The Partially Sighted Older Computer User

Assessing the Ease of Use of Two Input Devices

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Abstract

In a computer course, provided by the Royal Dutch Visio, some partially sighted older clients had difficulty operating a computer. Clients are taught to use a keyboard, which may be difficult to use for a number of older adults. Studies comparing input devices conclude that the touch screen results in the greatest task performance for older adults. However, existing research mainly compares older adults without visual impairments. An experiment was conducted which compared task performance of two input devices (keyboard and touch screen) in two age groups (younger and partially sighted older adults). Task execution times and errors were obtained in three computer tasks. The results indicate that the touch screen outperformed the keyboard in both age groups in simple point-and-tap interfaces. But, there are activities and controls that caused difficulties, e.g. entering text and using a scroll bar.

ACT-R, an influential cognitive architecture, was used to model task performance of the partially sighted older computer user to better understand the use of input devices. ACT-R parameters were updated to model the effects of age-related changes and visual impairments, which are not presently part of the architecture. Keyboard and touch screen models were developed which simulated task performance in a task from the experiment. Analyses revealed a good fit between the touch screen model and older adult data, although the keyboard model needs some more refinements.

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1. Introduction

We have a rapidly graying population and an increasingly technological society. In the western world the role of the computer is ever expending. The computer can be used to perform ever more daily activities a lot faster and easier. Some examples are online banking, using a program to do your tax return, online shopping and of course staying in contact with all of your friends and family using services like e-mail, Facebook and Skype.

Unfortunately, the older adult has difficulty using the computer and all of its complex functionalities (Morris, 1994) and is less likely to use technology compared to younger adults (Rogers & Fisk, 2010). Learning how to use a computer can be difficult. Especially for older adults who did not use computer technology during their working life and whose information processing abilities have diminished over time. Age-related differences in the use of technology can be attributed to products being too difficult to learn to use or because of psychological effects of ageing, like reduced perceptual abilities due to a visual impairment. However, this does not mean that older adults do not want to use new technology, such as the computer.

The Royal Dutch Visio, a centre of expertise for blind and partially sighted people, offers a computer course to its clients. The purpose of the computer course is to give partially sighted older adults the opportunity to continue to participate in society through computer and Internet use.

The computer course consists of a basic training in which clients learn to use a keyboard, Microsoft Windows, Microsoft Word, Internet Explorer and Windows Mail. The contents of the course are shaped according to the preferences and potential of the client by removing or adding course material. The course is part of a rehabilitation program that serves the blind or visually impaired to cope with a visual impairment in and outside home and is reimbursed through the Exceptional Medical Expenses Act (AWBZ). After referral from a general practitioner, ophthalmologist, or on their own initiative, clients can receive advice in one of the regional centres of Visio. During an intake interview the request for help will be examined and advice is given about what tools and software are suitable for the client. In practice this means that clients who have (limited) capabilities in working visually primarily use ZoomText from Optelec, a screen magnification program that enlarges and enhances everything on the computer screen.

It appeared that some of the clients had difficulty operating a computer in a Windows environment. One of the challenges older adults face when interacting with a computer involves using an input device (Wood, Willoughby, Rushing, Bechtel & Gilbert, 2005). Because of reduced motor skills and visual impairments due to ageing the clients are taught to use a keyboard, instead of a mouse. The use of this input device requires the user to learn and remember key locations and functions and makes it harder to interact with an interface that consists of several elements.
The touch screen, a popular input device, provides a direct form of control and might improve the interaction between a computer and partially sighted older adults. Learning how to use a touch screen is easier, because the user does not need to memorize and apply functions to perform an action (e.g. enter key for confirmation), the user just taps on the screen with a finger. And because a touch screen is used for input and output an external device is no longer needed to operate a computer. However, existing research mainly compares older adults without visual impairments.

Ease of use keyboard and touch screen

Our goal in this thesis is to learn more about the use of computer input devices by partially sighted older adults by answering the question: which input device, a keyboard or a touch screen, is the easiest to use for partially sighted older adults? And why? Based on earlier research that concluded that the touch screen resulted in the best task performance, as compared to mouse devices, for older adults (Murata,2005; Sears & Schneiderman, 1991) and because of the advantages the touch screen has over the keyboard, we hypothesise that the touch screen is easier to use for partially sighted older adults, compared to a keyboard.

To accomplish this goal we first explore the effects of age-related eye diseases and the age-related changes in perceptual, motor and cognitive processes. We also give an overview of existing literature that explored the effects of ageing on human-computer interaction, emphasizing on visual search and input device.

We conducted an experiment which compared the ease of use of two input devices, a keyboard and touch screen, in two age groups: younger and partially sighted older adults. The experiment was designed to test if the touch screen was easier to use (faster selection, fewer errors and lower perceived task load) than the keyboard for partially sighted older adults in three common computer tasks.

Modelling the partially sighted older adult

The field of cognitive modelling can provide insight into underlying human cognitive processes and offer advantages in the field of interface design, by predicting task performance. Although computer use by older adults have received increased attention (Wagner, Hassanein, Head, 2010), currently capabilities and limitations of older adults are not accounted for in the earliest stages of design (Jastrzembski & Charness, 2007).

In an attempt to better understand age-related performance Jastrzembski & Charness (2007) updated the parameters of the Model Human Processor Model (Card, Moran, & Newell, 1983) to make more accurate performance predictions for older adults. Jastrzembski & Charness (2007) developed models that fit the task performance (use of mobile phones) of older adults well. But, the developed models analysed human performance at the keystroke-level, providing a simplified view on human cognition. Computational models based on a cognitive architecture take a more detailed view of human cognition. ACT-R, an influential cognitive architecture, incorporates theories about how human cognition works, based on a wide selection of human experimental data (Byrne, 2003; Bothell, 2005). However, these cognitive architectures are based on human experimental data which has been largely generated from studies using younger adults (Jastrzembski & Charness, 2007) and the effects of ageing on human performance are currently not part of the ACT-R architecture.

To provide a better understanding of the limitations of older adults when interacting with a computer we used ACT-R to model task performance of the partially sighted older computer. We simulated the use of a keyboard and touch screen in one of the tasks from the experiment. ACT-R parameters were updated to model the effects of age-related changes and visual impairments, which are not presently part of the architecture.

2. Ageing and Human-Computer Interaction

Populations world-wide are ageing. Important factors contributing to this effect are the decline in fertility rates and the increase in life expectancy (Ewijk, Kuipers, Rele, Ven & Westerhout, 2000 and Morris, Goodman & Brading, 2007). In the Netherlands the group of older adults aged 65 years and older in the total population is expected to increase from 14% at present to 23% in 2040 (Ewijk et al., 2000).

Older adults, 50 years and older, make up the fastest growing consumer segment of computer users in the USA (Hart, Chaparro & Halcomb, 2008). The segment of older adults aged 65 and older who owned a computer in the USA increased from 1% in 1988 to 28.4% in the year 2000 (Hart, Chaparro & Halcomb, 2008).
In the Netherlands 85% of the group of older adults aged 50-64 years owned a computer in 2005 and 77% were connected to the internet, which is almost identical to figures for the whole Dutch population (Duimel, 2007). Research from The Netherlands Institute for Social Research (Duimel, 2007) also indicated that the group of 65-74 year-olds made much less use of computers and the Internet than the younger age groups. In this age group 54% used a computer in 2005 and 42% had an Internet connection at home. In the group aged over 75 the figures were even lower: 24% had a computer and 18% had a Internet connection. Figures for older adults in the EU are about the same. In 2004 26% of the men and 16% of the women aged between 55 and 74 have used internet.

Thus, although computer and internet usage is increasing there are still older adults that have yet to embrace this new technological age. According to Morris, Goodman & Brading (2007) there is a general agreement among researchers that "while ICT uptake among older citizens in the EU and USA is increasing, this age group is much less likely to be online or have broadband access than younger people and that this divide will continue for the foreseeable future." Older age groups (65-74 years olds) also use the internet less frequently then younger age groups (55-64 years olds). It seems that the older one becomes, the less one uses a computer and the Internet. This statement is supported by Wagner, Hassanein & Head (2010) who describe that as age increases, attitudes toward computers tend to become more negative. A few of the barriers for not using a computer or the internet by older adults are fear of technology combined with rapid hardware and software development, little or no exposure to technology, little awareness of the potential benefits that technology offers (Hart, Chaparro, Halcomb, 2008), lack of knowledge, experience and computer training, a steep learning curve and age-related functional restrictions, such as a visual impairment (Mann et al, 2005, Morris, Goodman & Brading, 2007).

Although the older age groups (65 and older) currently make up a small group of computer users, it is expected that the number of older computer users will expand in the future. The computer has become increasingly important for daily activities. Some activities, like controlling finances and doing your tax return, may eventually only become possible with a computer that is connected to the Internet. There are however some concerns: the currently dominant interfaces, which are developed for a younger age group, are not always usable for the older computer user (Hawthorn, 1998).
Computer and web interfaces will be more usable for older users if they make use of larger fonts, simpler interfaces that have fewer distractions and which provide memory cues; thus, if age-related decline in physical and cognitive performance are taken into account.

Effects of ageing on Human-Computer Interaction

Human-computer interaction (HCI) is a discipline concerned with the study, design, evaluation and implementation of the interaction between people and interactive computing systems (Dix, Finlay, Abowd, & Beale, 2003). Much of the research in HCI designed products around the needs of the younger user (Jastrzembski & Charness (2007).
When designing efficient and easy to use computer systems it is important to know the user. Because the domain of concern in this thesis is how partially sighted older adults interact with computers we explored the effects of ageing on human processing systems, emphasizing on the visual system.

2.1 Effects of ageing on vision

When interacting with a computer output mainly consists of visual information. Thus, effective interaction with a computer is in a large part dependent on the visual sensory mechanisms and perception. Problems with vision tend to appear in the early forties due to visual impairments than can cause low-vision (Fozard, 1990).
A visual impairment can be defined as "a functional limitation of the eye(s) or visual system due to a disorder or disease that can result in a visual disability or a visual handicap" (Freeman et al., 2007, pp. 6). An age-related progressive visual impairment is one of the most distinct areas of decreased performance in older adults (Hawthorn, 2000). The classification of visual impairment varies worldwide. The National Eye Institute had a wider definition of low-vision, as a visual impairment not correctable by standard glasses, contact lenses, medication or surgery, that interferes with the ability to perform activities of daily living (Freeman et al., 2007).
Because the effects of ageing on vision can have negative effects on the task performance of older computer users we discuss the most common causes: age-related eye diseases and visual impairments.

2.1.1 Eye diseases

The most common age-related eye diseases in the adult population are, macular degeneration, cataract, glaucoma and diabetic retinopathy (Freeman et al., 2007).

Age-related macular degeneration
Age-related macular degeneration (AMD) is the leading cause of age-related low-vision at present in the Western world (Burmedi, 2002a; Bressler, Bressler & Fine, 1988), mainly affecting people over the age of 60 (Freund, Klancnik, Yannuzzi & Rosenthal, 2008). AMD is a disease that causes a gradual decline on acuity, or sharpness of central vision by affecting the macula (Freund et al., 2008;). The macula is the small central portion of the retina in the eye and is responsible for seeing fine detail. In the early stages of macular degeneration drusen, waste products which accumulate under the retina, may form. These drusen may cause mild vision loss (Freund et al., 2008). At this point the disease may progress in on of two forms: wet or dry macular degeneration (National Eye Institute, 2009).
Dry macular degeneration is the most common and least severe form of AMD causing vision loss because of accumulating drusen. Dry macular degeneration rarely causes severe vision loss (Freund et al., 2008). Symptoms of dry macular degeneration are loss of central vision and occasionally a growing blind spot in the centre of the visual field called a scotoma.
In wet macular degeneration, a more serious form of the disease, blood vessels may leak blood or fluid under the retina causing the retinal surface to become uneven (Freund, et al., 2008). Symptoms are blurred, distorted vision and blind spots, as depicted in figure 2.1. Fortunately, wet macular degeneration is not as common as dry macular degeneration, but it does cause a more sudden and a greater loss of central vision (Freund, et al., 2008).

Figure 2.1. Blurred, distorted vision and a blind spot, symptoms of wet macular degeneration (from Freund et al., 2008).

Cataract
A cataract is a clouding of the lens in the eye which reduces vision (National Eye Institute, 2003). Symptoms of age-related cataracts are blurred vision, reduced (colour) vision due to a tinting of the lens, glare and double vision (National Eye Institute, 2003), as depicted in figure 2.2.

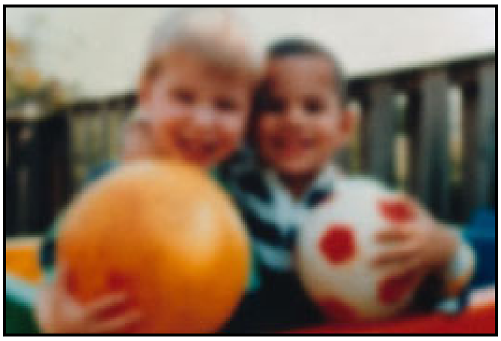


Figure 2.2. Reduced vision due to a cataract (from National Eye Institute, 2003).

Glaucoma
Glaucoma is an eye disease that damages the eye's optic nerve due to a increased fluid pressure in the eye (National Eye Institute, 2012b). Without treatment the disease can permanently damage the affected eye(s) and may cause blindness. Glaucoma can slowly develop and lead to a loss in peripheral vision, as depicted in figure 2.3. If left untreated central vision may also be affected.

Figure 2.3. Loss of peripheral vision caused by glaucoma (from National Eye Institute, 2012b).

Diabetic retinopathy
Diabetic retinopathy is the most common diabetic eye disease (National Eye Institute, 2012a). It causes retinopathy, damage to the retina, caused by complications of diabetes mellitus. Symptoms of the disease are blurred vision caused by macular edema, which is swelling of the macula from leaking fluid (National Eye Institute, 2012a). If new blood vessels grow on the surface of the retina, as a part of proliferative diabetic retinopathy, they may bleed into the eye and block vision. These haemorrhages can form spots "floating" in the visual field, as depicted in figure 2.4.

Figure 2.4. Symptons of diabetic retinopathy (from National Eye Institute, 2012a).

2.1.2 Visual impairments

Also older adults free from identifiable eye diseases show an increased difficulty performing visual tasks due to ageing (Kosnik, Winslow, Kline, Rasinski & Sekuler, 1988; Morris, 1994; Jackson & Owsley, 2003). Decline in visual abilities result from age-related changes in the optics of the eye and degeneration of the visual neural pathways (Jackson & Owsley, 2003). Visual functions that are affected due to ageing are visual search, speed of visual processing, light sensitivity, near vision and dynamic vision (Kosnik et al., 1988). Table 2.1 shows the most frequently reported declines in visual functions due to ageing.

Table 2.1. Decline in visual functions due to ageing.

Visual functions	Impairments
Visual search (e.g. read and locate information)	• size of the visual field is reduced • visual acuity declines • contrast sensitivity declines • decline in colour recognition • longer saccadic reaction time • decline in accurate estimation of depth • prolonged persistence
Speed of visual processing	• reduced reading speed • decline in recognition of patterns • increase perceptual processing time
Light sensitivity	• reduced sensitivity to light • eye is slower to adapt to dim conditions • more vulnerable to glare
Near vision (read small print)	• reduced ability to adapt the lens of the eye sufficiently to allow focus at short distances
Dynamic vision (detect motion)	• less able to detect minimal motion by objects

Visual search

Problems in visual search, for example locating and reading a sign, can be caused by multiple impairments in vision due to ageing. One important factor is the reduction of the useful field of view, which emerges from around the age of 60 (Hawthorn, 2000). The useful field of view is the total visual region in which useful information can be attained without making eye and head movements (Ball, Beard, Roenker, Miller & Griggs, 1988). Declines in visual acuity, contrast sensitivity and colour recognition make it harder to detect and distinguish patterns and shapes. Visual acuity, the ability to detect fine detail, declines with age, even when people are wearing their best optical correction (Jackson & Owsley, 2003). A decline in contrast sensitivity, or the amount of contrast a person needs to detect a pattern, seems to be largely the result of age-related changes in the eye's optics (Jackson & Owsley, 2003). Age-related changes in colour vision are usually caused by a loss in colour discrimination, especially along the blue-green axis (Jackson & Oswley, 2003; Schieber, Fozard, Gordon-Salant & Weiffenbach, 1991).

When people perform visual tasks (e.g. read, search for an object) they constantly make sudden, swift eye movements called saccades. In between saccades the eyes remain relatively still during fixations in which information is perceived. Each visual task differs in the number of saccades and fixation duration (Rayner, 1998). According to Scialfa & Joffe (1997) older adults make more saccades, their saccadic reaction times were slower and their average fixation durations are higher as compared to younger adults. Munoz, Broughton & Goldring (1998) measured saccadic eye movements in subjects ranging from 5 to 79 years and found strong age-related effects on the saccadic reaction time (SRT), the time to onset of the eye movement. There is a reaction time associated with making a saccade (at least 150-175ms in younger adults) because there are motor movements that require time to plan and execute (Rayner, 1998). Older adults (60-79 years old) had higher saccadic reaction times than younger adults, with the greatest number of SRTs above 300 ms. Also, saccadic velocity (the speed of the saccade) decreases with age (Munoz et al., 1998; Schieber et al., 1991).

Stereopsis, the ability to estimate depth or distance, also declines in older adults (Schieber et al., 1991). According to Morris (1994) depth perception begins to decline between the ages of 40 and 50. Persistence, the sensation that a stimulus is still present after the presentation has ceased, has been found to be more prolonged in older adults (McFarland, Warren, & Karis, 1958).

Speed of visual processing
Another visual function affected by the effects of ageing is visual processing. Akutsu, Legge, Ross & Schuebel (1991) measured reading speed and revealed that older adults (60-74 years old) showed a deficit when reading very small of very large characters. However, older adults read as fast as younger adults for normal character sizes. Older adults need more time to make visual discriminations, as compared to younger adults (Jackson & Owsley, 2003) and the recognition of patterns appears to be slower with age (Hawthorn, 1998). In a meta-analysis Jastrzembski & Charness (2007) estimated the perceptual processor cycle time, the amount of time that passes between the onset presentation of a stimulus and the time at which the information becomes available in working memory. The mean perceptual processor cycle time was calculated to be 178 ms for older adults (Jastrzembski & Charness, 2007), as compared to a mean of 100 ms for younger adults (Card, Moran, and Newell, 1983).

Light sensitivity
Scotopic sensitivity, sensitivity to low light conditions, declines in many older adults (Jackson & Owsley, 2003). According to Schieber et al. (1991) age-related declines in visual function become worsened in low light conditions. Older adults are more vulnerable to glare (Jackson & Owsley, 2003). Glare refers to a loss of visual acuity or contrast when a light source is present.

Near vision
Presbyopia, or a reduced ability to adapt the lens of the eye sufficiently to allow focus at short distances (Jackson & Owsley, 2003) is one of the most frequent impairments in vision due to ageing. This impairment can cause problems when older adults are trying to read text with a small print. Fortunately, presbyopia is highly treatable by using glasses with plus-lenses (Jackson & Owsley, 2003).

Dynamic vision
Dynamic vision refers to the ability to perceive motion. Everyday problems caused by age-related impairments in dynamic vision are reading moving signs or credits on TV (Kosnik et al., 1988). According to Kline & Scialfa (1996) older adults are less able to detect minimal motion by objects and may give more cautious estimates of speed of real life objects.

2.1.3 Older computer user: visual search
In this section we will discuss studies that compared younger and older adults' performance in computer tasks to give an overview of the effects of ageing on visual search.

When using a computer interface, part of the interaction consists of performing visual search to locate information on screen. For example, when selecting an item in a menu. Factors that facilitate visual search are similarity of targets and distractors and the development of efficient search strategies (e.g. automatic attention response (Fisk et al., 1997). When using an efficient search strategy individuals learn not only which features to search for, but also the optimal order in which to search for those features (Fisk et al., 1997). There is a general agreement among researchers that the nature of the search process changes with the experience of the user (Nilsen, 1991). Novice users will take a long time searching for items. A greater familiarity with the items causes users to use a "direct search" strategy, where the desired menu item is fixated on immediately (Card, 1983). With many practice trials an automatic attention response can become associated with the target item in which target items will attract more attention, relative to other items in the display, and will be responded to automatically (Fisk et al., 1997).

Fukuda & Bubb (2003) observed younger and older adults behaviour during search tasks on the web. Results showed that older adult required longer fixations than younger adults, especially when the visual objects were small. Older adults also used inefficient navigational strategies which caused more navigational steps.
Not only partially sighted older adults with visual field loss show problems in visual search. Owsley, Ball, Keeton (1994) examined target localization problems in older adults with varying degrees of visual field loss (none to severe) due to visual impairments. Results indicate that even older adults who have good visual field sensitivity have serious difficulty localizing objects. The correlation between visual sensitivity and localization performance grew weaker when distracting (non-target) stimuli were

added to the display. This suggests that the localization problems older adults have are caused by impaired attentional skills. A similar conclusion was drawn by a study discussed by Kramer, Boot, McCarley, Peterson, Colcombe, Scialfa (2006) that indicated that older and younger adults show similar search times in feature search (e.g. search for a red X target among green O distractors). However, younger adults were significantly faster than older adults in conjunction search (e.g. search for red X among red O and green X distractors). Targets that can be distinguished from distractors on the basis of a unique feature will be detected quickly while targets which are similar to distractors will take substantially longer to find. A number of studies discussed by Kramer et al. (2006) suggest that the age-related slowing in conjunction search is due to a deficiency in the feature integration stage (binding of visual features into a coherent whole), a decrease in target detectability, problems in re-orienting attention in the visual field and a smaller breadth of attention for older as compared to younger adults. Thus, it is likely that the problems that older adults have in tasks involving visual search not only stem from visual sensory impairments, but also from attentional deficits (Owsley et al., 1994).

In summary, older adults require longer fixations than younger adults, which results in less efficient search strategies. The problems older adults have in visual search tasks are not only caused by visual impairments, but also because of attentional deficits.

2.2 Effects of ageing on cognition

Short-term memory (STM), the capacity to store small amounts of information, declines with age. STM can be assessed by various tasks, e.g. the digit span and Corsi block tapping task. In the digit span test individuals are presented with a list of digits and are required to immediately repeat back the list. According to Parkinson, Inman & Dannenbaum (1985) the mean digit span drops from 6.6 items to 5.8 over the course of an adult life. The Corsi block tapping task tests spatial span by requiring individuals to tap certain sequence patterns on nine wooden blocks. The spatial span drops from an average of 5.1 to 4.7 blocks in older adults (Spinnler, Della Sala, Bandera & Baddeley, 1988).

Working memory (WM) is a system for temporary maintenance and manipulation of information (Baddeley, Eysenck & Anderson, 2009). It differs from STM because WM does not only temporarily store information, it also manipulates it. There are many tasks that have been developed to measure working memory capacity, e.g. the digit span task, in which participants are required to repeat a series of digits in reverse order. Most WM tasks require the participant to process and hold information in memory in the face of interfering processes or distractors.
There is general agreement that WM declines with age (Verhaeghen, Marcoen & Goossens, 1993). According to Jastrzembski & Charness (2007) there are multiple studies that explain age-related decline in cognitive performance by a deterioration of WM capacity. Card et al. (1983) estimated the effective WM capacity to be seven (plus or minus 2) items for younger adults. Jastrzembski & Charness (2007) calculated the effective WM capacity for older adults to be 5.4 items.

The decline in WM capacity is probably because older adults have a reduced capacity to inhibit irrelevant stimuli and are therefore easily distracted from the task goal (May, Hasher & Kane, 1999; Hasher & Zacks, 1988).

According to Salthouse (1996) the cognitive effects of ageing can best be explained by the reduced speed of processing, which the author concluded on a extensive series of correlational studies. Older adults are, overall, slower in most task than younger adults.

Declarative memory, a part of long-term memory, includes episodic (memory for specific events) and semantic memory (knowledge of facts). According to Craik (2005) there is a overall decline in episodic memory in older adults. Two variables affecting this decline are the processing capacity of the learner and the environmental support (factors in a retention test that support retrieval) provided during retrieval. According to Naveh-Benjamin, Guez & Marom, 2003) an age deficit in episodic memory is caused by an impaired capacity to form associations between previously unrelated stimuli. It seems that the basic learning capacity of older adults declines with age.
Semantic memory seems to be maintained in older adults. It even seems to grow slightly with age, as measured by vocabulary knowledge (Giambra, Arenberg, Zonderman & Kawas, 1995).

2.3 Effects of ageing on motor control

Older adults generally have more trouble in performing physical tasks, compared to younger adults. Age-related changes in motor and musculoskeletal systems affect physical abilities of older adults, which include reduced muscle strength, reduced range of motion and increased difficulty executing fine motor movements (Chaparro et al., 2000).
Older adults are less able to prepare for a movement than younger adults, are slower in response execution, show slower movements overall (accelerate and decelerate) and take more time monitoring their responses (Goggin & Stelmach, 1990). This causes a decline in motor reaction time - the time until a response is initiated after a stimulus has been presented) and movement time - time taken to complete a movement. It seems likely that older adults try to be more accurate and are more cautious because they do not want to make mistakes (Goggin & Stelmach, 1990).

2.4 Input device

The use of an input device could be a challenge for partially sighted older computer users. Input devices vary greatly, some devices are more flexible and accommodate the older user, others do not. Traditional input devices for a computer are the keyboard and mouse. Present graphical user interfaces largely rely on the use of these two input devices (Chaparro, Rogers, Fernandez, Bohan, Choi, Stumphhauser, 2000). According to one estimate, these input devices are used 30-60% of a computer users time, as described by Chaparro et al. (2000).
However, the computer mouse is less suitable for partially sighted older adults (Mann, 2005; Hollinworth, 2009). The use of a mouse by older adults can cause difficulties because of reduced motor skills due to ageing, as mentioned previously. Problems can occur during point-and-click interactions, such as drag and drop. Also, reduced vision because of age-related visual impairments (prolonged persistence and a dynamic vision deficit) affects the use of a mouse by partially sighted older users, e.g. tracking an on-screen mouse pointer.

In this section we will discuss the advantages and disadvantages of the keyboard, which is used by the partially sighted older clients in the computer course of Visio, and the touch screen (an overview is provided in table 2.2). And we will discuss existing research which compared input devices for older adults.

Keyboard
A keyboard is more suitable for partially sighted computer users. Physical demands are lower because interaction consists of simple down- and upstrokes of a finger to press the keys (providing tactile feedback). And, by the use of large print labels (which can be attached to the keys) the keys are easier to read. Alternatively, a high contrast keyboard can be used; for example a black keyboard with black keys with yellow characters. In addition, the use of screen magnification/reader software enlarges on-screen text and graphics and provides speech support. The software can pronounce every key that is pressed so that the user can receive feedback as they type. And finally, the keyboard is designed to easily enter text, making it the most efficient when large sections of text must be entered.
But the keyboard also has some disadvantages. The keyboard is an external device which requires the user to alternate their view between the keyboard and the screen to search for the next key to press. Operating a computer with a keyboard also makes it harder to control an interface consisting of several elements (such as a website). Because the user has to switch between elements to select a certain item (using the tab key) the number of user steps is higher than when operating a mouse. And, although physical demands for the keyboard are lower than that of the computer mouse, using a keyboard does however require the user to memorize locations of keys and their function. This imposes a greater demand on cognition, mainly working memory and requires learning time.

Table 2.2. Overview of the advantages and disadvantages of the keyboard and touch screen.

Keyboard		Touch screen	
Advantages	Disadvantages	Advantages	Disadvantages
Low physical demands	Memorize key locations and functions	No need to memorize keys	Arm fatigue
Adaptable for partially sighted	More user steps	Fewer user steps	Less precise
Effectively enter text	Alternate view between keyboard and screen	Little hand-eye coordination	Less effective for typing

Touch screen

One input device that has recently gained much popularity in smartphones and tablet-PCs is the touch screen. Although keyboard and mouse input devices are still widely used on a desktop computer, touch input also seems to become more popular in this market. One example of this increased popularity is the development of the new Windows 8 interface, which is optimized for touch-centric hardware. Windows 8 can also be used for desktop touch screen computers.

The touch screen, a popular input device, provides a direct form of control and might improve the interaction between a computer and partially sighted older adults. In contrast to the keyboard and mouse, there is no need for an external device (the user simply touches the screen to make a selection). This makes the interaction more intuitive (Albinsson & Zhai, 2003) and provides direct hand-eye coordination (no need to switch focus between a keyboard and screen). And there is no need to memorize commands.

Disadvantages of the touch screen, as discussed by Rogers, Fisk, McLaughlin & Pak (2005), are arm fatigue (from reaching across to the computer screen for extended periods), difficulty with precision (e.g. selecting small areas), inadvertent activation (unintentionally activating the screen), lack of feedback and the user's finger or arm may obscure the screen. And, the touch screen, in contrast with the keyboard, is not designed to (easily) type in text. Although an onscreen keyboard can be used on a touch screen it does not give tactile feedback and does not have the large dimensions of a keyboard (which is designed for fast typing using both hands).

Comparison of input devices

Considerable research has been done that investigated the impact of input devices among younger and older adults (Wood et al., 2005). Growing attention has been recently paid to investigate touch interfaces and how they can promote computer use by older adults (Leonardi, Albertini, Pianesi & Zancanaro, 2010). Leonardi et al. (2010) discuss several studies that suggest that pointing and touching an item on a touchable surface can provide advantages, e.g. reduce mental effort and support learnability because the interaction is one of the most natural ways to select something on a computer.

Sears & Schneiderman (1991) showed that selection times of younger adults when using a touch screen were lower than when using a mouse for targets as small as four pixels per side. However, the mouse resulted in the fastest and most accurate selection when a target had to be selected of a single pixel, compared to a touch screen.

There is also a benefit of the use of a touch screen for older computer users. Murata (2005) compared young, middle-aged and older adults' (ranging from 20-75 years old) pointing times using a mouse and a touch screen. The participants were required to touch or point to a target as quickly and accurately as possible. Results showed that the pointing time for the touch screen did not differ significantly among the three age groups. In other words, the older adults could point just as fast as the younger adults when using a touch screen. The pointing times for the mouse, however, increased with age group showing that older adults had more difficulty in using the mouse for pointing tasks. No significant differences in the error rates between both input devices were found.

Wood et al. (2005) compared older adults' task performance using four input devices: a touch screen and touch pad and two types of computer mouse: a regular two-button mouse and a stationary trackball (Easyball). Participants played two computer games in which they had to match two icons presented on screen. Wood et al. (2005) concluded that the regular mouse resulted in the most efficient and accurate performance for experienced older computer users, whereas less experienced older users showed the best performance using the trackball. Performance of the touch devices (touch screen and touch pad) fell far below the mouse devices. However, in the survey older adults indicated problems with the need to sustain pressure when using the touch screen (Wood et al., 2005). These problems have been overcome by current capacitive touch screens which are more sensitive to the smallest touch.
According to Rogers et al. (2005) the selection of the optimal input device for a particular system can be made according to an analysis of the controls that are mainly used in the interface. For example, if the system contains pointing tasks with drop-down lists, a touch screen would be preferable for younger and older adults. Up/down buttons (scrolling) showed lower response times (as compared to the rotary encoder) and may be generally difficult to use, especially for older adults. Fisk (2000) suggests to use simple point-and-tap interfaces when using a touch screen as an input device.
However, the existing research mainly focuses on comparing mouse and touch screen use by older adults without visual impairments. And, much of the existing literature was conducted early on in the development of input devices and, mainly the touch screen, has been enhanced and refined affecting the efficacy of touch screen devices (Wood et al., 2005).

3. Experiment

The Royal Dutch Visio offers a computer course to its partially sighted older clients. The computer course aims to give visually impaired older adults the opportunity to participate in society through computer and Internet use.
It appeared that some of the clients had difficulty operating a computer in a Windows environment.

One of the challenges older adults face when interacting with a computer involves using an input device (Wood et al., 2005). Because the computer mouse is less suitable for (visually impaired) older adults because of reduced motor control and age-related visual impairments, clients are taught to use a keyboard. Operating a keyboard to control a computer may be easier for partially sighted older users because of lower physical demands, it is designed to efficiently enter text and because a keyboard can easily be adapted to support the partially sighted user by attaching large print stickers on the keys.
However, a keyboard imposes a greater demand on working memory because it requires the user to learn and remember key locations and their function. In a complex interface the user often needs to complete a large sequence of steps to perform a specific action, e.g. switching between elements.

The touch screen, a popular input device, might improve the interaction between partially sighted older adults and a computer. Operating a touch screen allows for a more direct form of control because no external device is needed (the touch screen is used for input and output). This eliminates the need to memorize keys and their function and reduces demands on working memory. An added benefit is the reduced number of necessary steps that are required to perform an action, because the user provides (direct) input by pressing a specific element on the screen. Furthermore, the touch screen allows direct hand-eye coordination, because the user does not need to switch focus between a keyboard and the screen.
Disadvantages of the touch screen, as mentioned in the previous chapter, are arm fatigue, difficulty with precision, inadvertent activation, lack of tactile feedback and the user's finger or arm may obscure the screen (Rogers et al., 2005).

Several studies comparing input devices conclude that the touch screen results in the greatest task performance (faster pointing times) for older adults (Murata, 2005). However, the existing research mainly focuses on comparing mouse and touch screen use by older adults without visual impairments. And, much of the existing literature was conducted early on in the development of input devices and, mainly the touch screen, has been enhanced and refined affecting the efficacy of touch screen devices (Wood et al., 2005).

We conducted an experiment to assess the ease of use of the keyboard and touch screen for partially sighted older adults. We designed two selection tasks (email and web) and a typing task that are similar to computer activities performed by older adults in the Visio computer course: opening email, surfing the web and typing in text. The purpose of our experiment was to evaluate the ease of use of both input devices by task performance (task execution times, errors) and workload (NASA-TLX) in each of the three experimental tasks (email, web and typing task). Two age groups, partially sighted older adults and younger adults, participated in the experiment. The group of younger adults served as a reference group.

Based on earlier research that compared the touch screen to mouse devices (Murata, 2005) we assume that the touch screen results in the greatest task performance (faster selection and fewer errors) in selection tasks for partially sighted older adults. We formulated the following hypotheses that assume that the touch screen is easier to use in selection tasks (email and web task) for partially sighted older computer users:

1. Older participants have faster selection times when operating the touch screen, compared to the keyboard.
2. Older participants make fewer errors when operating the touch screen, compared to the keyboard in selection tasks.
3. The perceived workload of older participants when operating the touch screen is lower, compared to the keyboard in selection tasks.

And, because the keyboard, in contrast to the touch screen, is designed to efficiently enter text we formulated the following hypotheses that assume that the keyboard is easier to use for typing in text for partially sighted older computer users:

4. Older participants can type the fastest when operating the keyboard, compared to the touch screen.
5. Older participants make fewer errors when typing with the keyboard, compared to the touch screen.
6. The perceived workload of older participants when typing with the touch screen is higher, compared to the keyboard.

3.1 Participants

Thirteen partially sighted older adults and ten younger adults participated in the experiment.

The older participants were recruited by their computer trainer from the Royal Dutch Visio and volunteered freely. Inclusion criteria for recruitment of participants in the older group were a minimum age of 60 years, current or past participation in the computer training at Visio and use of a maximum magnification level of 400% and / or voice support. The older group's age ranged from 60 to 88 years (M = 76.4, SD = 8.0).

The control group included ten younger adults between the ages of 22 to 29 years (M = 24.9, SD = 2.0), all of whom had normal or corrected-to-normal vision. Participants in the younger group were students in Groningen (Netherlands) and volunteered freely.

3.2 Tasks and materials

The experiment was run on an all-in-one desktop touch screen PC (Dell Inspiron One23), as depicted in figure 3.1. The 23" touch display was set to a 1920x1080 resolution at 60 Hz.

Participants were randomly assigned to either the keyboard or the touch screen condition. In the touch screen condition all participants used the touch screen (using a finger to tap on the screen) to complete the entire experiment. The older adults in the keyboard condition used a keyboard with high contrast letter stickers (black letters on a white background) that was also used in the Visio computer course. The younger adults in the keyboard condition used a wireless Dell keyboard which was provided with the touch screen PC (see figure 3.1).

Figure 3.1. The all-in-one touch screen PC used in the experiment.

The experiment consisted of three experimental tasks. The tasks were programmed in Java. The interface of the experiment was sized to fit on the touch screen display, which was 1920 pixels wide by 1080 pixels tall. We enlarged the dimensions of the control elements (e.g. buttons) and text size (font size of 36 points) as to correspond to a magnification level of 400% (the maximum magnification level used by the older participants).
Experimental data consisted of task data and keystroke data, stored in two separate text files. In the task data file participants' task data was stored (e.g. trial number, target that had to be selected, selected item, total selection time). The keystroke file stored the reaction time (from the start of a trial) of each keystroke or tap on the screen and the pressed element (e.g. start button).

Experimental tasks

We developed three experimental tasks: [1] an email task, [2] web task and [3] a typing task, as a representation of the most frequently performed computer tasks by the Visio clients. The task interfaces in the experiment were designed to resemble the interfaces of software applications the clients have used during the Visio computer course. We compared the ease of use of both input devices by analysing the operation of different control elements. The control elements which are included in the experimental tasks are: buttons, lists, radio-buttons and hyperlinks.

Email task

The purpose of the email task was to compare the use of a keyboard and a touch screen when operating a email program. The interface of the email task resembled a simple version of Microsoft Mail, as depicted in figure 3.2. The participants in the keyboard condition had to use the tab, return and arrow keys and the participants in the touch screen condition used their finger to tap on the screen.
Each trial started with a screen presenting a randomly chosen target folder and target message (e.g. "select 'Tom' in 'Inbox'"). The participant then had to press a start button to begin the task. The email task involved pressing a radio-button to select the target folder (left of the screen) and select the target message in a list (right of the screen). Pressing the next button (bottom of the screen) completed the trial. The same folders were used in all trials in a fixed order: *Inbox*, *Concepts, Sent* and *Trash*. Names (e.g. "Paul") were used as messages and were also presented in a fixed order. The Concepts and Trash folder contained four and five message items respectively. The Inbox and Sent folder contained eight message items and needed a scroll bar to view the eighth message in the list. The email folders had different numbers of messages to imitate an email account in use. To reduce the cognitive load on short-term memory the targets remained visible during the entire trial duration (at the top of the screen) in all three experimental tasks.

Figure 3.2. Screenshots of the email task. Top left: screen presenting the targets. Top right: start of the email task, after the start button was pressed. Bottom left: the "Trash" folder was selected and the corresponding messages are shown on the right of the screen in a list. Bottom right: both targets are selected, pressing the next button ended the trial.

Web task
The purpose of the web task was to compare the use of a keyboard and a touch screen when operating a simplified web page. The interface of the web task was similar to the mobile version of a well-known Dutch news website, NU.nl, as depicted in figure 3.3. The participants in the keyboard condition had to use the tab and return keys and the participants in the touch screen condition used their finger to tap on the screen.
Again, each trial started with a screen presenting randomly chosen targets. In the web task a news item had to be selected in a news category (e.g. "select 'Obama debate' in 'Economics'"). The participant had to press a start button to begin the trial. The task involved the participant to use buttons, resembling hyperlinks, to select the news category at the top of the screen and a news item at the centre of the screen. Pressing the news item completed the trial. The news category items were presented in a fixed order: *Frontpage*, *General*, *Economics* and *Sports*. Each news category had four news items, also presented in a fixed order, with accompanying pictures.

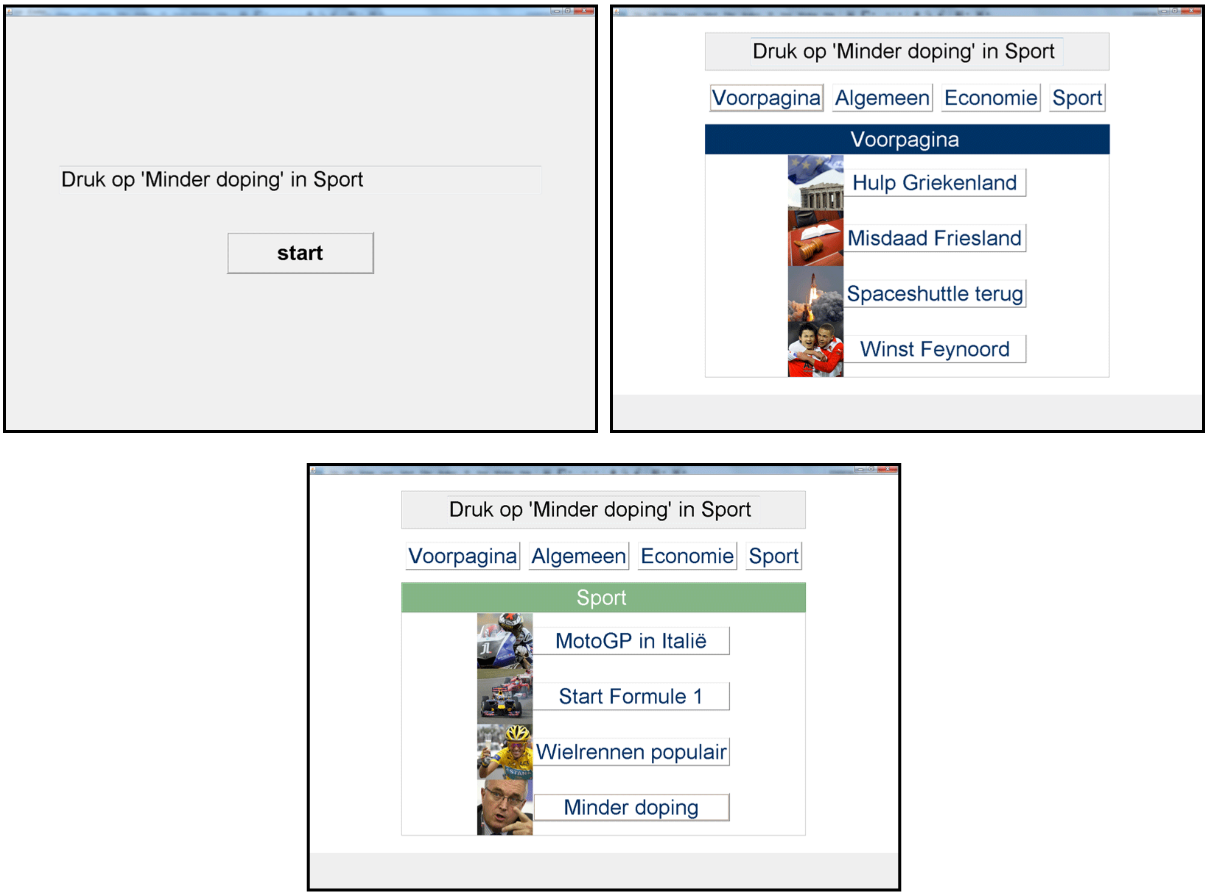


Figure 3.3. Screenshots of the web task. Top left: screen presenting the targets, the participant had to press the start button to begin. Top right: start of the web task. Bottom: the news category "sports" is selected, pressing a news item ended the trial.

Typing task

The purpose of the typing task was to compare the operation of a keyboard and a touch screen when typing in words. The interface of the typing task was composed of an input field and a next-button.
Each trial started with the presentation of a randomly chosen target word from a list of ten simple words (four to eight characters). The participants pressed the start button to begin the trial. Participants were required to type in the target word (e.g. "photo") in the input field. In the touch screen condition participants used the Windows 7 on-screen keyboard to type in the words (figure 3.4). To open the on-screen keyboard participants had to press the input field once and subsequently press a keyboard icon that appeared next to the input field. In the keyboard condition participants used the attached keyboard to complete the task. Pressing the next-button completed the trial.

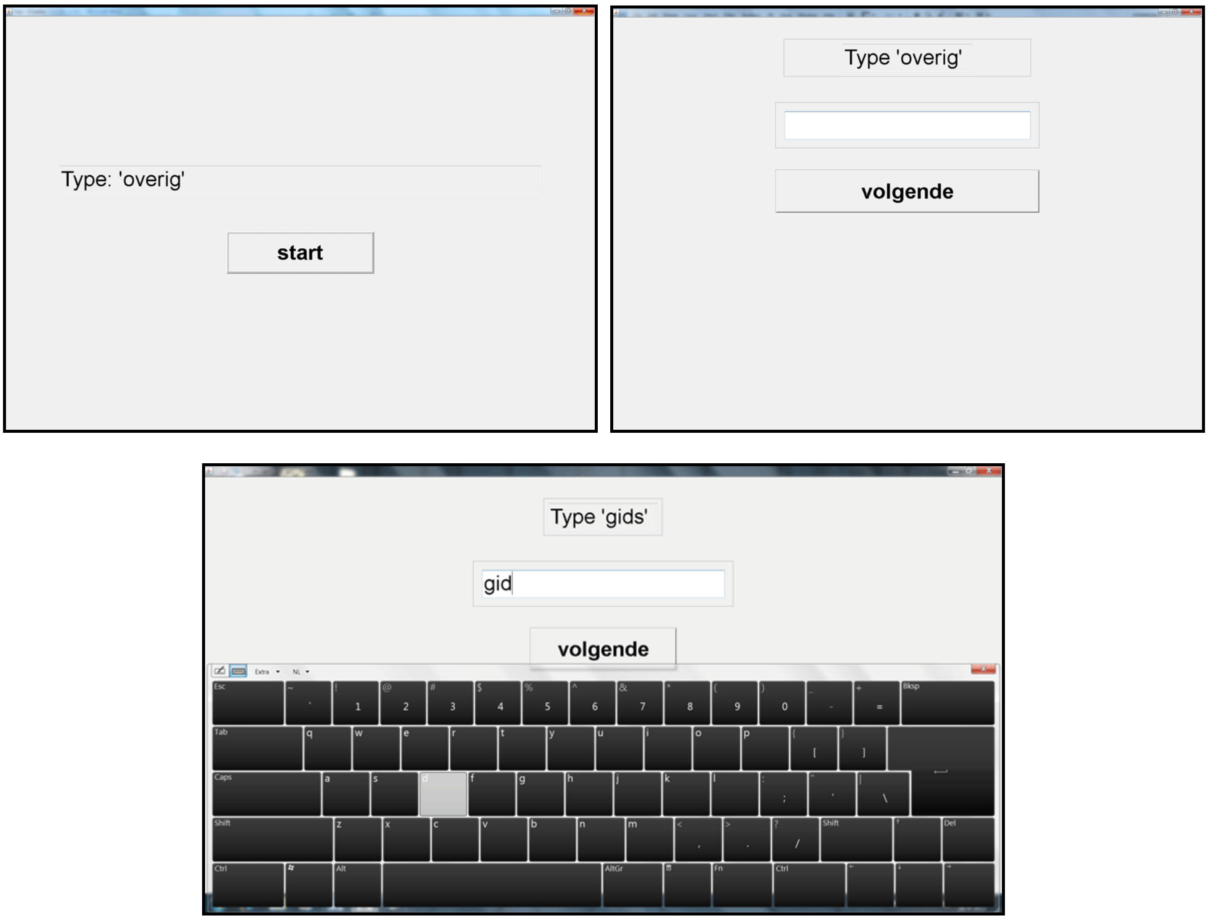


Figure 3.4. Screenshots of the typing task. Top left: screen presenting the word the participant had to type in. Top right: screen just after pressing the start-button. Bottom: the on-screen keyboard in the touch screen condition.

Training
At the start of the experiment all participants completed a training to gain experience in operating the following control elements: [1] buttons, [2] lists, [3] radio-buttons (see figure 3.5 for screen examples). The participant had to search for and select a randomly chosen target item which could be any of five items: *documents*, *images*, *messages*, *music* or *games*. These were always presented in this order. Each trial started with a screen presenting the target item (e.g. "messages"). After reading the target the participant was required to press the start button and then pressing the item which matched the target. In the case of the list and radio-buttons the participant also had to press the next-button.

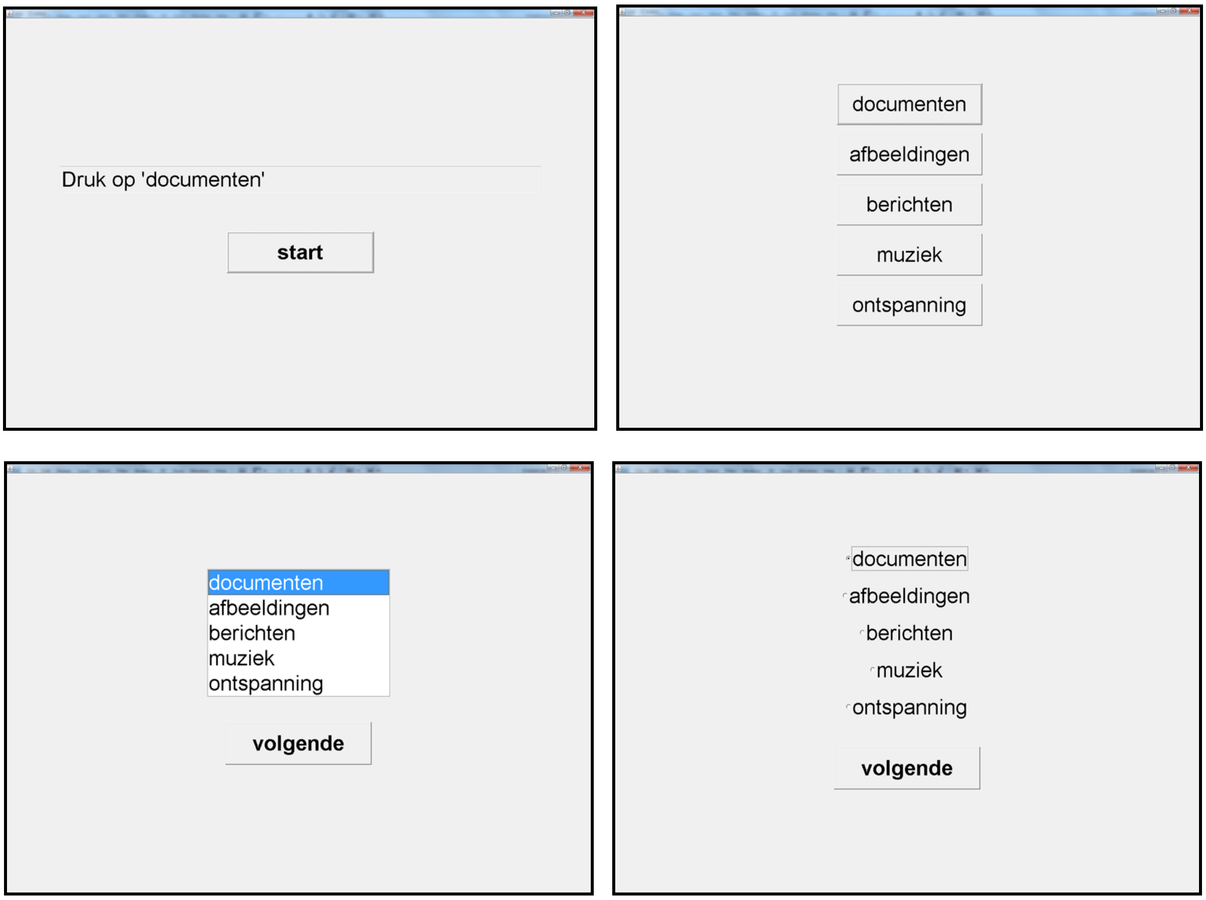


Figure 3.5. Screenshots of the practice trials in the training task. Top left: screen presenting the target. Top right: buttons. Bottom left: list. Bottom right: radio-buttons.

3.3 Measures

The ease of use of both input devices was measured by task performance (task execution times and errors) and workload in each of the three experimental tasks.

Task performance

In the email and web task the following task execution times were measured during the experiment:

- *reading time*: time taken for the participant to press the start button.
- *total selection time*: sum of first and second selection time.

And the following task execution times were calculated, after running the experiment, from the measured keystroke reaction times:

- *first selection*: time taken for the participant to press the first target minus the time taken to press the start button.
- *second selection*: time taken for the participant to press the second target minus the time taken to press the first target.

Figure 3.6 visualizes the measured and calculated task execution times in the email and web task. In the email task the second selection was made in a list, therefore an additional next button was needed to end the trial. In the web task a next button was not necessary because the participant had to press a button for the second selection (news item), which ended the trial.
An error was classified as an incorrect selection (the selected items did not match the targets).

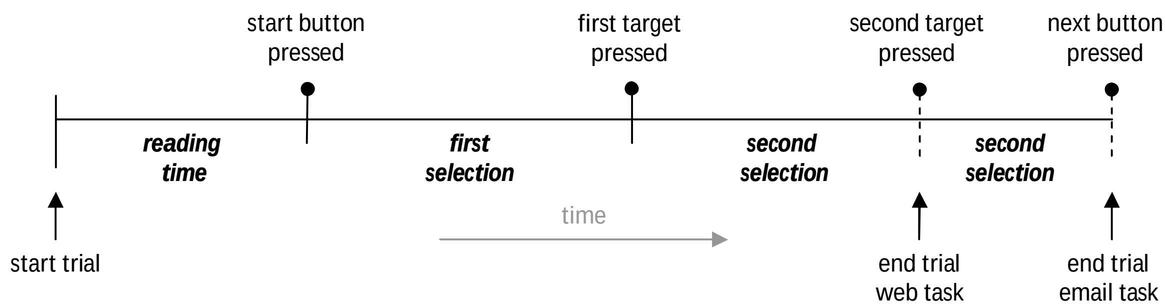


Figure 3.6. Figure depicting the measured (reading time) and calculated (first and second selection) task execution times in a trial of the email and web task. Note that in the email task the participant had to press the next button to end the trial, whereas the participant in the web task only had to press the second target (news item) to end the trial.

In the typing task *reading time* (time taken for the participant to press the start button) was measured during the experiment and the *input times* for the first four letters were calculated after running the experiment, as depicted in figure 3.7. The words used in the typing task had different lengths (four to eight characters) and by only measuring the first four letters average input times could be calculated for all words. The letter input times were calculated by subtracting the previous letter input time of the current letter input time. An error was classified as a mistyped word or omitted word (pressing the return key before a word was entered).

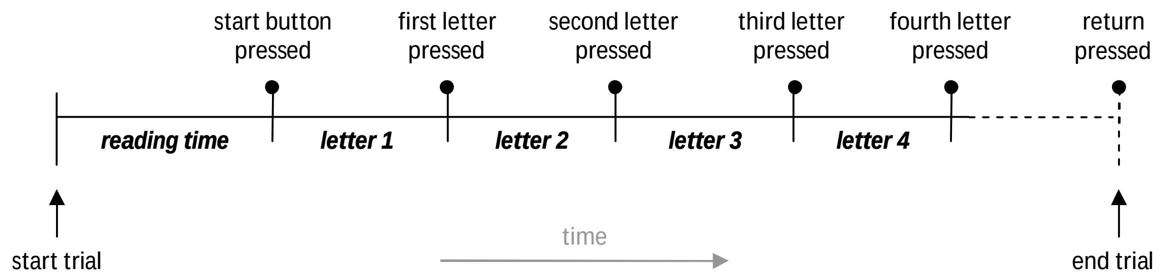


Figure 3.7. Figure depicting the measured (reading time) and calculated (input times letters) task execution times in a trial of the typing task.

Workload

In the older group the paper and pencil version of the NASA-TLX (Hart & Staveland, 1988) was administered to rate the perceived workload after each experimental task. We measured workload in each task and the overall workload of all tasks to assess how much workload was experienced when operating both the keyboard and touch screen. Participants rated workload on six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration.

In table 3.1 an overview of the measured variables for both age groups is shown.

Table 3.1. Overview of the variables that were measured before, during and after the experiment in both age groups.

	Younger group (N=10)	Older group (N=11)
Email task & web task	reading time first selection second selection total selection time errors	reading time first selection second selection total selection time errors workload
Typing task	reading time letter input times errors	reading time letter input times errors workload

Computer use

We used questionnaires before and after the experiment. In the first questionnaire we assessed the participants' computer experience and their use of input devices. After completing the experimental tasks a questionnaire was conducted to determine which input device was preferred by the older adults in the touch screen condition.

3.4 Procedure

The experiments with the older adults took place in a Visio location in a room that was adapted to the optimal light conditions for each older participant. The experiments with the younger adults took place in a well-lit room.

We first conducted a questionnaire to assess earlier experience with input devices and computer use of the participant. Participants were seated in front of the touch screen computer equipped with or without a keyboard, depending on the condition they were assigned to. All participants were given a brief introduction to the use of the input device in the experiment.

They then received training in operating each of the following control elements [1] buttons, [2] list, [3] radio-buttons. Participants completed three consecutive blocks of twenty trials (twenty trials for each control element). The task interfaces used for the practice trials are depicted in figure 3.5. The task goal in all practice trials was to select the correct target item as fast as possible. The training was finished after the participant completed all sixty trials.

Following training, participants performed three main tasks, in a fixed order: [1] email task, [2] web task, [3] typing task. In the email and web task the participant had to complete a selection task in which two randomly chosen targets had to be selected in each trial. In the email task the participant had to select an email message in a folder and in the web task the participant had to select a news item in a news category. And finally, in the typing task the participant had to type in a randomly chosen word in each trial. Each task contained thirty trials.

Participants were asked to complete the tasks on their own and were instructed to perform as fast as possible without making errors. If necessary, participants were given instructions on how to operate the control elements and complete the selections on the first five trials. At the end of each experimental task there was a short break in which the older participants filled out the NASA-TLX form.

After the experiment we conducted a final questionnaire to determine which input device was preferred by the older participants in the touch screen condition.

3.5 Statistics

The experiment was conducted as a between-subjects design. We chose this design because a within-subjects design would have resulted in carryover effects (fatigue in one condition affecting performance in another condition).

The independent variables were age (younger and older adults) and input modality (keyboard, touch screen). Dependent variables in the email and web task were task execution times (reading time, first selection time, second selection time and total selection time), errors and workload (older participants). Dependent variables in the typing task were task execution times (reading time, letter input times), errors and workload (older participants).

Because our research design had multiple independent and several dependent variables a multivariate analysis of variance (MANOVA) would have been the appropriate statistical test procedure. However, since the sample size in each cell was smaller than the number of dependent variables and the data showed multiple outliers which caused non-normality (and impact on the type I error rate), the MANOVA test is not appropriate for our analysis. Therefore the Mann-Whitney U test, a distribution-free procedure, was used for the task performance data. The workload (NASA-TLX) data, however, was normally distributed. Thus, to asses differences in the NASA-TLX scores for the two input device groups we used an independent samples t-test.

4. Experiment: Results

Task performance measures for the three main experimental tasks (email, web and typing task) were analyzed, with input device and age group as between-subjects factors. The emphasis was on the older group and on input device differences in performance. Data from two older participants, one in the touch condition and one in the keyboard condition, were deleted from the analysis because of their inability to complete the training.
The group of younger adults served as a control group. From the total of 30 trials per task per participant, the first five trials were counted as practice trials and were not analyzed. From the remaining 25 trials only the correct trials were analysed.

4.1 Questionnaire

Participants in the older group were novice computer users but had experience using a Windows-PC using a keyboard, typing with a keyboard and using Microsoft Outlook and/or Windows Mail. The older group used a computer ranging from 3 to 21 hours per week ($M = 9.6$, $SD = 5.6$) and made use of magnification software (at the Visio computer training and at home) set to a maximum enlargement of 400% by their computer trainer. Although all the participants in the older group only used a keyboard as an input device at the computer training at Visio, 64% of the participants ($n=7$) also used a mouse on their computer at home. Furthermore, one participant (assigned to the keyboard condition) also used a touch screen equipped tablet at home.
The younger adults used a computer, on average, for 25.5 hours a week ($SD = 13.2$) ranging from 6 to 45 hours per week. All participants had some experience using a touch screen device and 40% ($n=4$) used a touch screen device (smartphone and/or tablet-PC) on a daily basis. However, none of the younger participants ever used an all-in-one touch screen PC, as used in the experiment.

4.2 Speech support

Because some of the participants in the older group also used speech support in the Visio computer course there was a possibility to turn on speech support in the experiment. Two participants in the keyboard condition used speech support. The task execution times of the two older adults who used speech support showed some differences with the other participants in the keyboard condition. In the email task the task execution times of the participants with speech support had less variance and were slightly lower. In the web and typing task the task execution times of the participants with speech support had more variance and were higher. However, a Mann-Whitney U test showed no significant differences between the task execution times of the subjects who used speech-support and the subjects who did not use speech-support in the email, web and typing task. Therefore we analyzed all the data of the older adults in one group.

4.3 Missing data

Unfortunately, in certain cases keystrokes and corresponding reaction times in the keystroke files were not stored. However, if the keystroke of the first target was saved in the keystroke file, but the keystroke of the second target was not, we were able to calculate the reaction time of the second target. This was done by subtracting the reaction time for the first target of the total selection time. However, if the reaction time for the first target is not stored in the keystroke file, the reaction time for the second target could not be calculated. The number of missing values per task are therefore the number of trials where the first and second target could not be calculated. Table 4.1 provides an overview of the percentage of missing values for the task execution times.

Because there was only a small loss of data in the email task (6-8% of the total correct trials) the analyses will also include the selection times of the first and second target. However, in the web task 20-25% of the total correct cases were missing for these task execution times. Because of this large loss of data in the web task, only the total selection time and the reading time (which had no missing values) were used as dependent variables in the web task. The typing task had no missing values.

Table 4.1. The percentage of missing values of the total correct trials per experimental task for the task execution times after reconstructing the selection times (first selection time, second selection time, reading time and total selection time).

	First and second selection				Reading time and total selection time			
	Younger		Older		Younger		Older	
	Correct trials	% missing	Correct trials	% missing	Correct trials	% missing	Correct trials	% missing
Email	248	6.0%	256	19.7%	248	0%	248	0%
Web	249	7.8%	265	25.3%	249	0%	249	0%
Typing	247	0%	238	0%	247	0%	247	0%

4.4 Errors

An error in the selection tasks (email and web) was classified as an incorrect selection (the selected items did not match the targets) and in the typing task as a mistyped word or omitted word (pressing the return key before a word was entered. An overview of the percentage of errors over all participants is shown in table 4.2.

The participants in the older group had the highest percentage of incorrect responses, compared to the younger group. The percentage of incorrect trials of the older participants in the keyboard condition was 7.5% over all trials and experimental tasks, versus 8.2% in the touch screen condition. The lower percentage of errors in the keyboard condition is mainly due to the typing task, in which less errors were made when using a keyboard. Older adults using a touch screen in the typing task had an error percentage rate which was roughly twice as large compared to the keyboard condition. The percentage of errors made in the selection tasks (email and web task) were lowest for the touch screen condition, 4.7% and 2.7% respectively versus 9.6% and 4.8% in the keyboard condition. The percentage of errors made in the younger group were negligible.

We conducted a Mann-Whitney U test to test for significant differences between the amount of errors made in the keyboard and touch screen condition. We found no significant effect of input device on the amount of errors made in any of the three tasks separately or on the total errors made over all tasks, for both the younger and older adults.

Table 4.2. The percentage of incorrect trials (of the total number of trials) per input device for the three experimental tasks over all participants.

	Younger				Older			
	Keyboard		Touch screen		Keyboard		Touch screen	
	Total trials	% incorrect	Total trials	% incorrect	Total trials	% incorrect	Total trials	% incorrect
Email	125	.01%	125	.01%	125	9.6%	150	4.7%
Web	125	0%	125	.01%	125	4.8%	150	2.7%
Typing	125	.01%	125	.02%	125	8.0%	150	17.3%
Sum	375	.005%	375	.01%	375	7.5%	450	8.2%

4.5 Email task

4.5.1 Keyboard versus touch screen

Younger adults. The medians of the **reading time**, the time taken to read the target items, in the keyboard and touch screen condition were 1.31 s and 1.26 s, respectively. We ran a Mann-Whitney U test to evaluate the differences in the reading time for both conditions. The effect of input device on the median reading time was not significant in the younger age group.

The younger adults were faster in **selecting the folder and message targets** when using a touch screen, as compared to a keyboard. In the keyboard condition the medians of the folder selection, message selection and total selection time were 2.1 s, 2.4 s and 4.3 s, respectively. In the touch screen condition the medians of the folder selection, message selection and total selection time were 0.9 s, 1.9 s and 2.9 s. All task execution times are depicted in figure 4.1. A Mann-Whitney U test was conducted to compare selection times in both conditions. There was a significant effect of input device on the **folder selection time** (U=0, Z=-2.61, p<.005, r=.83 one-tailed) and on the **total selection time** (U=1, Z=-2.4, p<.01, r=.76 one-tailed). However, the effect of input device on the **message selection** time was not significant.

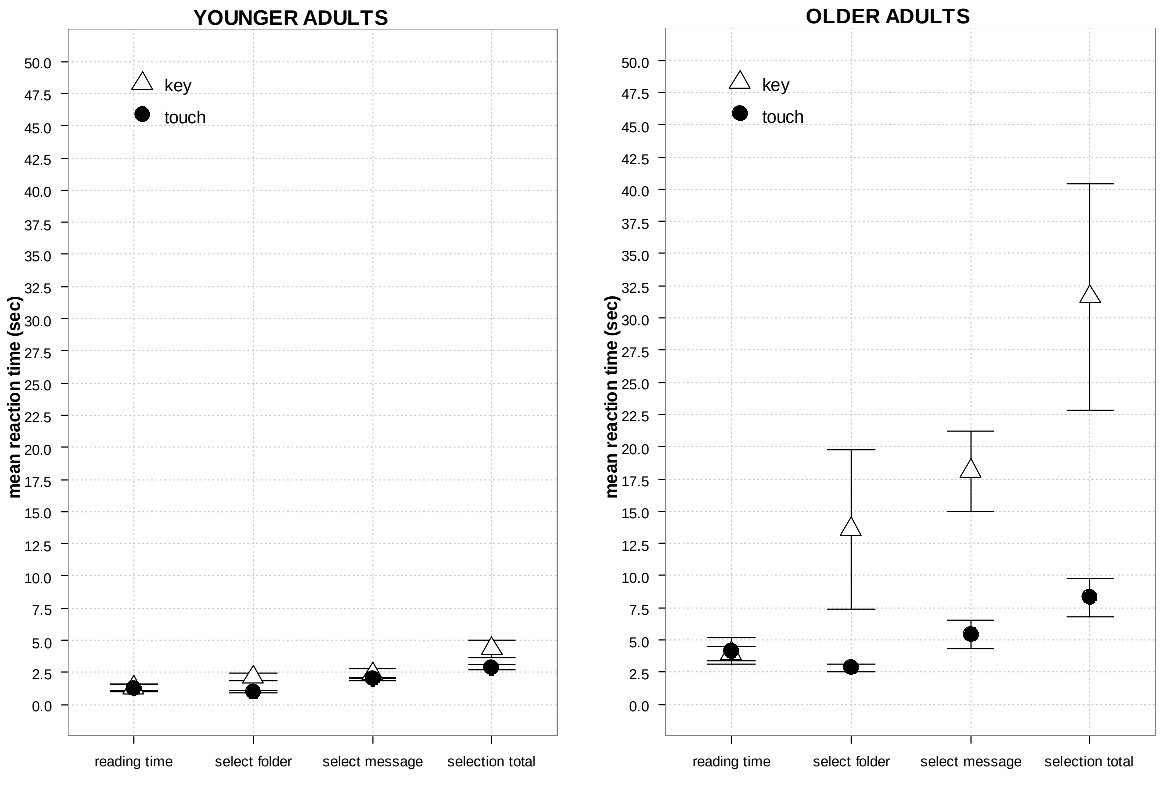


Figure 4.1. Median task execution times (sec) in the email task for the younger and older group. A comparison is made between the keyboard and touch screen condition. Error bars represent standard errors.

Older adults. The medians of the **reading time**, the time taken to read the target items, in the keyboard and touch screen condition were 3.9 s and 4.1 s, respectively. We ran a Mann-Whitney U test to evaluate the differences in the reading time for both conditions. The effect of input device on the median reading time was not significant in the older age group.

The older adults were faster in **selecting the folder and message targets** in the touch screen condition, as compared to the keyboard condition in the email task. The medians of the folder selection, message selection and total selection time were 13.6 s, 18.1 s and 31.6 s, respectively, in the keyboard condition. In the touch screen condition the medians of the folder selection, message selection and total selection time were 2.9 s, 5.4 s and 8.3 s, respectively. A Mann-Whitney U test was conducted to evaluate the hypothesis that older adults would have lower selection times in the touch screen condition as compared to the keyboard condition in the email task. In the older group there was a significant effect of input device on the **folder selection time** ($U=0$, $Z=-2.74$, $p<.005$, $r=.83$ one-tailed), **message selection time** ($U=3$, $Z=-2.19$, $p<.05$, $r=.66$ one-tailed) and on the **total selection time** ($U=0$, $Z=-2.74$, $p<.005$, $r=.83$ one-tailed).

4.5.2 Younger versus older adults

Keyboard condition. In the keyboard condition there was a significant effect of age group (younger vs. older adults), on the **reading time** ($U=0$, $Z=-2.61$, $p<.005$, $r=.83$ one-tailed), on the folder selection time ($U=0$, $Z=-2.61$, $p<.005$, $r=.83$ one-tailed), on the **message selection time** ($U=0$, $Z=-2.61$, $p<.005$, $r=.83$ one-tailed), and on the **total selection time** ($U=0$, $Z=-2.61$, $p<.005$, $r=.83$ one-tailed). The data in the email task showed a large difference in the selection times between both age groups in the keyboard condition. The median total selection time for the older adults was 86% higher than the younger adults'.

Touch screen condition. In the touch screen condition there was a significant effect of age group on the **reading time** ($U=2$, $Z=-2.37$, $p<.01$, $r=.75$ one-tailed), on **folder selection time** ($U=0$, $Z=-2.74$, $p<.005$, $r=.87$ one-tailed), on **message selection time** ($U=0$, $Z=-2.74$, $p<.005$, $r=.87$ one-tailed), and on the **total selection time** ($U=0$, $Z=-2.74$, $p<.005$, $r=.87$ one-tailed). As in the keyboard condition younger adults in the touch screen condition showed again lower selection times than the older adults. Although the differences in selection times between both age groups were smaller. The median total selection time for the older adults was 65% higher than the younger adults'.

4.6 Web task

4.6.1 Keyboard versus touch screen

Younger adults. Median **reading times** for the younger adults in the keyboard and touch screen condition were 1.41 s and 1.35 s, respectively. However, a Mann-Whitney U showed no significant effect of input device on the reading time in the younger age group.
The younger adults were faster in selecting both targets (news category and news item) when using a touch screen, as compared to a keyboard. In the keyboard condition the median total selection time was 4.0 s. In the touch screen condition the median total selection time was 2.1 s. A Mann-Whitney U test showed a significant effect of input device (keyboard vs. touch screen) on the **total selection time** (U=2, Z=-2.19, p<.05, r=.69 one-tailed) in the younger group.

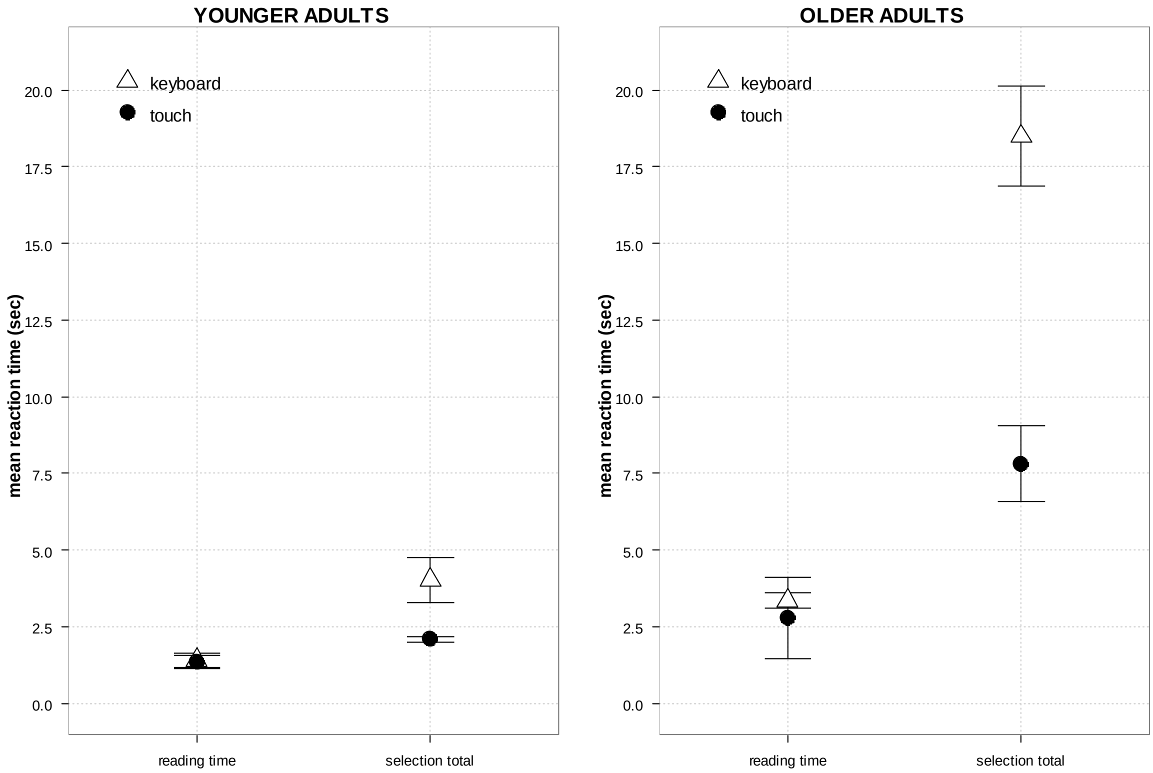


Figure 4.2. Median task execution times (sec) in the web task for the younger and older group. A comparison is made between the keyboard and touch screen condition. Error bars represent standard errors.

Older adults. Median reading times for the older adults in the keyboard and touch screen condition were 3.4 s and 2.8 s, respectively. A Mann-Whitney U test showed, again, no significant effect of input device on **reading time**.
In the web task the older adults showed lower selection times in the touch screen condition, as compared to the participants in the keyboard condition, as shown in figure 4.2. The median total selection time in the keyboard condition was 18.5 s, as compared to 7.8 s in the touch screen condition. A Mann-Whitney U test was conducted to evaluate the hypothesis that older adults would have lower selection times in the touch screen condition as compared to the keyboard condition in the web task. A Mann-Whitney U test showed a significant effect of input device (keyboard vs. touch screen) on the **total selection time** (U=1, Z=-2.56, p<.005, r=.77 one-tailed) in the older group.

4.6.2 Younger versus older adults

Keyboard condition. In the keyboard condition there was a significant effect of age group, on the **reading time** (U=0, Z=-2.61, p<.005, r=.83 one-tailed) and on the **total selection time** (U=0, Z=-2.61, p<.005, r=.83 one-tailed) in the keyboard condition. The median total selection time of the older adults in the keyboard condition was 78% higher than the younger adults'.

Touch screen condition. There was also a significant effect of age group on the **reading time** (U=3, Z=-2.19, p<.05, r=.69 one-tailed) and on the **total selection time** (U=0, Z=-2.74, p<.005, r=.87 one-tailed) in the touch screen condition. The median total selection time for the older adults in the touch screen condition was 73% higher than the younger adults', similar to the keyboard condition.

4.7 Typing task

4.7.1 Keyboard versus touch screen

Younger adults. The median **reading time** for the younger adults in the keyboard was 1.0 s and in the touch screen condition 1.9 s. A Mann-Whitney U showed a significant effect of input device (keyboard vs. touch screen) on the reading time (U=0, Z=-2.61, p<.001, r=.83 one-tailed).
The younger adults were faster typing in the words with a keyboard than with a touch screen. In the keyboard condition the median input times for the first four letters were .4 s, .2 s, .2 s, .1 s. In the touch screen condition the median input times for the first four letters were 3.2 s, .4 s, .3 s and .3 s, respectively. We conducted a Mann-Whitney U test to evaluate the differences in letter input times. We found a significant effect of input device (keyboard vs. touch screen) on the **first** (U=0, Z=-2.61, p<.001, r=.83 one-tailed), **second** (U=0, Z=-2.61, p<.001, r=.83 one-tailed), **third** (U=0, Z=-2.61, p<.001, r=.83 one-tailed) and **fourth letter** (U=0, Z=-2.61, p<.001, r=.83 one-tailed).

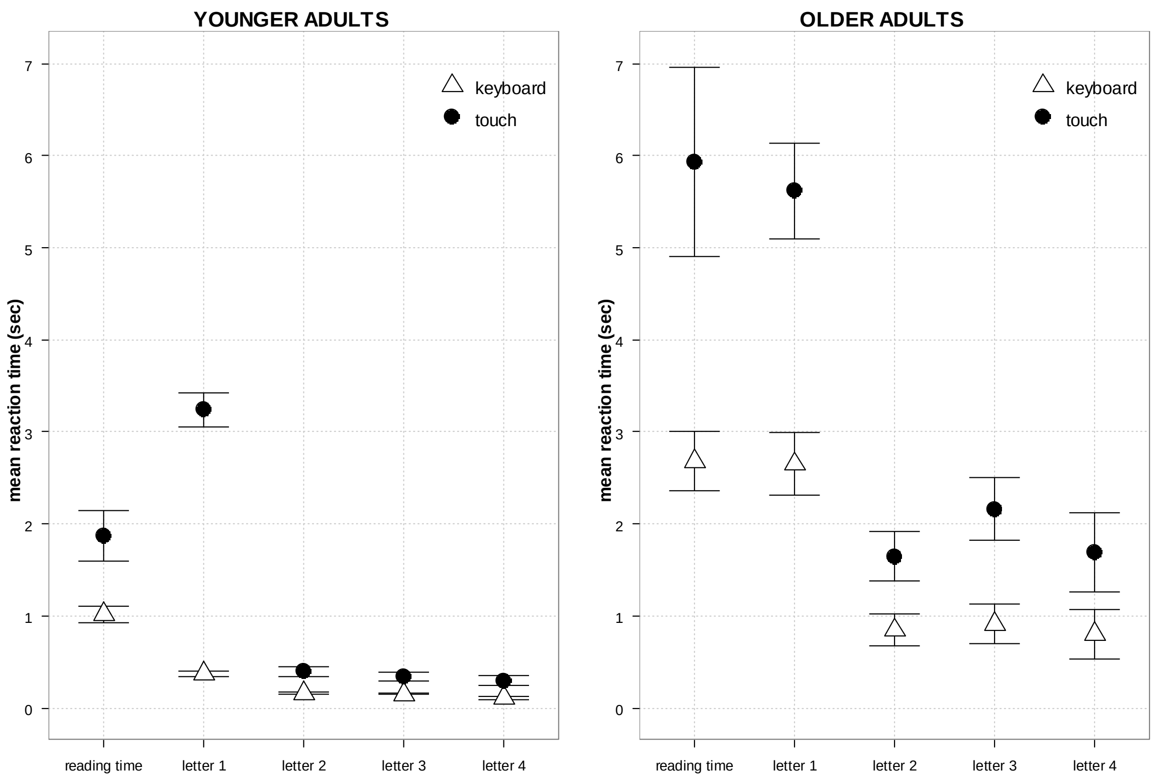


Figure 4.3. Median task execution times (sec) in the typing task for the younger and older group. A comparison is made between the keyboard and touch screen condition. Error bars represent standard errors.

Older adults. The differences in mean reading time and input time for the letters between both input devices and groups is depicted in figure 4.3. The median reading time for the older adults in the keyboard was 2.7 s and in the touch screen condition 5.9 s. However, a Mann-Whitney U test showed no significant effect of input device on **reading time**.
The older adults were, as the younger adults, faster typing in the words with a keyboard than with a touch screen. In the keyboard condition the median input times for the first four letters were 2.6 s, .8 s, .9 s, .8 s. In the touch screen condition the median input times for the first four letters were 5.6 s, 1.7 s, 2.2 s and 1.7 s, respectively.
A Mann-Whitney U test was conducted to evaluate the hypothesis that older adults would have lower letter input times in the keyboard condition as compared to the touch screen condition. A significant effect of input device on the mean input time for the **first letter** (U=1, Z=-2.56, p<.0005, r=.77 one-tailed) was found in the older group. The mean input time for the **second, third and fourth** letter showed no significant effect of input device.

4.7.2 Younger versus older adults

Keyboard condition. In the keyboard condition there was a significant effect of age group, on the **reading time** (U=0, Z=-2.61, p<.001, r=.83 one-tailed), on the **first** (U=0, Z=-2.61, p<.001, r=.83 one-tailed), **second** (U=0, Z=-2.61, p<.001, r=.83 one-tailed), **third** (U=0, Z=-2.61, p<.001, r=.83 one-tailed) and **fourth** letter (U=0, Z=-2.61, p<.001, r=.83 one-tailed). The median input time of the younger adults over all letters was 86% lower than the older adults' in the keyboard condition.

Touch screen condition. In the touch screen condition there was a significant effect of age group on the **reading time** (U=2, Z=-2.37, p<.01, r=.75 one-tailed), on the **first** (U=2, Z=-2.37, p<.01, r=.75 one-tailed), **second** (U=1, Z=-2.56, p<.01, r=.81 one-tailed), **third** (U=1, Z=-2.56, p<.01, r=.81 one-tailed) and **fourth** letter (U=0, Z=-2.739, p<.005, r=.87 one-tailed). The mean difference in input times for both age groups was lower in the touch screen condition.

4.8 NASA-TLX

In the older group the perceived workload in each experimental tasks was assessed by using NASA-TLX scorecards for each older participant. The average overall workload for the participants in the keyboard condition for the email task was 38, out of a maximum score of 100, and for the touch screen condition it was 33. For the web task the average workload score was 34 in both conditions. The overall average workload score for the typing task in the keyboard condition was 33 and in the touch screen condition it was 38. However, independent-samples t-tests for the three experimental tasks separately showed no significant effect of input device on the average overall workload scores, or any of the six factors contributing to the overall workload score.

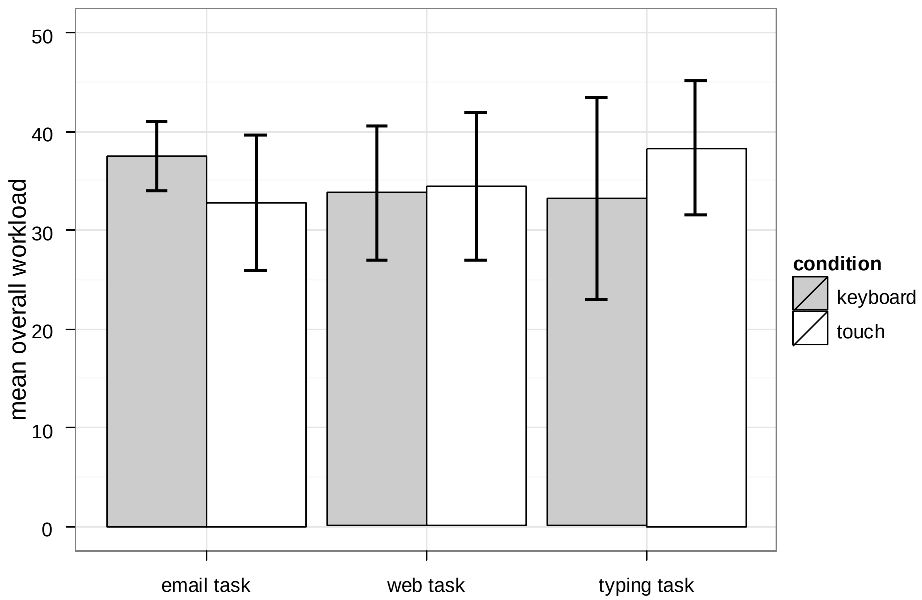


Figure 4.4. The NASA-TLX average overall workload for the three experimental tasks. Error bars represent standard errors.

4.9 Older adults' input device preferences

In the touch screen condition the participants in the older group were asked for their experiences and preferences after finishing the experiment using the touch screen. Four out of six participants in the touch screen condition said that they would prefer using a touch screen instead of a keyboard. The majority of participants who would prefer the touch screen rated it as "more relaxing" and "easy to use", because "you can keep your eyes on the screen, instead of alternating your sight between the keyboard and the screen". One of these four participants rated the touch screen as more fatiguing, as compared to using a keyboard as an input device, because of the required arm movements. Two out of the six participants in the touch screen condition said they would not like to replace their input device and also rated the touch screen as more fatiguing as compared to using a keyboard. Supporting arguments are "I do not want to re-learn", or, "I would like to test it some more before I replace my keyboard".

Four out of six participants in the touch screen condition also noted that typing in words using a touch screen was "difficult", because "keys are harder to find without the (tactile) markers" and "the characters on the keys are smaller".

5. Experiment: Discussion

Selection tasks
Our first hypothesis stated that the older participants have faster selection times when operating the touch screen, compared to the keyboard. We observed that the older adults indeed had significantly faster selection times when using the touch screen, compared to the keyboard, in both the email and web task. We also observed that participants in the touch screen condition had the lowest percentage of errors in the email and web task, about half the percentage of errors in the keyboard condition.
Differences between both input devices, with respect to selection times, were the greatest in the email task. We also observed that in the email task the selection time data in the keyboard condition had the highest variability, compared to the web task. It seems that the use of a keyboard had a negative influence on task performance in the email task, where some older participants had more difficulty using a keyboard in the email task than others. Using a keyboard to complete the email task required the user to remember and execute multiple actions, e.g. pressing a tab key when the folder was selected, which imposes a greater demand on working memory because the user is required to remember the key locations and functions and the number of steps that had to be completed in order to make the selection was increased. Whereas the older participants in the touch screen condition had a more direct form of interaction, which resulted in similar selection times for all older participants, even though these participants had never used a touch screen before.
There was an aspect of the email task in which the use of the touch screen was likely to be more difficult, compared to a keyboard. In the email task the participant was required to first select a folder followed by a message in a list. In the touch screen condition the message selection time was higher than the folder selection time, whereas in the keyboard condition this was the other way around. This is most likely due to difficulties older adults had when operating a scroll bar with a touch screen. A study that we discussed in the ageing and HCI section also concludes that some controls are more difficult to use for older adults, e.g. up/down buttons (Rogers & Fisk, 2000).
It seems that the older participants had less difficulty in completing the web task, as reflected in smaller differences in selection times between both input devices and less variability, compared to the email task. In the web task the participants in the keyboard condition were only required to use the tab and enter key to make the selections and it seems the older participants benefited from the decrease in variety of motor actions and demands on working memory. Another explanation for the increased performance of older participants in the web task could be because the older participants were able to apply a more efficient search strategy, using an optimal order in which to search for target features (Fisk et al., 1997).

Our second hypothesis stated that older participants make fewer errors when operating the touch screen, compared to the keyboard in selection tasks. We did not find any significant differences between the number of errors made in the keyboard condition and the number of errors made in the touch screen condition.

Our third hypothesis stated that the perceived workload of the older participants when operating the touch screen is lower, compared to the keyboard in selection tasks. We did not find any significant differences between the workload scores of the keyboard and the touch screen condition.

Typing task
Our fourth hypothesis stated that older participants can type the fastest when operating the keyboard, compared to the touch screen. Older participants seemed to have greater difficulty typing in words with an on-screen touch keyboard than with a computer keyboard. Although we only found a significant difference between both input devices for the first letter, we observed that the average letter input times and error rates in the typing task were roughly two times higher in the touch screen condition than in the keyboard condition. A cause for the lower typing speeds when using the touch screen is because the touch screen is not as adapted for effective typing as the keyboard. Typing with an on-screen keyboard requires the user to make arm movements to tap on the letters which is physically more demanding. And the touch screen has no tactile feedback which can provide an extra information source when using a keyboard: the sense of touching each key. Another possible cause for difficulties in using the touch screen is inadvertent activation (hovering over the screen which can cause an unintentional response).

Our fifth hypothesis stated that older participants make fewer errors when typing with the keyboard, compared to the touch screen. We did not find any significant differences between the number of errors made in the keyboard condition and the number of errors made in the touch screen condition in the typing task.

Our final hypothesis stated that the perceived workload of older participants when typing with the touch screen is higher, compared to the keyboard. We did not find any significant differences between the workload scores of the keyboard and the touch screen condition.

Caveats

There are some limitations of our study. First, because of missing data we did not have complete information of all participants on all the relevant variables involved in the analysis and this could have resulted in a reduction of precision. Because the sample was small we chose not to exclude the participants with missing data from the analysis. Excluding participants would have resulted in a very significant loss of information and would have a negative impact on the analysis (a greater reduction in the precision of estimation).
Secondly, we used multiple univariate significance tests, in stead of one multivariate analysis of variance. Multiple univariate tests inflate the overall type I error rate and can ignore important information (association between dependent variables).
In order to prevent these limitations we recommend to use a larger sample of older participants and, if possible, create groups of older users on the basis of their visual disorders. If the participants' eye disease (which is a very likely cause for the increased variance in the data of the older participants) is used as a blocking factor this source of variability can be reduced and thus leads to greater precision.
Finally, our experiment only included a subset of all possible computer tasks, that is why we would recommend further research which takes in to account the effects of the computer task on the use of a touch screen.

Conclusion

In this experiment we aimed to assess the ease of use of the keyboard and touch screen for partially sighted older computer users. Our findings confirm that for simple point-and-tap interfaces the touch screen would be preferable over a keyboard for partially sighted older computer users. The touch screen seems to result in the easiest and fastest interaction. This is probably due to reduced demands on working memory by eliminating the number of actions the user has to perform to accomplish a task goal. However, touch typing using an on-screen keyboard seems to be more difficult for partially sighted computer users than using a keyboard which is probably due to an increase in physical demands and the lack of tactile feedback.
Thus, we would advice to use a combination of the touch screen, for simple point and tap actions, and a physical keyboard for typing in text, e.g. when typing an email message.

6. Modelling the older adult

In order to better understand human cognition, cognitive architectures are used to simulate intelligent behaviour. A cognitive architecture is a computer simulation program which incorporates theories about how human cognition works, based on a wide selection of human experimental data (Byrne, 2003, Bothell, 2005).

Cognitive architectures are integrative. They include theories of perception and attention, learning and memory, problem solving and decision making and language processing (Byrne, 2003). In order to perform a certain task the cognitive architecture has to be supplied with task-specific information. The combination of this information and the cognitive architecture is usually referred to as a model. The model incorporates the researcher's assumptions about the particular task. These assumptions can be tested by comparing the model's results with the results of people doing the same task (Bothell, 2005).

Apart from learning more about human behaviour a model can also be used to predict human behaviour. Such a predictive model can be helpful in designing new user interfaces. The usual approach when testing a new interface involves recruiting participants to do tasks with the new interface while their performance is being measured. Such studies are usually time-consuming and costly (Johnsen & Taatgen, 2005). A predictive model, or cognitive model, has several advantages over human participants. It can be used repeatedly to test changes in the interface, or to compare multiple interfaces, and, each small step (e.g. attention shift, encoding information) can be analysed which can help to understand the nature of the task.

As mentioned in the introduction of this thesis, the effects of ageing are currently not part of the ACT-R architecture. Jastrzembski & Charness (2007) were able to develop simplified models at the keystroke-level which accurately predicted performance of older adults by adjusting parameter settings. That is why it is hypothesized that by adjusting parameter settings in ACT-R the performance of the partially sighted older adult can be accurately predicted.

In order to provide evidence for the hypothesis described we developed models of keyboard and touch screen performance in the email task from the experiment. In this chapter we first introduce ACT-R and discuss the modelling process. We conclude with the presentation of the model results and the discussion of these results.

6.1 The ACT-R Theory

ACT-R (adaptive control of thought-rational) is an influential cognitive architecture, which has been used to model a variety of tasks. Within the architecture models were developed which simulated part of these tasks: learning a language (Taatgen & Anderson, 2002), driving a car (Salvucci, 2006) and using graphical interfaces (Chikhaoui & Pigot, 2008). Each model differs only in the way facts and skills that are relevant for the task are programmed. In ACT-R there are two types of knowledge: declarative and procedural.

Declarative knowledge in ACT-R is represented in terms of chunks: factual pieces of information. Each chunk is composed of slots and associated values which provide the chunk with properties, for example, the sum of three and two is five.
Procedural knowledge is represented by production rules. A production rule consists of "if then" conditions and actions to specify how to retrieve and use the declarative knowledge. If the condition of the production rule is true the specified action for the production is executed. An action is a particular operation, for example, a keystroke or an eye movement. Each production is regarded as being a basic step of cognition (Anderson & Lebiere, 1998).

The environment with which a model interacts is called a device (Bothell, 2005). Typically it is a computer: the model is virtually sitting in front of a monitor and operates a keyboard and a mouse. ACT-R/PM was developed as a separate system for ACT-R providing the model access to an external world through a vision, motor, speech and an audition module (Byrne, 2001). These modules are now fully integrated with ACT-R version 6 and provide the ACT-R model with a way to interact with a device. The vision and motor modules were used to model the partially sighted older adults.

Vision module

The vision module provides the model with information of what can be seen in the current device and also models visual attention (Bothell, 2005). The vision module comprises two subsystems, a "where" and a "what" system. The where system is used to find a location. It can take requests with constraints (colour, location, whether the location has been attended to) and returns a chunk which meets these constraints. The what system shifts attention to the visual location, which is provided by the where system, and processes it. A chunk representing the visual object is placed in the visual buffer.

The default vision module of ACT-R does not model eye movements. Therefore Salvucci (2001) developed EMMA (Eye Movements and Movement of Attention) as a way of modelling eye movements and shifts of attention. EMMA is a system which was built as a replacement for the default vision module of ACT-R and is not part of ACT-R version 6. The default vision module in ACT-R assumes that encoding time is constant for all visual objects and shifts of attention are not affected by eye movements. EMMA distinguishes between eye movements and shifts of attention and provides a better account of eye movements and visual encoding. First, the new visual object requires a visual attention shift to encode the object in a visual representation. The visual encoding time (T_{enc}) in EMMA is influenced by the eccentricity (ε_i) and the frequency of occurrence of the visual object (f_i) and by two constants: the encoding factor (K) and the encoding exponent (k):

$$T_{enc} = K \cdot \left[-\log f_i\right] \cdot e^{k\epsilon_i}$$

The frequency and eccentricity of the visual object is based on research in the domain of reading. Salvucci (2001) discusses research that showed that readers spent less time looking at frequent words than infrequent words and that words that are farther in the periphery, with greater eccentricity, take more time to encode. Thus, encoding time increases when the visual object's eccentricity increases and as object frequency decreases.
The second component in the EMMA model calculate eye movements. Eye movements in EMMA run through two stages: preparation and execution. Preparation time is set as a fixed parameter of 135 ms. The execution time of an eye movement is based on multiple factors, including a saccade execution time of 20 ms and an additional 2 ms for each degree of visual angle subtended by the saccade (the longer the saccade the greater the execution time).

Motor module

The motor module functions as the model's hands (Bothell, 2005). Default devices in ACT-R are a virtual mouse and keyboard. The virtual keyboard has a two-dimensional button layout which can be utilized to model, for example, a downstroke with the index finger of the right hand on the enter key. The virtual mouse is an one-button device located right of the keyboard and is operated by the model's right hand. The amount of time that a movement takes to execute depends on the type of movement and the distance of movement. Simple movements have a minimum movement time (e.g. pressing a key that is directly below the finger) and more complex movements (moving the hand or mouse) have a longer execution time based on Fitts' Law (Bothell, 2005):

$$T = b \cdot \log_2\left(\frac{D}{W} + 0.5\right)$$

where T is the time of the movement in seconds, the b parameter is dependent on the type of motor action which can be used to model the pointing time, D is the distance to the target (inch) and W is the width of the target (inch).

6.2 The exhaustive search model

In this section the modelling process of the email task from the experiment (chaper 3) is presented. ACT-R models were developed for both conditions from the experiment (keyboard and touch screen), emphasizing the perceptual and motor parts. The initial ACT-R models that were developed tried to fit the younger user data, without adjusting the default parameter settings. To model the effects of ageing and low-vision, parameters were adjusted to fit the user data of the older adults. Figure 6.1 shows all the steps the models need to perform to accomplish the email task.

Task analysis

The participant had to select a target message in a target folder. The first goal in the email task was to read the folder and message target. The interface of the email task is simulated using a virtual display in the Lisp environment. At the start of the trial the model is presented with a random target folder and target message in the visual interface. The targets are presented in an entire sentence, e.g. "select 'Tom' in the 'Inbox'", but the model only reads both target words from the display. The experimental data showed that it is likely that participants only fixate on the two target words in the sentence. If the model were to read all the words in the sentence it would not match the experimental data.

To encode the targets ACT-R uses the vision module to find and attend the targets which are located at fixed visual locations. Chunks for the visual location and text of the target items are stored. When both target items are encoded the model presses the start-button. After the start-button has been pressed the virtual display is cleared and the folder and message items are presented, as depicted in figure 6.2.

The second goal is to find and select the target folder. Visual search is exhaustive in that every unattended item will be examined from top-to-bottom in a restricted visual area. A chunk of each attended folder item is stored in the imaginal buffer and is labelled as "attended". The model retrieves the target folder from declarative memory and compares it to the currently selected folder item. If the current folder item matches the target folder the model presses the folder item to open it. If no match is found the model will return to step 2.1 to find the next unattended folder item.

In the third and last goal the model will try to find and select the target message in a list. The first four steps are identical to the first four steps in the second goal. If the current message item is not the target message (there is no match found) the model will go to the next message item. In the keyboard model an arrow-down key press is required to select the next message item; the model virtually goes down one item in the list (step 3.5). If there is a match between the current message item and the target message the keyboard model will switch to and press the next-button which will complete the trial (steps 3.6 and 3.7). If the target message is found the touch screen model has to select the message first by pressing it (step 3.5). Subsequently pressing the next-button completes the trial.

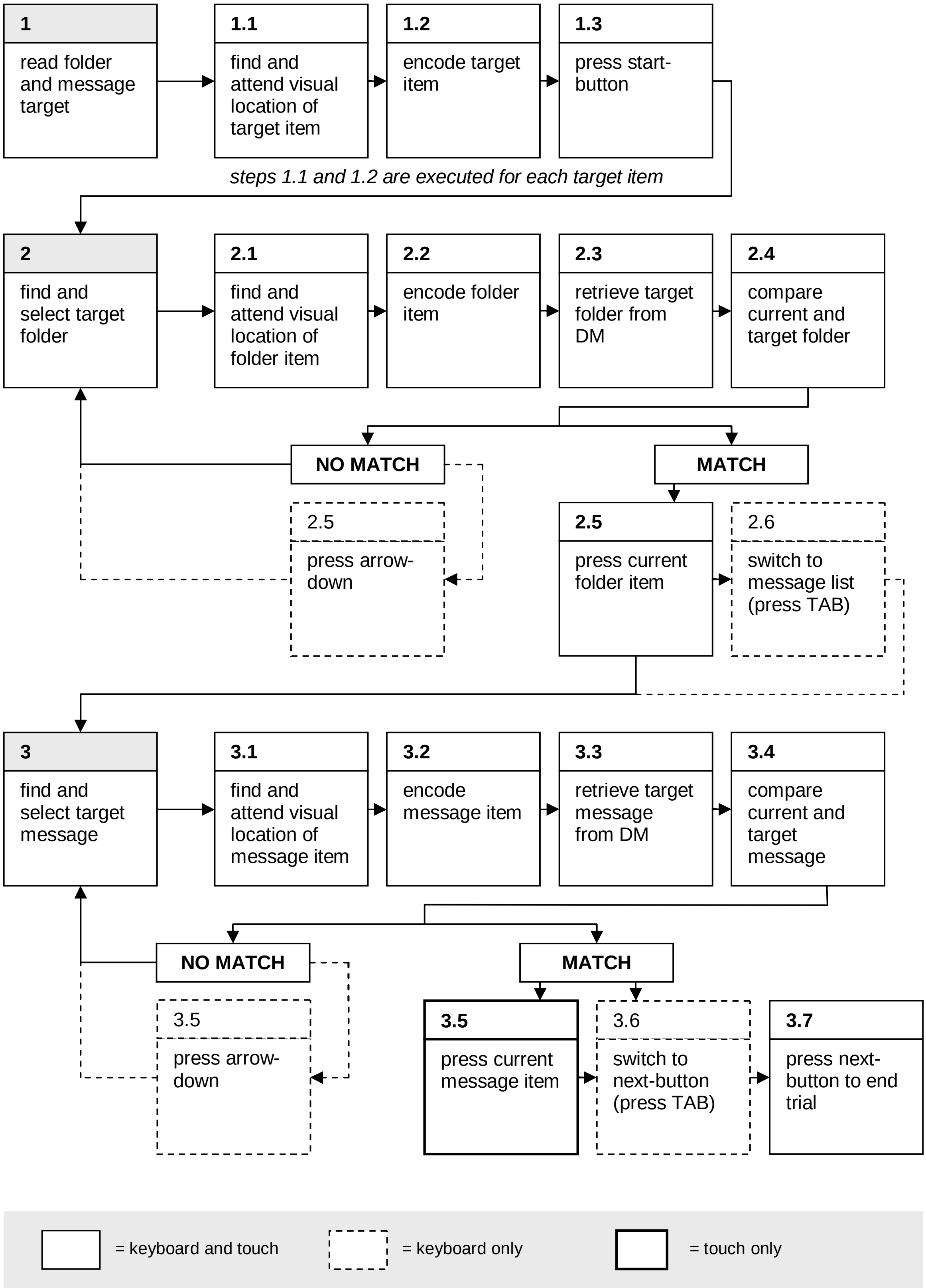


Figure 6.1. Hierarchical Task Analysis of the email task for the keyboard and touch screen model. The (motor) steps that are only executed in the keyboard model are depicted with dashed lines and the steps that are only executed in the touch screen model with thick lines.

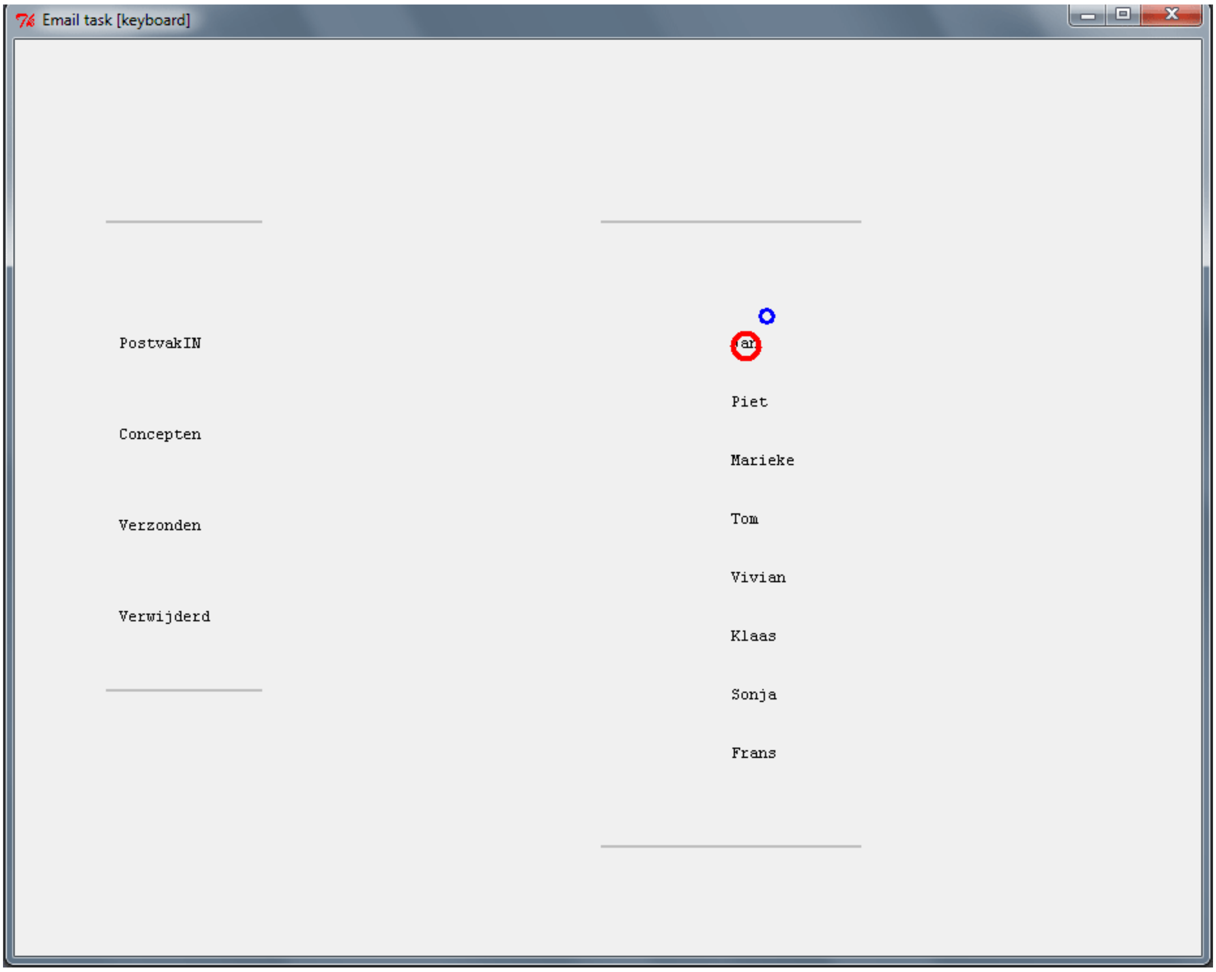


Figure 6.2. The virtual display of the ACT-R model. The red circle represents the location of the model's visual attention, the blue circle represents the model's eye movements (EMMA).

The motor phase differs in the keyboard and touch screen model. All motor actions in the keyboard model are executed by using ACT-R's virtual keyboard. Participant's behaviour is simulated by setting the initial position of the left hand on the *tab* key and the right hand on the *enter* key. Two types of movement were used in the keyboard model: a "punch" and a "peck-recoil". A punch movement is a simple downstroke followed by an upstroke of a finger for pressing a key that is directly below a given finger (Bothell, 2005). The peck-recoil movement is a directed movement of a finger to a location followed by a keystroke, after which the finger moves back to the location at which it started its movement (Bothell, 2005). In the keyboard model punch movements are used to press the enter and tab key and peck-recoil movements to press the arrow-down key.
In the touch screen model all motor actions are executed by the virtual mouse device, because there is no touch screen device available in ACT-R. However, it is assumed that the default mouse device is sufficient to simulate a touch screen interface, because, from a visual standpoint there is no difference between a touch screen and a normal computer display. The existing mouse-based actions provide an acceptable simulation of pointing at a touch screen, because ACT-R's mouse movement timing is determined by Fitts' Law which also governs pointing actions.
To use the virtual mouse the initial position of the right hand is set on the virtual mouse location (next to the virtual keyboard). A motor action resulting in a tap on the screen is simulated by a "move-cursor" and a "click-mouse" movement. The move-cursor moves the virtual mouse to a given location in space and the click mouse action results in a punch action by the right index finger on the primary mouse button. The assumption however is that the finger is essentially only moving in the plane of the screen, the model does not pull the hand away and towards the screen.

In the keyboard model of the email task the model requires additional motor actions, as depicted in figure 6.1. Selecting the next folder or message item requires an arrow-down key press (steps 2.5 and 3.5) and switching between elements a tab key press (steps 2.6 and 3.6).

6.3 Parameters settings older computer user

The keyboard and touch screen model for the younger adults use the default parameter settings. These younger adult ACT-R models were developed to accurately simulate the email task and served as baseline models. To model the effects of ageing and low-vision a number of parameters were adjusted in these baseline models to fit the performance of the older computer user, as shown in table 6.1.

Table 6.1. Adjusted parameter settings for the partially sighted older computer user.

parameter	information	default value	set value
:dat	The default action time specifies the time it takes to fire a production	50 ms	56.5 ms
:imaginal-delay	controls how long it takes a request or modification request to the imaginal buffer to complete	200 ms	280 ms
:visual-encoding-factor	[K] constant, scales the encoding time	0.01	0.1
:visual-attention-latency	Controls how long a visual attention shift will take in sec	85 ms	180 ms
:eye-saccade-rate	2 ms for each degree of visual angle subtended by the saccade	2 ms	8 ms
:saccade-base-time	The saccade execution time	20 ms	80 ms
:visual-object-freq	[fi] constant, default visual object frequency	0.01	0.008
:motor-burst-time	Minimum time required for the execution of any motor module movement	50 ms	146 ms
:peck-fitts-coeff	The *b* coefficient in Fitts' Law equation for the timing of peck style movements (keyboard model).	75 ms	175 ms
:mouse-fitts-coeff	The *b* coefficient in Fitts' Law equation for aimed movements which is used when the model moves the mouse cursor.	100 ms	175 ms

The default action time reflects the information processing speed, like the processor cycle time in another cognitive architecture called EPIC (Meyer, Glass, Mueller, Seymour & Kieras, 2001). Meyer et al. (2001) set the mean cognitive processor cycle time to 56.5 ms, about 13% longer than that of younger adults. An increase in the time it takes before the imaginal buffer takes a request reflects a greater difficulty for the model to create and hold task relevant information. The 'imaginal-delay' parameter was determined by fitting the model data with the user data. Both parameters were set to reflect an age-related decline in working memory.

Because the material used in the email task is not conceptually difficult the limiting factor for the selection time seems to be the eye-movement rates and how much the user takes in with each fixation. Because the participants were partially sighted adults it is assumed that their visual impairments causes them to make many eye movements to perceive visual objects from the screen, because central vision could be impaired or because of other visual impairments. As depicted in table 6.1 there were multiple parameters adjusted to simulate an increased difficulty to perceive visual information and increase visual search times.
The saccade execution time was increased to match results from Scialfa & Joffe (1997), which showed that the greatest number of older adult's saccadic reaction times were above 300ms. The saccade-rate was increased to reflect a decline in saccadic velocity with age (Munoz et al., 1998; Schieber et al., 1991).
Impairments that cause greater difficulty reading and locating information, e.g. a decline in visual acuity and contrast sensitivity (Jackson & Owsley, 2003), are reflected in a decrease in the default frequency of visual objects (making them less salient) and an increase in the time it takes to complete a visual attention shift. The visual encoding time was determined by fitting the model data with the user data.

Finally, two parameters were adjusted to simulate an age-related decline in the performance of motor skills. In a meta-analysis Jastrzembski & Charness (2007) calculated the mean motor processor cycle time, the time required to initiate a motor response, to be 146 ms for older adults, as compared to 70 ms for younger adults. And, the movement rate, or the b coefficient in the Fitts' Law to be 175 ms/bit for older adults as compared to a movement rate of 100 ms/bit for younger adults (Card, Moran & Newell, 1983). So, the time needed to execute a motor movement was increased to 146 ms and the movement rate was increased to 175 ms.

6.4 Exhaustive search model results

R^2 and RMSD (root-mean-square deviation) values were calculated to assess the goodness-of-fit between the user data and the model data in the email task. R^2, or the square of the correlation ratio, expresses the correlation between the model and the data. The RMSD is a distance measure and a good measure of accuracy. Four data points were analyzed for each model which correspond with the average reading time, folder selection, message selection and total selection. The results of the keyboard and touch screen models are displayed in figure 6.3 and 6.4. Note that we compared mean values here rather than the median values we used in the experiment (chapter 4).

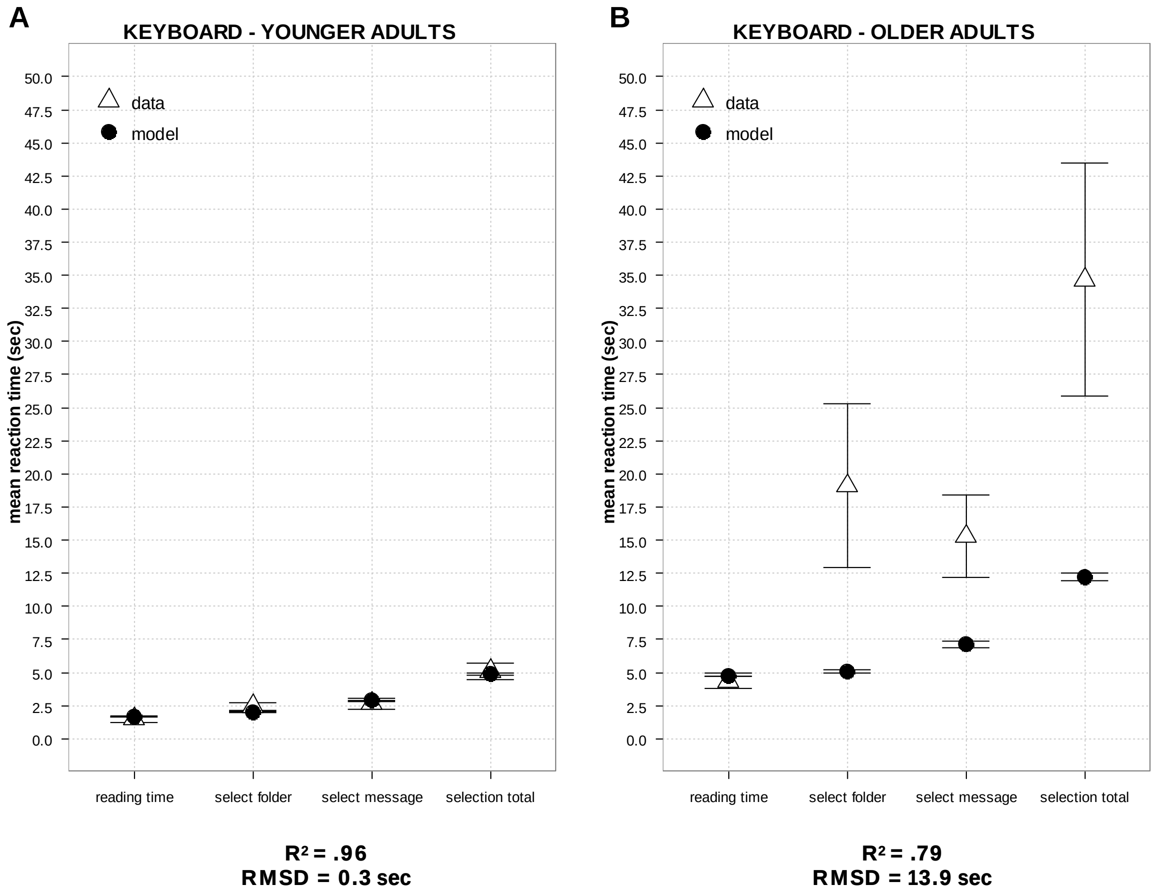
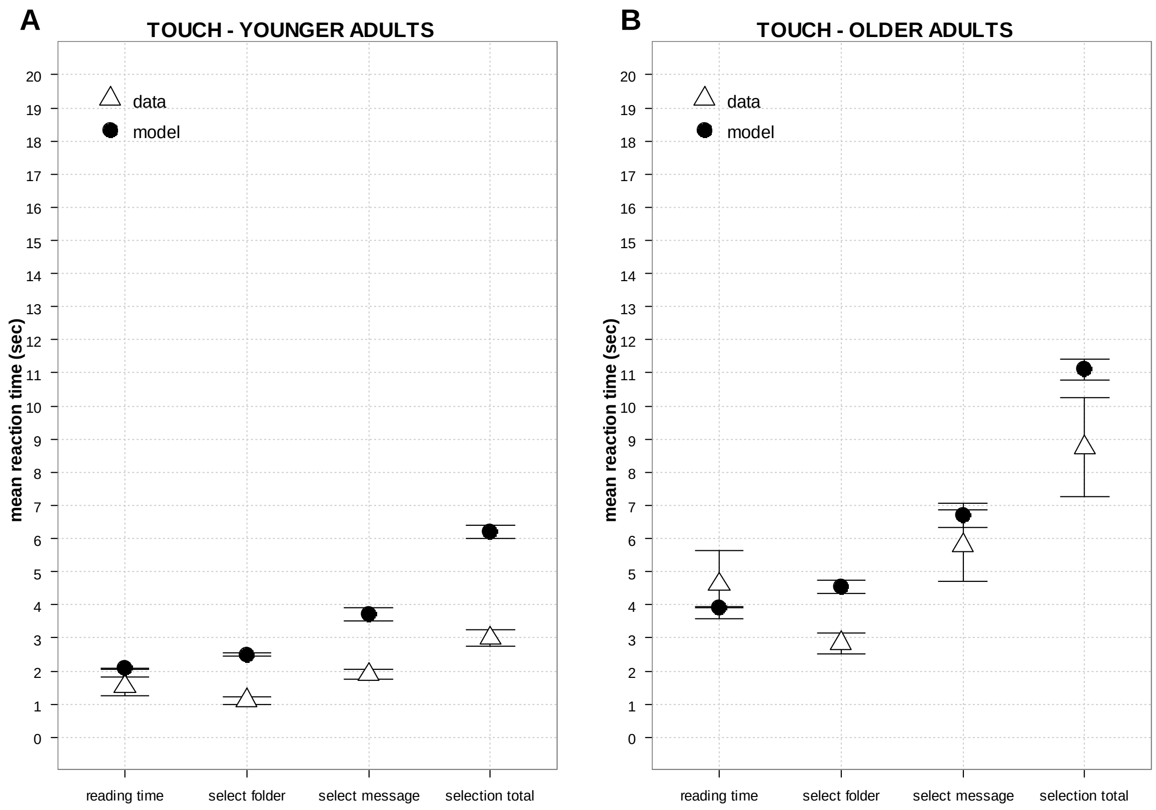


Figure 6.3. Mean task execution times of the model and human data in the keyboard condition using an exhaustive search strategy. Panel A: ACT-R model fits for the keyboard model for younger adults. Panel B: ACT-R model fits for the keyboard model for older adults. Error bars represent standard errors.

The keyboard model of the young adults shows a good fit. R^2 and RMSD values show a high correlation and a small distance between the user data and model data. However, the RMSD between the older adult model data and the user data reveals a rather large difference.



R^2 = .91
RMSD = 1.9 sec

R^2 = .86
RMSD = 1.6 sec

Figure 6.4. Mean task execution times of the model and human data of the touch screen condition using an exhaustive search strategy. Panel A: ACT-R model fits for the touch screen model for younger adults. Panel B: ACT-R model fits for the touch screen model for older adults. Error bars represent standard errors.

Although the touch screen model data for the younger adults shows a high correlation with the user data, the RMSD reveals that the model is a lot slower than the younger adult human participants. The selection time data shows that the model is about two times slower than the human younger adults.

The older adults model results also show a high correlation with the data of the human older adults. The older adult model is, like the younger adult model, slower in making the selections than the (older adult) human participants. However, the distance is slightly smaller, with a RMSD of 1.6 sec.

The difference in selection times for the model data and the user data is probably because the model checks every item until the correct one is found. In other words, visual search is exhaustive. However, as Nilsen (1996) discussed, the nature of the search process changes with the experience of the user. Especially for younger adults, with a greater experience in using a computer, a direct search strategy (where users fixate immediately on the desired menu item) could result in a better fit.

6.5 Direct search

The touch screen model, like the keyboard model, simulates an exhaustive visual search process in selecting items. Selection times for the menu items increase linearly on the basis of serial position.
In the keyboard condition the task requires the user to press keys on the keyboard and observe the result on screen. Information from the visual search is needed in order to know which key to press subsequently. However, when a selection is made using a touch screen, the movement can begin before the visual search is completed, on the basis of partial information (Nilsen, 1991). It is therefore possible for a user to move a hand towards the touch screen while searching for the correct item to select. This may result in a faster, "direct search", which produces similar reaction times for all items in the email task.

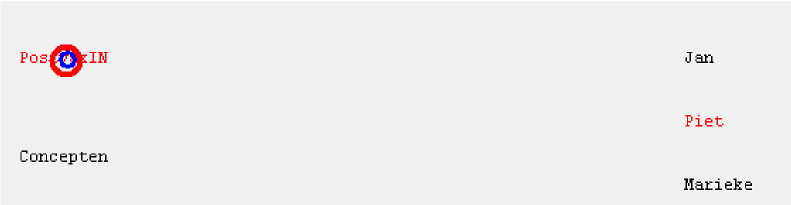


Figure 6.5. A screenshot of the target items in the direct search ACT-R model.

The touch screen ACT-R model is modified so that it selects the target items immediately, in stead of checking each item serially. In the developed direct search model the folder and message item that have to be selected are coloured red, as depicted in figure 6.5. A constraint is added to the visual location buffer that causes the ACT-R's visual system to only attend text that is coloured red.

6.5.1. Direct search model results

The results of the direct search touch screen model for younger and older adults are displayed in figure 6.6. R^2 and RMSD measures reveal that a direct search strategy results in a better fit between the model and user data for younger adults. The R^2 value increased from .91 to .95 and the distance between the user data and model data, as measured by the RMSD, was decreased from 1.9 sec to 0.5 sec for the younger adult model fit.

For the older adults the R^2 value, or the proportion of variability in the user data that is accounted for by the model data, increased slightly from .86 to .88. However, the RMSD increased from 1.6 sec to 2.6 sec.

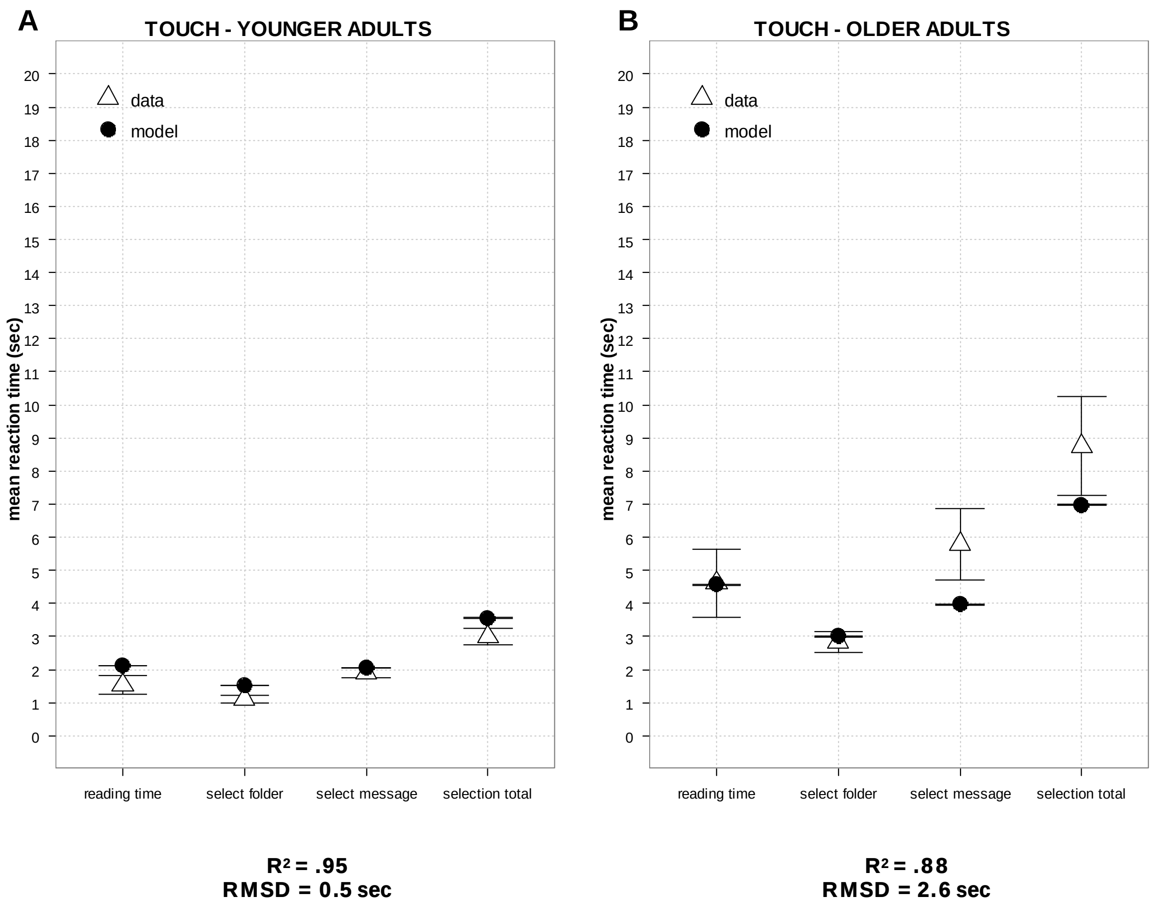


Figure 6.6. Mean task execution times of the model and human data of the touch screen condition using a direct search strategy. Panel A: ACT-R model fits for the touch screen model for younger adults. Panel B. ACT-R model fits for the touch screen model for older adults. Error bars represent standard errors.

6.6 Discussion

We hypothesized that by adjusting parameter settings in ACT-R the performance of the partially sighted older adult can be accurately predicted. The ACT-R models we developed provided reasonable to good fits of the user performance obtained in the experimental task.

The keyboard model that used an exhaustive search strategy, without parameter-settings, showed a good fit with the younger adult human data. Our ACT-R keyboard model seems to confirm that the use of a keyboard resulted in an exhaustive search strategy in the email task. Because information from visual search is needed in order to know which key to press subsequently, the participant in the keyboard condition had to observe the output (e.g. the active element) on screen resulting in an forced exhaustive search strategy. In other words, every unattended item was examined by the participant in a serial order.

We also observed that the exhaustive search keyboard model with the ageing parameter settings was less able to explain the human data than the baseline keyboard model (younger adults). The ACT-R model of the older participants showed a rather large difference between model and human data. This could be because the older model did not account for the large individual differences in the older participant data. The ACT-R model always selects the target in a single try, without skipping the correct item. Whereas the older human participants, probably, did not always use such a systematic search. It is very likely that older participants searched the same place more than once until they selected the correct item. As mentioned in the Ageing and HCI section, the nature of the search process changes with the experience of the user (Nilsen, 1991) and less experienced users take a long time searching for items. This reduced performance in visual search tasks may be because older adults use less efficient search strategies (Fukuda & Bubb, 2003), which are likely caused by visual impairments and attentional deficits (Owsley et al., 1994) because older adults are less able to inhibit irrelevant stimuli, compared to younger adults (May, et al., 1999; Hasher & Zacks, 1988).

In contrast to the keyboard model the touch screen model using an exhaustive search strategy resulted in a large difference in performance between the model and the younger adult data. Because the task performance of the touch screen model (slower selection times) could well be explained by the use of the exhaustive search strategy we modified the ACT-R model to use a direct search strategy. The direct search strategy resulted in a very good fit between the touch screen model and the user data of the younger adults. It seems that the younger adults using a touch screen can result in a direct search strategy where the movement can begin before the visual search is completed, on the basis of partial information (Nilsen, 1991).
Both touch screen models with ageing parameter settings, using the exhaustive and direct search strategy, showed a good fit with the human data of the older participants. This may imply that the older participants used different visual search strategies, some more effective than others. Although the biggest difference in selection times between the model data and human data of the older participants using the direct search strategy was observed in the message selection and total selection time, which is likely caused by the absence of a scroll bar in our ACT-R model of the email task. Whereas the human participants in the email task had to use a scrollbar to select a number of messages and the older user data seems to indicate that they had difficulty using the scrollbar.

Our results show that ACT-R can explain task performance of partially sighted older adults at a good level with adjusted ageing parameter settings. We recommend future eye-tracking research, in which eye movement and eye position are measured, in order to determine if the touch screen does indeed result in a more efficient visual search strategy.

7. General discussion

We tried to assess the ease of use of a touch screen for partially sighted older computer users. We conducted an experiment to compare the use of a keyboard and touch screen in selection tasks and a typing task. Our findings confirm that a touch screen is easier to use than a more traditional interaction device (keyboard) in interfaces that can be operated by point-and-tap actions, what is probably caused by reduced demands on working memory (reduced number of user steps due to a direct form of interaction).
However, when typing we would recommend the keyboard for partially sighted computer users, in stead of the touch screen. Because the keyboard is designed to effectively enter text it has lower physical demands and the keyboard can easily be adapted to partially sighted people.
Because the effectiveness of the input device depends on the task that is being performed, we would advice to use a combination of the touch screen, for simple point and tap actions, and a physical keyboard for typing in text, e.g. when typing email messages.

We also developed ACT-R models which simulated the use of the keyboard and touch screen by the partially sighted older computer user. By adjusting parameters in the ACT-R architecture we were able to simulate the effects of ageing on human processing systems.
The developed ACT-R models suggest that the touch screen resulted in more efficient search strategies for younger and older adults, where the user is able to select the desired item faster. We would advice to use further eye-tracking research to confirm that the touch screen does indeed result in a more efficient visual search strategy.

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