Design of Activation Modules for People Aging in Place and at Long Term Care

by

Henrique Matulis

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in

Inclusive Design

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Abstract

The Canadian population is aging with an increasing proportion of people over the age of 65. Already the number of Canadians over the age of 65 exceeds the number of Canadians under 15. As the population ages, there is an increasing number of people with dementia, and an increasing number of people in long term care. Once individuals enter long term care, they often experience physical and cognitive decline. While there are programs for therapeutic recreation and other activities, they are, at best, only available for a few hours a day, leaving many hours where there is very little to do except watch television, sit or lie around. This research thesis addresses the problem of creating input and output modules that can facilitate technologies for physical and cognitive activation. After motivating the work with an analysis of how activities carried out change as people age (using US timed activity usage data), I then describe the design of a number of modules intended to simplify interactions with technology for elderly users. These modules include a wireless button input device that could control games shown on a tablet or monitor, a driving wheel (using an optical reader for detecting rotation) that can be used as a control device for a driving simulator or for navigating through 360-degree travel videos, and curved displays to provide immersive interactions.

Keywords: Inclusive Design, Design for elders, Design for People with Dementia (PwD), Tangible User Interfaces, Natural User Interfaces, Human Factors, Cognitive activities, Physical activities, Social activities.

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Dedication

For Monika Ivanauskas Gritenas (in memoriam), Augusto Gritenas (in memoriam), Petras Matulis (in memoriam), Zofija Rudokas Matulis (in memoriam), Chrissoula Demetre Athanase Spanoudis (in memoriam),Demetre Spanoudis (in memoriam), Sophia Gritenas Matulis and Henrique Matulis Sr

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Chapter 1 Introduction

Although older people have increasing life expectancy, they often experience difficulty in dealing with unfamiliar new technology. At the same time, when designed appropriately, technology can help to compensate for the declines in perceptual, cognitive, motor and social functioning that often occur as people age. Thus, technologies for “aging well” create exciting opportunities to improve the quality of the longer lives that are being lived. However, technological interactions for the elderly have to be designed carefully to capitalize effectively on their remaining capabilities. My intention with this research was to study the need for activation in the elderly and to propose novel design solutions that can form the basis for interactions with technology that are better suited for older people.

The Problem

Many older people are relatively unfamiliar with modern devices such as smartphones, tablets and computers. They have witnessed successive waves of technological revolution in their lifetimes, from voice message and voice menus to mobile phones and the smart phones, from TVs to VCR, CDs, DVDs, streaming media and so on. Just within computers, there have been massive advances under the inexorable weight of Moore’s law as computers got faster, smaller, and cheaper, while also being better connected and with an ever-expanding range of functions. With each new wave of technology, people advancing through their lives had to learn how to interact with the novel devices they were confronted with.

For many people the devices eventually became too daunting or troublesome, and they opted out, thereby losing access to the functions and capabilities that the new devices provided. This dropping out and disconnection of the elderly has been exacerbated by the fact that current technological devices are designed for the general population and do not explicitly take the needs of the elderly into account. Thus, as devices become more and more optimized for the young, who prize novelty, they become harder for older people to relate to and use. I expect that today's "digital natives" will in their turn find the novel technologies of their old age just as difficult to use as today's elders find today's technologies, but the situation can be improved both for now and the future by designing elder-appropriate interaction devices and methods.

Purpose of the Thesis Research

The purpose of this thesis is to investigate what elders are doing nowadays and explore some technological alternatives to support their life in the activities they actually perform.

Objective

The objective of the thesis is to characterize declining activation in aging through analysis of data from a detailed survey on how much time people spend on different activities at different ages and develop three devices that can potentially support elders doing current activities in a more healthy, productive, interactive, interactive and immersive way.

Rationale

Chronic diseases and disabilities are increasingly prevalent as people age, but the risk of accelerated physical and cognitive decline is much greater when people are physically and cognitively inactive and when they have weak, or absent, social connections. The prevalence of depression increases as people lose functionality and become more socially isolated, and quality of life generally suffers due to the long-term effects of inactivity, declining functional abilities, and decreasing social connection.

Scope and Limitations

Due to the complexity of the subject, this study focused on analyzing how elder Americans spend their time and propose and develop technological interfaces that can be tested and validated in future studies.

Thesis Outline

In Chapter 2 - Background, I analyze how people age, how universal technologies are not a fit for the elders, social and cognitive activities for elders based on technologies and finally existing alternatives for physical and cognitive activation.

Chapter 3 discusses the research strategy followed in this thesis.

Chapter 4 provides an overview of problems related to low level activation, and traces how activity patterns change with aging through analysis of a large set of detailed US activity data.

Chapter 5, 6 and 7 each address a specific interaction problem and show how two input devices, and one output device, respectively can be redesigned so as to better accommodate users and elderly users in particular. Chapter 5 addresses the problem of selection inputs. Chapter 6 addresses the problem of controlling navigation through a 3D space. Chapter 7 addresses the issue of how to make displays more immersive without cutting older users off from the outside world and potentially creating disorientation.

Chapter 8 concludes this thesis with a discussion of the adopted approach, contributions made, and lessons learned. It also discusses limitations of the research and makes suggestions for future work.

Chapter 2 Background

Ageing

According to the US Census Bureau ("Older People Projected to Outnumber Children for First Time in U.S. History," 2018), the population 65 years and older will jump from 60 million to 100 million people in the next 40 years and the population over the age of 85 will more than triple in the same period.

The American Federal Interagency Forum on Aging-Related Statistics (Interagency Forum on Aging-Related Statistics, 2016) reported on wellbeing for older Americans. The report states that more than 50% of people over 65 have at least one chronic disease such as arthritis, diabetes, asthma and chronic bronchitis and emphysema, hypertension, heart disease, and obesity.

The same report states that one fifth of men and one quarter of women over 65 have at least one disability that prevents them for being able to do day-by-day tasks like dressing, washing, understanding, moving, etc. In addition, prevalence of dementia accelerates with age, and is ten times higher in women 85 and over, as compared in women between the ages of 65 and 74. For men the corresponding increase is five-fold in those 85 and older.

For Americans, TV is the most extensively performed activity after sleeping. The time spent watching TV for seniors (people 65 or older) is almost double the amount of time spent by 15-24 year old ("American Time Use Survey: Charts by Topic: Older Americans," 2016). Marcum (2013) showed that, as age increases, people spend less time with others. Thus, increasing use of television may also be a consequence of increasing social isolation.

According to Vaportzis, Giatsi Clausen, & Gow (2017), despite being eager to use technology, elders perceive technology as complex and hard to master. And when technology is mastered, it tends to be used in a sedentary fashion. Natural User Interfaces are intended, as the name suggests, to be natural to use, not requiring older people to learn new skills in order to perform a task.

Although Shneiderman (1991) was correct in predicting that touch screens would be used more and more, with cellphones and tablets replacing computers as the preferred device, a significant part of the elder population does not use touchscreen computing devices.

When Morris, Goodman, And, & Brading (2007) asked elders about factors that would encourage them to learn to use the internet in the future, 60% said "Nothing/will never use it in the future". The second main reason was training (32%) and cost (19%) was the third.

Social and Cognitive Activities

Cognitive abilities decline over time (e.g., (Levy (1994)) and cognitive decline is a predictor of mortality (Tilvis et al., 2004) Socioeconomic status is also a factor as cognition status is related to wealth at time of retirement (McArdle, Smith, & Willis, 2009). Hu, Lei, Smith, & Zhao (2012) conducted a study among 2,685 individuals (45+) and found a positive relationship between social and cognitive activities.

All this evidence directs to the need to provide elders with alternatives to social engagement and cognitive reinforcement.

Physical Exercise and Physical Decline in Aging

Since the study of Hill (1925) about sports performance and age, relationship between age, performance and sports and how it affects the quality of life have being researched.

Tavares, Moraes, Deslandes, & Laks, (2014) found that even elders with depression can benefit from a better quality of life when exercising. Rejeski & Mihalko (2001) analyzed more than 60 studies and all of them reported improvement of the quality of life. These resonant findings leave almost no doubt about the importance of physical exercising.

The Problem of Low Activation

According to the U.S. Department of Health and Human Services – (HHS, 2016) in the Physical Activity Guidelines for Americans 2nd edition, “For substantial health benefits, adults should do at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) to 150 minutes (2 hours and 30 minutes) a week of vigorous-intensity aerobic physical activity, or an equivalent combination of moderate- and vigorous-intensity aerobic activity. Preferably, aerobic activity should be spread throughout the week.”

The HHS goes on to say that adults over the age of 65 should follow the general adult guidelines where possible, adjusting as necessary for fitness levels and safety issues associated with chronic disease. Despite this recommendation, 65+ Americans spend, on average, only 10 minutes a day exercising (ATUS (2015)).

Schneider & Pichora-Fuller (2000) analyzed the relationship between perceptual and cognitive decline in aging. The authors concluded that age-related cognitive deterioration is more extensive than the loss of visual and auditory sensitivity, suggesting that cognitive impairment may in general be a greater problem than perceptual impairment in aging.

Another issue concerns depression and dementia which are both common in older people. Bennett & Thomas (2014) reviewed 34 studies that explored cause, consequence and coincidence of dementia and depression and found convincing evidence that early life depression is associated with an increased risk of dementia. They also found that late-life depression is a prodrome of dementia.

The problem of inactivity is particularly challenging in dementia, where people who are institutionalized may spend most of the day either sitting or lying down (McArdle et al., 2009). This is in spite of the fact that physical exercise has been shown to provide a protective effect against cognitive decline in aging generally, as well as in Alzheimer’s disease (Norton, Matthews, Barnes, Yaffe, & Brayne, 2014). Like older people in general, people living with dementia are short of exercise, and the problem is particularly severe for people living in long-term care (Salguero, Martínez-García, Molinero, & Márquez, 2011).

In summary, older people typically do not get enough physical activity, and they also suffer from problems like cognitive impairment and depression that may be treatable, or preventable, through greater levels of activation.

Universal technologies are not a fit for elders

Typical alternatives to a standard TV set are complicated to interact with, have a high learning curve, depend on memorization of long series of tasks, and vendors don’t share a common interface platform.

In the book “An Introduction to Usability”, (Kobus, 1999) uses VCR programming as an example of a complicated and ineffective interface, where even features added to help usability was found to have the opposite effect.

Tasks are usually completed under a system so that the user is required to have a knowledge of the system as well as the task in order to achieve the desired goal. For example, to perform a search, people need to know how to use a browser. Systems are usually embedded into other systems, for example, a browser needs to run in a computer operating system (Windows, MAC) or cell phone system (IOS, Android). In order to balance the needs of productivity and usability, designers tend to target the highest value demographic segments, which typically do not include elders. Consequently computers, tablets and cellphones typically do not take into account the needs of those 65+.

With the advent of tablets and touch operations, interfacing with computers, tablets and cell phones have become more affordable, but connectivity remains a problem for many older people. Around 11% of Americans don’t use the internet

(Anderson & Perrin, 2017), but the rate of non-use for the 65+ age group is much higher (35%) than the 2% non-use rate for young people (18-29).

We need new forms of connectivity and computing that can address the needs of the broadest possible range of older people. In the same way that the graphical User Interface (GUI) made computers accessible to a broad range of users in the 1980s we now need tangible user interfaces (TUI) and natural user interfaces (NUI) that can bring usability interactions and applications to the elderly population. The main objective of this thesis will be to explore new devices that can simplify and enhance interactions for elderly users.

Existing Alternatives for Physical and Cognitive Activation

In 2018, Shoppers Drug Mart, the biggest pharmacy retail chain in Canada, with more than 1,300 locations in Canada opened 43 physical stores targeting aging population and looking forward to provide products and goods. The new chain is called Wellwise and also sells over the internet. The section “Active Living - Fitness” provides 48 products, ranging from C$ 15 to C$ 350. The products vary from home gym products such as weights, grips, hand exercisers, bands and mats, a few therapy products like foot rollers and therapy putty and finally portable peddlers and elliptical trainers.

There’s a “tools and gadgets” section, but none of the products are related to cognitive activities. This shows that the market is still immature and is short of activation products. However, there is an enormous number of websites and apps that claim to help people keep their brains active using games. Since these activities are available for computers, tablets and cellphones they tend to be less accessible for older people since around ⅓ of the elder population in North America don’t use computers and with similar or larger rates of non-use for tablets and smartphones. This puts into question the use of computers and variations like cellphones and tablets as channels to deliver cognitive activities to elders.

Chapter 3 Research Strategy

Since technologies are not being used extensively by elders and there are problems with accessibility, new options outside the current paradigms should be explored.

There are several approaches that can be used to achieve this objective, including the design of new operating systems and new graphical user interface models. Due to the special characteristics of elders, regarding perceptual, cognitive, physical, psychomotor and motivational domains, the path of Natural User Interfaces was chosen as an option to create more affordable interfaces.

As watching TV is by large the second most performed activity by elder Americans (Figure 3.1), transforming watching TV into interactive and immersive experiences can potentially open roads for exercising and socializing, that can lead to better life experiences. An important part of the research was confirming this hypothesis, with the analysis of American Time Use Survey data that was conducted in chapter 4. In addition, chapter 4 looks for evidence of lower activation.

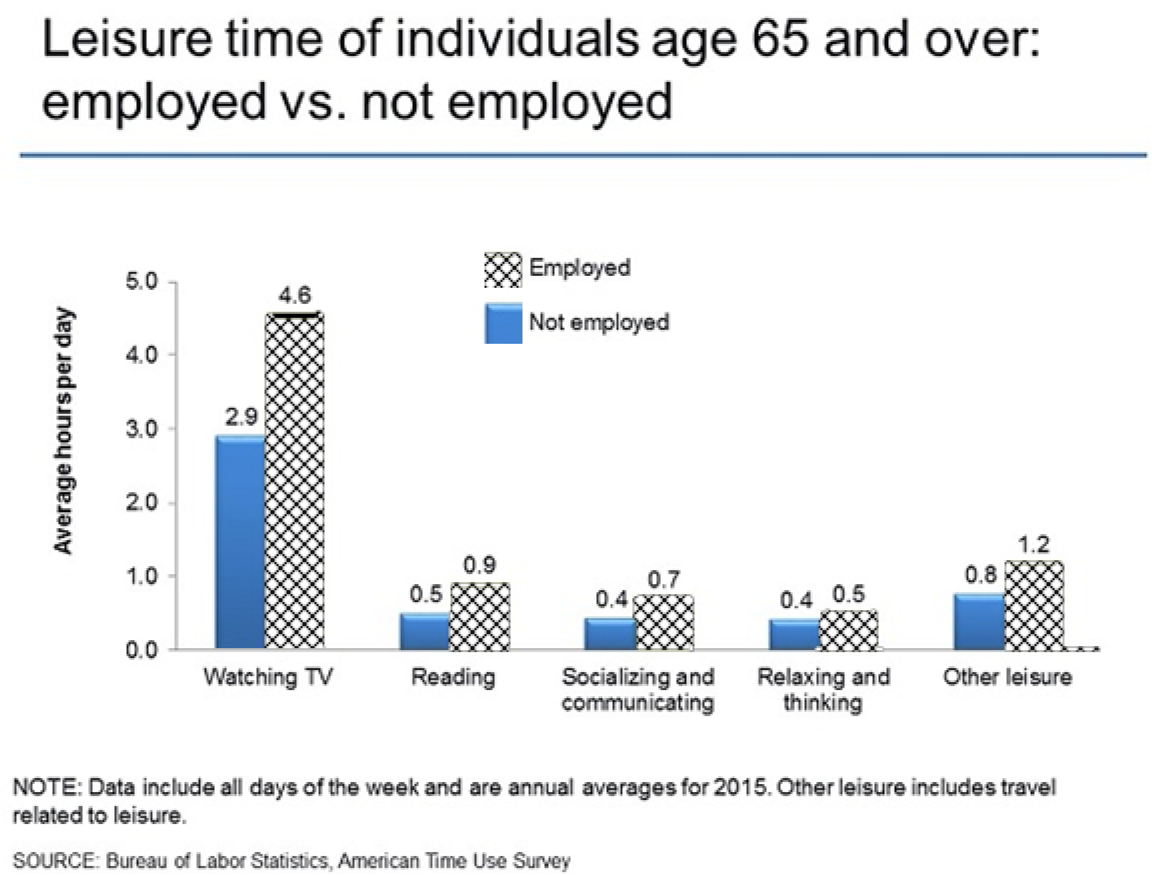

Figure 3-1:Watching TV over 65

Average Hours per day	Employed	Not Employed
Watching TV	2.9	4.6
Reading	0.5	0.9
Socializing and Communicating	0.4	0.7
Relaxing and Thinking	0.4	0.5
Other Leisure	0.8	1.2

Accessible data - figure 3-1

Three problems for Aging Interaction were selected for the scope of this research:

- Selecting content on a screen
- 1-D control with a steering wheel
- Creating Immersiveness without goggles

Selection of content on a screen is a classic problem in human computer interaction. Previous solutions have included hierarchical menus navigated through mouse selections and tapping buttons and icons on touchscreens. However, since many older people have poor fine motor skills, I examined other solutions that might be more broadly usable by the elderly population.

Control input in a two-dimensional, or three-dimensional space is also a classic input problem in human-computer interaction. For younger people devices like joysticks permit fast navigation in three-dimensions. However, control in multiple dimensions is difficult for many older people. One way of simplifying a control task is to make it into a one-dimensional control task and to use a familiar control input device like a wheel, and this is the strategy I adopted in developing a control input device for the elderly.

The third problem that I tackled was how to create a sense of immersiveness that is generally suitable for the elderly. Use of VR goggles to display 3D content can cause simulator sickness, or disorientation due to the person’s awareness becoming separated from the surrounding world. However, immersiveness can be a key component in creating engaging and rewarding experiences and thus I examined the properties of curved displays as alternatives to goggles in creating immersiveness.

For each of the problems addressed (content selection, 1-D control input, display immersiveness), better and/or less expensive solutions are needed for aging users. Tables 3.1, 3.2 and 3.3 summarize the design problem and requirements, and the selected approach.

Table 3-1:Overview of actual selection devices

Current Alternative	Problem	Requirement	Proposed Approach
Remote Control	Too many options, items too close, small captions	proper size, proper separation, simpler interface	Screen Button unit
Mouse	Requires fine motor skills, no feedback on the device	Haptic feedback, Gross motor skills	Screen Button unit
Tablet	Touch screen doesn't have feedback, Slippery, small buttons/icons	Nice touch and feel , Haptic feedback, proper size	Screen Button unit
Remote Control, Tablet	Users' hands may obscure the screen	Display detached from the input selector	Separate units (indirect)
Remote Control, Tablet	Screens need to be installed at a lower position and tilted to reduce arm fatigue	Ergonomic design	Separate units (indirect)

Table 3-2: Overview of actual control task devices

Current Alternative	Problem	Requirement	Approach
Mouse	Requires fine motor control	Gross motor preferred over fine	Driving wheel
Keyboard	Un-natural, short movement	Natural, Ample Movements	Driving wheel
Finger control-Tablet	Un-natural	Natural	Driving wheel
Gaming devices	Not related to the demographics, requires dexterity, relies on fine motor control	Gross Motor, Related to demographics	Driving wheel

Table 3-3:Overview of Immersive alternatives

Current Alternative	Problem	Requirement	Approach
VR Googles	Elders feel disorientation with VR googles	Immersive but not blocking	Curved display
VR Googles	Elders perceive VR as hard to learn and use	low or no learning curve perception	Curved display
VR Googles	VR Googles are uncomfortable to wear for some	non invasive	Curved display

This research project consists of three parts: 1) Analyze data about how elderly people spend their time and how their activity profiles change over time, in order to inform the subsequent design work; 2) Develop, test and evolve three devices intended to provide input/output capabilities activities that are usable by a wide range of older people.

Chapter 4 conducts a detailed analysis of American Time Use Survey from 2010-2017 and chapters 5 to 7 describe each of developed devices and the process of development.

Chapter 4 Changing Activities as People Age

In this chapter I analyze activity time use data from the U.S. Bureau of Labor and Statistics to track how activities change as people age. Analyses were carried out using American Time Use Survey (ATUS, 2003-2015) downloaded from the Kagge website (https://www.kaggle.com/bls/american-time-use-survey).

The goal of the ATUS is to measure how people spend their time, as assessed using a large set of coded activities. ATUS respondents are interviewed only one time about how they spent their time on the previous day, where they were, and whom they were with aged from 80 to 84 (N>5000). Those aged 85 and above (N>2500) were assigned a single age code (hence the two large spikes on the right side of the graph). Figure 4.1 shows the distribution over age.

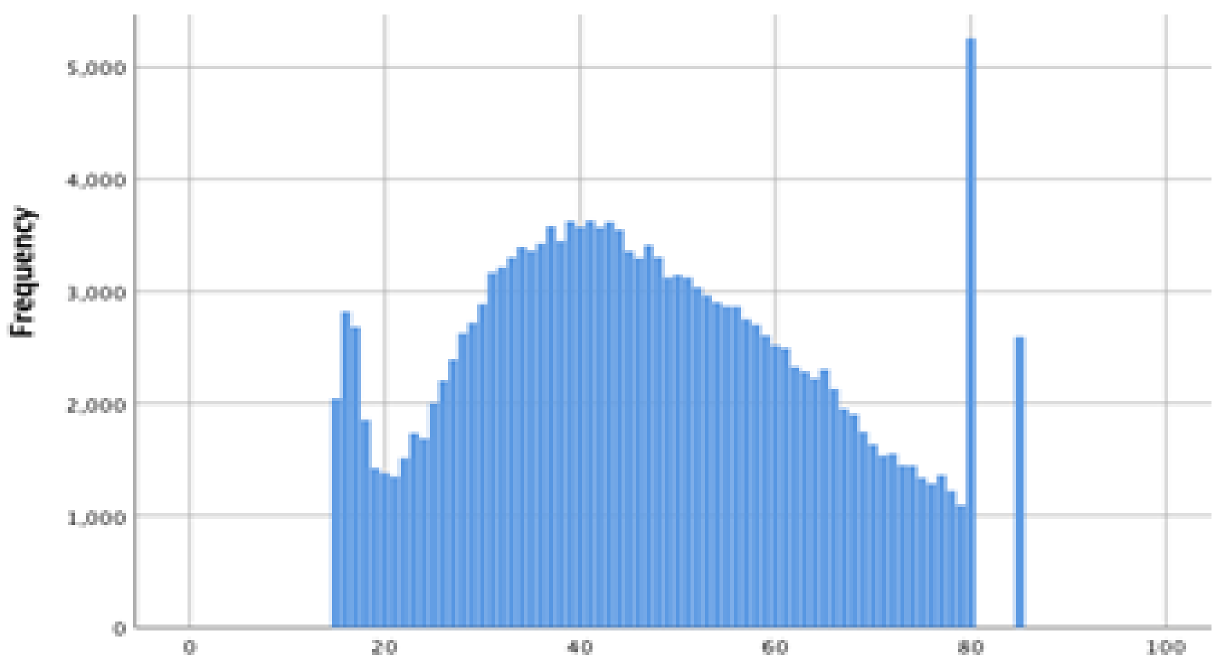

Figure 4-1:Demographic Distribution of the ATUS Survey

Table 4-1:ATUS Activities that Maximally Distinguish between Seniors and Non-Seniors (Standardized discriminant function coefficients in decreasing order of absolute value)

ATUS Activity	ATUS Code	Weight
Reading for personal interest	t120312	0.424
Television and movies	t120303	0.394
Work main job	t050101	-0.376
Relaxing, thinking	t120301	0.262
Eating and drinking	t110101	0.221
Gap/can't remember	t500106	0.188
HH and personal mail and messages	t020903	0.162
Washing, dressing and grooming oneself	t010201	0.14
Playing games	t120307	0.139
Physical care for household children	t030101	-0.138
Sewing, Repairing and maintaining textiles	t020103	0.128
Travel related to caring for children	t180381	-0.125
Talking with/listening to children	t030186	-0.094
Health related self-care	t010301	0.093
Shopping except groceries, food and gas	t070104	-0.086
Playing with children, not sports	t030103	-0.085
Listening to the radio	t120305	0.085
Laundry	t020102	-0.082

In order to characterize changes in activity as people age, two discriminant analyses were carried out. The first analysis contrasted people 65 and older vs. people between the ages of 40 and 64. Dependent measures used in the analysis were activity codes that were assigned, on average, more than one minute a day. Stepwise discriminant analysis was carried out and 49 activity codes were included in the resulting discriminant function which significantly differentiated between the groups (Wilk's Lambda - .791, $p<.001$). Table 4.1 shows the activation codes that had the largest discriminating function coefficients.

It can be seen that the sedentary activities such as reading, watching television, and eating, increase in the senior population. Unsurprisingly, time spent at work decreases after normal retirement age, and gaps in memory also increase.

A second discriminant analysis contrasted people aged between 70 and 79 with people aged 80 or over. Stepwise discriminant analysis was again carried out and 33 activity codes were included in the resulting discriminant function, which significantly differentiated between the groups (Wilk's Lambda - .942, $p<.001$).

Table 4-2:ATUS Activities that Maximally Distinguish between people aged 70-79 and those aged 80 and over (Standardized discriminant function coefficients in decreasing order of absolute value

ATUS Activity	ATUS	Weight
Relaxing, thinking	t120301	0.542
Sleeping	t010101	0.539
Television and movies	t120303	0.483
Reading for personal interest	t120312	0.467
Eating and drinking	t110101	0.321
Washing, dressing and grooming oneself	t010201	0.314
HH and personal mail and messages	t020903	0.24
Playing games	t120307	0.202
Sleeplessness	t010102	0.197
Work main job	t050101	-0.196
Gap/Can't remember	t500106	0.191
Listening to the radio	t120305	0.177
Socializing, communicating with others	t120101	0.161
Health related self-care	t010301	0.154
Shopping except groceries, food and gas	t070104	-0.131
Sewing, Repairing and maintaining textiles	t020103	0.119
vehicle repair and maintenance	t020701	-0.116
Financial management	t020901	0.112

Table 4.2 shows the activation codes that had the largest discriminating function coefficients. It can be seen that there is considerable overlap in the most discriminating activities for the two age contrasts. However, sleeplessness seems to be more important issue for people over the age of 80. Communicating and socializing with others is noted more by people 80 and older, perhaps because there are few opportunities for communication and socialization in formal work environment or when carrying out activities such as shopping outside the house.

Other hints about changing lifestyle in the 80s include less playing with household children (likely because grandchildren are reaching adulthood) and less time on vehicle repair (as people drive less). However, the tendency for people to use computers for leisure less over the age of 80 may be a generational change rather than a consequence of aging per se.

The following bar charts (with error bars showing 95% confidence intervals) show the time associated with some of the discriminating activity codes for different age groups. Age groups are defined as :1=40-44; 2=45-49; 3=50-54; 4=55-59; 5=60-64; 6=65-69; 7=70-74; 8=75-79; 9=80=84; 10=>85

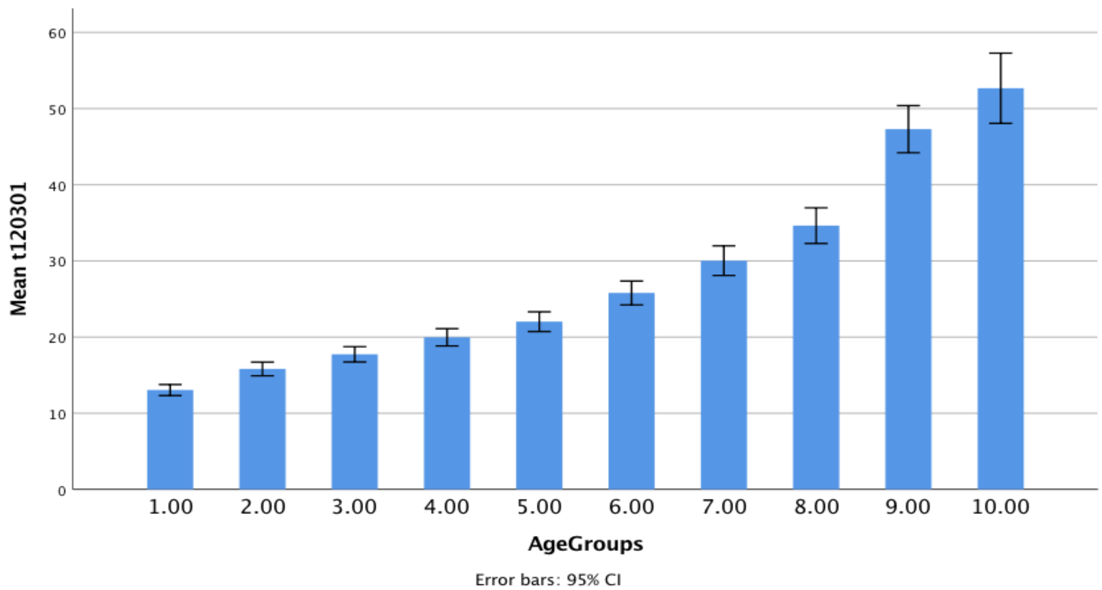

Figure 4-2:Time spent "relaxing or thinking" per day for different age groups

As can be seen in Figure 4-2, time spent "thinking and relaxing" is a major marker of age, increasing from around 10 minutes a day in the 40s to close to an hour a day in the 80s.

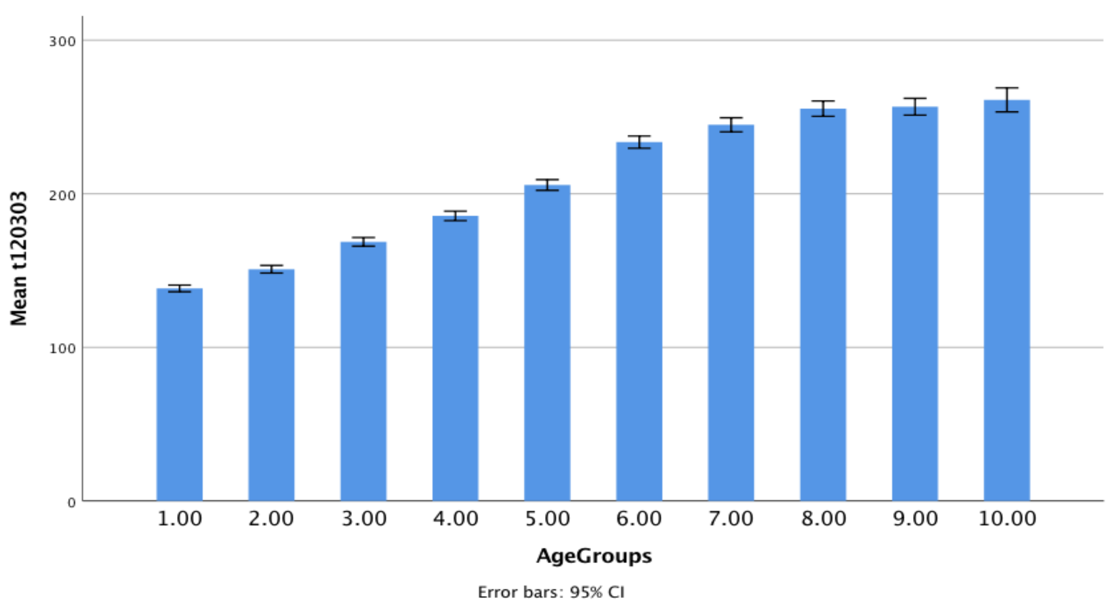

Figure 4-3:Time spent watching Television and Movies for Different Age Groups

As shown in Figure 4-3, time watching television appears to increase steadily before asymptoting around age 75.

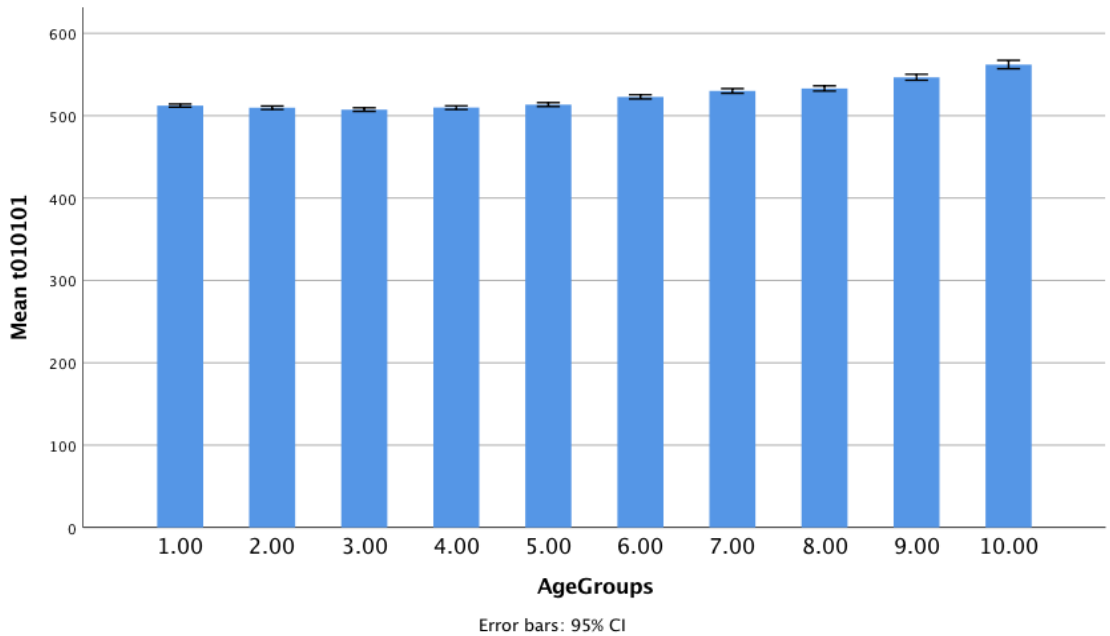

Figure 4-4:Time spent sleeping for Different Age Groups

Time reported sleeping is relatively stable at a little over 8 hours prior to retirement age after which it rises steadily to around 9 hours a day.

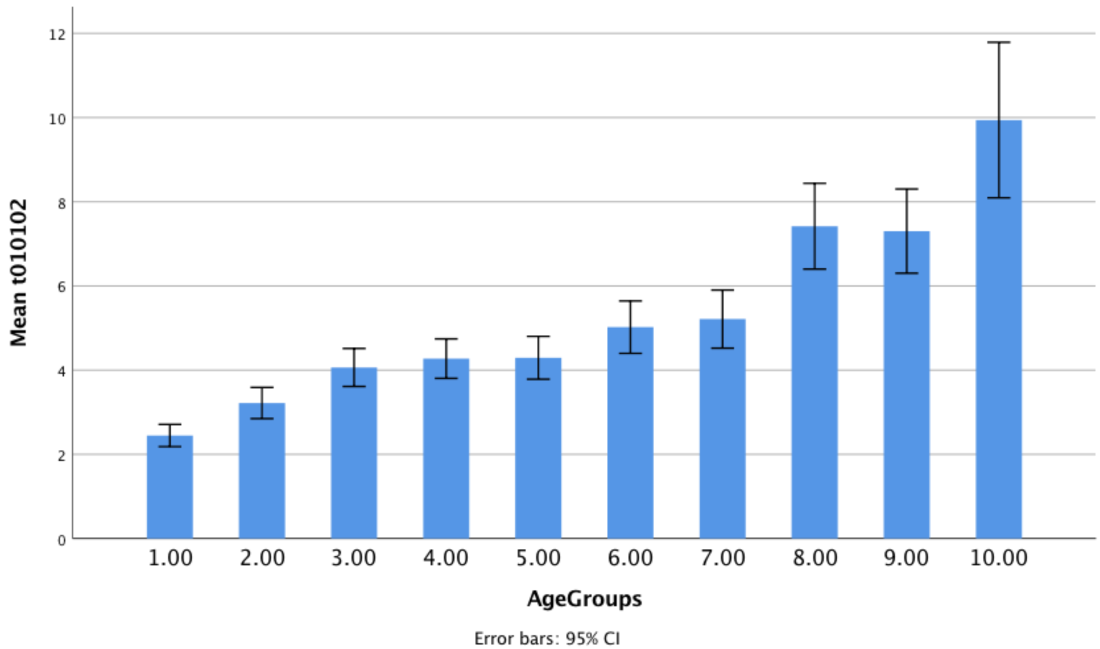

Figure 4-5:Increase of sleeplessness by age group

Figure 4.5 shows that sleeplessness is an increasing problem with age, rising to around 5 minutes a night on average in the early 70s and then increasing to around 10 minutes a night after the age of 85.

The overall picture of aging that is shown in the ATUS data is of increasing time spent sleeping and in sedentary activities such as reading and watching television. As children grow up and restrictions on mobility (e.g., less driving) occur, people spend less time on car repair but also less time shopping and less time outside. The reported increase in sleeplessness as people age may be due to a number of health conditions, including dementia and depression and may be a marker of difficulties experienced when aging. These results, and much other research showing a lack of physical activation in the elderly point to a need for greater activation.

Chapter 5 Selecting content on a screen

Input devices for selecting content on a screen go at least as far back as the 1950s with early TV channel selectors that used a rotary switch to select among a fixed number of channels. Remote controls for TVs were also developed. The remote control started as a wired version and later evolved to a wireless version using infrared light. Modern remote controllers are mostly membrane/rubber dome based and have a few dozen buttons. The Universal Remote Control on figure 5.1 has 43 buttons and represents an average remote control in the market.

The membrane/rubber buttons don't click when pressed, and modern remote controls are difficult for older people to use.

Figure 5-1:Universal Remote Control

Design goals for the screen button set developed in this research were as follows:

- Dynamic content
- Tactile feedback
- Audio feedback
- Proper size for older adults

- Small number of buttons

The design evolved through several iterations, from custom screen set development to tablet screens, from direct to indirect mapping over a series of prototypes that were used and validated during demos and evaluations.

Embedded Screen Button

The objective was to create direct association of actions performed by pressing the button with dynamically loaded images that recalls those actions. The first challenge was to select proper image size. There's a tradeoff between screen size and ease of use versus cost. Bigger screens are more expensive but potentially provide better interaction. A set possible screen sizes were evaluated, varying from 1 to 5 square inches (figure 5.2), price, size, refresh speed, interfacing used to select a subset for testing.

Figure 5-2:Screen options evaluated for the Button Unit

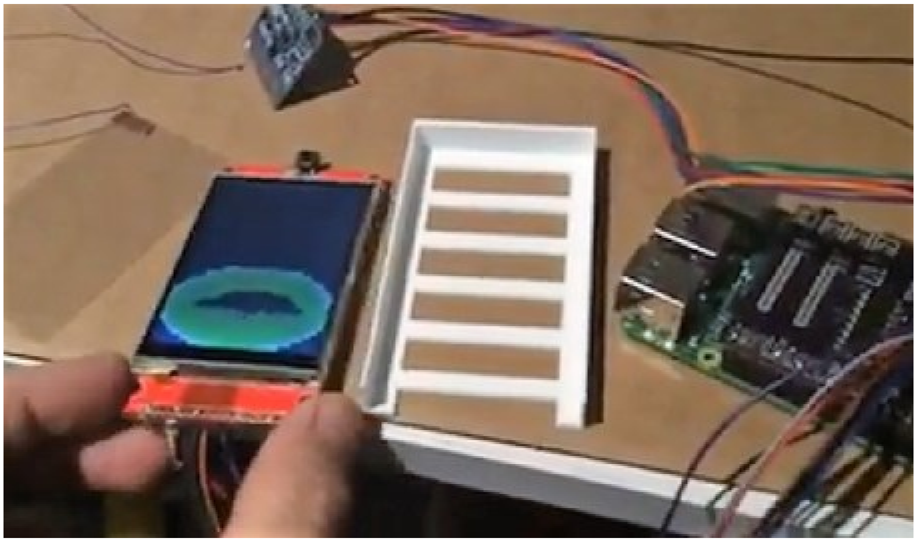

Figure 5-3:Screen Enclosure (button unit)

A screen with 3 square inches was selected with cost of around C$ 12 each, in order to attend the objective of C$ 100.00 per module (figure 5.3).

An enclosure with an embedded switch was added to provide tactile feedback (figures 5.4 and 5.5).

Figure 5-4:Screen Enclosure (detail)

Figure 5-5:Screen Enclosure Set

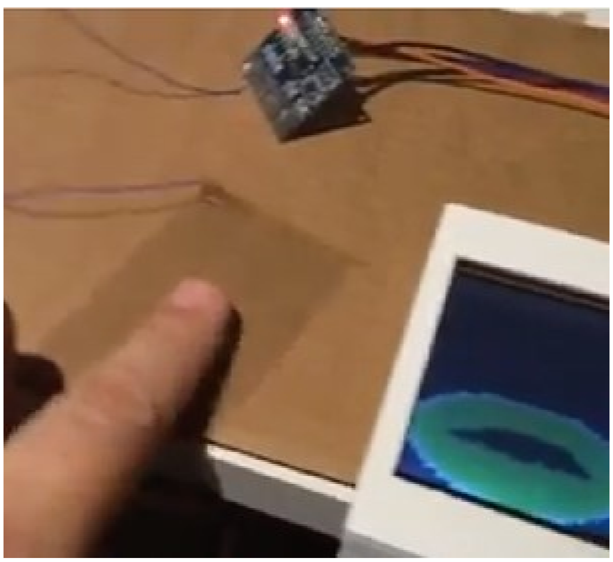

Figure 5-6:Screen capacitive Touch option

An alternative using capacitive touch was also developed for people who had difficulty in clicking the button (late stages of dementia or other impairments) as illustrated in figure 5.6. Several options were developed and tested in terms of hardware platform:

- Single Arduino
- One Arduino per Screen

- Raspberry PI only
- Raspberry PI in conjunction with Arduino

The combination of the Raspberry PI with Arduino was eventually chosen. The Raspberry PI brings flexibility and high-level interfaces while Arduino brings analog interfaces and a dedicated and simple platform. A prototype of the chosen platform was built (figures 5.7 and 5.8).

Figure 5-7:Multi button unit set evaluations

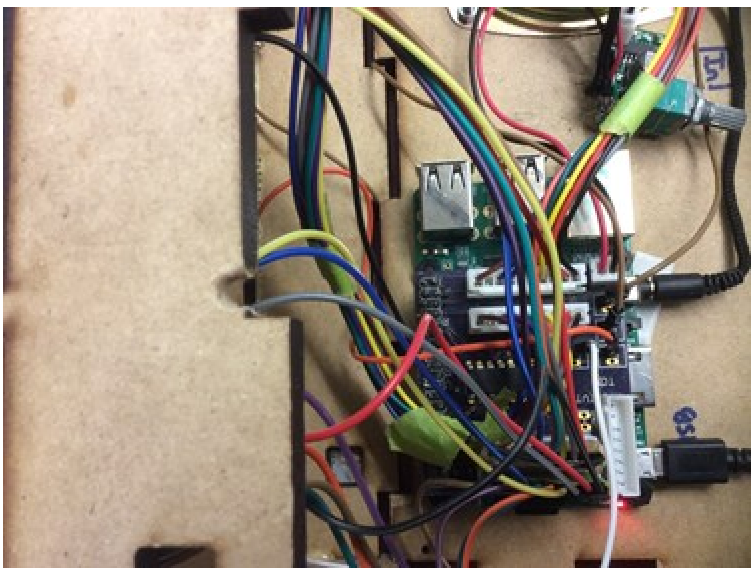

Figure 5-8:Multi Button custom board controller for Raspberry PI

A speaker was added to make the unit autonomous and capacitive touch abilities were inserted. Test applications were developed using Python and an enclosure was created with an added lever (figure 5.9).

Figure 5-9:Four button unit with added lever

Tablet Sleeve Button

As the first iteration proved to be hard to manufacture in small batches, hard to expand in terms of app development and also expensive for more than 3 screens buttons, a new version was developed using a sleeve over a tablet (figure 5.10). The sleeve had 6 buttons with tactile feedback buttons under a transparent layer of polycarbonate (figure 5.11). Several prototypes were produced in order to test possible buttons, with the objective of having tactile feedback and increasing the height by a minimum amount.

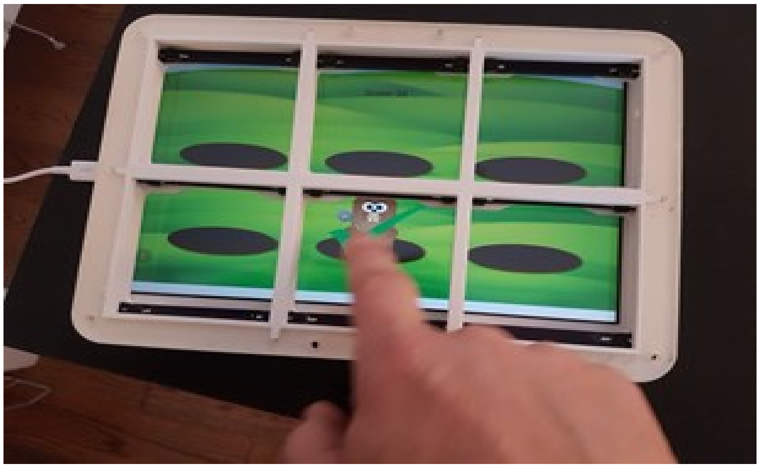

Figure 5-10:Tablet Sleeve

Figure 5-11:Tablet Sleeve tactile button in action

The sleeve presented some challenges like inserting and removing the sleeve for tablet regular operation, removing the sleeve connector for charging and then reinserting the sleeve for operation and also it was tied to the very specific form factor of the tablet, which varies a lot from vendor to vendor, and also from model to model and even from evolutions of the same model.

Indirect Mapping Button

A new line of exploration was open in the direction of indirect mapping. A big and bulky button unit (figure 5.12) was developed with illuminated arcade buttons with fixed colors.

Figure 5-12:Button unit with fixed color arcade buttons

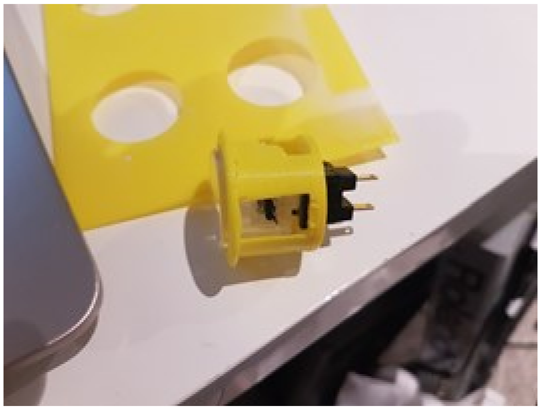

Figure 5-13:Custom button development

As the first prototype proved that this option can be fruitful due to acceptance at demos and talks, a more versatile and smaller version was envisioned and developed.

Due the potential of having a vast number of applications, the new unit was developed using configurable and dynamic colored buttons (figure 5.13). This was achieved by the construction of a custom button with an RGB LED that can be configured dynamically by the application.

Figure 5-14:Tablet insert with tilt adjustment

A 3D printed enclosure was developed and a tilting adjustment was inserted to improve the ergonomics whereby (figure 5.14) the tilt of the buttons could be adjusted to allow for a more neutral position of the wrist (minimizing flexion).

Figure 5-15:Enclosure with wood top

In order to create a better identity with the target population, and to make the device look less like a toy, a mix of plastic and wood was developed (figure 5.16). Due to the large size of the device, there was a lot of warping in the 3D printing process. Thus, a new box made of wood only was tested using a specially adapted wooden box.

Figure 5-16:Dollar store box version

The wooden box version was then made wireless and a new iteration added battery power (figure 5.16).

On the actual design a switch mounted at the front-center of the box allowed users to select types of activities (to be used by apps) and two rotary switches were also added - one for volume on the left and one for selection on the right.

To summarize this design cycle, the proposed solution started with an autonomous unit with custom electronics and applications developed in python running on a Unix platform (Raspberry PI) with meaning directly mapped to the button’s screens. The proposed design changed to a tablet based (still direct mapping), but using a more affordable hardware and software platform, that allowed either Android Apps or Browser Based Apps to be developed and tested and finally the last iteration was made to evaluate indirect mapping with custom color buttons referencing zones on a tablet or computer screen, in order to facilitate the production, lower the cost and have a flexible solution that can be used in conjunction with any computer or tablet. The cycle ended with the improvement of the prototype visually, adding ergonomic options and enabling portability and ease of use.

Chapter 6 1-D control with a steering wheel

To create interactive applications over a 3D scene an input device is required to navigate through a 360-degree space. As keyboard shortcuts and mouse inputs do not seem natural without a great deal of training, I began my investigation with a custom-made joystick.

A joystick resembles an airplane controller and is a 3D input device. However, testing in elderly samples with navigation in 3D video showed that the joystick was too difficult to use, and that people had trouble keeping track of where they were in the visual scene (e.g., getting lost in the sky). Thus, there was a clear need for a simplified interface that used 1D control.

One of the most common activities performed by humans is driving and a steering wheel is a highly familiar 1D input device. I chose the driving task based on feedback from an occupational therapist at Toronto Rehab Hospital who suggested that navigation of 360-degree travel videos should be supplemented with a specially developed driving simulator for the elderly. Driving is an activity that many older people are familiar with and memories of a lifetime of driving are associated with discovery, enjoyment, freedom, revenge, love, wealth, power and more. This is illustrated by how cars are referenced recurrently in songs. FlourishAnyway (2019) compiled a list of 105 songs that refers to driving.

There are several options available in the market for the gaming community that target racing and competitive aspirations of those gamers but they aren’t a fit for the activities for the target population.

Bruun-Pedersen, Pedersen, Serafin, & Kofoed (2014) suggested that the use of Virtual Exercising (VE) while pedaling can be provide enjoyable experiences. The steering wheel input device that I developed was intended as the input control device for two applications, a driving simulator, and a 360-degree travel video browsing system. In the case of travel videos, the wheel input allowed the user to pan around the video while maintaining a constant tilt, so that only one dimension of control was required.

Design goals:

- Resonates with the elder population looking for relaxing driving experiences
- Lightweight and portable (wireless), so the position can be easily adjusted for better ergonomics, including using it in a wheelchair
- Resemble a real steering wheel experience but doesn't relates to competitive activities
- Used to provide choice over scenes and angles in conjunction with an image system
- Translate rotational movement to data
- Tiltable for ergonomic adjustment
- Adjustable friction control to accommodate how smoothly the driving wheel turns
- Height control is not obligatory as it can be achieved by chair controls
- Relative changes (Infinite number of turns), so there's no need for a center position that need to be adjusted.
- High sensitivity

Those design goals were not defined a priori but have been identified based on the design experience that was gained in the project.

The design was developed in a spiral process, where feedback from demos and usage provided feedback for improvement on the next iterations.

The first iteration (Figure 6.1) used a mechanical approach and a heavy box. The main idea was to provide a stable surface that was integrated with a table. The mechanical approach proved unreliable and inaccurate. The 3D printed mechanism broke a few times and also the device was extremely heavy to carry for demos and evaluations.

Figure 6-1:Steering Wheel mechanical version

A second iteration was developed with an optical reader in order to provide more accurate readings of the position of the wheel (Figure 6.2).

Figure 6-2:Steering Wheel optical version (optical sensing mechanism not shown) and testing app

The third iteration (Figure 6.3) aimed to build a lighter device. To achieve this objective, a lighter steering wheel made of injected plastic was used. Also, the original case was replaced with two wood sheets connected by a hinge. Carbon fiber tubes were used to connect the sheets using 3D printed knees and joints. The 3D printed joints and knees proved fragile.

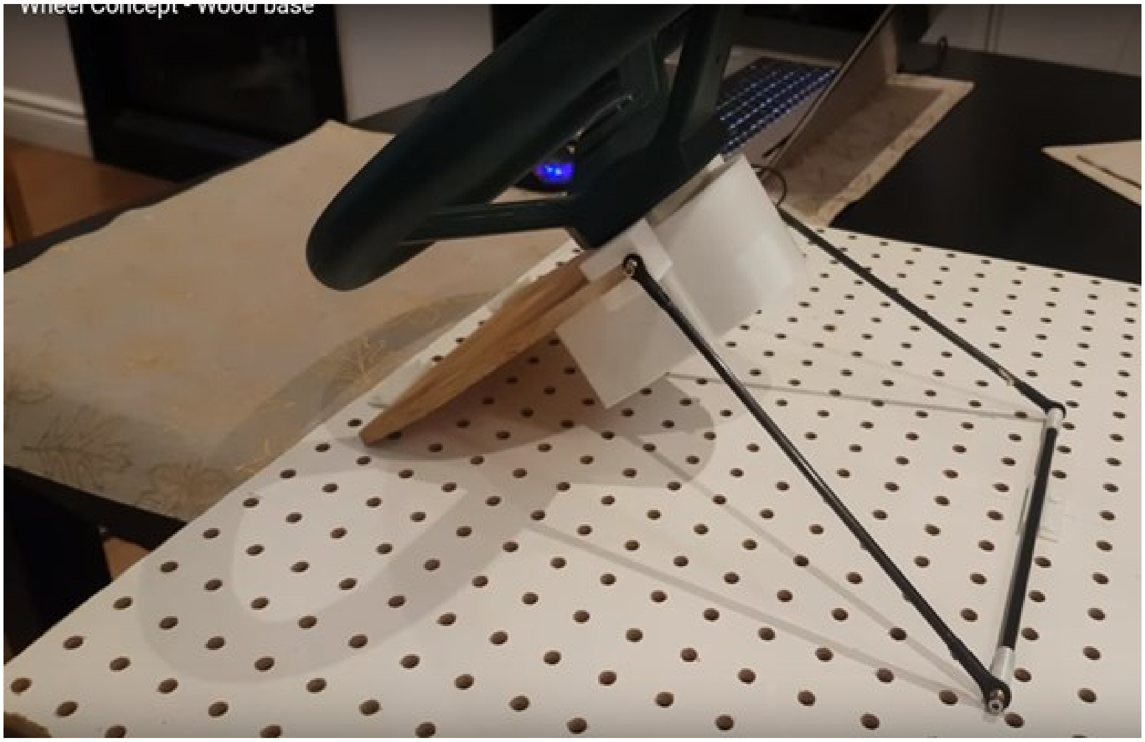

Figure 6-3:Steering wheel adjustable tilt prototype

A fourth interaction (Figure 6.4) was built using a pair of tiny but sturdy metal shock absorbers. Also, a tilting mechanism was implemented to provide ergonomic options.

Figure 6-4:Optical Steering Wheel with adjustable tilt set

To summarize, a first approach was made using joysticks to navigate through 3D spaces, which proved tricky to use. A second generation explored the use of a mechanical wheel that simplified the interface and was very wheel accepted, but improvements of the design had to be made in order to increase the accuracy (optical reading), portability (decreasing the weight by 5), ergonomic options (tilt control) and a visual that relates more with the demographics, in other words, that resembles regular steering wheel more closely.

Chapter 7 Creating Immersiveness without Goggles

Immersivity has been a goal in computer interactions for decades. Sensorama (figure 7.1), developed in the sixties by Morton Heilig probably is one of the first electronic devices that explored immersive, multi-sensory experiences (Figure 7.1). Rheingold (1991) described his experience using the Sensorama - a bicycle ride in Brooklyn. The equipment displayed images in 3D images in wide angle, and was able to tilt the body of the user, emit aromas and generate wind. Heilig patented the Sensorama, but didn't find funding to create a commercial product.

Figure 7-1:Sensorama - "The Sensorama machine (scriptanime.wordpress.com)" by Minecraftpsyco is licensed under CC BY-SA 4.0

Despite the stereoscope being invented in 1938, the first generation of commercially 3DTV (3D Television) started to be commercialized at the begging of the 2010 decade. They target immersive 3D experiences by tricking the eyes by alternating different images for the left and right eye. Despite being a great sensation at the beginning in 2013 they were declared dead by analysts (Sebastian, 2013) and also were described as a hazard (Howarth, 2011).

Maximal immersiveness is achieved through the use of VR Googles, but they are often rejected by older users. Potentially the rejection of VR technology could be handled with training (Coldham & Cook, 2017). However, a significant number of people may not be willing to take part in training and when training is possible it is typically expensive because it needs to be facilitated by others.

The first approach in developing an immersive display was to use a low-cost custom spherical display as an alternative. An Ikea light fixture (figure 7.2 on the right) was combined with a very affordable ultra-wide lens. A pico projector with 200 lumens was also used (figure 7.3). The prototype can be seen at figure 7.4. As the image produced with the Ikea light fixture was judged to be dim, special coatings were investigated and used over acrylic clear balls with the coating material applied from both inside and outside.

Coating from outside proved easier to produce and gives a nice glossy finish with a smooth touch sensation, but it can be scratched easily. In contrast, coating from inside needs several coating thin layers application and is more time demanding and more prone to drip and run, creating an uneven surface.

Figure 7-2:Custom made spherical displays - custom coated (left) and Ikea light fixture

Figure 7-3:Affordable ultra-wide lens and projector (far back)

Figure 7-4:Spherical Display prototype

Figure 7-5:Hemispherical Display in action

To produce a hemispherical version, a Gakken Worldeye was disassembled and the hemispherical cap was used. A working version can be seen at figure 7.5. The original Worldeye product was not a fit due to its low 480x480 resolution.

Touch capabilities were also explored using capacitive stripes and an infrared camera but were abandoned when I decided to focus on the immersiveness of the display.

In June-July 2018 I had the opportunity to work in the Koike Lab at Tokyo Institute of Technology where I designed and implemented prototypes that were then used in experiments that compared the immersiveness and perceptibility of the different types of display. Custom hemi-spherical, concave and convex displays were constructed with different sizes and compared with commercial flat projection and also with a commercial spherical display.

The five displays (figure 7.6) were evaluated and user ratings of immersiveness and perceptibility were collected. Two sizes of spherical cap display were developed (figure 7.6 and figure 7.7). Each display could appear as either a concave or convex shape depending on whether it was viewed from the front or the back.

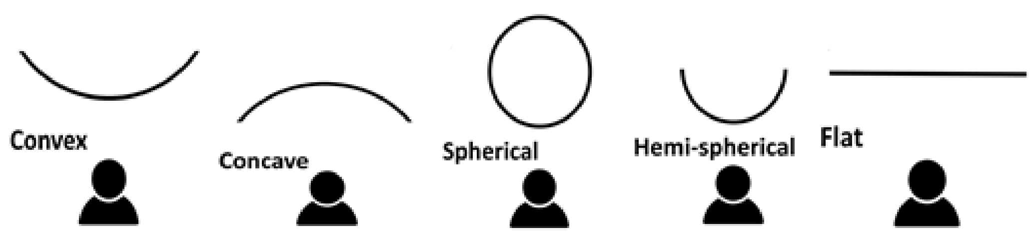

Figure 7-6:Display types

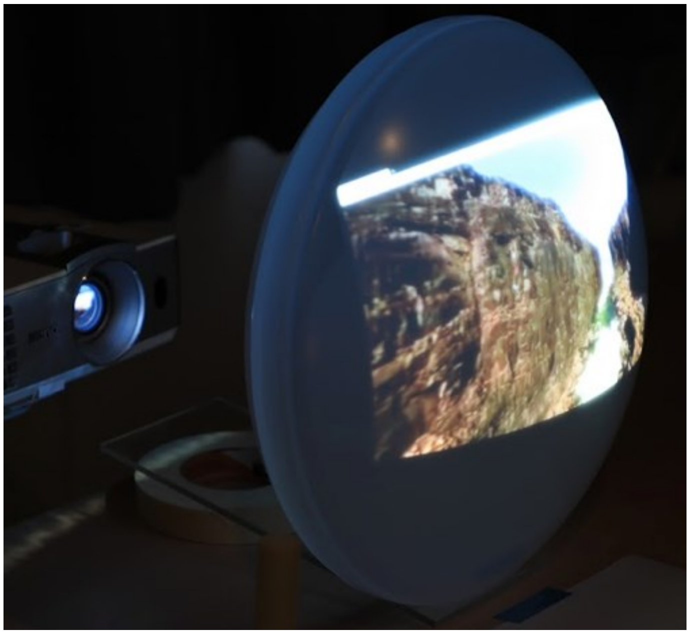

Figure 7-7:Large convex screen

Figure 7-8:Small concave screen

Using the designed prototypes, (Urakami et al., 2019) compared the displays in terms of immersiveness and perceptibility and investigated if there is a connection between those two properties and also how they differ among displays. 15 videos were presented to 24 participants in a naturalistic way. They first ranked and later scored all the videos in all displays in terms of immersion, perceptibility and overall preference. The study found a strong correlation between overall preference and immersiveness ($r = .61, p < .001$) , a strong correlation between overall preference and perceptibility ($r = .54, p <.001$) and also a correlation between perceptibility and immersiveness ($r = .58, p < .001$).

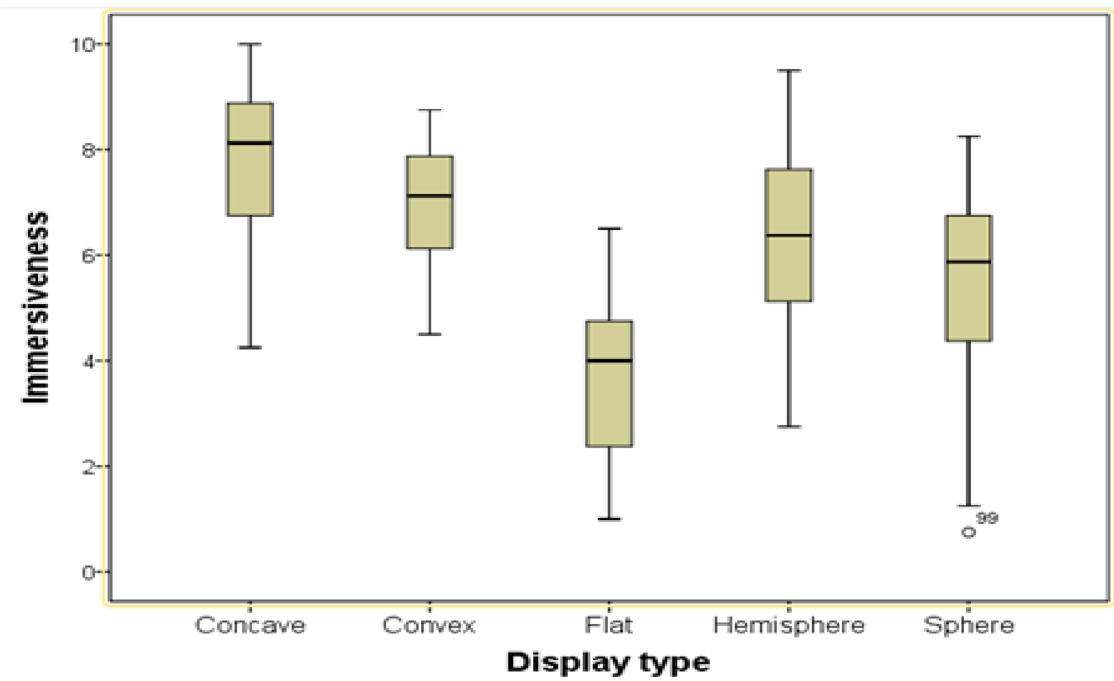

Figure 7-9::Participants' evaluation of immersiveness for each display type (from Urakami et al (2019)

In another study, Chignell et al. (2019) compared convex and concave displays at two different sizes. The study suggests that preference for display type in this study depended on display size. The study sample strongly preferred the convex display at the smaller size, but preferred the concave display at the larger size.

Despite being very hard to prototype due to the need of specific optics, projectors, projection surfaces and mechanical configurations, the experimentation proved that using uniformly curved displays is a promising road and further exploration should prove fruitful.

Chapter 8 Discussion and Implications

Introduction

Several aspects of design taken into account during the design and development phase of the devices prototypes, including:

- User Experience Design
- Physical: shape, materials, appearance
- Electronics: proto board x board
- Hardware platform: Arduinos, Raspberries, Tablets, Phones, Computers
- Modules internal architecture
- Sensors, Actuators output units Selection
- Software architecture
- Application development
- Cost and speed of production of prototypes and possible product

In the following discussion we examine the design decisions that were made with respect to the devices developed in the design exploration.

Discussion

Multi-switch selection is pervasive in current settings. It can be found in every home as light switch sets, remote controls, several devices like TV sets, microwaves, blenders. Frequently used alternatives to buttons like the mouse and touch screens are not well suited for most older people. The mouse is based on fine motor movement, and older people sometimes have a hard time using touch screens.

When used in tangible experiences, buttons or switches can either have a fixed association with a one-one mapping to functions or choices, or they may have multiple associations. When mapped to images or content distributed in different locations on a screen, the meaning of a button input may be indicated by what choice or information is shown in the corresponding location of the screen. In this case the meaning of buttons changes as the information/content displayed on the screen changes. Other implementations are more restrictive. For instance, phicons will generally be associated fixed meaning and will work like a switch/button - they can trigger events related to the associated meaning when they are being used. For instance, a figurine (phicon) that looks like the Statue of Liberty might be linked to a 360-degree tour of New York City.

In spite of their attractive properties and physicality (which is beneficial for older users), I ended up discarding phicons because of their limited mapping to content (i.e., for N content items there would need to be N phicons, creating storage problems as the number of content items increases). Thus, the main explorations took place with devices where the button meaning could be associated dynamically by means of a direct or indirect image or sound association.

The first design explorations with buttons involved direct associations where buttons had dynamic images that could be used to alter the meaning of the button depending on the activity. This was achieved using small screens sets with overlaid switches that provided audio and haptic feedback. The electronic design evolved from a single Arduino that controlled several screens reading the images from a SD card, to a combination of a Raspberry PI and Arduino in order to enable dynamically loaded content from the network.

In terms of size, several screen sizes, resolutions and technologies were evaluated and used in the prototypes. The screen sizes varied from 1” to 5”, the resolution varied from 32x32 to 1024x768 pixels, monochrome and color variations and different display technologies like LCD, OLED, backlit LCD and e-Paper. The final versions had 2.8” to 3.5” screens using color OLED. This size was the best solution for the price objective of less than per C$ 100 per module and with a size that is comfortable for elderly populations. The first version had 3 button-screens and the final had 4 button screens.

The choice was based on the proposed activities: Simon game, Memory pairs game and Whack-a-Mole game.

With the inclusion of the 4th button, the C$100 barrier per module was exceeded. The initial objective could still be achieved with mass production. The main challenge with the unit was producing it at low volume (10-100) at a reasonable price for field tests and evaluation.

With the possibility of using cheap (less than C$ 100) tablets like Amazon Fire and other Chinese Android based tablets, a new approach was evaluated. The main idea was to use a sleeve over the tablet, made of a set of haptic feedback transparent buttons (using polycarbonate or acrylic plates). Two lines and three columns of buttons were developed, providing a total of six buttons. The first version added a thickness of 30mm to the tablet, making the tablet bulky. Also, the use of a single switch made it hard to press the “button” from areas of the screen/button that were located a long way from the switch. The next version used four switches per button and also reduced the thickness to 15 mm. I found it challenging to produce several units for field testing and removing and inserting the sleeve proved too difficult, in spite of being a focus of the design. However, in my view these problems are potentially solvable and in large volumes the sleeve is potentially cheap and easy to produce

In contrast to the complexity of using an overlaid sleeve on a tablet, input using a separate button input device was much easier to design. However, button input involved an indirect mapping. Buttons are related to positions on a tablet or computer screen.

The advantages of button input devices are that they are haptic, with color and sound feedback, and they are affordable to produce. The button input devices that I developed are very inexpensive, based on inexpensive wood boxes and cheap buttons and LEDs. They run on rechargeable batteries with an embedded charger and connect to tablets or computers using Bluetooth. As of this writing they have proven to be a cheap and effective solution.

As a tentative design guideline, which needs to be further evaluated in future research:

- Convex or Concave displays should be used to increase perceptibility and Immersiveness
- Convex displays for display widths of less than 35cm and concave displays should be used for display widths of more than 40cm
- Tangible and Natural User Interfaces should be designed with the demographic in mind, which in the specific case suggests that devices should look like the ones people used in their life

- Devices should be easy to carry, adjust when needed and use, taking into account the increasing frailty that comes with age
- Even though direct mapping is more natural, indirect mapping should be considered where cost is a constraint
- Ideally an activation system should support daily activities and propose new ones that will be part of users' daily routine
- Systems should provide as many options as possible so each user can find her own way to interact with the system
- Devices should be adjustable, and where necessary, different versions of a device should be developed so as to accommodate a wide range of elderly users
- Gross movement-based devices should be preferred over fine movement based.

Within an aging society, there is enormous potential for developing specific solutions that enables elders to stay active and connected by making day by day activities or proposing new activities with mediation of facilitating technologies.

Chapter 9 Conclusions

Introduction

The goal of the Centivizer platform is to provide enjoyable physical, social and cognitive activation with low learning curve and to also collect data related to physical and cognitive abilities in order to follow up the evolution of those abilities and to provide feedback and suggestions about healthier living. In this project I explored input and output devices that would be usable by a wide range of older people and that could be incorporated into Centivizer products.

Contributions

Analysis of activity decline in the elderly using the ATUS data set and demonstration of the need for more activation

Design of an innovative input device which has been used successfully by people with dementia in the specialized dementia unit at Toronto Rehab Hospital.

Design of an optical sensor-enabled and tiltable steering wheel which has been used successfully by people with dementia in the specialized dementia unit at Toronto Rehab Hospital.

Design of curved displays that occupy different portions of the design space.

Limitations

This was an exploratory study. I had limited access to elderly stakeholders. However, I received considerable advice from Mark Chignell based on his experience with people in long term care, and I also benefited from the extensive research literature on this topic. The evaluations that I carried out generally used informal user testing. The initial devices and applications need to be extensively tested and evolved in the field.

Inexpensive Button Set Unit

To be charged, the button unit must be connected to charger with an USB cable. In future designs the unit should be charged wirelessly. I also recommend exploring ergonomic modifications that can lead to adjustable tilt angles or eventually a thinner box that can be better accommodated on the user's lap.

Steering Wheel Device

The original version of the wheel input device used mechanical gears and a rotational sensor but the input was jerky because of problems with friction and non-smooth rotation of the gears. This I replaced the rotational sensor with an optical sensor to get rid of the problem, resulting in smooth output. The steering wheel also received a tilting mechanism to aloud better ergonomics. In future designs adjustable resistance should be inserted. Also, all adjustable parameters (tilt, wheel resistance) should be automatically adjusted for the current user.

Curved displays

According to the findings about immersiveness and perceptibility they are very promising, but extensive develop of alternative designs are needed in order to find the sweet spot where elders can mostly benefit of them as I have only scratched the surface of using curved displays for elderly population.

Future work

Evaluation research is needed to determine if the input and output modules developed in this research are usable and attractive to the target population of aging Canadians. This evaluation work was outside the scope of my project which focused on the iterative design of a family of wirelessly connectable devices that could form a suitable basis for developing inexpensive activation systems when combined with suitable software applications.

There's also a need to understand in which conditions concave and convex displays are more immersive and also how form factors affect immersion.

Final Words

There is an urgent need for inexpensive Technologies that can provide physical and cognitive activation for the elderly. Inexpensive solutions are needed because public and private budgets for looking after older people are typically constrained and activation is needed by all older people, regardless of their income or economic situation. In this Project I carried out an exploration within the design space of specialized devices that can facilitate the development of activation technologies for the elderly. The devices that I have developed are currently in use in two Centivizer products that are under development. The first is the Cognitive Centivizer, which uses the button input device that I developed. The second is the Experiential Centivizer which uses the steering wheel that I developed, in addition to the button input device. Both the button input device and the steering wheel will be part of an evaluative trial being carried out at York Care Centre (Fredericton, New Brunswick) by a team led by researchers from the Université de Moncton. The trial is funded by the Centre for Aging and Brain Health Innovation and should be completed by the end of 2019.

Bibliography

American Time Use Survey: Charts by Topic: Older Americans. (2016). Retrieved from Bureau of Labor Statistics website: https://www.bls.gov/tus/charts/older.htm

Anderson, M., & Perrin, A. (2017). Technology use among seniors | Pew Research Center. Retrieved April 29, 2019, from Pew Research Center website: https://www.pewinternet.org/2017/05/17/technology-use-among-seniors/

Bennett, S., & Thomas, A. J. (2014). Depression and dementia: Cause, consequence or coincidence? *Maturitas*, *79*(2), 184–190. https://doi.org/10.1016/j.maturitas.2014.05.009

Bruun-Pedersen, J. R., Pedersen, K. S., Serafin, S., & Kofoed, L. B. (2014). Augmented exercise biking with virtual environments for elderly users: A preliminary study for retirement home physical therapy. *2014 2nd Workshop on Virtual and Augmented Assistive Technology, VAAT 2014; Co-Located with the 2014 Virtual Reality Conference - Proceedings*, 23–27. https://doi.org/10.1109/VAAT.2014.6799464

Chignell, M., Matulis, H., Zhang, B., Urakami, J., Miyafuji, S., Li, Z., & Koike, H. (2019). *Immersiveness and Perceptibility of Convex and Concave Displays*. Submitted to HFES - Human Factors Ergonomics Society Journal of Human Factors.

Coldham, G., & Cook, D. M. (2017). VR Useability from Elderly Cohorts Preparatory challenges in overcoming technology rejection. *2017 National Information Technology Conference (NITC)*, 131–135. Colombo, Sri Lanka: IEEE.

FlourishAnyway. (2019). 105 Songs About Cars and Driving. Retrieved April 24, 2019, from Spinditty website: https://spinditty.com/playlists/Zero-to-Sixty-Playlist-Pop-

Rock-Country-Songs-About-Cars

HHS. (2016). *Physical Activity Guidelines for Americans 2 nd edition*.

Hill, A. (1925). The physiological basis of athletic records. *The Scientific Monthly*.

Howarth, P. A. (2011). Potential hazards of viewing 3-D stereoscopic television, cinema and computer games: a review. *Ophthalmic and Physiological Optics*, *31*(2), 111–122. https://doi.org/10.1111/j.1475-1313.2011.00822.x

Hu, Y., Lei, X., Smith, J. P., & Zhao, Y. (2012). Effects of Social Activities on Cognitive Functions: Evidence from CHARLS. In *Aging in Asia: Findings From New and Emerging Data Initiatives*. Washington, DC: National Academic Press.

Interagency Forum on Aging-Related Statistics, F. (2016). *Older Americans 2016: Key Indicators of Well-Being*. Retrieved from http://www.dol.gov/ebsa

Kobus, D. A. (1999). An Introduction to Usability by Patrick W. Jordan 1998, 120 pages, $26.95 Bristol, PA: Taylor & Francis ISBN 0-7484-0762-6. *Ergonomics in Design: The Quarterly of Human Factors Applications*, *7*(2), 38–38. https://doi.org/10.1177/106480469900700211

Levy, R. (1994). Aging-Associated Cognitive Decline. *International Psychogeriatrics*, *6*(1), 63–68. https://doi.org/10.1017/S1041610294001626

Marcum, C. S. (2013). Age Differences in Daily Social Activities. *Research on Aging*, *35*(5), 612–640. https://doi.org/10.1177/0164027512453468

McArdle, J., Smith, J., & Willis, R. (2009). *Cognition and Economic Outcomes in the Health and Retirement Survey*. https://doi.org/10.3386/w15266

Morris, A., Goodman, J., And, +, & Brading, H. (2007). *Internet use and non-use: views of older users*. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.111.4268&rep=rep1&type=pdf

Norton, S., Matthews, F. E., Barnes, D. E., Yaffe, K., & Brayne, C. (2014). Potential for primary prevention of Alzheimer's disease: an analysis of population-based data. *The Lancet. Neurology*, *13*(8), 788–794. https://doi.org/10.1016/S1474-4422(14)70136-X

Older People Projected to Outnumber Children for First Time in U.S. History. (2018). Retrieved January 12, 2019, from US Census Website website: https://www.census.gov/newsroom/press-releases/2018/cb18-41-population-projections.html

Rejeski, W. J., & Mihalko, S. L. (2001). Physical Activity and Quality of Life in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *56*(Supplement 2), 23–35. https://doi.org/10.1093/gerona/56.suppl_2.23

Salguero, A., Martínez-García, R., Molinero, O., & Márquez, S. (2011). Physical activity, quality of life and symptoms of depression in community-dwelling and institutionalized older adults. *Archives of Gerontology and Geriatrics*, *53*(2), 152–157. https://doi.org/10.1016/j.archger.2010.10.005

Schneider, B. A., & Pichora-Fuller, M. K. (2000). Implications of perceptual deterioration for cognitive aging research. In *The handbook of aging and cognition, 2nd ed.* (pp. 155–219). Mahwah, NJ, US: Lawrence Erlbaum Associates Publishers.

Sebastian, A. (2013). 3D TV is dead. Retrieved February 5, 2019, from ExtremeTech Website website: https://www.extremetech.com/extreme/145168-3d-tv-is-dead

Shneiderman, B. (1991). Touch screens now offer compelling uses. *IEEE Software*, *8*(2), 93–94. https://doi.org/10.1109/52.73754

Tavares, B. B., Moraes, H., Deslandes, A. C., & Laks, J. (2014). Impact of physical exercise on quality of life of older adults with depression or Alzheimer's disease: a systematic review. *Trends in Psychiatry and Psychotherapy*, *36*(3), 134–139. https://doi.org/10.1590/2237-6089-2013-0064

Tilvis, R. S., Kahonen-Vare, M. H., Jolkkonen, J., Valvanne, J., Pitkala, K. H., & Strandberg, T. E. (2004). Predictors of Cognitive Decline and Mortality of Aged People Over a 10-Year Period. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *59*(3), M268–M274. https://doi.org/10.1093/gerona/59.3.M268

Urakami, J., Matulis, H., Miyafujia, S., Lia, Z., Koike, H., & Chignell, M. (2019). The magic of curved displays: Comparing immersiveness and perceptibility of spherical and curved displays. *Submitted to Applied Ergonomics Journal*.

Vaportzis, E., Giatsi Clausen, M., & Gow, A. J. (2017). Older Adults Perceptions of Technology and Barriers to Interacting with Tablet Computers: A Focus Group Study. *Frontiers in Psychology*, *8*, 1687. https://doi.org/10.3389/fpsyg.2017.01687