes multiple modalities are feed-forward and feedback. The feed-forward mode of thought portends that each sensory system works autonomously, however higher-level processing creates an accurate fully integrated sensation. A very important aspect of this view is that senses do not communicate with each other, essentially the auditory system concentrates on capturing sound, while vision concentrates on visual processing with no communication directly between the two. All of the sensory systems do not receive feedback from the product of the high-level multi-modality processing. Alternatively the feedback view believes that the different sensory systems do talk to each other at various levels, possibly even prior to any high-level modality processing takes place (Driver & Spence, 2000). This is believed to allow one sensory system to affect how another sensory system perceives the environment. For example, the visual system may communicate with the auditory system in determining the location of a sound (i.e., Ventriloquist effect). Currently there are no empirical findings to determine which of these two views are most accurate, with many researchers finding evidence for both frames of thought (Vroomen & de Gelder, 2004). Although there are no concrete answers to how multi-modal processing is achieved, it is believed that the systems do process multiple sensory inputs together in some fashion.

The combination of multiple modes of stimuli has been observed to affect overall user performance and perceptions. Over the years researchers have paired stimuli with multiple combinations comprised of visual, auditory, or tactile cues, while measuring performance on a number of different types of tasks. Most multimodal research examines three types of stimuli: unimodal or a single sensory input; bimodal or two separate sensory inputs; and trimodal or a combination of three sensory inputs. Individuals have been observed to have a "bimodal advantage" when reacting to stimuli that are a combination of two forms of feedback, most commonly visual and auditory. Miller (1982) conducted a popular study that showed strong evidence for a "bimodal advantage". Participants were instructed to respond when they were presented with an auditory tone, a simple light, or a combination of the two. Performance for this group was best for the bimodal stimuli, which resulted in significantly shorter reaction times (326 msec) when compared to the auditory tone only (409 msec) or the light only (412 msec). Reaction times to bimodal stimuli have been shown to be significantly faster when compared to unimodal feedback (Miller, 1982). The performance increments inherent in multimodal feedback have been observed consistently; however the majority of the research has focused upon young adults, with little attention being given to the potential benefits that may be possible for older adults (Diederich & Colonius, 2004; Patching & Quinlan, 2002; Patching & Quinlan, 2004).

Although there have been some studies that have examined multi-modal sensory effects for older adults, most have examined this topic in an applied manner in which it is difficult to pinpoint the actual effects on performance that are normally quantified by reaction time. For example, complex news casts, such as what may be seen on CNN or MSNBC, provide multiple streams of information at once through audio, video, and streaming text. Older adults have more difficulty with this type of information presentation; however it is difficult to determine if this is due to possible deficits in working memory or due to difficulty integrating multimodal information (Stine, E., Wingfield, A, & Myers, D., 1990). It is likely that older adults process the environment differently, possibly through utilizing strategies that limit possible sensory and/or cognitive deficits related to aging. It has been observed that older adults already use strategies when conversing by supplementing others' vocals with a strong focus on a speakers lip movements, thus reducing the effects on possible hearing loss (Cienkowski & Carney, 2002; Thompson & Malloy, 2004). Although these previous examples do not show evidence that can be directly associated with multimodal performance benefits; they do show promise that older adults use extra sensory information when interacting with the world.

Laurenti et al. (2006) attempted to bring forth some concrete findings on the effects of multimodal integration for older age groups. Older adults were prompted to provide a response to a simple reaction time task in which multiple combinations of stimuli were shown. The modality conditions tested included a visual only, an auditory only, and a multimodal condition in which the visual and auditory stimuli were combined. The multimodal stimuli (visual+auditory) provided quicker response times for all participants regardless of their age. Even more interesting is that the older adults were observed to have a higher performance gain for the multimodal stimuli over the performance gain observed in the younger adults. These findings show what other researchers had previously believed that older adults may have an overall larger reliance on extra sensory information, so much so that it has the potential of increasing their performance much more than it does younger adults. The multimodal stimuli actually allowed older adults to perform at similar levels as the younger adults when they responded to a single modality stimuli. Essentially older adults made up for their performance decrements and performed similar to younger adults when they were given multimodal stimuli instead of unimodal stimuli.

The performance benefits that were observed with multimodal feedback in older adults are interesting, especially when considering that response speed generally slows as one ages (Mathews et al., 2000). Older adults have been observed to have approximately 25% slower reaction times during simple tasks, regardless of the sensory system involved when compared to younger adults (Welford, 1977). This generalized slowing effect as one ages has been observed during auditory, visual, and simple motor tasks (Mathews et al., 2000). Currently researchers have had difficulty decoding each aspect of the generalized slowing phenomenon; however most feel that this slowing is not a product of a single aspect of human processing, conversely it is felt that there is a general slowing of multiple systems that work in conjunction when interacting with the world around us (Hicks & Birren, 1970; Birren & Fisher, 1995). The slowing observed in older adults is most often attributed to an overall slowing of the central nervous system. Although the central nervous system is a complex system and is attributed to many different aspects in controlling behavior, it is believed that the ability to process all different dimensions of information is a primary origin of generalized slowing (Birren & Fisher, 1995). Due to generalized slowing, it should be kept in mind that it would be unrealistic to fully negate all of the decrements that occur due to aging; however it is very promising when older adults are performing at similar levels as young adults with the addition of extra modalities. Since older adults have already been observed to use strategies that include the processing of extra sensory information it is beneficial to explore the benefits of multimodal feedback at a deeper level.

There is limited research available to further examine the benefits inherent in multimodal feedback for older adults; however research examining how the aged brain processes sensory information may provide some rationale for why these performance increments are so prevalent. Results of brain imaging studies have shown that older adults have different brain activity when compared to younger adults while performing similar tasks, even if performance has occurred at a comparable level (Grady, 2000; Hedden & Gabrieli, 2004). Brain activity during tasks that require psychomotor responses has also been shown to be higher for older adults. Repetitive finger and wrist movements that would be comparable to the movements necessary while using a mouse have been found to have higher levels of brain activity in older adults compared to younger adults (Hutchinson et al., 2002). It has also been observed that older adults have increased brain activity when creating complex limb movements (Heuninckx et al., 2005). These studies and previous research have consistently shown that older brains tend to have a more widespread pattern of brain activation.

One of the brain areas in which older adults experience more widespread activity is a region that has been linked to the processing of somatosensory information. Somatosensory systems are most often associated with the senses required for different aspects of touch, including but not limited to vibration, temperature, and pain. A study that required participants to do simple limb movements whenever an auditory tone (i.e. metronome) was heard, showed that older adults' brain activity reflected extra auditory processing when compared to younger participants (Hutchinson et al., 2002). The extra brain activity that is most often involved in all of the previous studies centers upon the integration of additional sensory information. For the psycho-motor tasks that older adults were given, additional brain areas associated with the processing of sensory information became active; however this was not always the case for younger adults. Brain imaging studies provide strong evidence that older adults process more of the sensory information that is available to them. The brain is a very complex system and many more years of research are necessary to completely understand how people of all ages decipher our environment; however the findings thus far are very compelling to the idea that older adults are processing the world differently than the rest of the population. These findings show evidence that as one ages one may naturally develop strategies that process more of the sensory information that is available. Due to older adults naturally processing more of the extrasensory information, all systems should leverage this and provide extra sensory cues in places in which none existed previously.

The predominance for older adults to rely heavily on sensory information may be due to a number of reasons; however it can be hypothesized that it is most likely due to the global additive effects from decrements in each sensory system individually. Because older adults have a higher reliance on extra sensory information it is likely beneficial to create systems that allow older adults to leverage their higher reliance on sensory information. This could be done through the addition of extra auditory, visual, or tactile cues. Tactile feedback is an area that has not been explored extensively in the past. The addition of tactile feedback while using a mouse may improve performance in older adults most likely due to the “bimodal advantage”; however older adults also process the environment differently than their younger counterparts. The performance gains observed are likely to be higher for the older adults during multimodal conditions when compared to younger adults. The extra tactile information will provide the extra sensory information that seniors are likely to process more closely.

Multimodal Feedback and Computer Input Performance

The addition of extra sensory information, specifically tactile feedback, to computer interfaces has been examined to a limited extent over the past two decades. This extra feedback is most important when using a graphical user interface (GUI) which requires visual perception as the primary conveyor of information. Tactile feedback has been shown to have very high signal to response times for the sensory system, thus its addition to a visual dominated system may act as a very useful aid (Nelson et al., 1990). It should be noted that research examining tactile feedback often includes force-feedback as well as vibro-tactile feedback. Vibro-tactile feedback is often administered through the use of a small motor built into a device that provides vibrations directly through the point of skin contact. Force-feedback, however, simulates forces acting against or with a device; for example a force-feedback mouse may simulate the pulling of a rubber-band by consistently increasing the force pulling forward on the mouse as one pulls back on the device. Due to the differences in perception and system implementation only vibro-tactile feedback is examined in this study; however research exploring computer interactions that are enhanced with force-feedback have shown promising results on user performance (Repperger, Phillips, & Chelette, 1995; Keyson, 1997; Dennerlein & Yang, 2001; Kyung, Kwon, & Yang, 2006).

A primary concern with the addition of any extra sensory information is that it may become a distraction to the user. Research in the aviation field has shown that tactile feedback is a viable means of communicating extra information, without being a distraction to pilots. Detection of system failures in a flight simulator was shown to be higher when tactile feedback alerted the pilots to these errors (Sklar & Sarter, 1999). These system failures were messaged via one of three ways: visual only, tactile only, and visual and tactile simultaneously. It was found that when participants performed the signal detection task with tactile feedback, regardless of whether visual feedback was present, they had significantly higher detection rates over visual feedback alone. Although these findings are not directly comparable to the interaction associated with a computer mouse, it provides evidence that tactile feedback may not interfere with a task and that a bimodal advantage will hold true in a real world application.

One of the earliest studies directly examining the use of tactile feedback in mice examined the benefits of this extra modality when using a mouse to do a tracking task, positioning task, and a target selection task with adults between the ages of 25 and 35 (Gobel et al., 1995). The positioning and the target selection tasks were both target acquisition tasks, however during the positioning task the mouse pointer was positioned onto a single line, while during the target selection task the pointer was positioned into a predefined area on the screen. The tracking task had participants targeting a continuously moving line with the mouse pointer.

This type of tracking is not often seen in computer interfaces, since most actual targets, such as icons, are static.

The positioning and target selection task were completed significantly faster with the addition of tactile feedback. On average participants completed these tasks 9% to 19% faster when the mouse was enhanced with tactile feedback. This reduction in total task time could be attributed to two factors. First the recorded time for final positioning of the mouse pointer on the target areas was faster when tactile feedback was enabled. Second participants were observed to take less time prior to initially moving the mouse pointer towards the target in the tactile condition. It is possible that the participants were depending more upon the tactile feedback to aid in accurate targeting, thus lowering the amount of time necessary for mental preparation of movement thus resulting in shorter initial movement times. The addition of tactile feedback to the tracking task had little effect on performance; however tracking is not a common behavior during most every day computer interactions. Considering positioning and target acquisition behavior is necessary for activating icons, most future research examining mouse interactions and tactile feedback should focus on tasks based upon target acquisition interactions.

The focus of tactile enhanced mice most often examines how it compares to other modalities during a target acquisition task. Akamatsu et al. (1995) had PC users complete a target selection task with a mouse that provided multiple methods of sensory feedback. The feedback was always given when the mouse pointer entered the target area. The five experimental conditions included no feedback, auditory feedback, tactile feedback, visual feedback and finally a combination of all three feedback modes. Highlighting the target when the mouse pointer touched the target area provided the visual feedback. The researchers collected timing data which was separated into two phases: total task time and final positioning time. Final positioning time was quantified as the amount of time necessary for a participant to press the left mouse button once the cursor entered the target area. The sensory feedback was observed to have the largest effect on final positioning time, most likely because the feedback was not delivered until the cursor entered the target area. Overall the final positioning time was lowest when the user interface had tactile feedback integration. The combination condition also affected performance in a very positive manner; however it is likely the tactile feedback may have increased the observed performance to levels similar to the singular tactile condition. It has been consistently shown that the addition of different multimodal stimuli will not result in a multiplicative effect on performance; most often it will peak at a specific level and the inclusion of additional sensory feedback will amount to limited gains in performance (Cockburn & Brewster, 2005).

The auditory and visual feedback conditions resulted in higher task times than the tactile condition, while the no feedback condition resulted in the worst overall performance. Although auditory feedback did increase performance over the no feedback condition, it resulted in longer task times because participants would often wait until the tone was finished playing before completing the task, thus elevating the total final positioning time. Auditory feedback is also not a good choice for feedback in general because in an office environment it can produce a lot of noise pollution, it can also lead to erroneous feedback due to too many peripheral auditory feedback notifications occurring simultaneously.

Researchers have also compared different types of haptic, which is a common term used to describe something that pertains to the sense of touch, mouse implementations, specifically force feedback and tactile feedback. Akamatsu and Mackenzie (1996) compared four separate conditions that included: no feedback, tactile, force feedback, and a combination of tactile plus force. Force feedback was implemented by increasing the drag of the mouse when a cursor enters the target area, in effect making it more difficult to move when in the target area. To discover if the size of the target has a main effect on the performance when using an enhanced mouse, the target sizes were varied between small, medium, and large. The primary measures used for this study were final positioning time and task performance as measured through an index of performance calculated by using Fitt's law.

As previously found, the real performance differences occurred when the mouse cursor entered the target area. It was found that tactile and force feedback tend to lower the amount of time it takes to stop the mouse when reaching the target area. The performance differences between the two forms of sensory feedback ends there however because tactile feedback was shown to yield significantly lower amounts of time to actually activate the mouse button than force feedback. These effects are further strengthened based upon the size of the targets. The tactile and tactile/force feedback conditions showed significantly improved performance with small targets compared to the other conditions tested. Performance for the tactile feedback condition, according to the results equated from the Fitts law index of performance, was 8.5% more efficient than when no feedback was present. The tactile+force condition resulted in performance that was 5.1% better than the no feedback condition. These findings show further evidence that combining multiple sensory feedbacks don't automatically increase performance, however the inclusion of tactile feedback appears to consistently increase performance.

Most of the previous research examining tactile feedback has focused primarily on target acquisition types of tasks. Although, target acquisition is a skill that is very prominent in a computing environment, real world mouse interactions are a mixture of multiple complex behaviors. In order to provide information on how additional feedback may affect a typical mouse task researchers assessed if different modes of feedback would be beneficial when added to a simple drag and drop task. A drag and drop task requires a user to hold down the left mouse button while moving the mouse to a target. A common example of this type of interaction would be dragging a file into the recycle bin. Vitenset, Jacko, & Emery (2003) directed participants to complete a drag and drop mouse task under a unimodal, bimodal, or trimodal condition. The unimodal condition was comprised of a single feedback mode consisting of either visual, tactile, or auditory feedback. The bimodal condition combined two separate sensory modes together resulting in three separate feedback conditions: haptic+visual, auditory+visual, and auditory+tactile. Finally, the researchers combined all three sensory modes (auditory, visual, and haptic) into a singular feedback condition which is referred to as the trimodal condition.

Each type of feedback was delivered when the mouse pointer broke the plane of the target. In the case of the auditory feedback there was an audible beep when reaching the target. The tactile feedback was very similar to the auditory feedback, however the mouse vibrated quickly (.30 of a second) when over the target. Lastly the visual feedback consisted of simply highlighting the target blue when an object was placed over it.

The researchers examined subjective workload (NASA-TLX), trial completion time (TCT), and target highlight time (THT). Analysis of the study showed that the most beneficial modality to human performance was the tactile+visual feedback. This condition not only showed high levels of user performance (TCT and THT) but also significantly lowered subjective workload levels when compared to the other modality conditions tested. This bimodal feedback condition increased performance yet it did not increase the perceived workload, which is invaluable information when deciding upon the various levels and types of feedback to include in a task. Another observation made was that the addition of auditory feedback may not be beneficial to task performance, especially when basing performance on task time. The participants were once again observed to wait for the auditory feedback to complete playing before finishing any actions. The article did not report the length of the musical tone used for feedback, however length of auditory cues should be taken into consideration when developing auditory feedback.

Although most studies do not examine user perceptions of bimodal feedback, it is important to consider this as well as performance. Many of the performance increments are on a very small scale (i.e., milliseconds), so a user's subjective feelings on the feedback condition should be given weight. Participants have reported liking visual feedback the most; however tactile feedback was chosen as the second most liked method of feedback (Akamatsu et al., 1995). It should be noted however that the tactile feedback in this study was slightly different than other studies concerning tactile sensation. The researchers had a pin pop-up under the left mouse button when the user entered the target. This implementation may be more jarring compared to the more often used vibration method of tactile feedback. Most vibro-tactile mice, such as the Logitech IFeel, have a small motor inside the body of the mouse that supplies distributed vibrations to the hand. It is a possibility that participants would have changed their preference if the standard method of vibro-tactile feedback had been in place. Regardless of the modality of feedback, participants prefer additional feedback when performing mouse tasks.

Multimodal Feedback, Computer Input Devices and the Older Adult

It has been established that tactile feedback enhanced mice increase performance in general populations; however little work has been done to establish how this additional feedback would affect the performance of older adults. The limited amount of research that has examined the benefits of a multimodal mouse for older populations have not used controlled target acquisition tasks, such as Fitts' Law. Also many studies have not controlled for previous computer experience, this is especially important because of the various levels of computer literacy older adults have attained. Computer experience is a factor that has often not been controlled in previous mouse studies. A person's mental model of a mouse interaction is highly dependent upon his or her level of computer experience, such as someone with a lot of experience will have certain expectations of the mouse interaction, while novices will have no preconceived notions. This is important because experienced computer users have fully developed mental models giving them the capabilities to complete a task much more efficiently than novice computer users (Van der Veer & Melguizo, 2002). This study predictably demonstrated higher performance in all conditions for older adults with computer experience when compared to older novice users.

Jacko et al. (2004) did account for older participant computer experience when examining the performance effects on a drag and drop task with multiple feedback conditions. The older participants were subjected to seven separate feedback conditions that were categorized as unimodal feedback, bimodal feedback, and multimodal feedback. The unimodal conditions consisted of singular sensory cue comprised of visual feedback, tactile feedback, or auditory feedback. The bimodal conditions were couplings of the unimodal feedback, while the multimodal condition was a combination of all three modes of feedback. The sensory feedback was administered when the mouse cursor was placed over the target.

The visual feedback was the least beneficial to performance for all of the older computer users, regardless of their experience level. This finding is consistent with other studies which have also examined similar feedback with younger computer users. The computer task is already very visually intense, so the addition of extra visual information can be lost or may be overwhelming to older adults. The tactile feedback condition resulted in mixed findings. The tactile feedback produced the best performance when it was combined with any other sensory feedback condition; however auditory feedback provided the best performance in the unimodal condition. Both the inclusion of auditory and/or tactile feedback provided best observed performance across all conditions tested regardless of the experience level. It should be noted that experience level was a main determinant of overall performance across all conditions as well. Although auditory was shown to increase performance the most, tactile feedback was the second most likely to increase performance.

The experimenters postulated that the tactile feedback may have not significantly affected older participants because the mouse did not produce a powerful enough cue. The researchers did not report the strength of the vibro-tactile feedback; however it is unlikely that the force would have been missed unless it had been lower than 30 Hz. It has been recommended that research examining tactile feedback with older computer users should consider using stronger tactile feedback signals, especially since older adults may be less sensitive to tactile sensory cues

(Hilz et al., 1998). These recommendations are generally accurate since it has been shown that in general older adults lose some sensitivity to vibration detection; however there is very little change in detection in older adults if the vibration is administered to the finger-tips. Stuart et al. (2003) found evidence that young adults (17 to 27 years of age) and older adults (55 to 90 years of age) do not significantly differ in detection of 30 Hz and 200 Hz vibrations when administered through their finger-tips. There was, however, a significant age effect for vibration detection when felt through the forearm, shoulder, or cheek. Due to a stable sensitivity for vibration in the finger-tips over one's lifetime, vibro-tactile feedback above 30 Hz should be adequately perceived by both young and old if felt through a mouse.

Older adults have also been observed highlighting text in a word processor, navigating hierarchical menu structures, or moving cells in a spreadsheet with a tactile enhanced mouse (Viau et al., 2005). The addition of tactile feedback was shown to have little positive effect on performance for all of the participants that were tested regardless of age. The addition of tactile feedback while navigating between spreadsheet cells actually decreased overall performance for the older participants below the levels recorded with no feedback at all. Although, these results may appear discouraging, problems with the research methodology may call into question what was actually tested. The researchers used commercial off the shelf software which provides ecological validity, however they tested the current implementation of tactile feedback in commercial products as it is today. For example, they tested Logitech's tactile feedback implementation in Microsoft Office. The actual current implementation has never been believed to improve performance. Since the setup results in a computer environment that is constantly outputting tactile feedback it is likely that this overwhelming amount of feedback could have been distracting. The researchers also did not control for previous computer experience or prior experience with spreadsheet or word processor software. Finally the sampling for older adults centered more on middle aged adults (M = 47 years of age) than truly older adults which should be at least over 60 years old. Due to the questionable methodology employed in the study these findings have to be looked at as not definitive evidence of the effects of extra sensory information in mouse use. As the authors themselves realize future studies examining tactile feedback must be at a formal level, then once we know the basic effects of tactile feedback when using a pointing device, applications based on these findings can be created.

Measuring User Performance: Fitt's Law & Steering Law

A thorough review of the literature on tactile feedback and mouse use yields two interesting findings. First it can be reasonably assumed that adding tactile feedback is likely to increase the performance of computer users. Second, and more importantly, is the lack of comparable methodologies that have been used when measuring user performance with these devices. Although typically most studies employ a reaction time and errors measurement paradigm when quantifying human performance, this often does not factor in the subtle differences in the interfaces that may affect task difficulty, such as target size, movement trajectories, and distance necessary to move the pointer into the target space. To achieve a better understanding and universality of results many HCI researchers have begun to employ the classic Fitts' Law as well as the newer Steering Law to measure user performance in pointer tasks.

Fitts' Law is a method for predicting the movement time necessary for acquiring targets with rapid and aimed motor movements. Essentially this law allows one to predict the amount of time necessary for a user to point to a target dependent upon its size. Intuitively it can be assumed that it takes longer for a user to point at a smaller target than a larger one; however Fitts' Law quantifies this seemingly simple relationship. Fitts (1954) discovered that task performance on a pointing task was a logarithmic function and thus an index of difficulty could be ascertained if the target distance and size were known. An important characteristic of this law is that it considers the physical properties of a motor dependent task. The original mathematical representation of Fitts' Law is as stated below:

$$MT = a + b \log2 (2D/W)$$

Where: MT = average movement time
a and b = empirically defined constants
D = distance to reach target
W = width of target

Fitts Law is based upon Shannon's Theorem 17, a theorem of communication systems. This law is synonymous with comparing the motor movements necessary for a pointing task to the transfer of information. Measuring task difficulty is a common use for this law with an index of difficulty (ID) that is computed in a unit called bits. So essentially a movement task is assigned an ID, which is represented in bits, and if this number is divided by the amount of the measured movement time of the task an index of performance (IP) can be equated.

Fitts' Law was created well before computer pointing devices were developed, thus pioneer researchers in the field of HCI were unsure if the performance model could be accurately used in the computer space. MacKenzie (1992) performed a thorough review of the HCI literature that measured input performance using Fitts' Law and found that although it appeared that differences in experimental designs caused situations in which the ID and IP could not be directly compared between experiments, the performance relationships found between devices tested within a study were similar to other studies. For example, the IP for the mouse and joystick in Card et al.'s (1978) study was 10.4 and 4.5 respectively, while in Epps' (1986) study the mouse IP was 2.6 and the joystick IP was 1.2. These numbers may be discouraging however when they are quantified as ratios (10.4/4.5 = 2.3; 2.6/1.2 = 2.2) the differences in the individual numbers dissipate.

Certain measures can be made when using Fitts' law for HCI applications to allow higher levels of compatibility between other research employing this law. First, the initial proposed mathematical Fitts' Law equation was found to result in situations in which a tasks ID could result in a negative number if a task becomes too easy (MacKenzie, 1992). To avoid this pitfall and get a better fit with other researchers' measured data most HCI research uses the Shannon formulation for determining ID as stated below:

ID = log2(A/W + 1)

Where: ID = Index of Difficulty in bits
A = target distance
W = target size or width

An example of an ID calculated using the Shannon formulation for a large target (41 pixels) that is close to the starting point (72 pixels away) would be 1.5 bits (ID = log2(72/41 + 1)). Considering that this task is relatively easy due to the large target and short distance away the calculated bits are low; as the target becomes smaller and the distance increases the bits would naturally become higher in number. A second recommendation that should be considered to stay comparable with other HCI studies is to keep the ID within a range of 1 to 7. This allows a set difficulty range that has generally been found to be accurate of current GUI interactions and also gives experimenters the ability to compare results with more ease. Third, the number of conditions should be enough to adequately allow for a wide range of ID. MacKenzie (1992) recommends that a reasonable number of conditions when conducting HCI work with Fitts' Law to be nine to twenty separate conditions.

Finally, average observed errors should not deviate from 4% to keep the underlying principles of Fitts' Law intact, particularly when calculating a prediction model. Although participants are instructed to complete a Fitts' task as fast and accurately as possible it is assumed that 96% of the responses will fall within the target area. If an error percentage other than 4% is observed the width should be calculated with the observed accuracy and an effective width of the target can be quantified (MacKenzie, 1992). This calculation can be made in the post hoc analysis, specifically before any regression analysis is conducted to create a prediction model. Currently many HCI researchers do not adjust the effective width; although to meet ISO standards (ISO 9241-9) for measuring non-keyboard input device performance requires effective width to be calculated. Although making these adjustments are recommended, most do not make this calculation due to the difficulty in making the calculation as well as the fact that there are multiple methods of making this calculation that can significantly affect the Fitts model. The most recent research recommends that if the width variable must be adjusted than a Combined-Coordinate (CC) system should be used due to ease in calculating and better fit with Fitts' regression models (Kong & Ren, 2006).

Fitts' law is primarily a target acquisition task, which is highly relevant when using a pointing device; however it does not encompass all of the possible pointer behaviors that may occur while using a GUI. Behaviors that require users to move the pointer over a defined area, such as navigating nested menus or drawing, are a very common computer interaction that Fitts' Law is not able to measure. Fitts' law is based upon targets, while these other behaviors rely much more on movement trajectories. General mouse use is a combination of multiple behaviors, and thusly when determining the performance of a pointing device multiple measures should be used to create an accurate representation of the benefits of a device.

A model of measuring pointer movement that has been proposed is the Steering Law. The Steering Law is based upon the action of navigating a mouse pointer through tunnels of various shapes and sizes (Accot & Zhai, 1997; 1999). When factoring in the tunnels length and width the movement time can be predicted very similarly to Fitts Law. Another similarity between the two models is that they both can quantify an Index of Performance and an Index of Difficulty (Accot & Zhai, 1997; 1999). The application of this law is limited however because the shape and angles of the tunnels are not given consideration when equating the ID. Different tunnel shapes, such as a circle, zig-zag, or straight tunnel are likely to be serious factors when defining task complexity and this law does not include this crucial piece. For example, if a straight tunnel and a circular tunnel have the same width and are of the same length from start to finish both result in the same ID with no regard to how the shape may play in performance. Although the work on Steering Law in HCI is seriously flawed in its current state, the primary premise of measuring user performance in pointer navigation tasks is an important one that is not considered in experiments that apply a Fitts law task. Measuring total movement time and errors while users navigate tunnels that require pointer steering has been conducted (Campbell et al. 1999) and has been shown to accurately reveal performance differences due to device and participant characteristics. The behavior of steering is an important trait that is necessary in computer interactions and it should be explored further in future studies before it is employed as a method of testing mouse proficiency. Due to the Steering Law being in an early stage of development it will not be used in favor of the much more widely accepted Fitts Law.

Conclusions

There is great opportunity to improve current human-computer interactions for older as well as younger users through the use of mice with additional tactile feedback. As the beneficial aspects of computers become more apparent to the elderly population and the baby boom generation moves into later adulthood there is opportunity to increase performance for older computer users. The current implementation of computer input has already been shown to result in lower levels of performance for older adults. Performance decrements that occur naturally to the motor skills of older adults have shown to have a negative effect on interactions with indirect-manipulation devices (Murata & Iwase, 2005). Although, a mouse will always have the traits of an indirect-manipulation interaction, the inclusion of additional feedback is very likely to increase the saliency of the task to the real world resulting in increases in performance. The addition of the absent tactile feedback to a mouse interaction will create a more robust computer interaction and provide an increased internal representation of the computer world (Biocca et al., 2002).

Previous research efforts exploring the benefits of tactile feedback have either been lacking in quality due to methodological issues or have been very limited in number. The purpose of this study is to provide an accurate measure of the effects of tactile feedback on mouse use in older adults. Some of the previous studies in this limited area did not examine this relationship in a concise valid way. This study plans to rectify this body of research through the application of a Fitts law task and improved sampling methodology. A mouse task using Fitts law has previously been shown to provide valid performance findings for a mouse pointing task. Parallels have been drawn between Fitts law and standard computer use due to the necessity to click on icons and buttons in computer interfaces, thus it is likely the best method to begin exploring tactile mouse use.

Research conducted on cross-modal integrations, and the processing of extra sensory information by older adults has provided evidence that a tactile mouse is likely to increase performance. Jacko et al. (2004) found that during a drag and drop mouse task older computer users had better performance when tactile feedback was introduced and Gobel et al. (1995) have shown that the addition of tactile feedback improved performance during a pointing task. It is likely that the inclusion of tactile feedback for older adults will significantly improve performance when compared to solely using visual feedback. The addition of tactile feedback may also decrease the amount of time that an older adult needs to click a target. Akamatsu et al. (1995) have found with younger adults that the time necessary to click a target once it has been highlighted is significantly less when tactile feedback is present. Similarly, previous research (Akamatsu & Mackenzie, 1996) has found that tactile feedback will make the task time significantly shorter when pointing to smaller targets for young adults. If these findings are examined in conjunction with previous research covering the well documented bimodal advantage it can be hypothesized that some of the previous findings with younger computer users may also hold true for older adults.

There is strong evidence for a bimodal advantage that is present in people of all ages; in addition there is also very strong evidence that older adults are a group that uses extra sensory information to increase their everyday interactions with the environment (Cienkowski & Carney, 2002; Thompson & Malloy, 2004). With a simple reaction time task it was shown that the gains in performance due to the addition of extra sensory information were vastly higher for older than for younger ones completing the same tasks (Laurenti et al., 2006). This provides some evidence of the importance of multimodal feedback to older adults. When using a tactile-enabled mouse for a pointing task it can be reasonably hypothesized that the older adults will use this tactile feedback more effectively than their younger counterparts and will likely have larger performance gains. The addition of tactile feedback may also reduce some of the effects inherent in the generalized slowing phenomenon that one experiences as one becomes older.

Purpose

The purpose of this research is to provide strong evidence that the addition of auditory, tactile, and visual feedback will increase mouse pointing performance for older adults. There has been previous evidence outside the HCI realm that suggests that the performance benefits of additional sensory feedback will have a greater effect on older adult performance compared to younger adults. Previous research within the field of HCI has shown that the addition of sensory feedback when completing mouse tasks allowed older adults to perform more quickly; however these studies did not employ a standardized pointing task and also did not account for previous computer experience. This research will provide strong evidence for the benefits of providing multimodal feedback to computer interactions for older populations.

CHAPTER THREE: METHOD

Participants

According to G*Power 3.0, a power analysis software tool, a sample size of 84 participants was required to achieve a power of .80 and a medium (.25) effect size. Participants were categorized into three age groups: young (18 to 30 years old), middle-aged (35 to 55 years old) and old (60+ years old). Each age group was recruited in order to maintain a 50/50 gender mix.

A total of 91 participants were recruited for this study; the extra 7 participants were run through the sessions as a possible replacement in case a participant achieved outside of the normal performance for their age group. These 91 total participants were split among separate groups based upon age and gender, which resulted in the following 6 groups: 15 young males, 15 young females, 18 middle-aged males, 14 middle-aged females, 15 older males, and 14 older females. The participants did not have any health limitations which would make using a mouse difficult and also used a computer mouse for at least 5 hours per week. Additionally, all of the participants were right handed and primarily used a mouse when interfacing with a PC. Please refer to table 1 and 2 for a full breakdown of the samples ages and computer experience. Participants also met certain sensory requirements that were required to accurately complete the study. These sensory requirements included: at least 20/40 vision, acceptable hearing, and the ability to perceive tactile sensations in their right hand.

Participants were recruited in a variety of ways. Some participants for this study were recruited from the University of Central Florida via the Department of Psychology participant recruitment system. Ads for recruitment were also placed on online classified sites, such as

Craigslist, and in the Orlando Sentinel newspaper. Recruitment was also done via flyers that were placed in locations surrounding the Orlando area that were likely to have a diverse age population, such as but not limited to senior community centers. Participants were compensated for their time with a choice of extra credit that could be used towards a psychology course or $20.

The participant sample initially only included the first 14 participants from each of the 6 groups and disregarded the extra participants. The initial sample of 84 participants was screened to ensure no outlying participants needed to be replaced. Since accuracy was a critical assumption of this target acquisition task, an initial scan of the data looked for participants that may not have balanced there speed and accuracy accordingly, which would have resulted in a higher than normal percentage of error. Box plots were used in order to determine which subjects may have been an outlier within each condition. If a participant's error percentage was 1.5 interquartile range (IQR) above the upper quartile (i.e., top 75% of scores) they were labeled as an outlier for that condition. Appendix A reports all participants from the initial sample of 84 participants that was found to be an outlier for each of the conditions. The criterion for participant removal was if 50% (i.e., 4 out of 8) of the conditions resulted in an outlying error percentage.

Two participants were removed from the analysis for having over 50% of their trials result in a higher than normal error rate. A middle-aged female was removed because she had a very high error rate on 7 of the 8 test conditions. Due to having no replacement participant available the middle aged female group was comprised of 13 participants. Additionally, a single middle-aged male was also removed for scoring poorly in 50% of the feedback conditions;

however he was replaced with one of the extra middle aged male participants. After the middle-aged male was replaced the data was re-checked to ensure the replacement participant was not in and of himself also an outlier. This additional analysis showed that the replacement was indeed a proper participant for this study.

After correcting the data to ensure that all participants were reasonably accurate when completing the task an additional analysis was conducted to find potential outliers when examining TMT. Since accuracy was deemed to be the better determinant of proper task completion, the data set was only screened for participants that were extreme outliers. An extreme outlier was defined as anyone that had a mean TMT that was 3 IQR above the upper quartile. An older male participant had to be replaced due to having extremely high TMT on all of the feedback conditions. This particular participant was on average 3 times slower than the mean of the group, which provided a strong rationale for him to be replaced with an extra older male participant. An additional participant from the older male group was also an extreme outlier for TMT on 6 of the 8 feedback conditions, which made it necessary to remove him from the sample. Unfortunately a suitable replacement was not available so the older male group had a total of 13 participants. After removing the outliers a final sample of 82 participants was used for further analyses. The sample was almost split evenly between the 3 age groups with a total of 28 young adults, 27 middle-aged, and 27 older adults.

Table 1. Summary of Participant Ages

Age Groups	Minimum Age	Maximum Age	Average Age
Young Adults	18	28	20.5
Middle-Aged	35	52	43.3
Older Adults	60	84	68.4

Table 2. Participant Computer Experience & Behavior

			Level of Computer Experience		
	Hours per week on PC	Years using PC	Beginner	Intermediate	Advanced
Young Adults	M = 26.9; SD = 18.8	M = 9.9; SD = 3.2	4%	79%	18%
Middle-Aged	M = 28; SD = 15.3	M = 16; SD = 5.9	4%	63%	33%
Older Adults	M = 17; SD = 14.9	M = 16.9; SD = 7.4	19%	67%	15%

Apparatus

Fitts Task

The Fitts Task was run on a Windows based PC with an Intel 2.4 GHz Core 2 Duo processor and a 19" flat-screen monitor. A Logitech iFeel 2-button optical mouse was connected to the computer and was the sole mouse used throughout the study. The iFeel mouse is able to provide tactile feedback through the implementation of a small actuator built within the mouse, which can provide a tactile frequency response from .01 to 500 Hz. The tactile feedback functionality could be turned on or off within the software reverting itself back into a standard desktop mouse.

The Fitt's Law task was developed using E-Prime, a popular psychological testing software suite. The objective of the Fitt's Law task was for the participant to move the mouse cursor from a starting position on the screen to a target as quickly and accurately as possible. The starting position and target were both square in shape. The target was located at one of 4 pre-determined angles from the starting position, either 45 degrees, 135 degrees, 225 degrees, or 315 degrees. In order to begin each task trial the left mouse button had to be clicked while the mouse cursor was within the starting position. If the left mouse button was pressed outside the confines of the starting position the trial did not start and no data was collected. Once the trial started a variety of measures were recorded for that specific trial. The Fitts task recorded the following data: total movement time (TMT) in milliseconds, total highlight time (THT) in milliseconds, slip errors, and trial outcome (i.e., miss or hit).

In order to record slip errors, misses, and total highlight time the software registered the exact moment the cursor hit the target as well as the number of times the cursor touched the target for each trial. When the participant pressed the left mouse button within the target the software recorded the total movement time (TMT) to complete the trial as well as the amount of time the participant was within the target prior to pressing the button (THT). If the pointer overlapped the target, but rolled off prior to the button being clicked the software registered a slip error. If the participant clicked the button outside of the target error, that trial was marked as an error and was re-administered at a random time during the session.

The Fitt's Law task also had the capability of presenting different feedback modalities when the cursor touched the target. The feedback modalities used included tactile, audio, or visual cues alone or in combination. If a feedback cue was present it was delivered when the cursor entered the target. The visual cue consisted of the target changing its visual state from white to blue whenever the mouse cursor touched the target. This feedback was continuous, so whenever the cursor was touching the target it remained blue. The auditory condition consisted of a discrete click sound played through headphones whenever the cursor entered the target region. This feedback only occurred on target entry and did not continuously play while the cursor was in the target. Previous research (Vitense et al., 2003) had shown that some users may wait to provide input until after the sound has completed playing, thus the audio sample was chosen for its brevity at approximately .1 second in length. The audio feedback was played at a volume level in which all participants were able to hear it and the volume level was held constant between the participants. Finally, the tactile cue consisted of a short medium to high strength vibration delivered each time the cursor initially entered the target. The tactile feedback was intended to last only .1 second in length.

In order to provide tactile cues an additional software package, Immersion Touchware, was installed onto the PC. This software converted sound waves to tactile feedback that could be used by the iFeel mouse. During the tactile condition the software played a sound, which the participant was not able to hear, whenever the mouse pointer entered the target area. The Immersion Touchware software package converted this sound to tactile feedback when needed. The amount of tactile feedback that was produced, unfortunately, could not be easily quantified; however the Touchware software had the capability of tuning the tactile signal to different strengths (i.e., very low, low, medium, and high). In order to be certain that all participants were able to discriminate the tactile feedback, the software was tuned to provide a medium to high vibro-tactile signal.

It was possible to play the visual cues in combinations thus the software had the capabilities to present bi-modal and tri-modal feedback cue combinations. The possible bi-modal conditions included the following feedback combinations visual+tactile, visual+auditory, tactile+auditory. The tri-modal condition was a combination of all three feedback conditions resulting in tactile+auditory+ visual. Additionally, it was possible to include no feedback cues, which provided the opportunity to have a no feedback condition.

Sensory Screening

Methods for measuring visual acuity, hearing, and tactile perception were used during this study. In order to measure visual acuity an OPTEC vision testing machine was used. This machine presented a Snellen chart to participants and upon completion allowed for an estimation of overall visual acuity.

A hearing test was developed using the E-Prime software. This hearing test consisted of 30 total trials in which after each trial the participant was instructed to report whether they heard an audio sample. Out of the 30 trials only 5 of them actually played the audio cue. If the participant correctly reported hearing a sound it was considered a hit. If they did not report hearing the audio cue when it was present it was considered a miss. False alarms were also recorded in cases in which the participant reported hearing the audio cue when it was not present. If the participant correctly reported that they heard the 5 samples and did not have any false alarms they were considered to have successfully passed the hearing test.

A tactile sensitivity test was also used during this study. A variation of the hearing test was used in which tactile cues were presented via the mouse instead of audio cues. This tactile feedback was exactly the same as the one that was employed as the tactile cue during the test sessions. The same criteria as the hearing test was necessary in order to successfully pass the tactile screening.

Pre-Test Questionnaire

A pre-test questionnaire that collected relevant health history and previous computer experience was developed for this study. This questionnaire had a subset of questions taken from the health assessment questionnaire (HAQ) (Fries et al., 1982). This subset of questions focused on physical limitations that may inhibit mouse use, such as arthritis or an inability to grip objects. Additionally, this questionnaire included a section that quantified previous computer experience, including frequency of computer use, years of experience and typical computer use. This pre-test questionnaire was intended to verify that the participants were acceptable for the study in regards to health and previous computer experience. A copy of the pre-test questionnaire can be found in Appendix C.

NASA-TLX

The paper based NASA-TLX was chosen to assess the workload experienced throughout the different tasks. The NASA-TLX is a subjective based measure of workload that can provide an overall estimation of the workload as perceived by the respondent. This has been shown to be the most valid measure of workload in comparison to competing measures, such as the SWAT (Hill et al., 1992). The NASA-TLX is based upon 6 weighted factors that include: mental demand, physical demand, temporal demand, performance, effort, and frustration. Each of these 6 factors is weighted according to how important each factor is to the successful completion of the task. These levels of importance are determined through a pair-wise comparison in which participants are asked to choose the more important factor contributing to the task among all of the different paired combinations. Each factor is also rated via an absolute score which is determined by the participants experience with that factor in the task. For example, the respondent scores their perceptions of mental workload on a 1 (Low) to 100 (High) scale based upon their experience with the previous task.

Based upon a methodology previously used to examine an auditory enhanced scroll-bar (see Brewster et al., 1994) the level of annoyance experienced from the task was added as an additional factor using the same 1 (Low) to 100 (High) scale that is found on the NASA-TLX. The annoyance factor was not included in the overall workload or the pair-wise comparison portions of the NASA-TLX. This factor was added due to the possible annoyance that may have arisen with any of the feedback conditions. It is believed that one of the biggest problems with auditory output in the realm of HCI is the annoyance that it may cause (Brewster, 2003). This measure provided the ability to highlight the possible differences in annoyance between the different types of feedback. A copy of the NASA-TLX used in this study can be found in Appendix E.

Feedback Preference Questionnaire

In order to determine the preferred feedback modality for the groups a preference measure was administered. This measure asked participants to rank the 8 possible feedback conditions from their most preferred to their least preferred. A link to this measure can be found in the Appendix D.

Experimental Design

This study used a 2 x 2 x 2 x 3 within mixed factorial design. The between subject factor was age at 3 different levels: young, middle-aged, and old. The within subject variables were the presence or absence of each of the three feedback modalities. Table 3 outlines the feedback combinations that were presented to each age group. There were a total of 8 possible feedback conditions presented to each participant.

Table 3. Feedback Combinations Presented

Tactile							
Present				Absent			
Audio				Audio			
Present		Absent		Present		Absent	
Visual		Visual		Visual		Visual	
Present	Absent	Present	Absent	Present	Absent	Present	Absent
T+A+V	T+A	T+V	Tactile	V+A	Audio	Visual	None

Independent Variables

Multiple independent variables (IV) were intricate to the completion of the study. As has been previously mentioned age was controlled for three separate levels: young, middle-aged, and old. Feedback was also an independent variable with a total of 8 levels when considering all possible feedback combinations: no feedback, visual, tactile, audio, visual+tactile, visual+audio, audio+tactile, and visual+audio+tactile. The target width was varied at three possible diameters which were 1/8 inch, ¼ inch, and ½ inch. The target widths chosen represented typical icon sizes that may be seen in a GUI. The distance the target was presented from the starting position, further referred to as the amplitude, was also varied between three distances: 2 inches, 4.5 inches, and 8 inches. Trials were presented with different combinations of target width and amplitude, which resulted in a total of 9 different types of targeting scenarios within each feedback conditions. Additionally, the target sizes and amplitudes chosen for this study provided multiple IDs that fall between 1 and 7 bits.

Dependent Variables

Task performance was measured using multiple dependent variables. Total movement time (TMT) was the total trial time in millisecond. Total highlight time (THT) was the total amount of time in milliseconds that the mouse cursor was within the target prior to activation, please see Figure 3. Slip errors were the number of times the mouse cursor hit the target and slipped out prior to successfully activating the target. Misses were the number of times that a trial ended with activation outside of the target. Workload was the calculated NASA-TLX score. Additionally, the separate factors of the NASA-TLX worksheet were also separately examined, which for this study included effort and the additional annoyance factor.

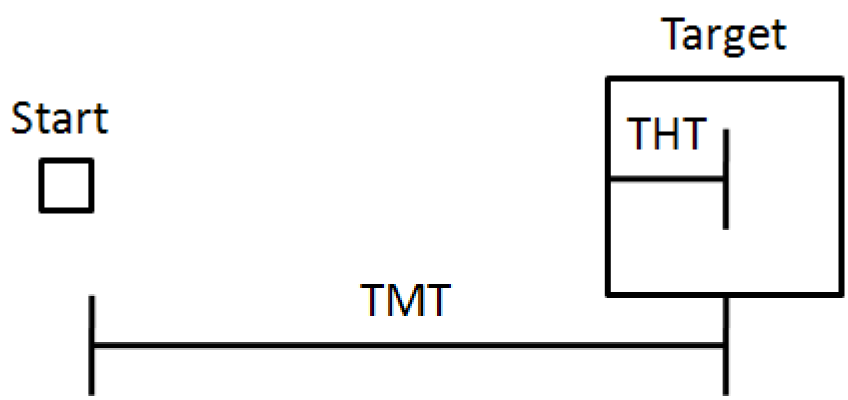

Figure 3. Difference between TMT and THT

Procedure

Upon arriving to the lab, participants were asked to sign an informed consent form (Refer to Appendix B). Upon completion of the informed consent the participant's vision, hearing, and tactile perception were tested. Following the sensory tests the pre-test questionnaire which included the health assessment and computer experience questions was given.

Participants were given a brief introduction to the testing apparatus and a practice period in order to get comfortable completing the task. The introduction was automated so that the complete directions of the task were presented via the software. The instructions explained what the session would entail, the goals of the task and provided a practice session. Following the instructions the practice sessions was administered during which the participants were shown each of the eight feedback condition 3 times in a combination of target widths and amplitudes resulting in a total of 24 practice trials. In order to verify that the participants had a firm understanding of the task objectives the participant could not begin the test sessions until they perfected the practice session. If a participant did not effectively complete the practice session then additional clarification of the task was given followed by a re-administration of the practice session.

The presentation of the different conditions and sessions was similar to MacKenzie's (1992) review and validation of Fitt's law tasks application to HCI experiments. The experiment included 8 randomly presented test sessions with each session comprised of one of the possible eight feedback conditions. In order to make certain that the presentation of the feedback conditions was counter-balanced a Latin square was used which resulted in 8 possible orders of presentation. Due to having 14 participants per group some of the orders had to be used twice.

Within each session there were 108 randomly ordered trials, with each possible amplitude and target width combination being shown 12 times. Additionally, each amplitude and target width combination was shown 3 times for each of the angle orientations (45 degrees, 135 degrees, 225 degrees, 315 degrees). Trials that result in a miss was not counted towards the total number of trials and a replacement trial for the erroneous trial was re-administered automatically during the session. For example, if a participant made 3 errors during the course of a session, then the total number of trials for that session resulted in 111. Each test session lasted approximately 4 to 5 minutes.

Upon completion of each session the participants were asked to fill out the NASA-TLX subjective workload measure. Participants were instructed to only think about the session that they just completed while filling out the workload measure. Once participants had finished the questionnaire they were required to take at least a 2 minute break prior to beginning the next test session. This break was mandatory and was included to reduce possible fatigue and boredom during the course of the study. After each participant had completed all of the sessions they were given a post-test questionnaire instructing them to rank the 8 feedback modalities from favorite to least favorite. The entire length of the study session took approximately 90 to 120 minutes.

Predictions

Hypotheses #1 through #10 predict findings for the different feedback conditions within each group. Hypotheses #11 through #14 are specific to differences that will be observed between the age groups.

1. Participants will have significantly lower TMT when feedback cues are present.
2. The presence of tactile cues will significantly lower TMT.
3. The TMT from the visual uni-modal condition will be significantly higher in comparison to audio or tactile uni-modal conditions.
4. Participants will have significantly lower TMT for small targets when feedback cues are present.
5. Participants will have significantly lower TMT for small targets when tactile or auditory cues are present in comparison to visual cues.
6. Participants will have significantly lower THT when feedback cues are present.

7. The presence of tactile cues will result in significantly lower THT in comparison to when visual cues are present.
8. Participants will have a significantly lower number of slip errors when feedback cues are present.
9. Participants will have a significantly lower number of slip errors when audio or tactile feedback is present in comparison to when visual cues are present.
10. Participants will have significantly lower workload when feedback cues are present.
11. The older age group will have significantly lower effort when feedback cues are present.
12. The young age group will have significantly higher IP for the mouse task compared to the older adults.
13. The change in IP from the uni-modal feedback conditions to the no feedback condition will be significantly larger in positive directions for the older adults in comparison to the young adults.
14. The change in IP from the bi-modal feedback conditions to the uni-modal feedback conditions will be significantly larger in positive directions for the older adults in comparison to the young adults.

CHAPTER FOUR: RESULTS

An alpha level of .05 was used as the criterion for statistical significance in all of the analyses conducted. Furthermore, all of the alpha levels are reported as two-tailed unless otherwise noted. In some instances a one-tailed alpha level was used if warranted by a directional hypothesis.

Prior to conducting each of the analyses the data were examined in order to ensure that the assumptions of normality were met. Skewness and kurtosis were examined by calculating a z-score by dividing the skewness or kurtosis statistic by the skewness or kurtosis standard error respectively. Based upon Tabachnik & Fidell's (1996) recommended conventional cut-offs for smaller samples, an alpha level of .001 was used in order to determine if any of the groups were significantly skewed or kurtotic. A number of the data sets were significantly skewed. Unless otherwise noted it should be assumed that the data was normalized using a Log_{10} transformation. Tables 4 and 5 shows the raw data for the TMT and THT for each of the age groups respectively.

Table 4. Raw data means and standard deviations for Total Movement Time.

	Young Adults N = 28		Middle-Aged N = 27		Older Adults N = 27	
Total Movement Time (ms)	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
No Feedback	903.75	121.28	1108.54	236.21	1126.1	177.21
Audio	894.05	125.19	1027.67	191.27	983.81	173.39
Tactile	915.63	137.21	1036.7	176.97	1053.63	139.33
Visual	900.16	137.45	1088.41	188.3	1096.83	160.95
Audio+Tactile	887.84	123.18	1057.66	180.34	1035.2	155.88
Visual+Audio	888.17	120.76	1047.49	185.89	1038.19	158.24
Visual+Tactile	883.22	135.39	1087.81	206.54	1078.24	162.43
Visual+Tactile+Audio	896.77	122.84	1050.45	211.75	1047.46	166.69

Table 5. Raw data means and standard deviations for Total Highlight Time.

	Young Adults N = 28		Middle-Aged N = 27		Older Adults N = 27	
Total Highlight Time (ms)	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
No Feedback	231.07	57.82	309.98	125.18	301.35	75.71
Audio	202.63	60.78	236.56	61.32	228.48	63.17
Tactile	209.87	67.4	240.13	83.86	240.12	73.5
Visual	207.42	56.05	266.72	69.22	266.83	75.5
Audio+Tactile	193.62	61.2	242.34	88.7	223.91	61.82
Visual+Audio	188.3	52.4	239.08	77.41	226.33	61.68
Visual+Tactile	192.97	59.63	251.07	85.43	234.09	74.3
Visual+Tactile+Audio	193.93	58.84	235.14	86.85	213.24	70.03

A correlation matrix containing the age group, feedback and the separate dependent measures recorded during the Fitt's task is shown in Table 6. A Spearman's correlation test was used due to the non-normal distribution of the timing data as well as the feedback and age group variables not being interval in nature. Age group was positively correlated with TMT ($r_s = .421$, $p < .001$), slip errors ($r_s = .200$, $p < .001$), THT ($r_s = .216$, $p < .001$), workload ($r_s = .165$, $p < .001$), and errors ($r_s = .272$, $p < .001$). This shows that all of the dependent measures increased as age increased.

Also of note is the significant correlations found for TMT. TMT was positively correlated with slip errors ($r_s = .376$, $p < .001$), and THT ($r_s = .742$, $p < .001$). As the TMT took longer, the number of slip errors also increased. This is to be expected since committing a slip error will add to the overall time necessary to successfully complete the trial. Additionally the strong correlation between THT and TMT is due to THT being a subset of the TMT, thus as the THT is increased it would also increase the overall TMT.

THT was also significantly correlated with feedback (r_s = -.234, p < .001) and slip errors (r_s = .517, p < .001). In terms of feedback, as additional feedback modalities were added to the task THT decreased. The THT also increased according to the number of slip errors committed. This shows evidence of participants slowing down in order to acquire the target after committing slip errors during the trial.

Table 6. Correlation Matrix

	Age Group	Feedback	TMT	Slip Errors	THT	Workload	Errors
			Total Sessions (N = 656)				
Age Group	-	.00	.42**	.20**	.216**	.165**	.272**
Feedback		-	-.07	-.077*	-.23**	.06	.24**
TMT			-	.38**	.74**	.06	-.16**
Slip Errors				-	.52**	.19**	-.02
THT					-	.04	-.52**
Workload						-	.2**
Errors							-

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

In order to assess the necessity of running multiple statistical tests to validate the separate hypotheses proposed for this study a multivariate analysis of variance (MANOVA) was computed for age group and feedback for the performance measures recorded. These performance measures included the following dependent variables: TMT, THT, slip errors, errors, and workload. The results of the MANOVA showed significant findings for age group (F(10, 1258) = 24.429, p < .001) and feedback (F(35, 3160) = 2.584, p < .001). Due to significant findings for the performance measures with both independent variables further analyses were conducted to validate each of the proposed hypotheses.

A primary tenet of a Fitt's task is that the index of difficulty has a strong influence on TMT. In order ensure the index of difficulty predicted TMT a linear regression was conducted. The index of difficulty accounted for 46% of the variation in TMT. Although the regression model is not as strong as previous Fitt's studies an upward trend in TMT as ID is present in the data, see Figure 4. Full results of the linear regression can be found in table 7.

The goodness-of-fit of this model is lower than what would be expected; however this is likely due to a higher than optimal average error rate. MacKenzie, (1992) suggested that for Fitt's data to optimally fit a regression model sustained error rate should be 4% or lower; however the data from this study had an average error rate of 7%. The higher error rate could possibly be attributed to variations of the speed and accuracy balancing between participants. For example, some participants may have balanced their performance so that they were quicker while committing more misses; while others may have paid more careful attention to the number of misses committed and lowered their speed. Effective width measurements should be recorded in future studies in order to avoid inflated error rates that may be caused by differences in accuracy balancing, experience, or other possible differentiators between participants.

Effective width calculates the points within and around the target that each participant is hitting (MacKenzie, 1992). The effective width is calculated by measuring the distance that 96% of participant's clicks have hit within and around the target, thus if 96% of the participants hits are within .75 inches when targeting the .50 inch target, the effective width would be .75 inches. This calculation would individualize the ID for each participant depending upon their performance. This calculation would alleviate issues that may arise due to participants balancing their speed and accuracy differently. Since this study did not account for effective width and the data does not fit the regression model as well as other Fitt's studies the resulting IPs should not be compared to other studies employing a Fitt's task. Any of the IPs reported are to demonstrate trends found within this specific study and should not be directly compared to IPs reported in previous or future work.

Table 7. Index of Difficulty x Total Movement Time Regression Results

	B	*SE B*	β
Constant	290.14	10.39	
Index of Difficulty	171.82	2.41	.68

R^2 = .46, F(1, 5902) = 5072.3, p < .001

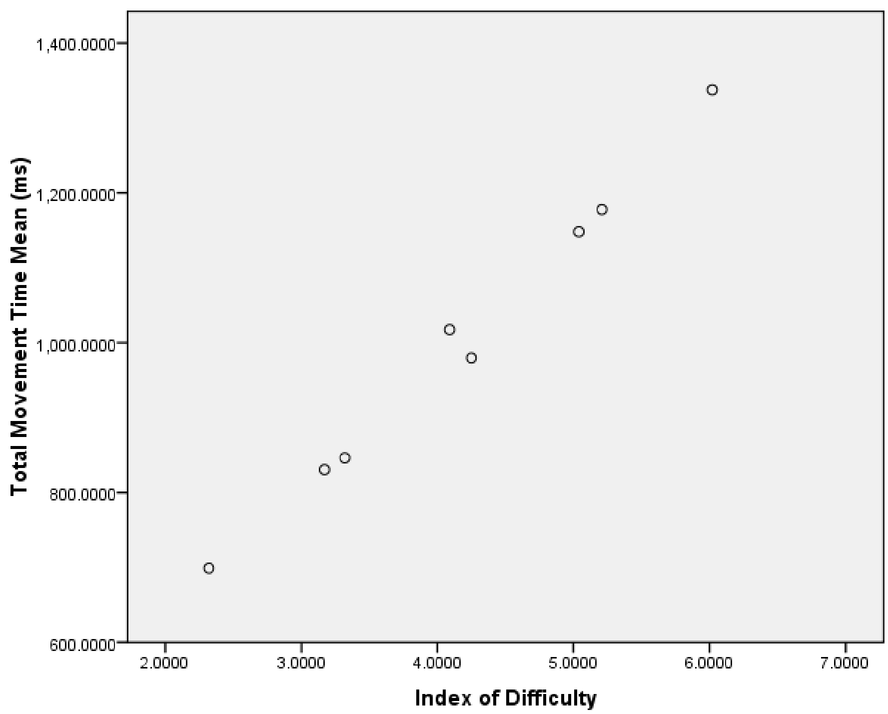

Figure 4. TMT Means for each ID

The sessions were constructed so that the angle of approach was balanced within each of the feedback conditions resulting in each presentation of the target being shown at 4 separate angles (45, 135, 225, 315) an equal number of times throughout each session. Previous research had not controlled for the angle of approach and this information was collected to ensure that it did not affect performance. In order to determine if angle of approach had an effect on performance an 8 (feedback) x 4 (angle of approach) one-way ANOVA was used to highlight any significant differences in TMT that may have been caused by the angle of approach. The data was significantly skewed so a Log_{10} transformation was necessary for the dataset. The results of the analysis showed no significant differences between the angles. It appears that the angle of approach did not affect the resulting TMT in a mouse based target acquisition task, thus further analyses will not include it.

The remainder of the results section is categorized according to each relevant factor from this research. The proposed hypotheses are addressed within the section in which it would be most relevant.

Total Movement Time

Total movement time (TMT) was the total amount of time in milliseconds that it took a participant to complete a trial. It was predicted that participants would have significantly lower TMT when any of the feedback modalities are present. In order to determine if the presence of feedback had any effect on TMT a 2 x 2 x 2 x 3 repeated measures general linear model was used. The within subject factors each had 2 levels for tactile, visual, and audio. The two levels for each of these factors were defined as each modality being present or absent during the trial. The between subjects factor was age group which had 3 levels (young, middle-aged, old). A

Mauchly's test of sphericity was used to determine if the data set met the assumptions of sphericity prior to conducting the repeated measures analysis. The results of this test were insignificant, thus sphericity is assumed during further analysis. It should be noted that the data used for this analysis was transformed with a Log_{10} transformation; however all charts and marginal means reported are based upon the untransformed data in order to provide better clarity.

A significant main effect was found for tactile feedback, $F(1, 79) = 4.160$, $p = .045$, see Figure 5. The mean of the conditions with tactile feedback included (i.e., tactile only, tactile+visual, tactile+audio, visual+tactile+audio) was 1002.6 ms; while the conditions without tactile feedback were 1012.7 ms. This finding shows that when tactile feedback was present the TMT decreased. These findings support the prediction that the presence of tactile feedback would significantly lower TMT.

A significant main effect was found for audio feedback, $F(1, 79) = 32.244$, $p < .001$, see Figure 6. The mean for conditions with audio feedback was 992 ms; while the mean for conditions in which audio feedback was not present was 1023.3 ms. According to this finding the inclusion of audio feedback significantly decreased TMT.

A significant two-way interaction was found between tactile and audio feedback, $F(1,79) = 16.352$, $p < .001$, see Figure 7. TMT was lowest when audio feedback was included without tactile feedback ($M =$ 988.1 ms); however when tactile was included with audio the TMT increased ($M = 995.9$ ms). TMT was at its highest when tactile and audio were both not present ($M = 1037.3$ ms). These findings show that tactile feedback and audio feedback both decrease TMT; however audio without tactile resulted in the optimal TMT. While overall the inclusion of tactile and audio affected TMT in a positive manner visual cues did not significantly affect TMT when it was present with or without other modalities.

A significant main effect was found between the age groups, $F(2,79) = 12.709$, $p < .001$. A Tukey HSD post-hoc revealed that the young group had significantly lower TMT than the middle-aged and older group with both significant at a $p < .001$ level. There were no significant differences found for TMT between the middle aged and older aged participants.

A significant two-way interaction was found between age group and the audio condition ($F(2,79) = 4.718$, $p = .012$). The presence of audio lowered TMT for the middle and older age groups. The older group had the highest TMT when audio was absent; however when audio was present their performance was comparable to the middle-aged group. The young group performed significantly better than the other age groups and although audio improved performance there was a smaller improvement in comparison to the other age groups, See Figure 8. No other significant interactions were found between the modalities and age group.

Lastly, it was predicted that the visual feedback uni-modal condition would result in significantly higher TMT in comparison to the auditory and tactile uni-modal conditions. A paired-samples t-test was used to determine if the visual feedback condition resulted in significantly higher TMT in comparison to the auditory and tactile conditions. The means reported are based upon the post-transformed normalized data; refer to Table 1 for the original means. The alpha levels reported are based upon a one-tailed test due to the implied directionality of the hypothesis.

On average it was found that participants had significantly higher TMT during the visual condition ($M = 3.0$ $SE = .008$) than in the audio condition ($M = 2.99$, $SE = .008$, $t(81) = 4.03$, $p <$

.001, $r = .85$). It was also found that participants had significantly higher TMT during the visual condition in comparison to the tactile condition ($M = 2.99$, $SE = .008$, $t(81) = 2.51$, $p = .007$, $r = .88$). These findings support the hypothesis that the visual uni-modal feedback condition would result in significantly higher TMT than the tactile or audio uni-modal conditions.

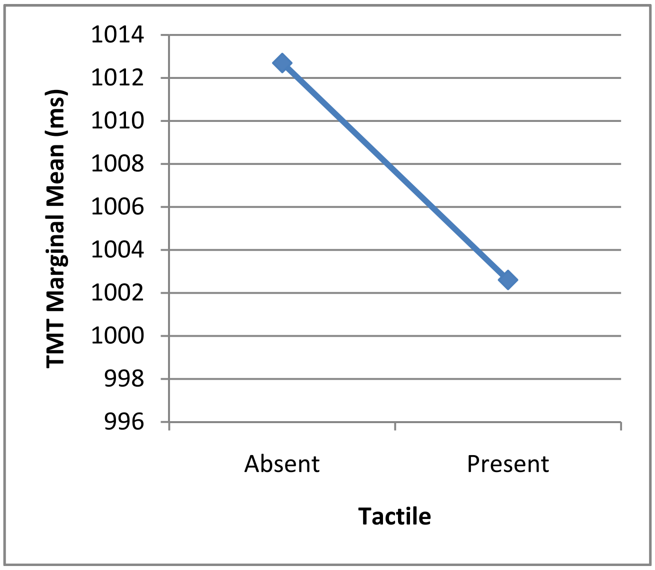

Figure 5. Tactile main effect for TMT

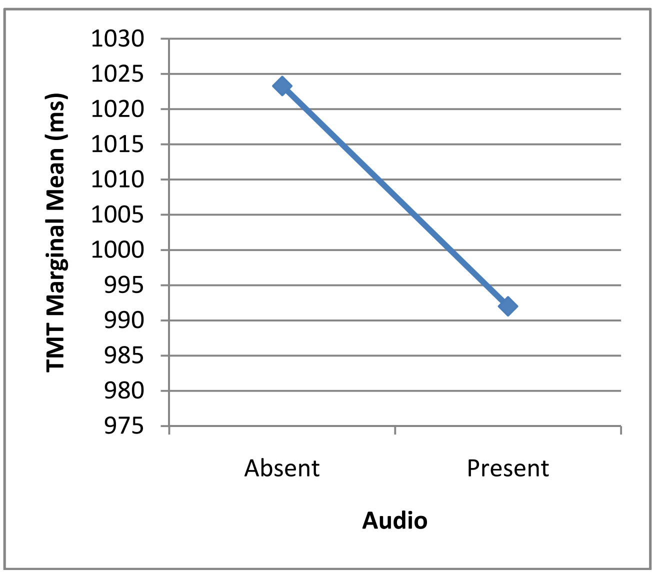

Figure 6. Audio main effect for TMT

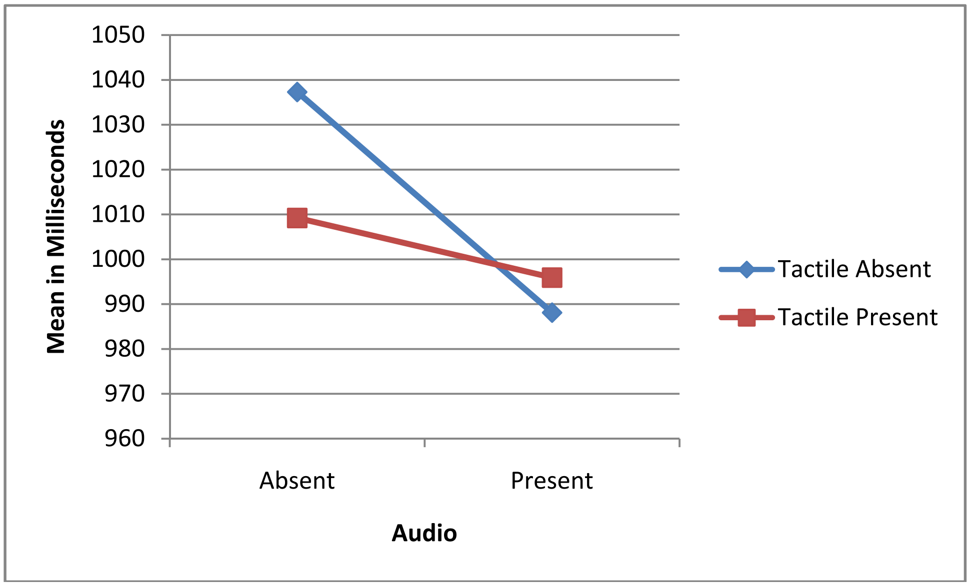

Figure 7. Tactile x Audio interaction for TMT

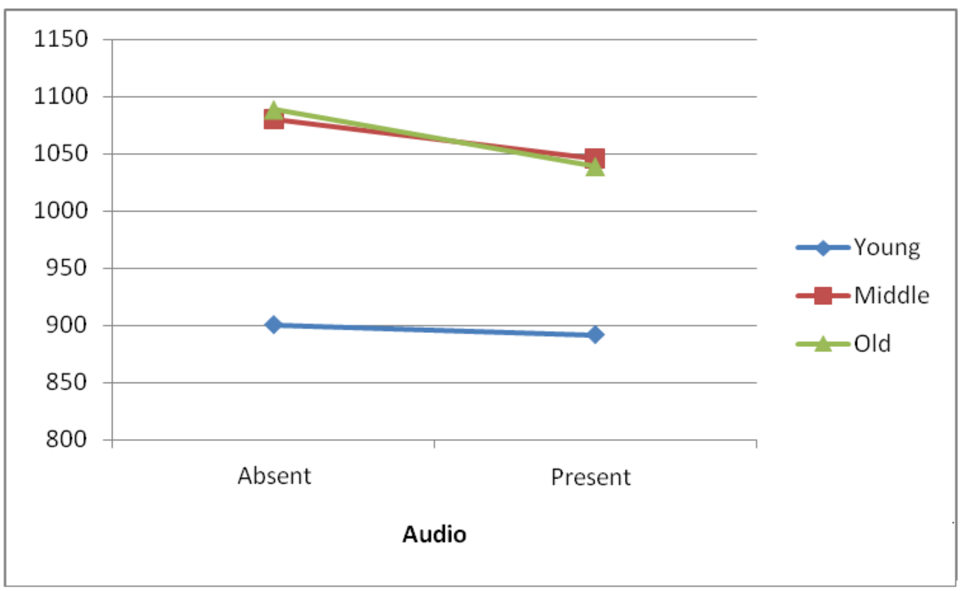

Figure 8. Significant interaction between age and audio.

Target Size

Further analysis was conducted to see how target size affected TMT with the different modalities. Three separate 2 x 2 x 2 x 3 repeated measures general linear models were conducted, one for each target size (i.e., small, medium, large). Like previous repeated measures the within factors were tactile, audio, and visual with each having two levels (absent or present). The between subjects variable was age group at three levels (young, middle-aged, old). The distributions of the three separate tests were significantly non-normal so a Log_{10} transformation was done for all of the analyses. This normalized the data and further S-K normality tests were insignificant post transformation. The separate data sets also met the assumptions of sphericity based upon insignificant findings from Mauchly's tests of sphericity.

Small Targets

The initial repeated measures analysis examined TMT when small (1/8 of an inch) targets were present. A significant main effect was found for audio feedback, $F(1,79) = 33.486$, $p < .001$, Figure 9. The conditions in which audio was present (M = 1157.4 ms) had significantly lower TMT in comparison to those conditions in which audio was absent (M = 1200.4 ms). There was a significant main effect found for tactile feedback, $F(1, 79) = 5.374$, $p = .011$, Figure 10. When tactile feedback was present (M = 1171.9 ms) participants had significantly lower THT in comparison to conditions in which the tactile feedback was missing (M = 1186 ms). The inclusion of visual cues did not significantly affect TMT; while tactile and audio both decreased TMT.

A significant two-way interaction was found between audio and tactile feedback, $F(1,79) = 14.574$, $p < .001$, Figure 11. The inclusion of tactile and audio feedback decreased TMT when they were both present; however when audio is present without tactile cues the TMT is lower than when tactile feedback is also present. In effect, the inclusion of audio with tactile lowers

TMT when compared to tactile alone; while the presence of tactile with audio increases TMT when compared to audio alone.

A significant two-way interaction was also found between visual and tactile cues, $F(1, 79) = 4.002$, $p = .002$, Figure 12. The presence of tactile without visual cues resulted in lower TMT when compared to when both tactile and visual cues were present. The pairing of visual or tactile cues increased TMT in comparison to when they were presented without each other.

A significant three-way interaction was found between visual, tactile, and audio cues, $F(1, 79) = 6.654$, $p = .006$, Figure 13. The presence of audio cues with visual cues did not result in different TMT in comparison to when audio was present without visual cues. Essentially when audio is present, regardless if tactile cues are present or not, the addition of visual cues has no effect on the resulting TMT. The lowest TMT overall was when audio was present with or without visual feedback. The addition of tactile feedback increased TMT when paired with audio. In conclusion, pairing visual cues with audio or tactile cues will result in no change or an increase in TMT. Pairing tactile and audio cues together will result in higher TMT in comparison to having audio cues only.

In conclusion, the presence of audio cues or tactile cues will significantly lower TMT; while visual cues do not. When tactile cues are added to audio cues TMT will increase compared to when audio cues are present without tactile cues. The presence of audio cues without tactile cues will result in the lowest THT. Finally, the inclusion of visual cues when audio cues are present will result in no difference in TMT. These findings support the hypothesis that participants will have lower TMT when audio or tactile are present. Visual cues did not significantly affect TMT in a positive manner in most cases.

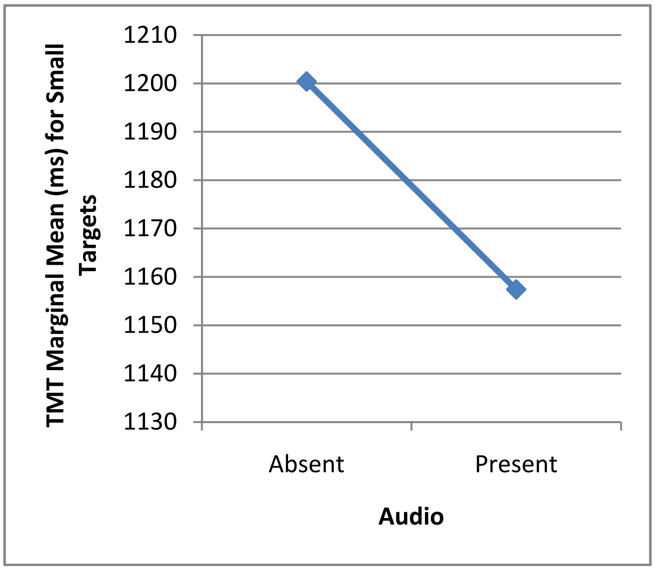

Figure 9. Audio main effect for TMT with small targets

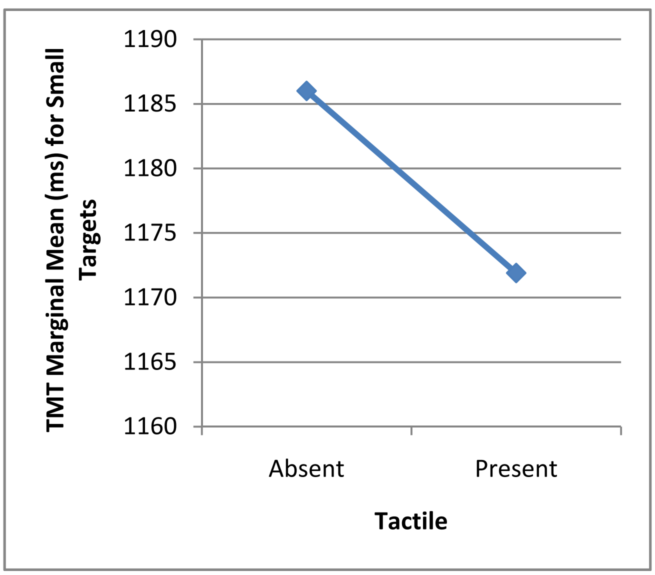

Figure 10. Tactile main effect for TMT and small targets

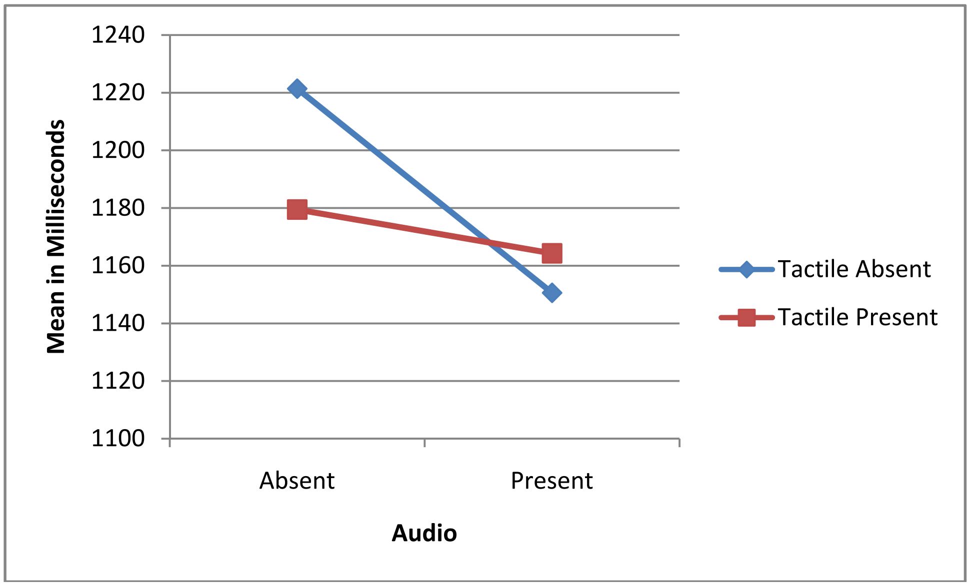

Figure 11. Tactile x Audio interaction for TMT with small targets

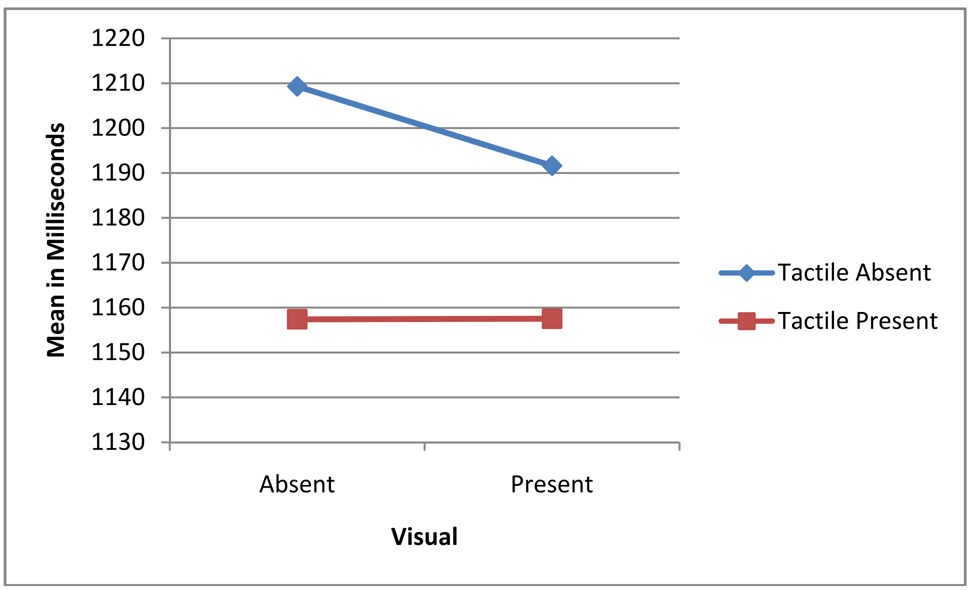

Figure 12. Tactile x Visual interaction for TMT with small targets

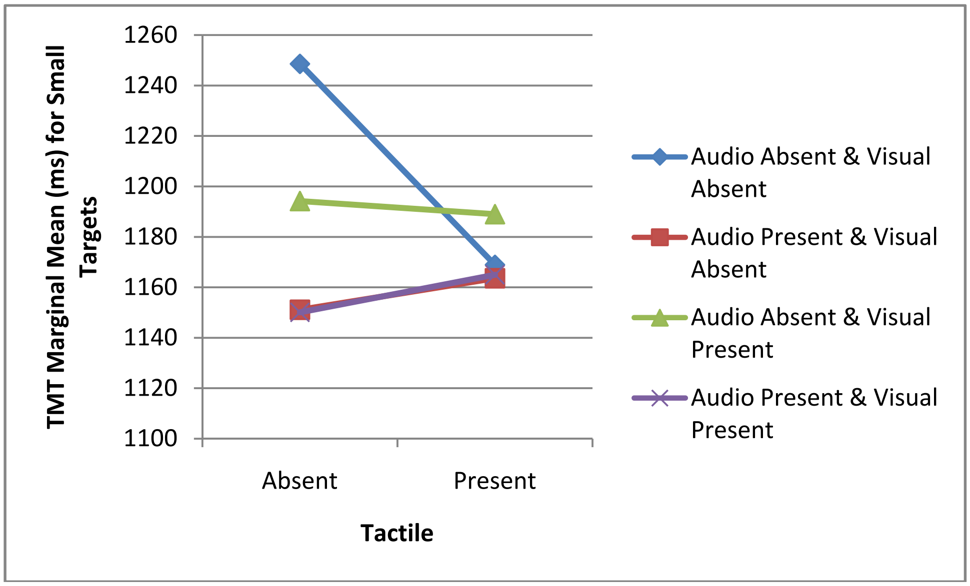

Figure 13. Tactile x Visual x Audio interaction for TMT with small targets

Medium Targets

A 2 x 2 x 2 x 3 repeated measures general linear model was conducted to examine the effects of feedback modality on TMT for medium (1/4 inch) sized targets. The same analysis that was conducted previously for the small targets was used; however the data included only the trials in which medium targets were presented.

There was a significant main affect for when audio was present ($F(1, 79) = 30.070$, $p < .001$), Figure 14. When audio was present the TMT was significantly lower when acquiring medium sized targets. A significant two way interaction was present between tactile and audio ($F(1, 79) = 8.106$, $p = .006$), Figure 15. The addition of tactile with audio increased TMT in comparison to when audio was present without tactile cues; however the inclusion of audio with tactile decreased TMT in comparison to when tactile was only present.

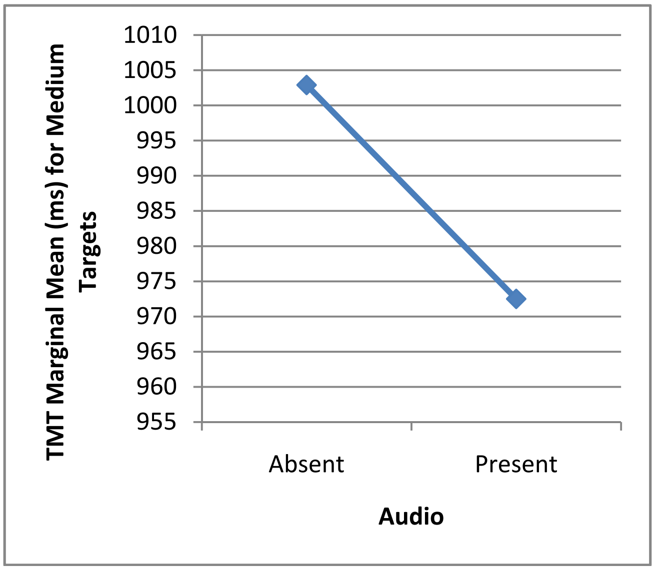

Figure 14. Audio main effect for TMT with medium targets

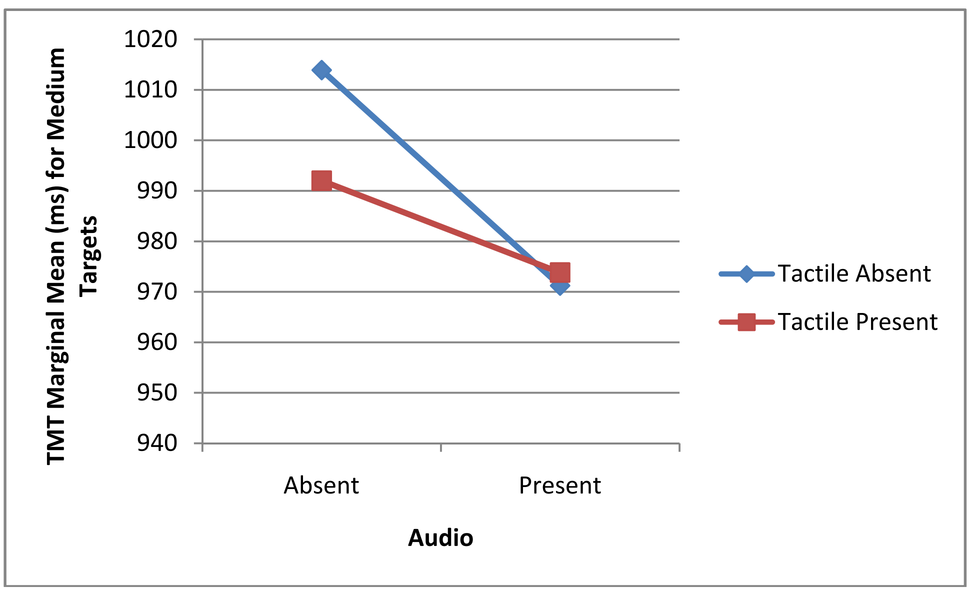

Figure 15. Tactile x Audio interaction for TMT with medium targets

Large Targets

A 2 x 2 x 2 x 3 repeated measures general linear model was used to examine the effect of feedback modality on TMT for large (1/2 inch) targets. Similar findings were found with the large targets as with the medium sized targets. There was a significant main effect on TMT for audio feedback ($F(1, 79) = 17.952$, $p < .001$), Figure 16. As was previously seen for other target sizes the presence of audio feedback significantly reduced TMT. A significant two-way interaction between audio and age group was also present for large targets ($F(2,79) = 4.49$, $p = .014$), Figure 17. The middle and older adults had lower TMT when audio was present; however the young adults had no change in TMT when audio was present or absent.

There was a significant main effect for the visual feedback ($F(1, 79) = 4.594$, $p = .035$), Figure 18. The presence of visual feedback increased TMT in comparison to when it was absent. There was also a significant two-way interaction between audio and tactile feedback ($F(1,79) = 13.461$, $p < .001$), Figure 19. As has been seen previously the presence of tactile feedback with audio feedback results in increased TMT than when audio is present without tactile feedback. However, the addition of audio to the tactile condition results in lower TMT than when tactile is present by itself.

A significant three-way interaction between tactile, audio, and age group was found ($F(2,79) = 4.505$, $p = .014$), Figure 20 & Figure 21. Once again the TMT of the young age group did not change when audio or tactile feedback was present. The middle and older adults had lower TMT when audio was present and tactile was not; however when tactile was added to audio the TMT increased in comparison to when audio was alone. Essentially, the presence of solely tactile or audio improves performance; however when tactile is added to audio the resulting TMT is higher than with audio alone.

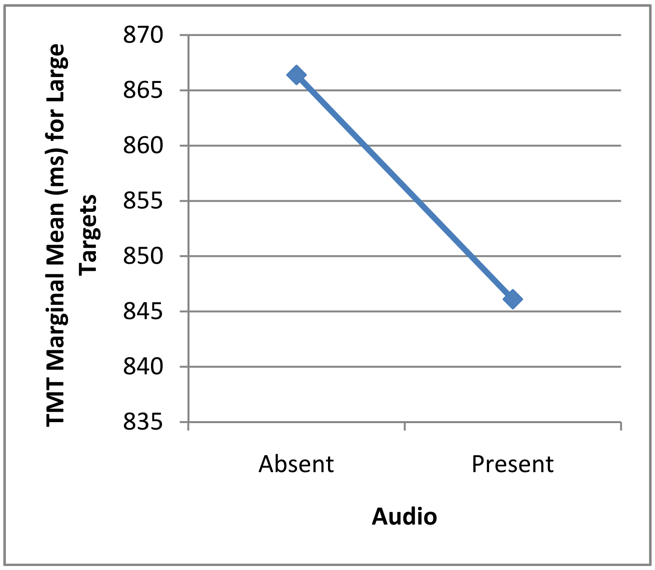

Figure 16. Audio main effect for TMT with large targets

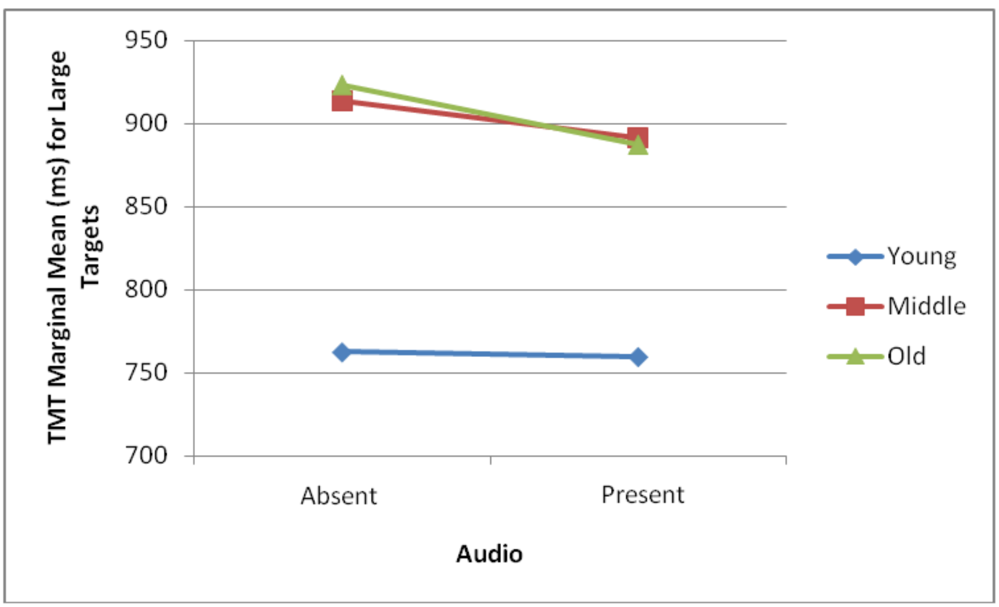

Figure 17. Significant interaction between age and audio for TMT and large targets

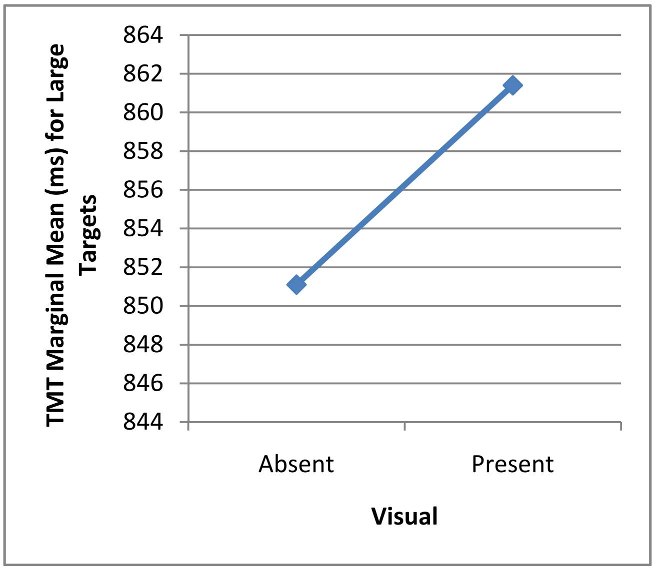

Figure 18. Visual main effect for TMT with large targets

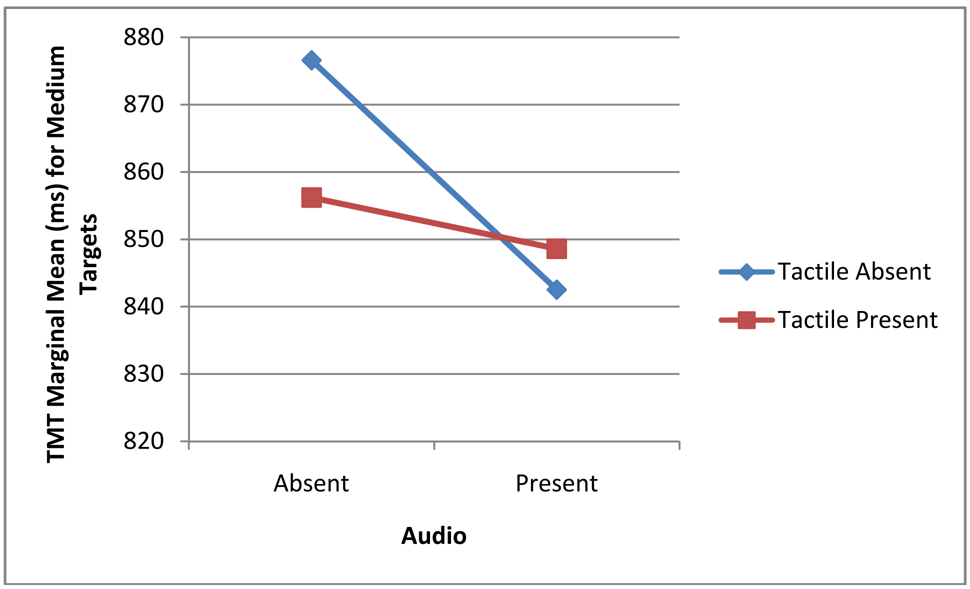

Figure 19. Tactile x Audio interaction for TMT with large targets

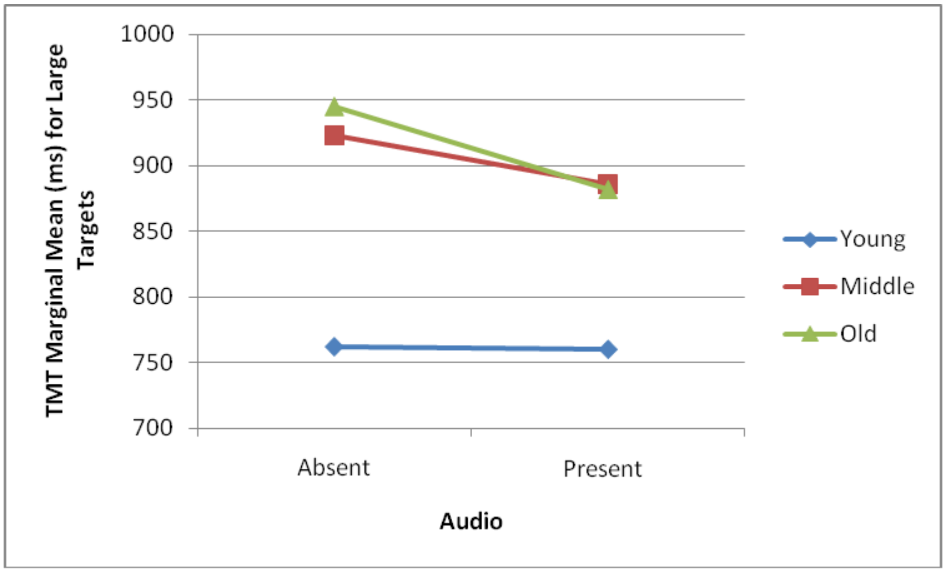

Figure 20. Tactile x Audio x Age Interaction for TMT with large targets with tactile absent

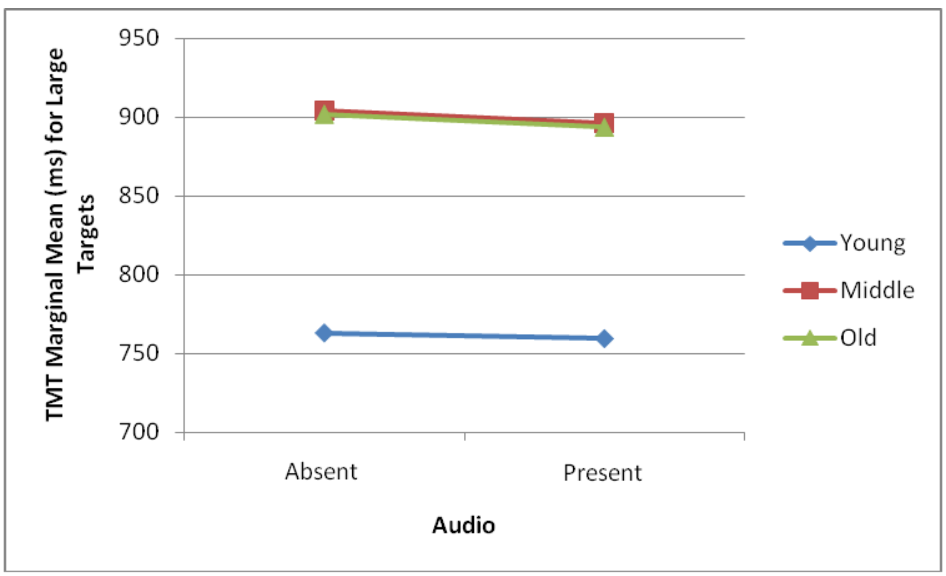

Figure 21. Tactile x Audio x Age Interaction for TMT with large targets with tactile present

Total Highlight Time

Total highlight time (THT) is the amount of time, in milliseconds, it takes for a participant to activate the target after the cursor has entered the target plain. It was predicted that participants would have significantly lower THT when any of the feedback modalities are present. In order to validate this claim a 2 x 2 x 2 x 3 repeated measures general linear model was conducted to determine if the presence of any of the modalities resulted in significantly lower THT. As with the previous repeated measures analyses the within factors were tactile, audio, and visual with each having two levels, present or absent. The between subjects variable was age at three levels (i.e., young, middle-aged, old). According to Mauchly's test of sphericity the assumptions of sphericity were met by this dataset. A one-tailed alpha level was used due to the directionality implied within the hypothesis. The raw data was not normally distributed so a Log_{10} transformation was done; however the figures and reported means are based upon the pre-transformation data.

There was a significant main affect between the age groups, $F(2,79) = 5.641$, $p = .005$. A Tukey HSD post-hoc analysis revealed that the young adults (M = 202.5 ms) were significantly faster than the middle-aged (M = 252.6 ms) and older adults (M = 241.8 ms) with significant alpha levels respectively at $p = .008$ and $p = .025$. There were no significant differences in THT found between the middle-aged and older adults. In terms of the feedback and age groups, there was a significant interaction between the tactile, visual, audio, and age groups, $F(2,79) = 3.22$, $p = .045$. There were no other significant interactions present for age group.

A significant main effect was found for the audio condition, $F(1,79) = 72.781$, $p < .001$. THT was lower when audio was present (M = 246 ms) in comparison to when it was absent (M = 218.6 ms). There was a significant main effect for the tactile condition, $F(1,79) = 45.863$, $p < .001$. When tactile feedback was included (M = 222.5 ms) the THT was lower than when it was absent (M = 242.1 ms). Lastly, there was a significant main effect for the visual condition, $F(1,79) = 20.091$, $p < .001$. The presence of visual cues (M = 226.3 ms) significantly reduced the THT in comparison to when it was absent (M = 238.3 ms).

A significant two-way interaction was found between audio and tactile cues, $F(1,79) = 33.226$, Figure 22. The conditions with audio and tactile cues present (i.e., audio+tactile and the trimodal condition) resulted in lower THT compared to the conditions in which they were both absent. The conditions when tactile is present without audio cues, such as tactile uni-modal and tactile+visual, do not achieve as low of a THT as when audio is present without tactile cues (i.e., audio, audio+visual). In effect, when tactile or audio are present the resulting THT will be lower; however audio is the stronger of the two cues in terms of lowering THT.

A significant two-way interaction was found between visual and audio cues, $F(1,79) = 6.222$, $p = .008$, Figure 23. The THT decreased when visual feedback or audio cues were present. Although when audio and visual were both present the lowest THT was observed for this interaction; however the change in THT between audio without visual and audio with visual was marginal. Audio once again was shown to be the larger manipulator of the resulting THT.

A significant two-way interaction was found between visual and tactile, $F(1,79) = 4.246$, $p = .022$, Figure 24. The presence of visual and/or tactile cues reduced THT. Conditions with both visual and tactile cues had the lowest THT; however the change in THT caused by the addition of visual cues to tactile was not as drastic as the change caused by adding tactile cues to visual cues. Conditions in which tactile cues are present and visual cues are not resulted in lower THT compared to when visual cues are present and tactile cues are absent. This interaction shows that tactile cues are more influential to reducing THT in comparison to visual cues.

A significant three-way interaction was present between visual, tactile and audio cues, $F(1,79) = 6.315$, $p = .007$, Figure 25. This significant interaction shows evidence that there is an additive affect when comparing between the uni-modal, bi-modal, and tri-modal conditions. As the cues were combined in the bimodal or trimodal conditions the resulting THTs were often lower than the uni-modal conditions. The visual+audio+tactile condition resulted in the lowest THT. Audio feedback influenced the THT the most, with it lowering THTs more with its presence in comparison to visual or tactile cues.

These results provide ample evidence in support of the hypothesis that feedback will significantly lower the THT. Although all of the feedback modalities decreased THT these results show that audio feedback was the strongest positive influence on THT followed by tactile and then visual. It is also apparent that combining cues will reduce THT, with a combination of visual+audio+tactile cues resulting in the overall lowest THT.

It was also hypothesized that participants would have lower THT during the tactile uni-modal condition in comparison to the visual uni-modal condition. A paired-samples t-test was used to determine if tactile feedback significantly reduced THT under what was observed during the visual uni-modal condition. On average, participants were significantly faster during the tactile condition (M = 230 ms) in comparison to the visual condition ($M = 247$, $t(81) = 3.76$, $p < .001$, $r = .81$). As expected these findings show that tactile feedback will significantly lower the amount of time necessary to click on the target after highlighting it in comparison to the visual feedback condition.

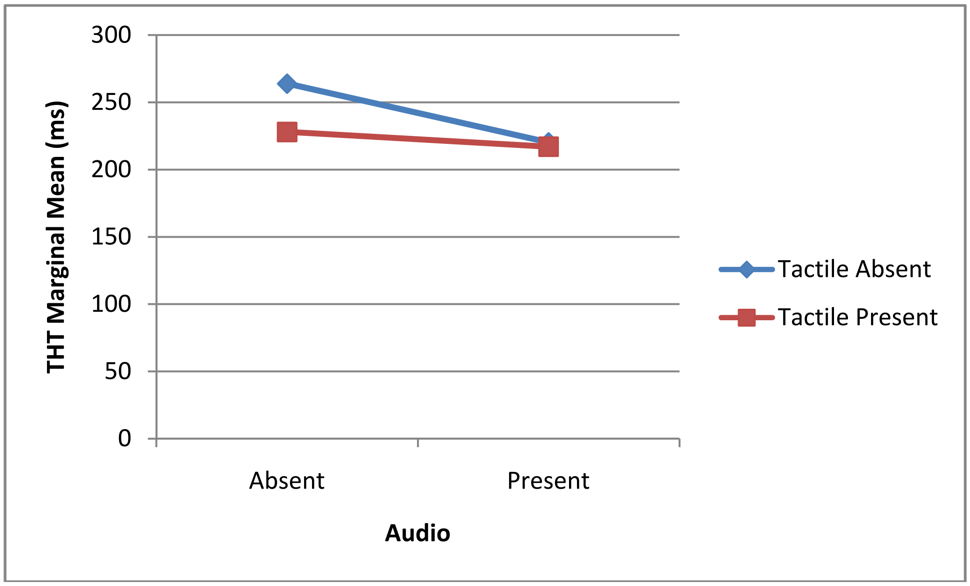

Figure 22. Significant two-way interaction between audio and tactile feedback for THT

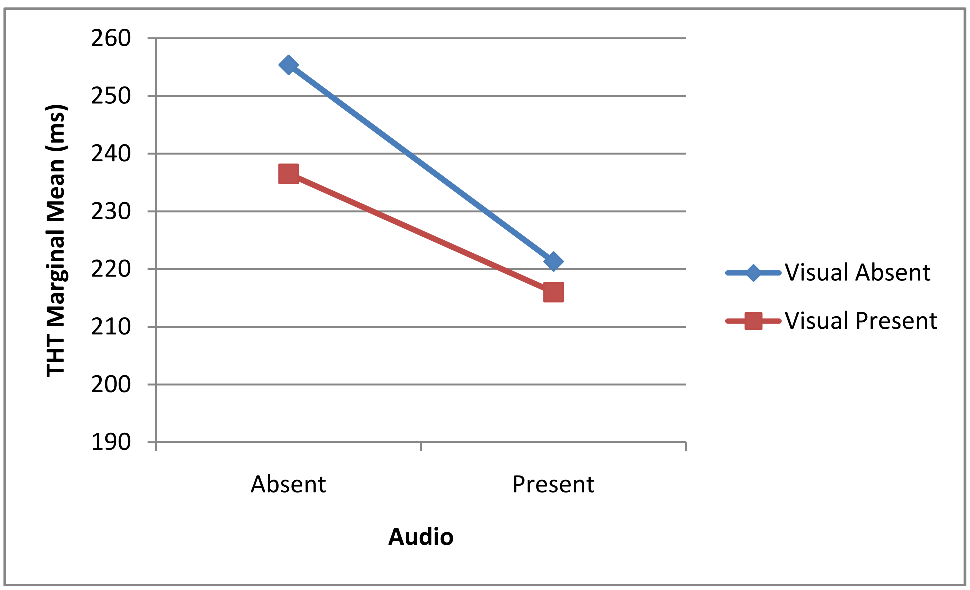

Figure 23. Significant two-way interaction between audio and visual feedback for THT

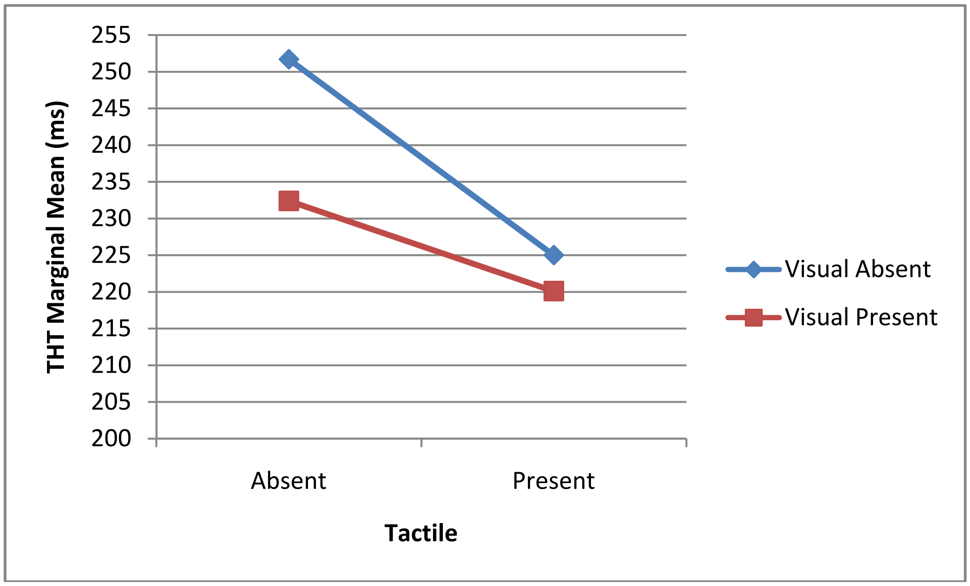

Figure 24. Significant two-way interaction between tactile and visual feedback for THT

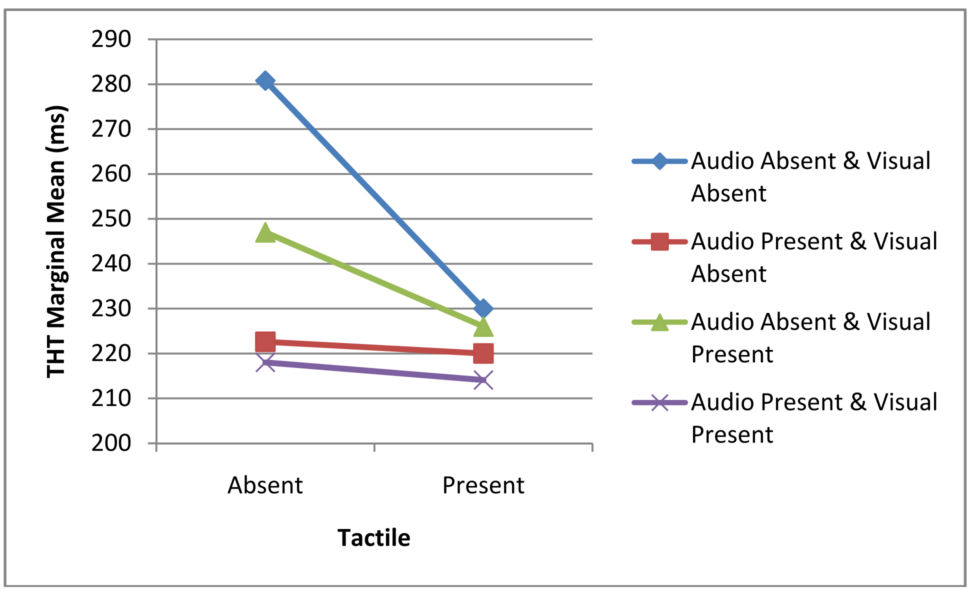

Figure 25. Significant three-way interaction between audio, tactile, and visual feedback for THT

Slip Errors

A slip error is defined as the number of times the cursor breaks the plain of the target but left it prior to successfully completing the trial. It is important to understand that for a slip error to be counted the trial must have ended in a successful hit of the target. It was hypothesized that participants would have a lower number of slip errors when a feedback modality was present. In addition, it was also predicted that participants would have a lower number of slip errors when tactile feedback or auditory feedback is present in bi-modal conditions. A Friedman's ANOVA, a non-parametric test, was used to validate these hypotheses. An initial analysis of the data showed that a normal distribution was not present for the raw slip error data. An attempt was made to transform the data via a Log_{10} transformation; however an S-K test of normality showed that the transformed data was still not a normal distribution. Due to the non-normal distribution a non-parametric test was chosen for the analysis.

The Friedman's ANOVA was used to determine if there was a significant difference in the number of slip errors between the different feedback conditions. The within subject variable was feedback condition with 8 levels, each representing a feedback condition. The results of the Friedman's ANOVA revealed a significant difference in the number of slip errors committed between the conditions, ($\chi^2(7) = 39.759$, $p < .001$).

A Wilcoxon test was used for additional post hoc analyses. The post hoc analyses were limited to comparing the number of slip errors for each uni-modal condition to the no-feedback condition. Additionally we compared the visual+audio condition and visual+tactile condition to the visual uni-modal condition in order to determine if the addition of visual or tactile feedback significantly lowered the number of slip errors. The total number of post-hoc analyses was limited to five in order to reduce the possibility of a Type I error. In order to further avoid the possibility of a Type I error a Bonferroni correction was used, which required a finding to have an alpha level below .01 in order for it to be considered significant.

The Wilcox signed ranks test revealed that not having any feedback (*Mdn* = 14) significantly increased the number of slip errors compared to the visual condition (*Mdn* = 11), $z = -4.084$, $p < .001$, $r = -.16$. The number of slip errors was also decreased when comparing the audio (*Mdn* = 10) condition to the no feedback condition, $z = -4.146$, $p < .001$, $r = -.16$. Finally, tactile feedback (*Mdn* = 11) also significantly reduced the number of slip errors in comparison to the no feedback condition, $z = -3.265$, $p = .001$, $r = -.13$. No significant differences were observed between the visual unimodal feedback conditions and the visual+tactile or visual+audio. These findings support the hypothesis that feedback will significantly lower the number of slip errors when it is present; however the results do not show any significant reductions in the number of slip errors when tactile or audio feedback is present in bi-modal situations.

Misses

A miss was defined as a trial that ended with a mouse activation outside of the target. It should be noted that trials that resulted in a miss were re-administered for each of the feedback conditions. In order to determine if the feedback modality had any effect on the occurrence of misses a Friedman's ANOVA was conducted. A Kolmgorov-Smirnov test of normality showed that all feedback conditions were significantly non-normal. Due to the non-normal distribution of the data a Friedman's ANOVA was employed for this analysis. The within subject variable was feedback with 8 separate levels that each represented one of the feedback conditions.

The analysis showed that the number of misses was significantly based upon which feedback modality was present (χ^2 (7) = 98.275, $p < .001$). A Wilcoxon test was used for further post hoc analyses. The post hoc analysis was limited to comparing each uni-modal condition to the no-feedback condition in order to see if the number of misses changed when feedback was added. Additionally we compared the visual, audio, and tactile conditions to each other to determine if there are significant differences between the feedback modalities. The number of post-hoc analyses was limited to six in order to reduce the possibility of a Type I error. A Bonferroni correction was used which resulted in an alpha level of .008 as the significant criterion.

No significant findings were found for the number of misses between the no feedback condition (*Mdn* = 2) and visual feedback condition (*Mdn* = 3). The tactile condition (*Mdn* = 5) resulted in a significantly higher number of errors in comparison to the no feedback condition, $z = -4.881$, $p < .001$, $r = -.19$. The audio condition (*Mdn* = 4.5) also resulted in a significant higher number of errors in comparison to the no feedback condition, $z = -5.028$, $p < .001$, $r = -.20$. From these findings it appears that visual feedback does not influence the number of misses committed; however the inclusion of audio or tactile feedback significantly increases the number of misses.

The visual feedback resulted in a significantly lower number of misses in comparison to the tactile feedback ($z = -4.398$, $p < .001$, $r = -.17$) and the audio feedback condition, $z = -3.263$, $p = .001$, $r = -.13$. Tactile and audio feedback did not significantly differ in the number of misses that were committed. Overall, having no feedback or visual feedback appears to result in the lowest number of misses. When comparing between the uni-modal conditions the visual feedback resulted in fewer misses, while the tactile and audio did not differ from each other.

Workload

The NASA-TLX was used to measure the subjective workload experienced from each of the feedback conditions. The NASA-TLX was administered after each feedback condition, so each condition had a corresponding workload score. Workload is quantified as the calculated NASA-TLX score for each of the feedback conditions. It was hypothesized that participants will have significantly lower workload when a feedback modality is present. To highlight the effects of feedback on subjective workload a 2 x 2 x 2 x 3 repeated measures general linear model was employed. As was conducted previously the audio, tactile, and visual cues were the within subject variables, with each having 2 levels, present or absent. Age group was the between subject variable and had 3 levels (i.e., young, middle-age, and old). The raw data was normally distributed so no transformation was necessary for this analysis. Due to the proposed directionality within the hypothesis a one-tailed alpha level was employed for this analysis. Additionally sphericity was assumed due to insignificant findings of the Mauchly's test of sphericity.

A significant main effect was found for audio, $F(1,79) = 6.828$, $p = .006$. When audio cues were present the level of workload increased ($M = 46.592$) in comparison to when audio was absent from the task ($M = 44.676$). There was also a significant main effect found for tactile cues, $F(1,79) = 3.562$, $p = .032$. As was found with the audio cues, when tactile cues were present the workload was significantly higher ($M = 46.284$) in comparison to when tactile cues were absent ($M = 44.985$). There were no significant differences in workload for age group or among the other feedback conditions.

The results of this analysis do not support the proposed hypothesis that the presence of feedback will significantly lower workload. On the contrary, when audio or tactile were present the level of subjective workload actually increased. These findings suggest that in general the addition of feedback cues do not have an effect on workload, except in cases in which audio or tactile cues may be present.

Effort

The NASA-TLX is comprised of 6 factors that include: mental demand, physical demand, temporal demand, performance, effort, and frustration. Each of these scales have a 1 to 100 continuous scale, with 1 being low and 100 being high. It was hypothesized that the older age group would have lower perceived effort when feedback was present. A 2 (Tactile) x 2 (Audio) x 2 (Visual) x 3 (Age) repeated measures general linear model was used to examine the relationships between age, feedback and the resulting effort scores.

A significant main effect was found for audio, $F(1,79) = 7.417$, $p = .008$. When audio was present the effort scores significantly increased ($M = 34.3$) in comparison to when audio was not available ($M = 30.8$). A significant 2-way interaction was found between tactile and visual feedback, $F(1, 79) = 4.135$, $p = .045$, Figure 26. It was found that visual cues without tactile cues had significantly lower effort than tactile feedback only; however when tactile feedback was added to visual cues the amount of effort significantly increased over the levels present when tactile or visual were presented without each other. No other significant findings were present.

These results do not support the prediction that older adults will have lower effort during feedback conditions. However, these findings showed evidence that audio increased effort and that the addition of tactile feedback to visual feedback will also significantly increase effort.

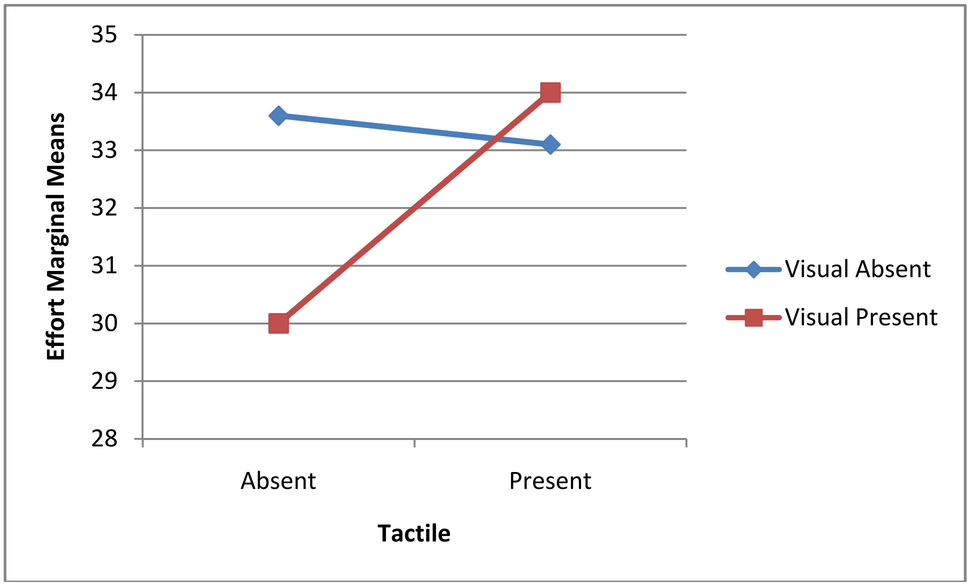

Figure 26. Visual x Tactile two-way interaction for effort

Annoyance

The version of the NASA-TLX given during this study was appended with an additional annoyance factor that was not calculated into the final workload score. In order to determine if there was an effect for feedback or age on the levels of annoyance a 2 (tactile) x 2 (audio) x 2 (visual) x 3 (age) repeated measures analysis was conducted.

A significant main effect was found for the audio modality ($F(1,79) = 19.922$, $p < .001$). When audio feedback was present ($M = 31.4$) the levels of annoyance were significantly higher in comparison to when it was absent ($M = 23.4$). A significant main effect was also present for tactile feedback ($F(1,79) = 4.119$, $p = .046$). When tactile feedback was present ($M = 28.7$) the levels of annoyance significantly increased over when it was absent ($M = 26$). A significant two-way interaction was observed between tactile and audio feedback ($F(1,79) = 5.044$, p = .027), Figure 27. The level of annoyance when audio is present with tactile or when audio is present without tactile is higher than conditions in which tactile is present without audio. This provides evidence that audio is the predominant annoyance factor and will result in the highest levels of annoyance.

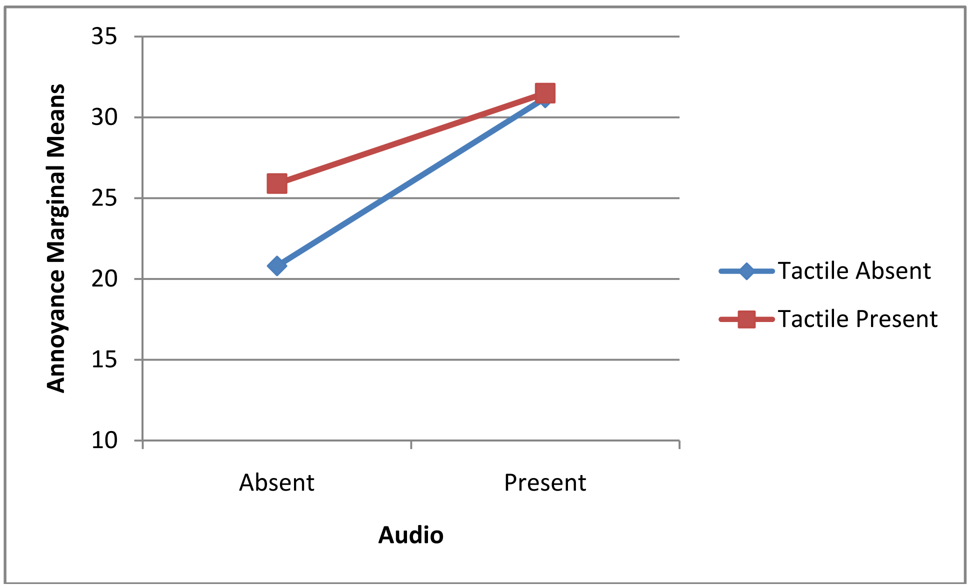

Figure 27. Audio x Tactile two-way interaction for annoyance

Index of Performance

The index of performance (IP) is based upon the performance metric outlined within Fitt's Law. The IP is calculated by dividing the index of difficulty by the TMT for each trial. Based upon Fitt's Law the index of difficulty is dependent upon the target size and amplitude for each trial. The IP is averaged within each feedback condition, resulting in each participant having 8 IP scores, one for each feedback condition.

It was predicted that the young adults would have a significantly higher IP for all of the conditions in comparison to the older group. In order to validate this hypothesis an 8 x 3 one-way ANOVA was conducted to determine if the younger age group had a considerably higher IP than the older age group in all of the feedback conditions present. The within subject variable was feedback at 8 levels, with each level representing a feedback condition. The between subject variable was age group at 3 levels: young, middle-aged and old.

A significant main effect between the age groups was found for all of the feedback conditions. Table 8 and Table 9 list the results of this analysis along with the means for each of the age groups. A Tukey HSD post hoc analysis found that the young adults had a significantly higher IP than the older adults in all of the conditions. Additionally the young adults had a significantly higher IP than the middle-aged adults for the audio, no feedback, visual, and visual+tactile; while no significant performance differences were found between middle-aged and older adults, please see Figure 28. These findings support the hypothesis that young adults would have significantly higher IP than the older adults in all of the conditions. These results further provide evidence for the generalized slowing that occurs as one ages.

Table 8. One-way ANOVA results age groups and index of performance

Feedback	F-Statistic	Significance
No Feedback	$F(2,79) = 9.284$	$p < .001$
Audio	$F(2,79) = 8.607$	$p < .001$
Visual	$F(2,79) = 8.416$	$p < .001$
Tactile	$F(2, 79) = 4.191$	$p = .019$
Audio+Tactile	$F(2, 79) = 4.387$	$p = .016$
Visual+Tactile	$F(2, 79) = 7.537$	$p = .001$
Audio+Visual	$F(2,79) = 6.047$	$p = .004$
Visual+Audio+Tactile	$F(2, 79) = 4.407$	$p = .015$

Table 9. Index of performance means for the age groups

	Young Adults		Middle Adults		Older Adults	
Feedback	Mean	SD	Mean	SD	Mean	SD
No Feedback	4.6	.56	4	.55	3.8	.94
Audio	4.8	.66	4.2	.66	4.1	.57
Visual	4.6	.61	4	.61	3.9	.91
Tactile	4.6	.64	4.2	.61	4.0	.94
Audio+Tactile	4.7	.54	4.2	.68	4.1	.57
Visual+Tactile	4.7	.66	4.1	.65	4.0	.94
Audio+Visual	4.7	.62	4.3	.62	4.0	.89
Visual+Audio+Tactile	4.7	.56	4.3	.64	4.1	.97

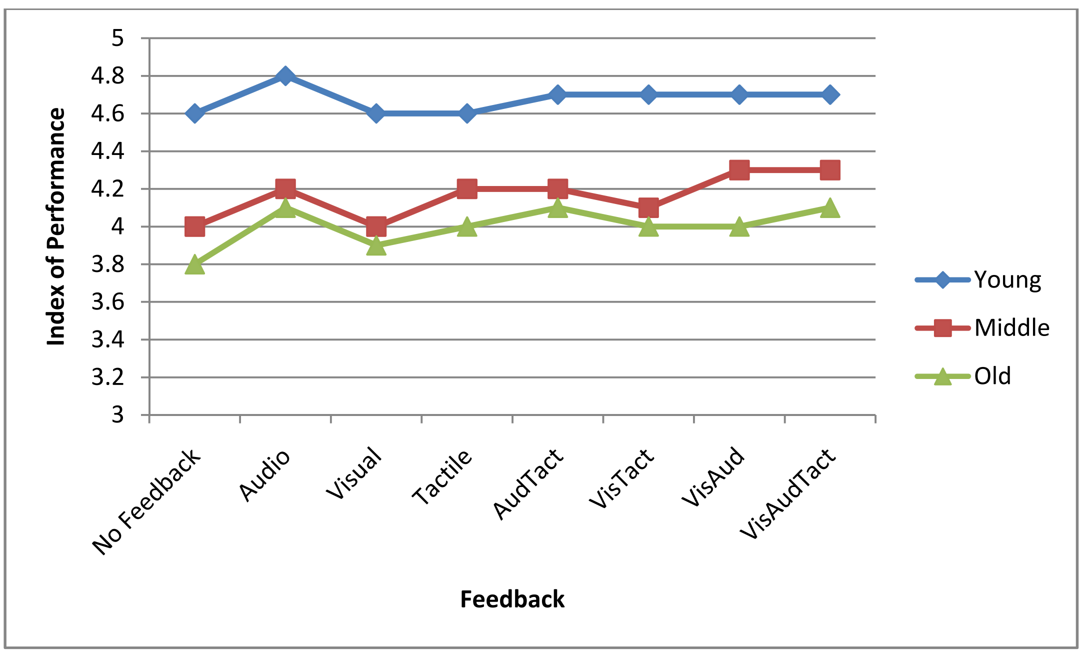

Figure 28. Average IP for the young and old age groups for each feedback condition

Additionally it was hypothesized that the difference in IP from the feedback conditions to the no-feedback condition would be significantly larger in a positive way for the older adults compared to the young adults. In order to test this hypothesis a 7 x 2 one-way ANOVA was conducted to determine if the change in performance between the no feedback condition and the feedback conditions resulted in the older adults having a significantly larger change in performance in comparison to the younger adults. The within subject variable was the change in performance when comparing each feedback condition to the no feedback condition, which resulted in 7 levels. The change in performance was quantified by subtracting the IP of the no feedback condition from each of the feedback conditions. For example, the visual IP minus the no feedback IP would equal the change in IP when visual cues were present. These calculations resulted in 7 separate variables that represented the change in performance when each modality or combinations of modalities were present. The between subject variable was age group, which had two levels: young and old. It should also be noted that this data set had a normal distribution so a Log_{10} transformation was not necessary.

All of the alpha levels are based upon a one-tailed analysis due to the proposed directionality within the hypothesis. Significant findings were present between the age groups and the change in IP when tactile feedback was present, $F(1, 53) = 4.805$, $p = .017$. The change in IP when tactile was present was significantly higher for the older adults ($M = .23$) in comparison to the young adults ($M = .02$). A significant main effect was found for the change in IP when audio+tactile feedback was present, $F(1, 53) = 5.067$, $p = .015$. The older adults had a much larger improvement in IP ($M = .29$) when audio and tactile feedback were present compared to the young adults ($M = .1$). There was a significant main affect for the change in IP for the visual+audio+tactile feedback condition, $F(1, 53) = 4.130$, $p = .024$. The older adults had a larger increase in performance (M = .27) during the trimodal condition compared to the young adults (M = .07). No other significant differences were found between the age groups.

The results of this analysis partially support the hypothesis that older adults will make larger gains in performance when feedback is present. During the tactile, audio+tactile, and visual+audio+tactile conditions the older adults did have significantly larger changes in performance in comparison to the young adults. However, for all other conditions both age groups had similar changes in performance. These results show that feedback will have a greater effect on the performance of older adults in some cases; however it cannot be universally assumed that all modality cues will significantly increase performance of older adults more so than their younger counterparts.

Finally, it was hypothesized that the difference in IP from the bi-modal feedback conditions to the uni-modal feedback condition would be significantly larger for the older adults compared to young adults. A one-way 6 x 2 ANOVA was conducted to see if the older adults had significantly larger increases in performance from the uni-modal to the bi-modal feedback conditions. In order to quantify the changes in performance all of the differences between each possible uni-modal and bi-modal condition was calculated. In total there were six possible changes that were calculated, these differences included: visual+tactile – visual, visual+tactile – tactile, visual+audio – audio, visual+audio – visual, audio+tactile – audio, and audio+tactile – tactile. The data was normally distributed so a Log_{10} transformation was not made. The within subject variables were the six computed changes in IP and the within subject variable was age group.

This analysis resulted in no significant findings. There were no differences in the changes in performance between the older and younger age groups when looking at the difference between uni-modal and bi-modal feedback conditions. These findings do not support the hypothesis. It should be noted that a change in performance may be present; but this change was not significantly different between the age groups.

Feedback Preference

After participants had experienced all of the different feedback conditions, they were asked to rank the 8 conditions from favorite to least favorite. Currently, there is not a lot known on what type of feedback is preferred when performing a mouse target acquisition task. This is a very important factor that is often overlooked. Due to the small performance differences these feedback conditions create, the acceptance of any of these feedback conditions is very important. If the users don't like the feedback the performance benefits that may be present could become a moot point. In order to understand if there is a preference for a certain type of feedback the an analysis of the feedback preference data was conducted. Other research has not previously examined feedback preference so no a priori predictions were made.

An 8 (feedback) x 3 (age) Kruskall-Wallis Test was employed to examine if there were any significant differences in preference between the age groups for each of the 8 feedback conditions. A non-parametric test was chosen because this analysis was based upon ranking data. The results of the analysis found that there were no significant differences in preference between the age groups for any of the feedback conditions. Based upon this data it can be assumed that as one ages preference in feedback modality does not significantly differ.

Due to there being no significant findings when examining preference based upon age, there was interest in examining how the preferences of the different feedback conditions compared across the entire group, not separating based upon age. An additional Kruskall-Wallis test that did not include age as a between subject variable showed that there was a significant difference in preference between the different modalities ($H(7) = 67.435$, $p < .001$). Figure 29 shows a box-plot of the different feedback conditions from this analysis. As demonstrated in the box-plot it appears that the visual feedback was generally more preferred than the other conditions.

In order to determine how the feedback conditions compared several Mann-Whitney tests were conducted. In order to avoid Type I errors the number of post-hoc comparisons were limited to 5. Each of the uni-modal (i.e., visual, audio, tactile) conditions was compared with the no-feedback condition to determine if there was a preference for one of these conditions over having nothing at all. Furthermore, due to the visual condition appearing to have ranked so well two further comparisons were conducted which compared the visual feedback condition to the audio and tactile conditions respectively. To avoid a Type I error a Bonferroni correction was made, which resulted in an alpha level of .01 being the criteria for significant results.

It was found that the visual feedback ($Mdn = 2.0$) was more preferred than the no-feedback condition ($Mdn = 3.5$), $U = 2509.5$, $p = .004$, $r = -.32$. There was no difference in preference between the no feedback conditions and the tactile or audio conditions. When comparing the preferred feedback method between visual and audio it was found that visual feedback was more preferred than the audio condition ($Mdn = 5.0$), $U = 1730.5$, $p < .001$, $r = .6$. The visual feedback was also found to be more highly preferred than tactile feedback (Mdn =

5.0), $U = 1649.0$, $p < .001$, $r = .63$. These findings show strong evidence that visual feedback is overall the most preferred among the tactile, audio, and the absence of feedback.

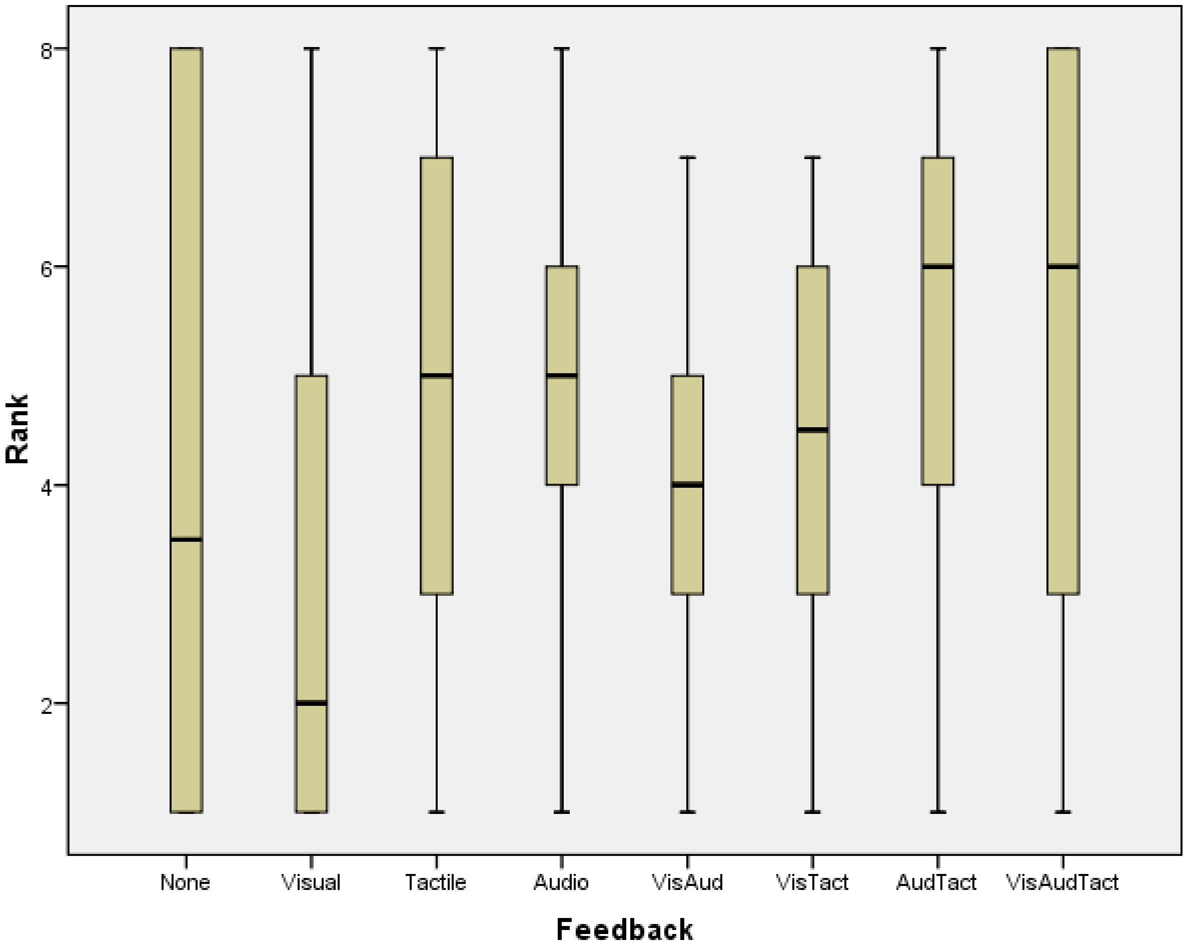

Figure 29. Box-plot of the preference rankings for each feedback condition

CHAPTER FIVE: DISCUSSION

The multiple measures taken in this study, TMT, THT, slip errors, misses, workload, and preference, all examine a specific portion of the task. The discussion will examine the findings for each of these measures separately and the overall findings of the study will be made in closing in the conclusions portion of the paper.

Total Movement Time

Previous studies (Akamatsu, 1995, Vitense et al. 2003, and Jacko et al., 2004) have found that the inclusion of additional feedback would reduce TMT and this research reinforced these previous findings. As was predicted the presence of feedback, specifically tactile and audio, significantly reduced TMT. Audio cues were shown to result in the lowest observed TMT, followed by tactile cues. The presence of visual cues did not significantly affect TMT, which is consistent with previous research (Jacko et al., 2004).

Interestingly, when tactile and audio cues were presented together TMT was increased compared to when audio was not paired with tactile cues. These findings may clarify inconsistent findings from previous studies that examined the effects of tactile feedback on performance. For instance, Gobel et al. (1995) found that tactile feedback significantly decreased TMT, while more recently Vitense et al. (2003) found that the presence of tactile feedback significantly increased TMT. The results of this study partially support both of these previous findings; although the relationship between the modalities is slightly more complex than what was outlined in the previous work. Tactile cues will reduce TMT; however including tactile cues with audio cues will actually increase TMT over what is observed with audio without tactile feedback. Essentially a bimodal advantage is not observed when tactile feedback is coupled with audio cues in comparison to when audio cues are presented alone; however the fact that the tactile cues did significantly reduce TMT, in most cases, supports the prediction that tactile feedback lowers TMT. Overall, as expected tactile feedback had a positive influence on TMT; however audio was shown to be the most beneficial to reducing TMT.

When factoring in how the target size affected TMT the findings were not dramatically different from the overall TMT as discussed previously. It was predicted that the presence of any of the feedback modalities would decrease TMT for small targets. Audio and tactile cues did significantly reduce TMT; however visual cues did not positively affect it for small targets. The same relationship that was previously observed between audio and tactile with the overall TMT was also found when acquiring small targets. Once again the audio feedback lowered TMT more so when not paired with tactile cues.

The pairing of visual cues with tactile or audio feedback increased TMT, which was similar to what was seen when tactile was presented with audio. When visual cues were presented with tactile cues the TMT was increased in comparison to when tactile cues were not presented with visual cues. Additionally, when tactile cues were presented with audio cues TMT increased in comparison to when audio was present without tactile. Overall across all of the target sizes audio cues significantly lowered TMT regardless of the size and the coupling of tactile or visual cues with audio either made no difference or increased TMT.

It was hoped that older adults would be able to acquire small targets more quickly with feedback; however there were no significant effects present for TMT and age for small or medium targets. Although there were no effects present for age with small or medium targets, it was found that audio significantly lowered TMT for older and middle-aged adults when acquiring large targets. The young adults did not benefit from having audio cues with large targets, which may be due to a ceiling effect. It is likely that the difficulty of acquiring large targets was very low for the young adults, thus feedback cues were not necessary to perform well on the task.

Regardless of target size, overall the audio cues had the greatest affect on performance for the older adults. Out of all of the modalities tested, the presence of audio cues significantly decreased TMT more so for the older adults than any of the other modalities. The positive influence on the performance of older adults due to audio feedback is reminiscent previous findings (Jacko et al., 2004). Audio cues made relatively small performance changes for the young adults; however when older adults completed trials with audio feedback the resulting TMT was significantly reduced. For all other modalities the age groups performed similarly.

It was expected that tactile feedback would affect TMT in a stronger manner than what was observed in this study. Overall it did reduce TMT significantly more so than visual cues or having no feedback at all; however it did not add any extra benefit between the age groups. Due to the high sensitivity and low degradation of tactile sensitivity in the finger tips that comes with age the tactile feedback was expected to decrease the TMT of older adults more so than what was observed. The lack of an effect for tactile feedback and age may be due to the delivery of the tactile cues. The cues may not have been delivered specifically to the finger tips for some of the computer users. Depending on how the user held the mouse, it could have been possible for the participants to not receive the tactile feedback fully to their finger tips. If the participant did not fully rest their finger tips on the mouse, the tactile feedback may have only been felt in the palm of their hands or whichever part of the hand that was resting on the mouse. Further research should take into account how the participants hold the mouse, if a portion of computer users do not rest their fingers fully on the mouse tactile feedback may not have the desired effects in older populations.

Total Highlight Time

Overall the young adults were significantly faster than the other age groups; however the feedbacks did not influence the THT of the age groups any differently. Overall the presence of any of the feedback conditions significantly lowered THT; however audio was once again the modality that improved performance the most. Previous research (Gobel etl al., 1995, Akamatsu et al., 1995, Vitense et al., 2003, Cockburn & Brewster, 2005) had previously found that tactile feedback often resulted in the lowest THT, which was not the case in this study. Tactile cues were significantly quicker in comparison to visual; however its presence did not result in the overall best performance. It is difficult to determine exactly why these results are different than previous findings; however it could have been due to the short length of the audio cue that was used for this study. Vitense et al. (2003) observed users waiting until the audio cue completed prior to making a response, if he had used a shorter audio clip, such as the .1 second clip from this study, his findings may have shown audio to be the better performer. Additionally, the delivery of the tactile feedback in this study may have been slower than the audio due to lag that accompanied processing the tactile cue. Although it is difficult to quantify, the computer setup had to convert an audio signal through second party software and then deliver it to the tactile mouse, which also took some time to spin up the motor. These delays, although seemingly insignificant on their own, may have been enough to slow down overall system responses when added together. With current technologies it may be difficult to avoid the delays that are inherent in using tactile feedback in a computer interface.

A bimodal advantage was observed for all of the feedback modalities, although audio accounted for the majority of the change in performance and adding visual or tactile to audio resulted in slight gains in performance. A truly additive effect was observed though and the tri-modal condition resulted in the overall lowest THT. Previous research (Akamatsu et al., 1995; Cockburn & Brewster, 2005) has found that a bi-modal advantage would not occur due to performance hitting a ceiling effect. The bimodal advantage for THT may be related to different aspects of the overall mouse task.

Target acquisition in this task can be broken down into two separate pieces: target approach and target activation. In the current study target approach may have more to do with the mental model of the task and less to do with the actual raw feedback cues that are delivered. This may explain why tactile and audio individually decreased TMT; however a strong bimodal advantage was not found for the two. If the two stages of the task were to be defined using the feed-forward and feedback theories as laid out in the work of Driver & Spence (2001) the differences in performance can be theorized. Since previous research (Vroomen & de Gelder, 2004) has shown strong evidence for both of these theories it may be postulated that the method of modality processing is dependent upon the sensations that are currently available. For example, since the target approach does not include significant modality cues, each of the sensory systems may be working autonomously and at a higher level processing, so a mental model of the task may be influencing a person's action. When the cursor enters the target the extra modalities are given and the task at this point is a purely stimulus-response task. If using the feedback theory of modality processing the sensory modalities communicates with each other prior to any higher level processing thus a response can be made without any high level processing influencing that response. When breaking down the task into two separate pieces the target activation is less influenced by the mental model of a task and is purely a response to the modality stimulus, thus a bimodal advantage similar to previous research (Miller, 1982) is observed.

Slip Errors

It was hypothesized that due to the feedback creating a more salient target the task would be similar to a direct manipulation task, thus the number of slip errors would be reduced. The study found that having any of the feedback modalities present would result in a significantly lower number of slip errors; however, there were no significant differences dependent upon the type of modality used. Having feedback present clearly lowered the number of slip errors; but none of the modalities outperformed each other. Additionally, a bimodal advantage was not observed when assessing the number of slip errors committed. These findings provide evidence that having visual, audio, or tactile cues will create a target that will allow for a higher level of accuracy when initially approached.

Misses

Feedback influenced the number of misses that the participants made. The absence of any feedback and visual cues actually resulted in the lowest number of misses; while audio and tactile had the most misses. The fact that the presence of visual cues or no feedback had resulted in a significantly lower number of misses, yet also resulted in the highest TMT and THT, shows evidence of a speed accuracy trade-off. Previous studies have also found similar findings; however none of them have been able to offer a reasonable rationale for these results.

Although, audio and tactile feedback both decreased TMT and THT, it is likely that a speed accuracy trade-off occurred. Both of these conditions resulted in a significantly higher number of misses in comparison to having no feedback or visual feedback present. So as performance increased the number of misses increased as well for the tactile and audio modalities. Previous research (Akamatsu & MacKenzie, 1996 & Cockburn & Brewster, 2005) has also shown evidence of a speed accuracy trade-off occurring with audio and tactile feedback. Akamatsu and MacKenzie hypothesized that the higher number of misses during tactile feedback conditions were due to a muscle response triggered by the tactile feedback that cannot be reversed even if the cursor is no longer in the target. If this was the case it would be believed that more slip errors would be observed for the tactile or audio conditions when a miss occurred in comparison to what may be seen during the no feedback condition. Through an analysis of the data it was found that approximately 62% of the trials that resulted in a miss also had a slip error present. The percentage of slip errors for trials ending in a miss across all of the feedback conditions only had a range of 4% (i.e., 60% to 64%). This likely does not back up Akamatsu & MacKenzie's assumption that participants could not reverse their response even after the cursor was no longer in the target.

These findings raise the question as to what is actually affecting the overall performance and reaction times. Is it the actual modalities used, or is it the user perception of how they should be performing? For example, since audio cues had lower reaction times and accuracy it can be argued that the targeting behavior may have been different. Participants may have falsely felt that they could achieve better performance with audio, so they attempted to do the task faster. Based upon the results of the study, it is unknown why participants performed the task differently when these feedback cues were present; however further research examining this relationship should be explored.

Workload & Feedback Preference

It was predicted that participants would have significantly lower workload when feedback is present. The findings of this study are actually opposite of what was expected. It was believed the inclusion of feedback would make the task easier to accomplish and less effort would be necessary to accurately complete the task. On the contrary, the inclusion of audio or tactile cues actually increased the level of workload. The visual cues did not result in significantly higher workload over having no feedback at all. It is difficult to explain why the workload would be higher when tactile or audio modalities are included. Additionally, the audio and tactile cues increased the effort required to complete the task. Effort increased even more when tactile was added to visual cues. In effect, when visual and tactile were added together the amount of effort necessary to complete the task was significantly higher than when either of them were present in a uni-modal condition.

Due to the higher reliance on extra sensory information that is evident in older adults, it was hypothesized that the tasks with extra feedback cues would result in significantly lower effort for the older adults. The results of the study showed that the age groups did not differ in their effort. As a whole these workload findings were disappointing; however there may be an explanation. It is likely that the target acquisition task itself, was just too easy. On average the NASA-TLX workload scores were in the low 40s; thus it can be assumed that the task was not mentally demanding which would result in the feedback not being useful. Future examination of the change in workload due to modality cues should likely use a more difficult task that requires a higher demand on visual perception. This may result in the extra modalities being more useful to the overall task.

An annoyance factor was included with this version of the NASA-TLX. This factor was added to ensure that the feedback cues did not significantly increase the levels of annoyance. It was found that both tactile and audio were significantly more annoying to participants. Although visual feedback did not have the overall best TMT or THT it did have lower workload and lower levels of annoyance in comparison to tactile or audio.

Participants were also asked for their preference between each of the feedback conditions. The modalities showed a correlation between level of workload and preferred modality. The most highly preferred modality was the visual cues; which also had the lowest workload and annoyance levels of the modalities tested.

These findings may be related to the dominance of visual perception over the other sensory systems. Colavita, (1974) found that when comparing the reaction times between visual and audio cues, the presence of visual cues often dictated reaction times. There was such a strong visual dominance that sometimes participants never even realized that audio cues were given with the visual cues. The previous findings that show a strong tendency for visual dominance may explain why the visual cues had lower workload in comparison to the other modalities. People use visual cues as the primary cues when determining a response, the addition of tactile or audio may have acted as a distracter resulting in a slightly higher amount of workload in order to perceive the ongoing task.

Index of Performance

Significant differences between the age groups were found for IP. As predicted and seen previously with the THT data, the young age group had a significantly higher IP than the older age group for all of the feedback conditions presented. These findings were to be expected simply because of the generalized slowing phenomenon. Although these findings are likely due to the slowing that becomes present as one ages prior experience should also be considered when examining these findings. The young adults in this sample spent considerably more hours per week on the PC in comparison to the older adults. On average the young adults spent 10 hours more per week on the PC than older computer users. Interestingly the middle-age group did not differ significantly from the older age group in terms of performance, although the middle-aged group spent a similar amount of time on the PC as the young age group per week. Although there was a conscious effort to recruit only experienced computer users, these differences may be a characteristic of the each of the age populations and would likely prove difficult to completely control.

The difference in performance between the age groups was to be expected and was not very surprising. The more interesting findings were the changes in performance between the age groups based upon the feedback conditions. Previous findings (Laurenti 2005; Cienkowski & Carney, 2002; Thompson & Mallou, 2004) suggested that older adults make better use of extra sensory information than young adults, it was predicted that the change in performance between each of the uni-modal feedback conditions (i.e., visual, audio, and tactile) and the no feedback condition would be significantly greater for the older adults. The findings of this study partially support this concept. There were significant changes in performance present between the age groups; however this was not the case for all of the modality cues.

The older adults had significantly larger changes in performance compared to the young age group when tactile feedback was present. With the exception of the visual+tactile condition, all other conditions with tactile feedback (i.e., tactile, tactile+audio, and visual+tactile+audio) resulted in a greater change in performance for the older group than the young group. This change in the performance of older adults is likely due to two factors. First it has been shown that the sensitivity to tactile feedback does not drop off as dramatically as other perceptions as one ages, especially when sensing tactile feedback in your finger tips (Stuart et al., 2003). Second, tactile feedback has a very quick signal to response time (Nelson et al., 1990). The combination of these two factors can explain the larger changes present in the older group whenever tactile feedback is present. The fact that the visual and audio feedback conditions did not create the high levels of change that was predicted is likely due to the sensory degradation that becomes evident as one becomes older. These findings show promise for the implementation of tactile cues into computer systems that may be used by older adults.

It was also predicted that the change between uni-modal conditions and bi-modal conditions would be greater for the older age group as well. There were no significant differences found in change in performance from the uni-modal to the bi-modal conditions for the young or old age groups. It is likely that the addition of extra-sensory cues does not necessarily result in an additive effect for the older age groups. Considering that the significant changes were observed for the older adults when tactile was present, it can be assumed that tactile feedback was the primary factor that drove the changes in performance.

CHAPTER SIX: CONCLUSIONS

Key Findings

The primary purpose of this study was to examine the effects of multimodal feedback on the performance of computer users, specifically older adults. Audio cues tended to have the largest positive effect on performance, with it significantly lowering overall TMT and THT more so than the other modalities. Additionally, audio was the only cue to continually influence the TMT regardless of target size. While the visual and tactile conditions did not influence TMT beyond small targets, the audio cues continued to have a positive influence during the acquisition of medium and large targets as well. The older adults were especially able to make use of the audio cues more than the other age groups when acquiring larger targets.

The tactile modality also significantly influenced performance in a positive manner; however to a lesser extent in comparison to the audio cues. The most exciting findings concerning tactile cues were that when present they made significantly larger positive changes in the performance of older adults in comparison to the young adults. These findings are exciting and validate some of the recommendations for including tactile feedback into systems in which older adults use. Additionally, as was expected the presence of visual cues did not have as strong of an effect on overall performance in comparison to the other modalities.

Although at face value it can be determined that additional feedback will increase performance, there are some contrasting findings that make it difficult to assume with certainty that the modalities used in this study should be applied to other systems. Although, audio and tactile feedback both decreased TMT and THT, it is likely that a speed accuracy trade-off occurred. Both the audio and tactile conditions resulted in a significantly higher number of misses in comparison to having no feedback or visual feedback present. So as performance increased the number of misses increased as well for the tactile and audio modalities. These findings raise the question as to what is actually affecting the overall performance and reaction times. Is it the actual modalities used, or is it the user perception of how they should be performing? For example, since audio cues had lower overall reaction times and lower accuracy it can be argued that the targeting behavior may have been different. Participants may have falsely felt that they could achieve better performance with audio or tactile, so they attempted to do the task faster. Based upon the results and methodology of the study, it is difficult to determine with any certainty why participants performed the task differently when these feedback cues were present.

It seems unlikely that the participants felt that they were performing better with tactile or audio feedback. A closer look at the performance factor within the NASA-TLX shows that the perceived performance was actually lower for the audio and tactile condition in comparison to visual cues or no cues at all. So, the participants felt they were performing worse when tactile or audio was present and accuracy was lower; however their reaction times and THT were reduced when they were present. It is unclear on why the participants were behaving in this way. If it was to be believed that the participants were overconfident in their abilities when audio or tactile cues were present we would expect to see perceived performance to be equal to or higher than having no feedback; but this is just not the case. Further work in this area should be completed to understand what is influencing participants to adjust their speed and accuracy when audio or tactile cues are present.

To further contrast the positive findings of this study, it was found that conditions in which tactile or audio cues were present were the least preferred by participants. Participants as a whole preferred no feedback or visual cues only. The high levels of annoyance towards tactile and audio cues may be relevant to the much lower preference to these modalities. Additionally, if the participants were cognizant of their lower accuracy with these two modalities, it may have also influenced their preferences.

There were some differences between the modalities that, although unlikely, cannot be ruled out as being a determining factor in performance and preference. The delivery of the modalities was fundamentally different. The tactile and audio cues were discrete feedback being only .1 second in length and delivered only when the mouse cursor initially hit the target. Conversely, the visual cue was a continuous feedback cue. When the mouse cursor was touching the target the visual feedback changed the actual state of the target, so continuous feedback of the task was given. Previous research in this area has not made the distinction between continuous or discrete feedback; however this is an avenue that should be explored in future research of this type.

Relevance & Contributions

Theoretical Implications

Previous studies have not examined the effects of feedback and age on the performance of a mouse based target acquisition task at a fundamental level. Previous studies (Vintense, 2003, Jacko et al., 2004) have looked at how extra modalities effect older adult performance; however the methodologies consisted of tasks that were applied to the computer human interface (i.e., drag and drop files) and did not look at how feedback affected performance at the most basic level of a computer mouse interaction. This study employed a methodology that is based upon a Fitt's task that examines the mouse target acquisition task at a fundamental level and additionally has previously been found to be relevant to HCI tasks (MacKenzie, 1992). Additionally, these findings can be attributed to a larger number of mouse tasks in comparison to a more specific mouse task, such as a drag and drop task. The outcomes of this study do support findings outside of the HCI realm that extra-sensory information will improve the performance in older adults more so than the young adults. Results such as these have been hinted upon in the work by Laurenti et al. (2004); however these findings further solidify evidence of the benefits inherent in extra modalities to older adults when working with a computer interface.

As exciting as the results found concerning the effect of multi-modal feedback on age are; the greater implications of the study come in the speed accuracy trade-offs that become apparent when tactile or audio cues are present. Previous studies have also shown evidence of a higher level of misses occurring when tactile cues are present; however this study has shown that this higher instance of misses is not likely due to a reflexive response to the feedback as implied by previous authors. When considering the increased performance in time-based metrics and the lower accuracy present with audio or tactile cues it becomes evident that a behavioral effect on how a person performs the task may be influencing the outcome of the performance more so than the feedback itself. Previous studies have not brought to light this possible relationship and it highlights an area in which future studies should be done. A better understanding of how people think additional feedback cues may affect performance prior to actually performing the task may shed some light on the underlying psychological benefits that people may think are present.

Practical Implications

This study has supported and provided additional evidence that audio and tactile cues are not preferred by computer users and are found to be annoying. These are important findings to be considered prior to any audio or tactile cues being applied in any type of user interface. The idea that any feedback is better than nothing may not always hold true if the feedback is found to be distracting, annoying, or simply not liked, as was found in this study with audio and tactile cues.

Additionally, due to the contrasting findings involving the measured performance and feedback preference it is currently not recommended that a novel sensory feedback, such as tactile, is integrated into a computer mouse interaction. Further research must be conducted concerning the basis of the speed-accuracy trade-off as well as the overall preference for these modalities prior to a suggested implementation. It is with great hope that continuation of this research will aid in the development of a computer user interface that integrates the benefits that have been shown to be evident for the older adults while also creating a more appealing interface for the entire computer user population as a whole. There is great potential for this work to change the face of computer interactions for a multitude of applications in the home, public spaces, or the workplace.

Limitations & Future Directions

This study has found significant results that add to the body of HCI research; however there were some limitations with the methodology. First and foremost, the fact that the visual cues were a continuous feedback while the audio and visual cues were discrete needs to be addressed. Rather than confound the results by age effects, it may be beneficial to look at the effect of continuous versus discrete feedback for a mouse task regardless of age. It would be beneficial to understand if the style of feedback (i.e., continuous or discrete) changes the performance, workload and preference during the mouse task. In order to examine this relationship it would be recommended to perform a study using the same Fitt's task; however feedback duration should be controlled, so each feedback modality will be presented as a .1 second duration discrete cue as well as a continuous cue. The findings of a study of this type could show evidence of why the visual feedback was preferred and may provide evidence that explains the speed accuracy trade-offs that were present for the audio and tactile modalities.

Additionally, due to the speed-accuracy trade-offs shown for the audio and tactile cues, future studies may not want to separate the feedback cues into separate sessions, with each trial consisting of the same feedback. In order to remove the possibility of feedback pre-determining performance, it may be beneficial to randomize the feedback present for each trial within a session. This would remove expectations and may show a direct link to how each feedback affects performance without any preconceptions altering performance.

Due to the positive results that have been found with the performance increases found with the addition of tactile feedback for older adults, further research should be done in this area. It may be beneficial to separate this analysis out from the realm of HCI and perform a similar task that examines this relationship using a signal to response paradigm, as used by Colavita (1974) or Miller (1982). Due to the computer experience effects that may be present between the age groups one cannot say with certainty that the differences found between the age groups can be attributed to these feedback modalities alone. Stripping the study down to a basic level may provide stronger evidence for the use of tactile cues with older adults.

Alternatively, a study examining the performance in which the participants of varying ages are given a more complex task with feedback modalities may yield interesting findings. The workload scores in this study were relatively low, so the easiness of the task may have made the extra feedback less useful for completing the task in comparison to a more mentally demanding task. Paring the different feedback modalities with a more complex task may find greater benefits of the different feedback modalities to older populations.

Finally, effective width should be added to future versions of the instrumentation. This addition would provide a corrective measure for individual differences that may be present regarding speed and accuracy balancing. The ability to remove these potential differences from this task would strengthen the relationship between Fitt's law and the data that is ultimately collected.

APPENDIX A: PARTICIPANTS WITH ERROR RATES ABOVE 1.5 IQR

Young Males								
Participant #	None	Visual	Audio	Tactile	VisAud	VisTact	AudTact	VisAudTact
11			X					
14			X		X			
27						X		
Young Females								
8	X						X	
12	X							
21							X	
Middle Males								
59	X							
64	X	X				X		X
68					X			
Middle Females								
73	X		X	X	X	X	X	X
63		X						
Older Males								
89			X	X	X			
77	X	X		X				
66	X							X
Older Females								
41								X
65		X						

APPENDIX B: INFORMED CONSENT

Researchers at the University of Central Florida (UCF) study many topics. To do this we need the help of people who agree to take part in a research study. You are being invited to take part in a research study which will include about 90 people. You can ask questions about the research. You can read this form and agree to take part right now, or take the form home with you to study before you decide. You will be told if any new information is learned which may affect your willingness to continue taking part in this study. You have been asked to take part in this research study because you use a computer for at least 5 hours a week and have no physical limitations that may affect your performance when using a computer mouse. You must be 18 years of age or older to be included in the research study and sign this form.

The person doing this research is Brian Oakley a graduate student from the UCF psychology department. Because the researcher is a graduate student he is being guided by Janan Smither, a UCF faculty supervisor in the Psychology department.

Study title: The Effects of Multi-Modal Feedback & Age on a Mouse Pointing Task

Purpose of the research study: The purpose of this research study is to assess how people respond to different types of sensory feedback, such as sound, auditory, or vibrations, when using a computer mouse.

What you will be asked to do in the study: In this study you will be asked to perform a large number of target acquisition tasks using a mouse. These target acquisition tasks are similar to the actions that would normally be taken when seeking and clicking on an icon on a personal computer. You will also be asked to provide some information concerning your previous computer experience. During the course of the study you will also be asked to fill out additional questionnaires that will be used to help us understand your experience during the tasks.

Voluntary participation: You should take part in this study only because you want to. There is no penalty for not taking part, and you will not lose any benefits. You have the right to stop participation at any time. Just tell the researcher that you want to stop. You will be told if any new information is learned which may affect your willingness to continue taking part in this study.

Location: This study will be held in a Psychology Department lab located on the Orlando campus of the University of Central Florida.

Time required: You will only need to participate in a single session that will take approximately 90 minutes to complete.

Audio or video taping: This study does not include any audio or video taping.

Risks: There are no expected risks for taking part in this study. You do not have to answer every question or complete every task. You will not lose any benefits if you skip questions or tasks. You do not have to answer any questions that make you feel uncomfortable.

Benefits: As a research participant you will not benefit directly from this research, besides learning more about how research is conducted.

Compensation or payment: The session will take approximately 90 minutes to complete and for your time you will be given a choice between two compensations. Upon completion of the study session you will have the option of choosing 4 points of extra credit or a $20 gift card. If you are a UCF student and decide to withdraw participation, you will receive 1 point of extra credit. If you choose extra credit as your compensation it is your responsibility to know the psychology courses in which you may use it. Some psychology courses may handle extra credit differently so it is up to you to understand how and if it will be used in your class. If you are not currently a UCF student and withdraw from participation you will receive $10 cash.

Confidentiality: Your identity will be kept confidential. The researcher will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from the information you give, and these two things will be stored in different places, a locked file cabinet for any papers and a password protected computer for digital files.

Your information will be assigned a code number. The list connecting your name to this number will be kept on a password protected computer. When the study is done and the data have been analyzed, the list will be destroyed. Your information will be combined with information from other people who took part in this study. When the researcher writes about this study to share what was learned with other researchers, he will write about this combined information. Your name will not be used in any report, so people will not know how you answered or what you did.

Study contact for questions about the study or to report a problem: Brian Oakley, Graduate Student, Human Factors Program, Psychology Department, (407) 797-7460 or by e-mail at ucfstudy@gmail.com or Dr. Janan Smither, Graduate Advisor, Psychology Department at (407) 823-4344or by email at smither@ucf.edu.

IRB contact about your rights in the study or to report a complaint: Research at the University of Central Florida involving human participants is carried out under the oversight of the Institutional Review Board (UCF IRB). For information about the rights of people who take part in research, please contact: Institutional Review Board, University of Central Florida, Office of Research & Commercialization, 12201 Research Parkway, Suite 501, Orlando, FL 32826-3246 or by telephone at (407) 823-2901.

How to return this consent form to the researcher: You may print out this document and bring it with you to your scheduled session. If you are unable or unwilling to print out this document a copy will be given to you prior to beginning the session.

By signing this letter, you give me permission to report your responses anonymously in the final manuscript to be submitted to my faculty supervisor as part of my course work and may also be included in journal publications.

☐ I have read the procedure described above

☐ I voluntarily agree to take part in the procedure

☐ I am at least 18 years of age or older

______________________________	______________________________	_________
Signature of participant	Printed name of participant	Date

____	_____________
Principal Investigator	Date

APPENDIX C: PRE-TEST QUESTIONNAIRE

Background Information Questionnaire

Participant ID: ___________

General Information

1. What is your age? _______
2. What is your gender? Male Female
3. Which is your dominant hand? Left Right Ambidextrous
4. Regarding your hand grip, are you able to open car doors?

1	2	3	4
Without Any Difficulty	With Some Difficulty	With Much Difficulty	Unable To Do

5. Regarding your hand grip, are you able to open previously opened jars?

1	2	3	4
Without Any Difficulty	With Some Difficulty	With Much Difficulty	Unable To Do

6. Regarding your hand grip, are you able to turn faucets on and off?

1	2	3	4
Without Any Difficulty	With Some Difficulty	With Much Difficulty	Unable To Do

7. Are you physically able to use a PC mouse?

1	2	3	4
Without Any Difficulty	With Some Difficulty	With Much Difficulty	Unable To Do

8. How much pain have you experienced in your right hand in the past week: Place a single vertical mark through the line to indicate severity of the pain

No Pain — Severe Pain

9. How much physical pain have you experienced when using a computer mouse in the past week: Place a single vertical mark through the line to indicate severity of the pain

No Pain — Severe Pain

Computer Experience

1. On average, how many hours a week do you use a PC? _____ hours

2. How many years have you been using a PC? _____ years

3. How would you rate your level of computer experience? (Please circle one)
    a. Beginner
    b. Intermediate
    c. Expert

4. For what purposes do you primarily use your PC? (Please circle **all** that apply)
    a. Communication (i.e., E-mail, Instant Messaging, Video Chat)
    b. Accessing the Web
    c. Gaming
    d. Productivity (i.e., Word Processing, Spreadsheets)
    e. Other (Please fill in): ______________________
    f. Other (Please fill in): ______________________
    g. Other (Please fill in): ______________________

5. What is your primary pointing device? (Please circle one)
    a. Mouse
    b. Touch-Pad
    c. Trackball
    d. Pointing Stick (also often referred to as a Pointing Nub)
    e. Other (Please fill in): ______________________

APPENDIX D: FEEDBACK PREFERENCE QUESTIONNAIRE

Feedback Preference Questionnaire

Participant ID: ____________

<u>INSTRUCTIONS</u>: For each of the following questions please place a vertical mark on the scale that represents your feelings regarding the feedback modes you experienced during the study.

1. No Feedback

Really Disliked — Really Liked

2. Visual-Only

Really Disliked — Really Liked

3. Vibration-Only

Really Disliked — Really Liked

4. Audio-Only

Really Disliked — Really Liked

5. Visual+Audio

Really Disliked — Really Liked

6. Visual+Vibration

Really Disliked	Really Liked

7. Vibration+Audio

Really Disliked	Really Liked

8. Visual+Vibration+Audio

Really Disliked	Really Liked

Feedback Ranking

INSTRUCTIONS: For the following section I would like you to rank the feedback conditions **in order** from most favorite (1) to least favorite (8). Please double-check your rankings to ensure you have only used each number once.

___ No Feedback
___ Visual Feedback
___ Vibration Feedback
___ Audio Feedback
___ Visual+Audio Feedback
___ Visual+Vibration Feedback
___ Vibration+Audio Feedback
___ Visual+Vibration+Audio Feedback

APPENDIX E: NASA-TLX WORKLOAD MEASURE

<u>Workload Rating Sheet</u>

Participant ID: ___________ Session: ______________

<u>INSTRUCTIONS</u>: On each scale place a mark that best indicates your experience with the task.

MENTAL DEMAND:

Low High

PHYSICAL DEMAND:

Low High

TEMPORAL DEMAND:

Low High

EFFORT:

Low High

PERFORMANCE:

Poor Good

FRUSTRATION:

Low High

ANNOYANCE:

Low High

Pair-wise Comparison of Factors

INSTRUCTIONS: Circle the member of each pair that represents the more important contributor to workload for the task.

PHYSICAL DEMAND or MENTAL DEMAND

TEMPORAL DEMAND or MENTAL DEMAND

PERFORMANCE or MENTAL DEMAND

FRUSTRATION or MENTAL DEMAND

EFFORT or MENTAL DEMAND

TEMPORAL DEMAND or PHYSICAL DEMAND

PERFORMANCE or PHYSICAL DEMAND

FRUSTRATION or PHYSICAL DEMAND

EFFORT or PHYSICAL DEMAND

TEMPORAL DEMAND or PERFORMANCE

TEMPORAL DEMAND or FRUSTRATION

TEMPORAL DEMAND or EFFORT

PERFORMANCE or FRUSTRATION

PERFORMANCE or EFFORT

EFFORT or FRUSTRATION

APPENDIX F: DEBRIEFING FORM

The Effects of Multi-modal Feedback & Age on a Mouse Pointing Task

DEBRIEFING

The purpose of this study was to assess your performance when using a mouse with varying types of feedback modalities. All age groups will likely be observed to have higher performance when feedback is present; however previous research has shown that older adults will benefit more from this additional feedback. In addition to observing performance this study was also interested in your feelings about using these additional modes of feedback. The results of this study will have implications on future design decisions in human-computer interactions as well as provide strong research in the area of multi-modal feedback and computer mice.

Please do not discuss the specifics of this experiment with your peers as some of them may not have participated yet.

Thank you for your participation in this research. If you have any further questions regarding the experiment or your participation, please contact either of the following individuals.

Principal Investigator: Brian Oakley
E-mail: ucfstudy@gmail.com
Phone: 407-797-7460

Graduate Advisor: Janan Smither
E-mail: smither@ucf.edu
Phone: 407-823-5862

Address: Department of Psychology
Univ. of Central Florida
4000 Central Florida Blvd.
Orlando, FL 32816-1390

APPENDIX G: IRB APPROVAL LETTER

University of Central Florida

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Expedited Initial Review and Approval

From : **UCF Institutional Review Board**
FWA00000351, Exp. 5/07/10, IRB00001138

To : **Brian P. Oakley**

Date : **June 05, 2008**

IRB Number: **SBE-08-05673**

Study Title: **The effects of multi-modal feedback & age on a mouse pointing task**

Dear Researcher:

Your research protocol noted above was approved by **expedited** review by the UCF IRB Vice-chair on 5/30/2008. **The expiration date is 5/29/2009.** Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The category for which this study qualifies as expeditable research is as follows:

7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Also report any unanticipated problems or serious adverse events (within 5 working days). Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at http://iris.research.ucf.edu .

Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies. The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 06/05/2008 11:21:53 AM EDT

Joanne Muratori

IRB Coordinator

REFERENCES

Accot, J., & Zhai, S. (1997). Beyond Fitts Law: Model for trajectory-based HCI tasks. *Proceedings of CHI '97, Atlanta, GA, 295-302.*

Accot, J., & Zhai, S. (1999). Performance evaluation of input devices in trajectory-based tasks: An application of the Steering Law. *Proceedings of the SIGCHI conference on Human factors in computing systems: the CHI is the limit, Pittsburgh, PA, 466-472.*

Akamatsu, M., MacKenzie, I.S., & Hasbroucq, T. (1995). A comparison of tactile, auditory, and visual feedback in a pointing task using a mouse-type device. *Ergonomics. 38(4), 816-827.*

Akamatsu, M., & MacKenzie, I.S. (1996). Movement characteristics using a mouse with tactile and force feedback. *International Journal of Human-Computer Studies. 45, 483-493.*

Alais, D., & Burr, D. (2004). The ventriloquist effect results from near optimal bimodal integration. *Current Biology. 14, 257-262*.

Baldock, M., Mathias, J., McLean, A., & Berndt, A. (2006). Self-regulation of driving and its relationship to driving ability among older adults. *Accident Analysis & Prevention, 38(5), 1038-1045*.

Biocca, F., Inoue, Y., Lee, A., Polinsky, H., & Tang, A. (2002). Visual cues and virtual touch: Role of visual stimuli and intersensory integration in cross-modal haptic illusions and the sense of presence. *In F. Gouveia (Ed.), Proceedings of Presence 2002. Porto Portugal: Fernando Pessoa University.*

Birren, J. & Fisher, L. (1995). Aging and speed of behavior: Possible consequences for psychological functioning. *Annual Review of Psychology, 46, 329-353.*

Bohan, M., Thompson, S., Scarlett, D., & Chaparro, A. (2003). Gain and target size effects on cursor-positioning time with a mouse. *Proceedings of the Human Factors and Ergonomics Society 47th Annual Meeting, Denver, CO, 737-740.*

Brewster, S., Wright, P., & Edwards, A. (1994). 'The design and evaluation of an auditory-enhanced scrollbar. In Adelson, B., Dumais, S. & Olson, J. (Eds.), *Proceedings of ACM CHI'94(pp. 173-179).* ACM Press, Addison-Wesley.

Brewster, S.A. Keynote: Haptic Human-Computer Interaction*. In Proceedings of CHINZ 2003, Dunedin, NZ, 3-4.*

Campbell, C., Zhai, S., May, K., & Maglio, P. (1999). What you feel must be what you see: Adding tactile feedback to the trackpoint. *Proceedings of INTERACT '99 (pp. 383-390).* IOS Press.

Card, S., English, W., & Burr, B. (1978). Evaluation of mouse, rate-controlled isometric joystick, step keys, and text keys for text selection on a CRT. *Ergonomics. 21, 601-613.*

Casali, S. (1992). Cursor control device use by persons with physical disabilities: Implications for hardware and software design. *Proceedings of the Human Factors Society 36th Annual Meeting, Atlanta, GA, 311-315.*

Charness, N., Holley, P., Feddon, J., & Jastrzembski, T. (2004). Light pen use and practice minimize age and hand differences in pointing tasks. *Human Factors, 46, 373-384.*

Charness, N., Bosman, E.A., & Elliot, R.G. (1995). *Senior friendly input devices: Is the pen mightier than the mouse?* Paper presented at the 103rd Annual Convention of the American Psychological Association Meeting, New York, New York.

Charness, N., Schumann, C.E., & Boritz, G.A. (1992). Training older adults in word processing: Effects of age, training technique and computer anxiety. *International Journal of Aging and Technology, 5, 79-106.*

Chisnell, D., Lee, A., & Redish, J. (2004). *Designing web sites for older users: Comparing AARP's studies to earlier findings.* Retrieved August 1, 2006, from http://www.aarp.org/olderwiserwired/oww-features/Articles/a2004-03-03-comparison-studies.html

Cienkowski, K.M., & Carney, A.E. (2002). Auditory-visual speech perception and aging. *Ear Hear. 23(5), 439-449.*

Cockburn, A., & Brewster, S. (2005). Multimodal feedback for acquisition of small targets. *Ergonomics. 48(9), 1129-1150.*

Cohen, C. (2001). Guiding seniors. *Internet, 64(2), 50-53.*

Colavita, F. (1974). Human sensory dominance. *Perception & Psychophysics, 16, 409–412.*

Czaja, S.J., & Sharit, J. (1998). Ability-performance relationships as a function of age and task experience for a data entry task. *Journal of Experimental Psychology: Applied. 4, 332-351.*

Czaja, S., & Lee, C. (2003). Designing computer systems for older adults. In A. Sears & J.A., Jacko (Eds.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications: 2nd Edition* (pp. 413-427). CRC Press.

Demirbilek, O., & Demirkan, H.(2004). Universal product design involving elderly users: A participatory design model. *Applied Ergonomics. 35(4), 361-370.*

Dennerlein, J. & Yang, M. (2001). Haptic force-feedback devices for the office computer: Performance and musculoskeletal loading issues. *Human Factors. 43(2), 278-286.*

Diederich, A., & Colonius, H. (2004). Bimodal and trimodal multisensory enhancement: Effects of stimulus onset and intensity on reaction time. *Perception & Psychophysics. 66(8), 1388-1404.*

Driver, J. & Spence, C. (2000). Multisensory perception: Beyond modularity and convergence. *Current Biology. 10, R731-R735.*

Epps, B. (1986). Comparison of six cursor control devices based of Fitts' law models. *Proceedings of the 30th Annual Meeting of the Human Factors Society, Santa Monica, CA, 327-331.*

Fitts, P. (1954). The information capacity of the human motor system in controlling the amplitude of movement. *Journal of Experimental Psychology, 47, 381-391.*

Fox, S. (2004). *Older Americans and the internet*. Retrieved August 1, 2006, from https://pewinternet.org.

Fries, J., Spitz, P., & Young, D. (1982). The dimensions of health outcomes: the health assessment questionnaire, disability and painscales. *Journal of Rheumatology, 9, 789-793.*

Gobel, M., Luczak, H., Springer, J., Hedicke, V., & Rotting, M. (1995). Tactile feedback applied to computer mice. *International Journal of Human-Computer Interaction. 7(1), 1-24.*

Grady, C. (2000). Functional brain imaging and age-related changes in cognition. *Biological Psychology.54, 259-281.*

Groves, D., & Slack, T. (1994). Computers and their application to senior citizens therapy within a nursing home. *Journal of Instructional Psychology, 21(3), 221-227.*

Hedden, T., & Gabrieli, J. (2004). Insights into the ageing mind: A view from cognitive neuroscience. *Nature Reviews Neuroscience, 5(2), 87-96.*

Heuninckx, S., Wenderoth, N., Debaere, F., Peeters, R., & Swinnen, S. (2005). Neural basis of aging: The penetration of cognition into action control. *The Journal of Neuroscience. 25(29), 6787-6796.*

Hicks, L. & Birren, J. (1970). Aging, brain damage, and psychomotor slowing. *Psychological Bulletin, 74(6), 377-396.*

Hill, S., Iavecchia, H., Byers, J., Bittner, A., Zaklad, A., & Christ, R. (1992). Comparison of four subjective workload rating scales. *Human Factors, 34, 429-439.*

Hilz, M., Axelrod, F., Hermann, K., Haertl, U, Duetsch, M., & Neundorfer, B. (1998). Normative values of vibratory perception in 530 children, juveniles and adults aged 3-79 years. *Journal of the neurological sciences, 159- 219.*

Hutchinson, S., Kobayashi, M., Horkan, C., Pascual-Leone, A., Alexander, M., & Schlaug, G. (2002). Age-related differences in movement representation. *NeuroImage, 17, 1720-1728.*

Jacko, J, Dixon, M., Rosa, Jr., R., Scott, I., & Pappas, C. (1999). Visual profiles: A critical component of universal access. *Proceedings of CHI, Pittsburgh, PA, 330-337.*

Jacko, J., Emery, V.K., Edwards, P., Ashok, M., Barnard, L., Kongnakorn, T., Moloney, K., & Sainfort, F. (2004). The effects of multimodal feedback on older adults' task performance given varying levels of computer experience. *Behaviour & Information Technology. 23(4), 247-264.*

Karavidas, M., Lim, N., & Katsikas, S. (2005). The effects of computers on older adult users. *Computers in Human Behavior. 21, 697-711.*

Keyson, D. (1997). Dynamic cursor gain and tactual feedback in the capture of cursor movements. *Ergonomics. 40(12), 1287-1298.*

Kline, D.W., & Schieber, E.J. (1985). Vision and aging. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology and aging (pp. 296-331).* New York: Van Nostrand Reinhold.

Koncelik, J. (2003). The human factors of aging and the micro-environments: Personal surroundings, technology, and product development. In R. Scheidt & P. Windley (Eds.), *Physical environments and aging: Critical contributions of M. Powell Lawton to theory and practice* (pp. 117-134). New York: Haworth Press.

Kong, J., & Ren, X. (2006). Calculation of effective target width and its effects on pointing tasks. *IPSJ Digital Courier, 2, 235-237.*

Kyung, K., Kwon, D., & Yang, G. (2006). A novel interactive mouse system for holistic haptic display in a human-computer interface. *International Journal of Human-Computer Interaction. 20(3), 247-270.*

Laurienti, P., Burdette, J., Maldjian, J., & Wallace, M. (2006). Enhanced multisensory integration in older adults. *Neurobiolog of Aging. 27, 1155-1163.*

MacKenzie, I. (1992). Fitts' Law as a research and design tool in human-computer interaction. *Human-Computer Interaction, 7, 91-139.*

Mathews, G., Davies, D., Westerman, S., & Stammers, R. (2000). *Human Performance: Cognition, Stress and Individual Differences.* UK: Psychology Press.

McGurk, H., & MacDonald, J. (1976). Hearing lips and seeing voices. *Nature. 264, 746-748.*

Meyer, J. (2001). *Age: 2000*. (Census 2000 Brief. C2KBR/01-12), US Census Bureau, USA.

Miller, J. (1982). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology, 14, 247-279.*

Morrell, R.W., & Echt, K.V. (1996). Instructional design for older computer users: The influence of cognitive factors. In W.A. Rogers, A.D. Fisk, & N. Walker (Eds.), *Aging and skilled performance: Advances in theory and application* (pp. 241-265). Mahwah, NJ: Lawrence Erlbaum Associates.

Murata, A., & Iwase, H (2005). Usability of touch-panel interfaces for older adults. *Human Factors. 47(4), 767-776*

Nelson, R., McCandlish, C., & Douglas, V. (1990). Reaction times for hand movements made in response to visual versus vibratory cues. *Somatosensory and Motor Research, 7, 337-352.*

Oxley, J., Ihsen, E., Fildes, B., Charlton, J., & Day, R. (2005). Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. *Accident Analysis & Prevention, 37(5), 962-971.*

Patching, G. R., & Quinlan, P. T. (2002). Garner and congruence effects in the speeded classification of bimodal signals. *Journal of Experimental Psychology: Human Perception and Performance, 28, 755-775.*

Patching, G., & Quinlan, P. (2004). Cross-modal integration of simple auditory and visual events. *Perception & Psychophysics. 66(1), 131-140.*

Park, D. (1992). Applied cognitive aging research. In E.I. M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 444-494), Mahwah, NJ: Lawrence Erlbaum Associates.

Prohaska, T., Belansky, E., Belza, B., Buchner, D., Marshall, V., McTigue, K., Satariano, W., & Wilcox, S. (2006). Physical activity, public health, and aging: Critical issues and research priorities. *Journals of Gerontology: Series B: Psychological Sciences and Social Sciences, 61B(5), S267-S273.*

Rau, P., & Hsu, J. (2005). Interaction devices and web design for novice older users. *Educational Gerontology. 31, 19-40.*

Repperger, D., Phillips, C., & Chelette, T. (1995). A study on spatially induced "Virtual Force" with an information theoretic investigation on human performance. *IEEE Transactions on Systems, Man, and Cybernetics, 25(10), 1392-1404.*

Rogers, W., Fisk, A.D., McLaughlin, A., & Pak, R. (2005). Touch a screen or turn a knob: Choosing the best device for the job. *Journal of Human Factors, 47(2), 271-288.*

Rogers, W., & Fisk, A.D, (2000). Human factors, applied cognition, and aging. In E.I. M. Craik & T.A. Salthouse (Eds.), *The handbook of aging and cognition* (pp. 559-592). Mahwah, NJ: Lawrence Erlbaum Associates.

Ryan, E., Anas, A., & Friedman, D., (2006). Evaluations of older adult assertiveness in problematic clinical encounters. *Journal of Language and Social Psychology, 25(2), 129-145.*

Salthouse, T.A. (1985). Speed of behavior and its implication for cognition. In J.E. Birren & K.W. Schaie (Eds.), *Handbook of the psychology and aging* (pp. 400-426). New York: Van Nostrand Reinhold.

Sandfield, J., & Jensen, B. (2005). Effect of computer mouse gain and visual demand on mouse clicking performance and muscle activation in a young and elderly group of experienced computer users. *Applied Ergonomics. 36, 547-555.*

Seidler, R., & Stelmach, G. (1995). Reduction in sensorimotor control with age. *Quest, 47, 386-394.*

Sklar, A., & Sarter, N. (1999). Good vibrations: Tactile feedback in support of attention allocation and human-automation coordination in event-driven domains. *Human Factors. 41(4), 543-552*.

Smith, M., Sharit, J., & Czaja, S. (1999). Aging, Motor Control, and the Performance of Computer Mouse Tasks. *Human Factors. 41(3), 389-396.*

Stine, E., Wingfield, A., & Myers, S. (1990). Age differences in processing information from television news: The effects of bisensory augmentation. *Journal of Gerontology. 45, 1-8.*

Stuart, M., Turman, A., Shaw, J., Walsh, N., & Nguyen, V. (2003). Effects of aging on vibration detection thresholds at various body regions. *BMC Geriatrics. 3(1).*

Tabachnik, B., & Fidell, L. (1996). *Using multivariate statistics* (3rd ed.). New York: HarperCollins College Publishers.

Teeken, J., Adam, J., Paas, F., van Boxtel, M., Houx, P., & Jolles, J. (1996). Effects of age and gender on discrete and reciprocal aiming movements. *Psychology and Aging, 11(2), 195-198.*

Thompson, L.A., & Malloy, D. (2004). Attention resources and visible speech encoding in older and younger adults. *Experimental Aging Research. 30, 241-252.*

Viau, A., Najm, M., Chapman, E., & Levin, M. (2005). Effect of tactile feedback on movement speed and precision during work-related tasks using a computer mouse. *Human Factors. 47(4), 816-826.*

Van der Veer, G., & Melguizo, M.C. (2002). Mental Models. In A. Sears & J.A., Jacko (Eds.), *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies and Emerging Applications: 2nd Edition* (pp. 52-80). CRC Press.

Vitenset, H., Jacko, J., & Emery, V.K. (2003). Multimodal feedback: An assessment of performance and mental workload. *Ergonomics. 46(1), 68-87.*

Vroomen, J., & de Gelder, B. (2004). Perceptual effects of cross-modal stimulation: Ventriloquism and the freezing phenomenon. In G. Calvert, C. Spence, & B.E. Stein (Eds), *Handbook of multisensory processes* (pp. 1-23). MIT Press.

Welford, A. (1977). Serial reaction times, continuity of tasks, single-channel effects, and age. *Proceedings of the Sixth International Symposium on Attention and Performance, Stockholm, Sweden, 79-98.*

White, H., McConnell, E., Clipp, E., Bynum, L., Teague, C., & Navas, L. (1999). Surfing the net in later life: A review of the literature and pilot study of computer use and quality of life. *Journal of Applied Gerontology. 18(3), 358-378.*

White, H., McConnell, E., Branch, L., Sloane, R., Pieper, C., & Box, T. (2002). A randomized controlled trial of the psychosocial impact of providing Internet training access to older adults. *Aging and Mental Health, 6(3), 213-222.*

Wirthlin Worldwide Prepared for AARP. (2003). *Wired generations*. Retreived August 1, 2006, https://www.aarp.org/olderwiserwired/