GUIDELINES FOR DESIGNING HANDHELD TOOLS FOR THE ELDERLY

by

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Abstract

This thesis includes a set of guidelines on the basis of which to design handheld tools for elderly people. Elderly people are a very special group of costumers. First, their bodies go through many changes with the aging process. One of the goals of thesis is to study in these physical changes to figure out how to design handheld tools for this special group of users. Secondly, the psychological states of older people are very different than those of normal healthy adults. If designers want to design products that are suitable for use by older people, then they need to do research on the physiology and psychology of aging.

Acknowledgement

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Table of Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Problem Statement

Today's world is an aging world. The number of people aged 65 and over in the world will more than double, from 7% in 2000 to 16% in 2050 (Ortman & Velkoff, 2014). Especially in the United States, due to the baby boom, the population of elderly people has been continuing to grow. However, as people grow older it becomes difficult for them to use normal tools that they can easily find in a supermarket because they were not designed with the aging processes of people in mind. For example, extrinsic and intrinsic hand muscles produce the force required for gripping objects (Carmeli, Patish, & Coleman, 2003). However, there is a great loss of muscle fibers that comes with aging that will result in the decline of muscle strength (Lateva, McGill, & Burgar, 1996). One's grip force will decrease with muscle degeneration. This situation makes older people unable to stably hold tools that were designed for normal, healthy people.

The guidelines provided in this paper provide specific criteria to consider when designing tools for elderly people.

1.2 Need for Study

The number of people aged 60 years and over has tripled since 1950, reaching 600 million in 2000 and surpassing 700 million in 2006 (Chucks, 2010). It is projected that the combined senior and geriatric population will reach 2 billion by 2050 (Chucks, 2010), and handheld tools are necessities of life. For these two reasons, designing a product for elderly people is a project that requires designers to have broad and long-term market outlooks.

People experience physical and psychology changes with age. Obviously, normal handheld tools cannot adapt to their users as they age. The guidelines proposed in this paper show designers the existing specifications of tools along with modifications needed for the elderly. Also, these guidelines include the design steps and the basic needs of the target users when adapting hand tool design.

1.3 Objective of Study

The following is a list of objectives that will be addressed in this study:

- Research the background of symbols, semantics, and emotional responses of elderly people.
- Study the relationships between elderly people and other social groups.
- Analyze different demands and requirements of elderly people at different phases of aging.
- Analyze the physiological psychological needs of elderly people.
- Explore some relative beauty, color, and psychological factors that can be reduced or even avoided in the design processes.
- Research current trends in handheld tool design.
- Study the color assortment, design criteria, and construction of some famous handheld tool products.
- Study different materials that can be used in the construction of handheld tools.
- Develop guidelines for designing handheld tools for elderly people.
- Demonstrate the effectiveness of the guidelines.

- Write a thesis.

1.4 Assumptions of Study

Today, there is an enormous amount that is unknown about handheld tools design for elderly people: the cultures, the styles, the marketing competition, and the influence of ergonomics. Therefore, some parts of this thesis are based on assumptions.

First and foremost, there is an assumption that when designers design handheld tools for elderly people, they should focus on physical aspects, such as ergonomics, or psychological aspects, such as emotions. It is difficult to determine which is more important in the lives of elderly people and it is difficult to consider both aspects in handheld tool design.

Secondly, there is another assumption, whether or not the product can really interrupt elderly's emotions and how to make pleasurable products for the elderly. There is no evidence that the process of using products will directly influence older people. If that does influence them, then we also do not know which parts of a product will interrupt older people in the emotional aspect, such as style, color and font.

1.5 Scope and Limitations

1.5.1 Scope

- Physical and psychological aging processes of humans and acceptance of technology.
- Existing controls, handles, displays, and form specifications of handheld tools.
- Define new controls, handle, displays, and form specifications for the elderly based on the changes that occur as a person ages.

1.5.2 Limitations

- People in United States
- Adult age: 16–64 years old
- Elderly age: 65–79 years old

1.6 Anticipated Outcomes

Through this study, we will learn the physical changes of elderly in every aging step. This research data can help designers design handheld tools that are suitable for use by elderly people. Also, we learn about the psychological changes that elderly people undergo. The psychological study of elderly people is a very important factor in design.

Chapter 2 Literature Review

2.1 Physical Characteristics of Elderly People

We live in a 'greying' society (Pheasant, 1996) Figure 1. shows some recent demographics in 2012 and demographic predictions in 2035 and 2060.

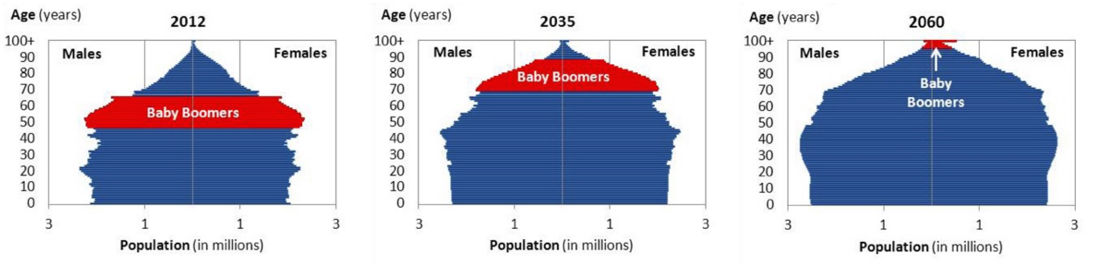


Table 1. The U.S demographic in 2012 and the demographic predictions in 2035 and 2060 (United States Census Bureau, 2017)

For most older adults, good health ensures independence, security, and productivity as they age. Yet millions struggle every day with health and safety challenges, such as chronic disease, falls, and mental health issues—all of which can severely impact one's quality of life (NCOA, 2016). In the design field, elderly people make up a special group of users. Their physical features are different from those of normal users.

> Beyond the middle years of life, most of us will tend to suffer from steady diminutions in our functional capacities, due partly to the aging process and partly to the effects of previous disease or injury from which recovery has been incomplete. As a consequence, we experience a steady increase in the number of critical mismatches that we encounter in the performance of the everyday tasks of life. The net effects of these changes are illustrated in Figure 2., which shows the percentages of people in different age groups that having one or more specific

disabilities (that is, one or more functional impairments that lead to significant difficulties in the performance of tasks in everyday life). The figure takes a dramatic upswing beyond the age of 60. As things stand at present, we typically continue working until we reach the age when our bodily framework starts to pack up on us. There is something of an irony in this (Pheasant, 1996).

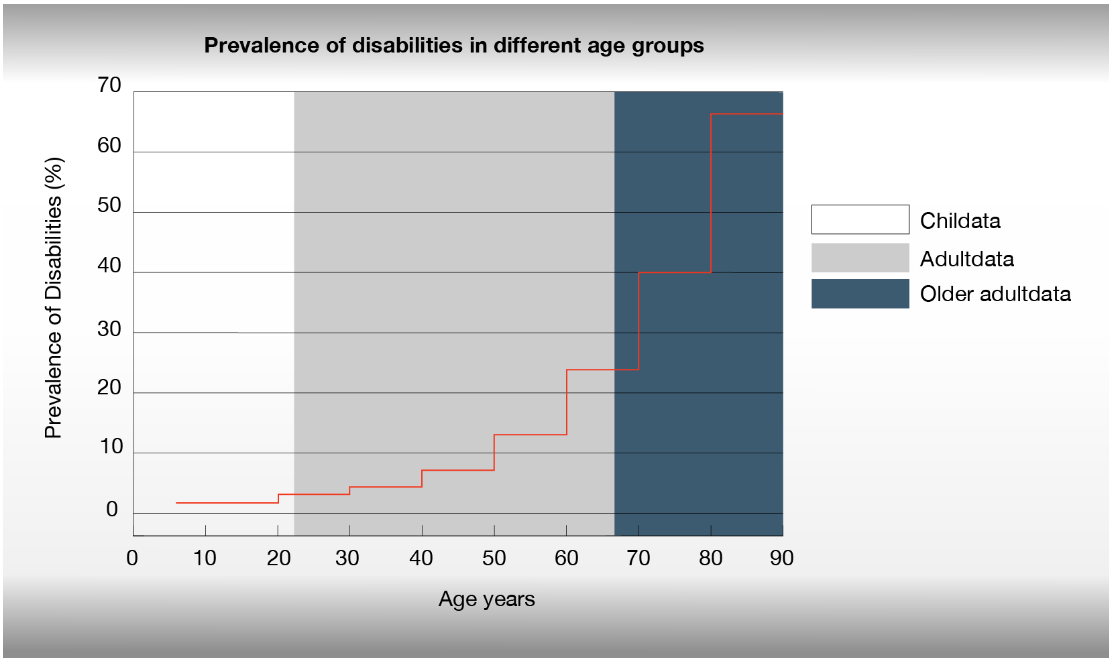


Table 2. Prevalence of disabilities in different age groups. Data from Martin et al. (1988). (Pheasant, Ergonomics, Work and Health, Macmillan, 1991)

Designing products for elderly people requires knowledge of their special physical features. In this chapter, the author focuses on the physical features of older people.

2.1.1 The Skin (Epidermis)

Two noticeable changes that normally occur with age are the graying and loss of hair. Both graying and baldness are, to some extent, genetically determined. Baldness is more common in males than females, but hair also becomes thinner in some females (Saxon & Etten, 2002). Hair loss problems become increasingly serious as people age, so hair must be considered when designing tools for elderly people. People's fingernails and toenails become tough and brittle with age and may not be cut properly or as often as necessary (Saxon & Etten, 2002). Many products need to be operated through the use of one's hands. Because aging people have weak nails, designers should consider how to protect people's nails when they use products.

2.1.2 The Musculoskeletal System

> Although its importance is not always fully appreciated, the musculoskeletal system allows for an amazing variety of body movements, ranging from movements of the entire body to those of very fast and highly precise movements. Such a wide range of mobility options is necessary to cope with varied and complex life situations (Saxon & Etten, 2002).

The musculoskeletal systems of elderly people are worthy of investigation because movement and posture changes are closely related to the musculoskeletal system, and with aging, the mobility of elderly people is limited. We need to know what movements need to be avoided when older people use products.

The aging process apparently produces muscle atrophy also (Saxon & Etten, 2002). The muscle atrophy is defined as muscle wasting, a decrease in size and of muscle (Walker, 2017). Elderly persons may have less muscle strength, move more slowly, and have a limitation for supported muscular contraction (Saxon & Etten, 2002). Due to the nature of physiological change, seniors have slower reaction times than adults. How efficiently our products can help older people complete their expected objectives deserves to be noticed.

Saxon & Etten discussed in their book *Physical Change and Aging* from 2002:

> As aging progresses, bones become more porous or less dense (osteoporosis). Statistically, the most frequent types of fractures associated with osteoporosis are vertebral fractures. These small vertebral fractures undoubtedly contribute to poor posture and to chronic back pain. Osteoporosis may also alter back alignment, causing the characteristic bent or stooped posture of many older persons. Changes that take place in body musculature and in the ligaments, tendons and bones of the skeleton, especially those in the vertebral column, produce postural modifications characterized by bent or stooped body flexion. Poor posture adversely affects the functioning of other organ systems of the body and thus adds yet another handicap to the aging body's already limited ability to cope and adapt effectively. General mobility is impaired to some degree by connective tissue changes associated with age. Connective tissue is distributed throughout the body and serves to bind parts together and to support body structures. With age, connective tissue becomes less flexible, even calcified in some instances, and thereby contributes to decreased body flexibility.

We can easily conclude that elderly people's bones are more fragile and not as flexible as those of young people. Older people may have difficulty when doing some postures or movements. Therefore, when designing handheld tools for them, tool designers need to avoid these postures and movements.

The most common form of arthritis in people over the age of 50 is degenerative arthritis or osteoarthritis (Saxon & Etten, 2002). Symptoms are pain and stiffness; concerned joints will get swollen after extended activity (Arthritis Foundation, 2017). Osteoarthritis is a slow progression disease. Over time, it can limit range of motion (Heitz &Higuera, 2017). Elderly people have limitations when operating products due to the degeneration of their joints. Therefore, when designing products for them, designers need to pay close attention to the motions required when older people use their designs, especially hand motions. Little joint motion in operating is ideal.

Due to the musculoskeletal changes as aging, there are many potential safety hazards in elderly people's daily life. Saxon and Etten (2002) talked it in their book:

> Most falls occur in the home, so attention should be directed to "accident proofing" the day-to-day environment. Although home arrangements ought to minimize stressful efforts such as reaching, bending, climbing, or stooping, physical activity in moderation is very desirable and provides beneficial exercise in conjunction with doing one's daily household tasks.

Besides keeping the floor dry, the motions mentioned above need to be avoided when elderly people use products.

In the home, furniture and interior design should accommodate elderly people's inflexible muscular and skeletal systems (Saxon & Etten, 2002). For instance, furniture should be with rounded edges and materials of furniture need to allow for easy cleaning. To prevent falling, doorways between rooms should not be with changes in ascent and sills, whilst the floor should be non-slippery (Hrovatin, 2015).

Handheld tools designers need to consider the design tips mentioned above. Handheld tools should be designed to be automatic to accommodate elderly people's inflexible muscular and skeletal systems.

> Aging muscles and bones have significant effects on the efficiency of other organs or organ systems. One's sharpness of vision decreases with age, partially because of the weakening of the small muscles attached to the lens, the focusing element of the eye (Saxon, & Etten, 2002).

Changes of vision will occur with muscle degeneration. The author provides a detailed discussion about age-related vision changes in the section following the discussion of the hand musculoskeletal system.

2.1.2.1 Hand Musculoskeletal System

2.1.2.1.1 Hand Muscles

> Our hands, as important parts of our bodies, help us operate most tools in our daily lives, so they are worthy of detailed discussion. There are 11 intrinsic muscles and 15 extrinsic muscles with direct functional roles in the hand. Extrinsic and intrinsic hand muscles produce the force

required for gripping objects (grip force) (Carmeli, Patish, &Coleman, 2003).

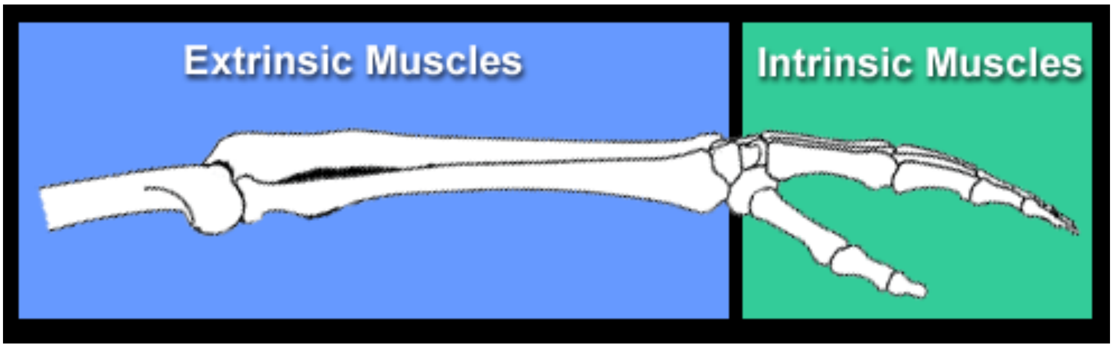


Figure 1. Extrinsic and intrinsic hand muscles (Richards & Loudon, 1997)

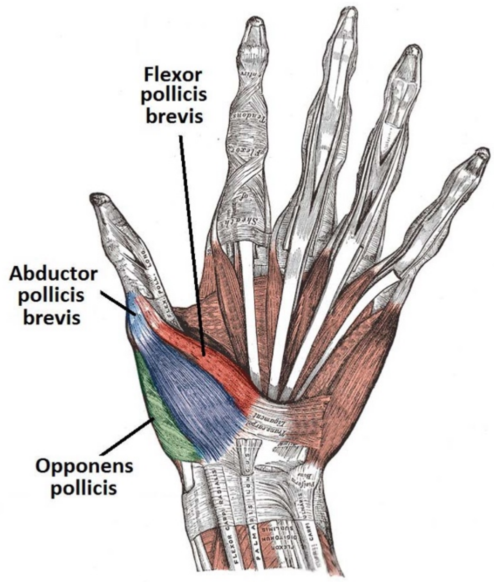


Figure 2. Palmar view of the thenar muscles. (Jones, 2017)

The aging process is accompanied by a substantial loss of muscle fibers and decreased muscle-fiber length, particularly in the thenar muscle group (Lateva, McGill, & Burgar, 1996). As Figure 2 shows above, the thenar muscles consist of three short muscles (Flexor pollicis brevis, Abductor pollicis brevis, Opponens pollicis) located at the base of the thumb (Jones, 2017), which constitute approximately 40% of the total intrinsic musculature of the hand (Tuttle, 1969). And it plays important roles in stabilizing the thumb during the strong grasping of objects (Marzke &Marzke, 2000). However, these muscles commonly show age-related dysfunction (Chan, Raja, Strohschein, & Lechelt, 2000).

The degeneration of hand muscles will contribute to the decrease of the strength of the hands, especially when griping and pinching. This definitely impedes older people from operating hand tools.

2.1.2.1.2 Hand Tendons

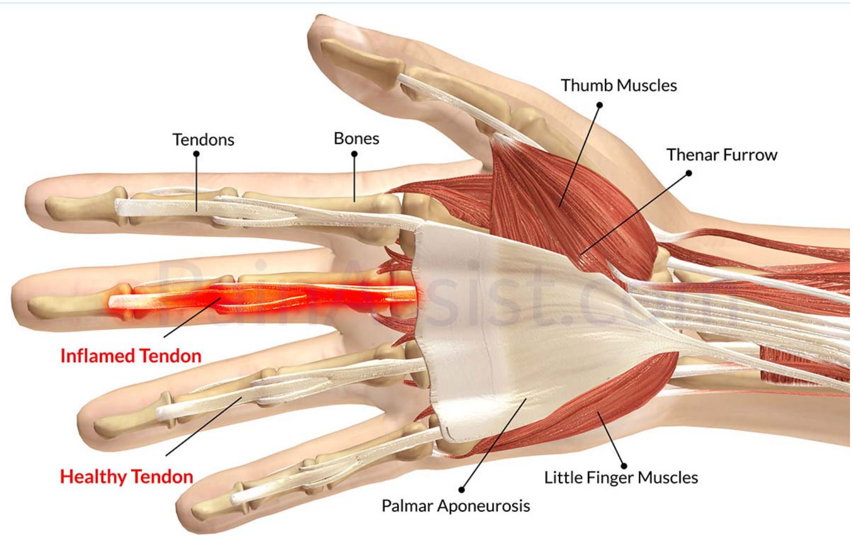


Figure 3. Hand tendons (epainassist, 2017)

Tendons are composed of dense connective tissue, primarily formed by densely packed, orderly arranged, collagen fibers. The primary function of tendons is to attach muscles to bone and to transmit muscle force to the skeletal system with limited stretch or elongation (Deuschl & Lucking, 1990). The tensile strength of tendons is a measure of the elongation of the tendon during tensile testing. It has been found that the ultimate tensile strength of hand tendons ranges from 50 to 150 kg/mm. The ultimate tensile strength values for aged tendons are decreased by 30–50% compared to those of healthy adults. Biochemical changes in aging tendons result in stiff, irregular, and dense connective tissue (Carmeli, Patish, & Coleman, 2003). The decrease of tendon tensile strength that comes with aging limits the range of motion of the hands. As a result, how to enable elderly people to easily operate tools needs to be considered when designing hand tools.

2.1.2.1.3 Hand Bones and Joints

Figure 4. Rheumatoid arthritis and osteoarthritis (Johnson, 2017)

With aging, the hand bones (19 long bones and 8 short bones) and joints, especially the synovial joints, are accompanied by morphological and pathological changes that are common to aging skeletal tissues. Aging hands and fingers are especially prone to osteoarthritis (Burkholder, 2000) and rheumatoid arthritis (Brosseau, Welch, & Wells, 2000).

Osteoarthritis of the hand and finger joints is a disease process that destroys interphalangeal cartilage, synovial membranes, and the joint capsule (Ralphs & Benjamin, 1994). The consequences of osteoarthritis of the fingers include pain, swelling, joint deformities, bone spur formation, restricted range of motion of wrist and fingers, and difficulty in performing manual activities that require gripping and pinching (Burkholder, 2000).

Designing tools for elderly people requires a designer to measure every range of motion of the hands of older people. In this way, we can make products friendly for them to use.

2.1.2.1.4 Age-Related Effects on Hand Strength

In 1992, Denno et al. have published an article named "Human factors design guidelines for the elderly and people with disabilities". This guideline has mentioned:

> It is well-documented that muscle strength declines with increasing age for all muscle groups. Here, only the changes of hand strength with respect to age are presented (Mathiowetz, 1985). "The actual strengths and percentage losses, as age increases, of hand grip, lateral pinch, tip pinch strength, and palmar pinch (Figure 5.) are illustrated in the following eight figures… The data was gathered from a sample of 310 males and 328 females, ages 20 to 94 years old. The percentage losses were calculated based on the grip data of the 20- to 24-year-old participants... Table 3-1 to 3-8 show that, in most cases, the peak of hand strength occurs between 30 and 40 years of age, and no more than a 10% decline in strength occurs before age 50 or 55.

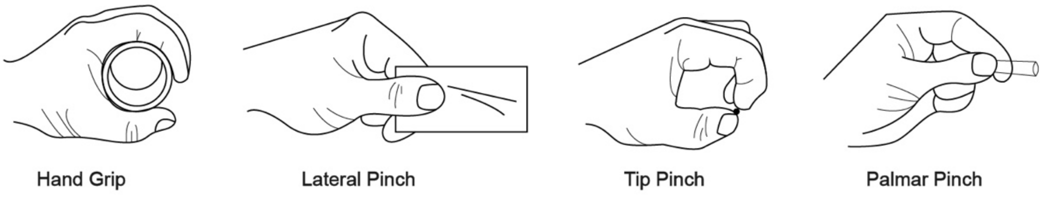


Figure 5. Hand grip, lateral pinch, tip pinch and palmar pinch (Digital resource foundation, 2017)

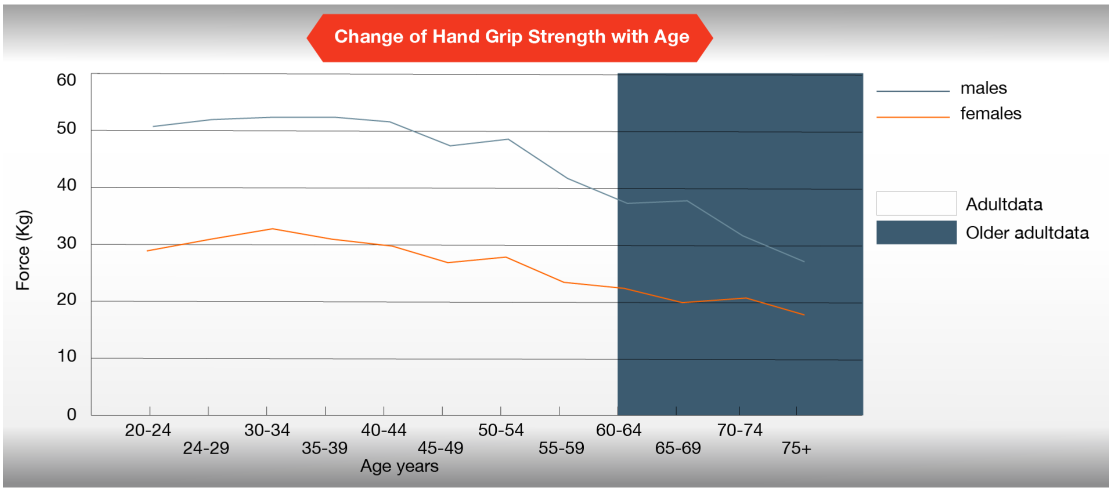


Table 3-1. Change of Hand Grip Strength with Age (Denno et al, 1992)

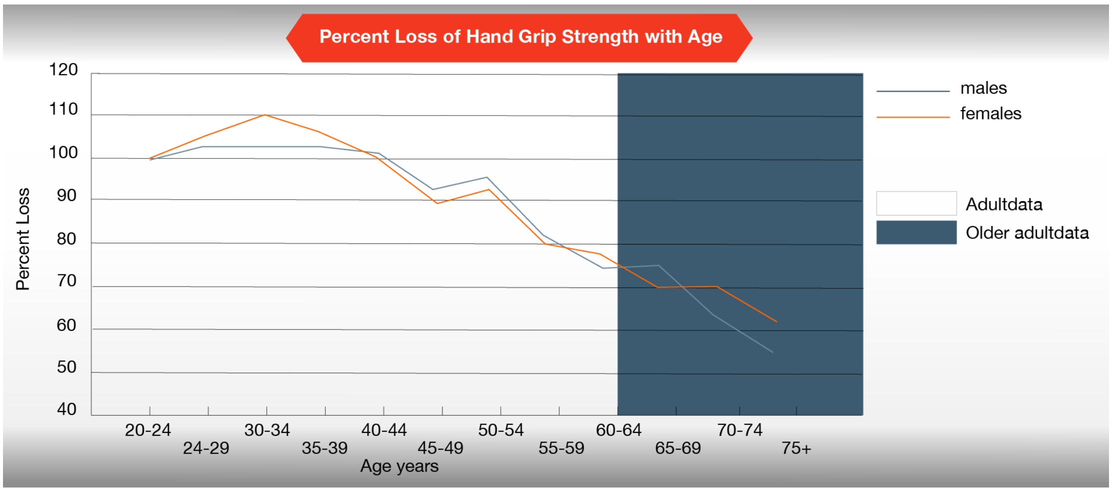


Table 3-2. Percent Loss of Hand Grip Strength with Age (Denno et al., 1992)

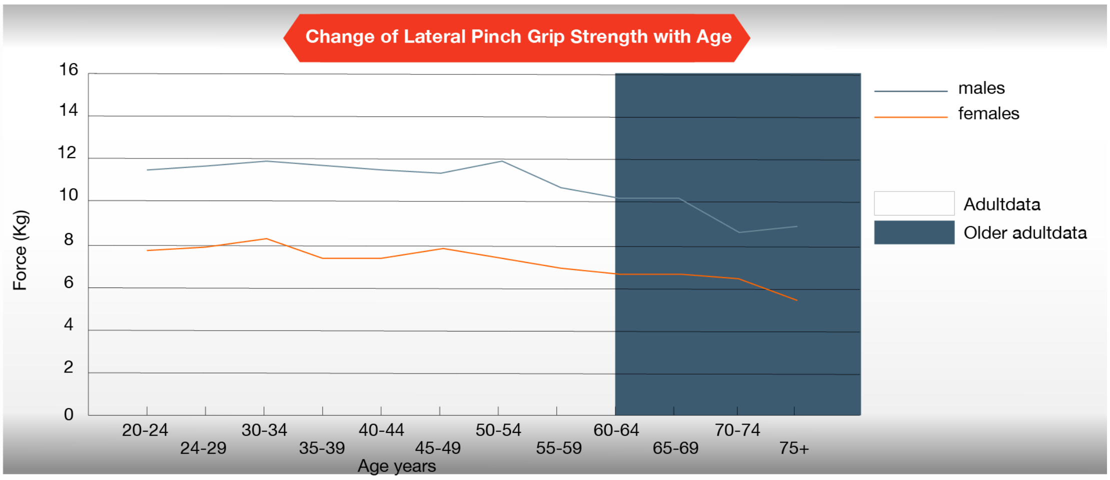


Table 3-3. Change of Lateral Pinch Grip Strength with Age (Denno et al., 1992)

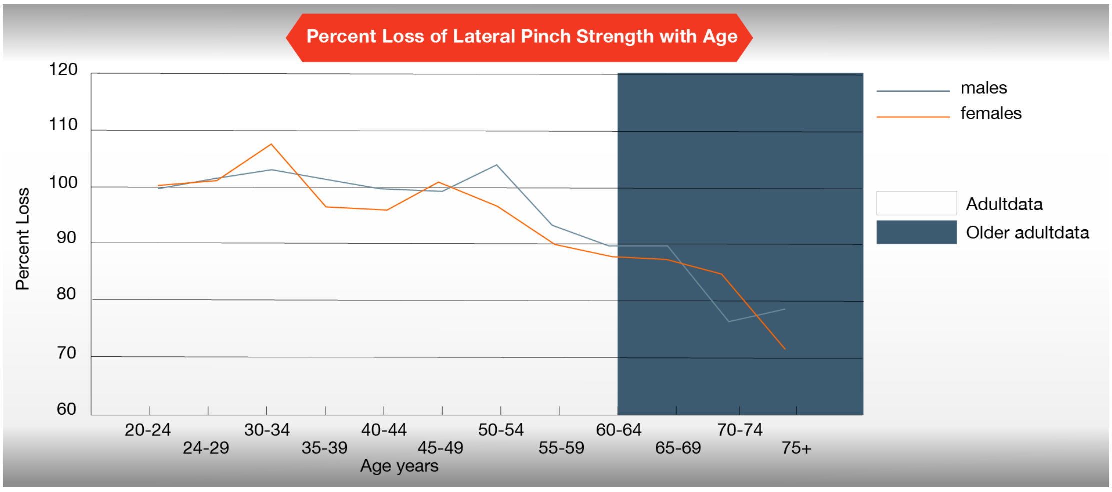


Table 3-4. Percent Loss of Lateral Pinch Strength Age (Denno et al., 1992)

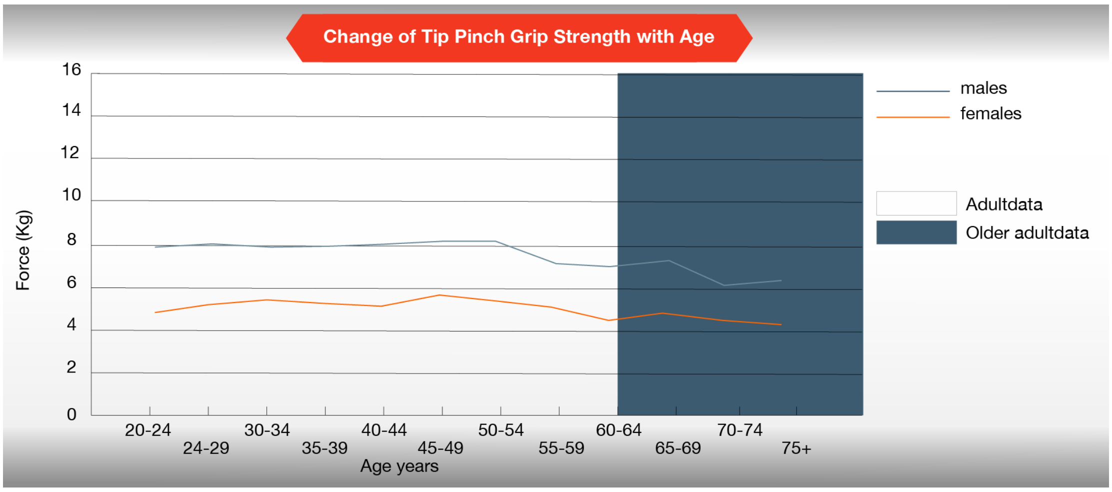


Table 3-5. Change of Tip Pinch Grip Strength with Age (Denno et al., 1992)

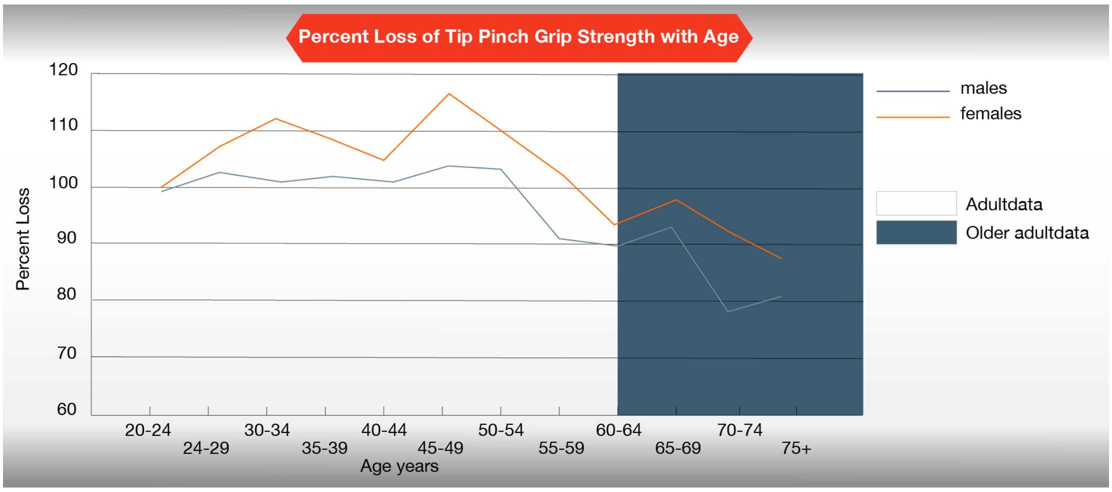


Table 3-8. Percent Loss of Tip Pinch Grip Strength with Age (Denno et al., 1992)

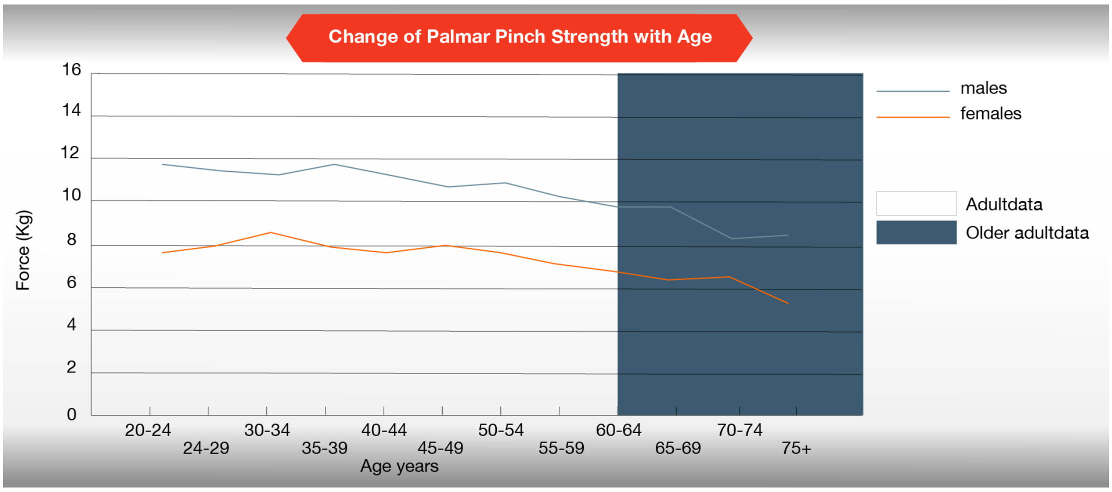


Table 3-7. Change of Palmar Pinch Strength with Age (Denno et al., 1992)

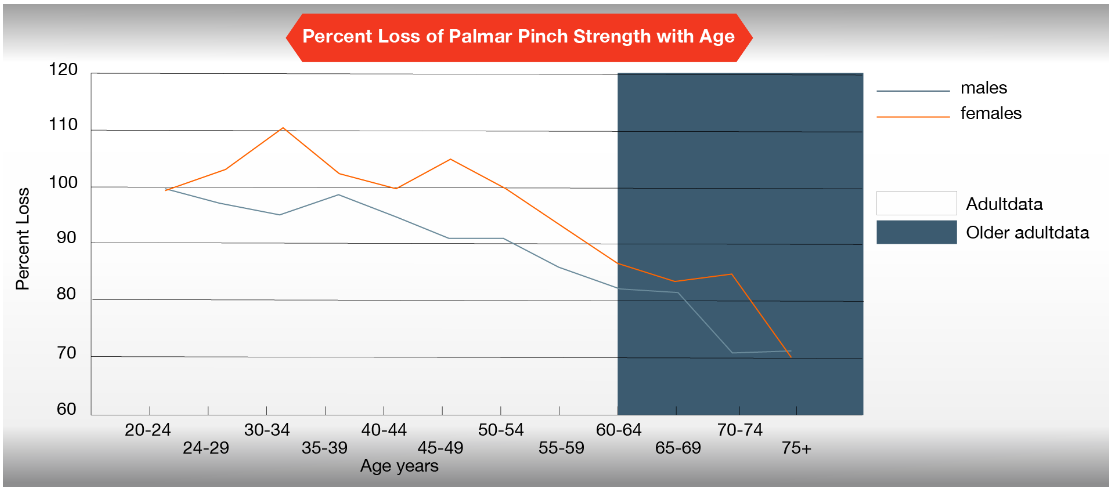


Table 3-6. Percent Loss of Palmar Pinch Strength with Age (Denno et al., 1992)

As shown in the figures above, most declines in hand strength occur after the age of 55, which means older people find it difficult to operate tools by hand due to the loss of hand strength that comes with age. How to enable older people to easily use products need to be considered by designers.

2.1.3 Vision

The sensory systems of major concern in the study of aging are visual (sight), auditory (hearing), gustatory (taste), tactile (touch), olfactory (smell), vestibular (balance), and kinesthetic ("muscle sense"). Each contributes a specific type of information that is necessary for continuing adaption and adjustment (Saxon & Etten, 2002). When people use products, the sensory systems are important to build a communication link between users and products. With aging, every sensory organ will gradually decrease in ability, so products that are designed for elderly people should have specific features that are different from those of the products that healthy adults use.

2.1.3.1 Age-Related Changes in Vision

"The visual threshold increases with age. The most significant change in the visual system, or at least the change with the most implications for behavior, is that more lights are needed to adequately stimulate visual receptors" (Saxon & Etten, 2002). When using indoor handheld tools, due to limits in the vision capacities of aging people, there must be plenty of lighting.

Visual acuity (sharpness of vision) decreases with age. Changes in the lens, pupil size, composition of vitreous humor, and ability to shift from near to far vision all serve to decrease the sharpness of visual images as we grow older. (Saxon & Etten, 2002). To be useful to older people, reading material should be printed with a larger than usual font with a clear, distinct type face. The font size in the instructions that accompany a product need to be big enough for older people to easily read.

2.1.3.2 Age-Relative Disorders of Vision

a. Presbyopia

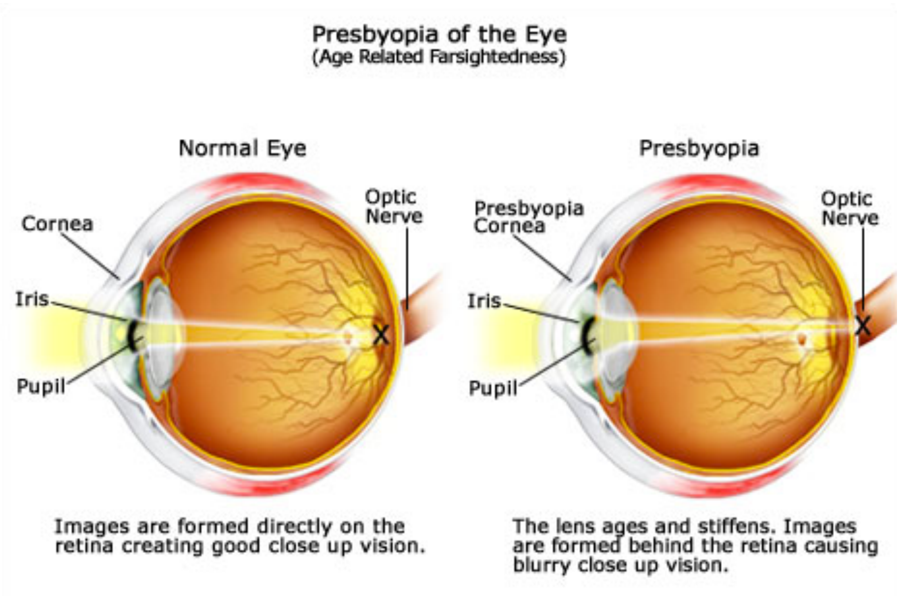


Figure 6. Normal eye and presbyopia (Medlibes, 2017)

After the age of 40, many people gradually find that focusing on close objects becomes difficult because of presbyopia. This is a perfectly normal loss of focusing ability due to the hardening of the lens inside the eye (Heiting, 2017). To satisfy elderly people's requirements, the font sizes on products need to be studied and defined.

b. Decreased Color Vision

As aging occurs, the lens tends to become yellow, the amount of light that enters the eye decreases, and color perception may be influenced. Older people with distorted color perception are often able to discriminate between reds and yellows better than between blues, greens, and purples (Saxon & Etten, 2002). We need to avoid using blues, greens, and purples together when designing products for elderly people.

The cells of the retina that are responsible for normal color vision decline in sensitivity along with the normal aging process, causing colors to become dull and the contrast between different colors to be less noticeable than they once were. In particular, blue colors may appear faded (Heiting, 2017). When designing products for elderly people, the color blue needs to be avoided.

2.1.4 Skin

The skin senses are touch, pressure, heat, cold, and pain. The loss of senses primarily concerns personal safety. Burns are likely to occur if older people do not accurately perceive temperatures (Saxon & Etten, 2002). Research reported in NASA technical reports server showed that when the temperature of any generally used material is lower than 113°F (45°C) and higher than 59°F (15°C), it will meet the touch temperature requirements for all contact times (Ungar & Stroud, 2017). To prevent scalding, the material of the tools' handle need to have the ability to keep its temperature in this properly range when the tools be placed in specific environments, such as under the sun.

2.1.4.1 Skin Changes in the Aging Hand

> Studies showed changes in vascular patterns in the skin of the aged hand. A decline in the number of capillary loops results in a decrease in heat-induced cutaneous blood flow and blood volume, and it interferes with thermal adaptation in elderly adults. Elderly people are more susceptible to feeling cold in their hands than younger people, and this is probably due to the poorer blood flow in the elderly hands. Impaired peripheral circulation with aging results in decreased muscle bioenergy metabolism and oxygenation (Kutsuzawa, Shioya, Kurita,

Haida, & Yamabayshi, , 2001).

The reduction in the tactile sensation of the fingers in elderly adults is a result of the loss of the various sensory mechanoreceptors (Figure 7), the terminations of sensory neurons with somas placed in the dorsal root ganglia (Squire, 2009), which results in misoperation and even injury when older people use tools. Moreover, the materials used for tool handles need to be considered because elderly people are sluggish regarding temperature-awareness.

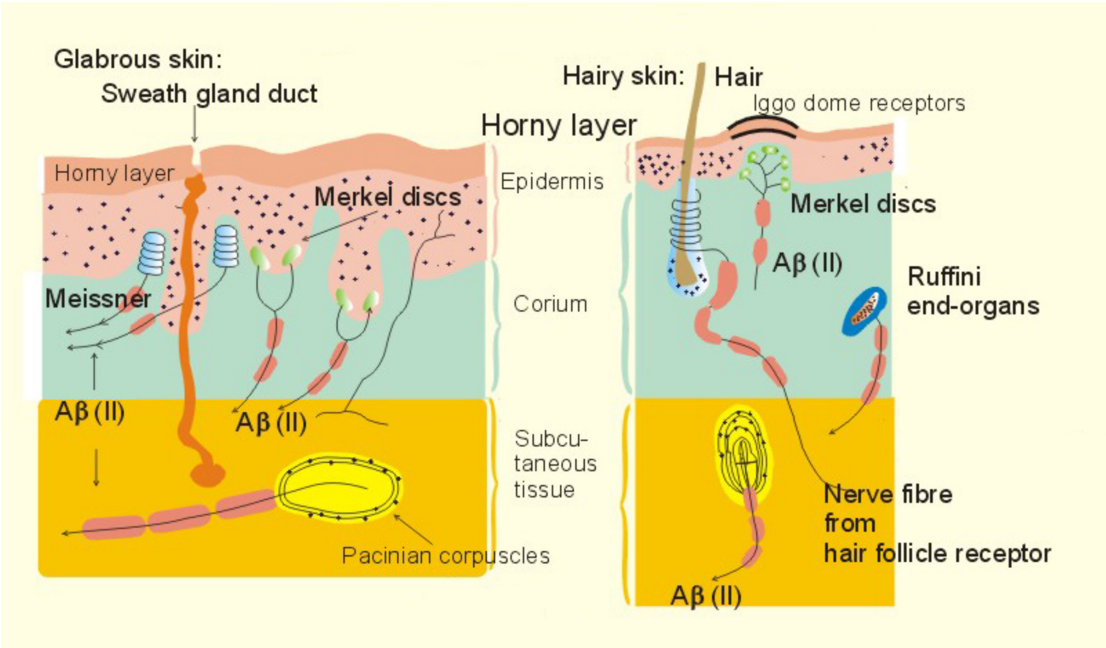


Figure 7. Sensory mechanoreceptors (Paulev-Zubieta, 2017)

2.1.5 Hearing

Starting in one's 40s, there are subtle changes in hearing that become increasingly serious with advancing age (Saxon, & Etten, 2002). In the United States, about 33% people between the ages of 65 and 74 has hearing loss, and approximately 50% of those older than 75 have difficulty hearing (NIDCD, 2017).

Sound is always used as a communication signal when people use hand tools. However, hearing as one of the crucial senses that becomes impaired with aging.

Therefore, designers need to think about how to enable elderly to easily use tools when they are hearing impaired.

2.1.5.1 Age-Related Changes in Hearing

a. Conductive Impairments

There are three categories of hearing impairments, which are generally classified as conductive, sensorineural and mixed (Saxon & Etten, 2002). "Conductive impairments occur when sound is not conducted efficiently through the outer ear canal to the eardrum and the tiny bones (ossicles) of the middle ear" (American Speech-Language-Hearing Association, 2017).

With aging, the musculoskeletal system becomes senescent, which results in conductive impairments.

b. Sensorineural Impairments

About sensorineural impairments, Marieb and Hoehn (2013) have defined in their article:

> Sensorineural impairments result from disorders of the of inner ear (especially loss of hair cells with age) affecting the transmission of sound to auditory receptors and through the auditory pathways. Other possible causes of sensorineural deafness are degeneration of the cochlear nerve, stroke, tumors in the auditory cortex, and drug toxicity.

As we know, older people may take drugs in their daily life. Some drugs would result in sensorineural impairments of hearing, which Saxon and Etten (2002) have demonstrated in their book:

"Many drugs commonly used by older adults such as antibiotics, aspirin, NSAIDs, and diuretics have potential side effects that affect hearing (ototoxicity). Usually ototoxicity will be reversed with discontinuation of the particular drug."

Handheld tools always use sounds as signal to direct users using tools. However sensorineural impairments will decline hearing ability as aging, which will affect the communication between older people and products. How to make older people listen to the signal sounds clearly needs further studies.

2.1.5.2 Age-Related Disorders of Hearing

a. Presbycusis

The presbycusis appertain to sensorineural impairment, caused by the natural aging of the auditory system (Roland, 2017). The symptoms of presbycusis is being unable to hear clearly and unable to distinguish to higher-pitched sounds of speech, such as /s/ and /th/ (HEAR net Online, 2017).

To effectively use sound communication for old people, designers need to discover which frequencies of sound are in the clearest range for elderly people.

b. Tinnitus

Saxon and Etten (2002) have defined *Tinnitus* in their book:

> Tinnitus is the perception of sounds in one or both ears in the absence of an auditory stimulus. It can occur in those with or without hearing loss. Eighty-five percent of those with hearing or ear problems experience tinnitus, and it is more common in older adults. Sounds are described as a ringing, buzzing, whistling, or roaring in the ears.

Moreover, tinnitus can lead to increased stress, anxiety, irritability, and depression. Each of these ailments is affiliated with the brain's emotional processing systems (Medical Express, 2017). Because many older people have tinnitus and researchers have determined that tinnitus can influence people's emotion, designing tools for elderly people requires the designer to appropriately consider their special emotional problems.

2.2 Psychological Characteristics of Elderly People

2.2.1 Special Psychological features of elderly people

The feelings we experience play a key role in various affect-related special-purpose learning and cognitive systems (Barkow, Cosmides, & Tooby, 1992). And because the older people as a special group of study subjects, the psychological aspect requires additional attention when designing tools for old people.

Elderly people tend to have more troubles in falling asleep and staying asleep than when they were younger. It is a common myth that sleep needs drop with aging. Actually, research determined that our sleep needs remain constant throughout adulthood (National Sleep Foundation, 2017). However, lack of sleep does play a key role in causing depression. People who are unable to sleep that lasts over a long period of time may be depressed (WebMD, 2017).

We can conclude that elderly people are prone to depressive emotions due to age-related declines in sleep quality. When designing handheld tools and products for daily use by older people, designers need to consider the users' emotions in the design process. Giving users pleasurable product-use experiences is one of the most important goals.

Changes in higher brain functions in old age may impede subcortical functions, leading to the prevalence of certain emotional energies—feelings of frustration, anger, and loss (Magai &McFadden, 1996). From the perspective of most people in today's society, peaceful emotions are positive and the contrary feelings of anger and anxiety are negative. How to make users produce pleasurable perceptions while using the tools needs to be considered.

Several studies support the notion that staying in the home environment is highly desirable for elderly people who are at risk of injury, such as those who lose their capacity to function autonomously, recently experience widowhood, or live in suboptimal environments (e.g., single-room elderly occupants in New York City) (Birren & Schaie, 2001). This fits well with other results that show that elders, when forced to make housing choices, generally prefer to remain in their own homes (Birren & Schaie, 2001). Because elderly people often lack a sense of security, remaining at home can give elderly people a sense of security. The designs of handheld tools need to reduce negative impacts on users' emotions, such as by avoiding cold colors and sharp shapes.

Chapter 3

Design Guidelines for Handheld Tools

3.1 Handle Design

The purpose of a handle is to facilitate the transmission of force from the musculoskeletal system of the user; to the tool or object he is using; in the performance of the task or purpose for which he is using it (see Figure 8). As a general rule, we can say that to optimize force transmission is to optimize handle design. (Pheasant, 1996)

As discussed in Chapter 2, when people age, the strength of their hand muscles will decline. This results in a decrease in the strength of the hand. In this section, the author of this paper discusses how to optimize handle design for elderly users.

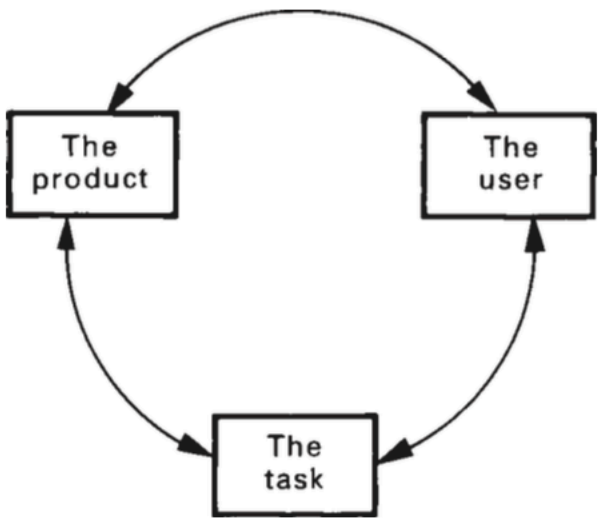


Figure 8. User-centered design: The product, the user and the task (Pheasant, 1996)

3.1.1 Handle Length Design

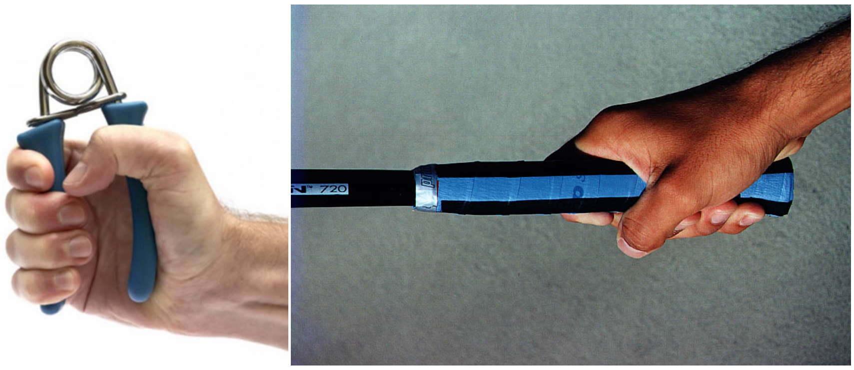


Figure 9. Hand positions of using handheld tools (Muscle & Fitness, 2017)

Common hand positions when using hand tools are shown in the figure above (Figure 9). We can conclude that the length of the handle is determined by the sum of the lengths of hand breadth and thumb breadth (Figure 10). We can determine the best handle length for hand tools for elderly people by measuring older people's hand breadths and thumb breadths.

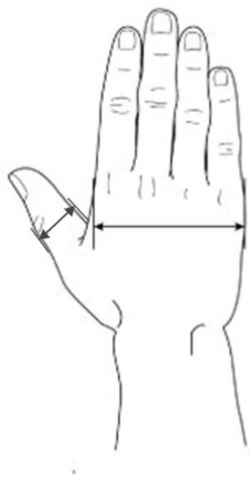


Figure 10. Hand Breadth and Thumb Breadth (Open design lab, 2017)

	Men				Women			
Dimension	5th %ile	50th %ile	95th %ile	SD	5th %ile	50th %ile	95th %ile	SD
1. Hand length	173	189	205	10	159	174	189	9
2. Palm length	98	107	116	6	89	97	105	5
3. Thumb length	44	51	58	4	40	47	53	4
4. Index finger length	64	72	79	5	60	67	74	4
5. Middle finger length	76	83	90	5	69	77	84	5
6. Ring finger length	65	72	80	4	59	66	73	4
7. Little finger length	48	55	63	4	43	50	57	4
8. Thumb breadth (IPJ)[a]	20	23	26	2	17	19	21	2
9. Thumb thickness (IPJ)	19	22	24	2	15	18	20	2
10. Index finger breadth (PIPJ)[b]	19	21	23	1	16	18	20	1
11. Index finger thickness (PIPJ)	17	19	21	1	14	16	18	1
12. Hand breadth (metacarpal)	78	87	95	5	69	76	83	4
13. Hand breadth (across thumb)	97	105	114	5	84	92	99	5
14. Hand breadth (minimum)[c]	71	81	91	6	63	71	79	5
15. Hand thickness (metacarpal)	27	33	38	3	24	28	33	3
16. Hand thickness (including thumb)	44	51	58	4	40	45	50	3
17. Maximum grip diameter[d]	45	52	59	4	43	48	53	3
18. Maximum spread	178	206	234	17	165	190	215	15
19. Maximum functional spread[e]	122	142	162	12	109	127	145	11
20. Minimum square access[f]	56	66	76	6	50	58	67	5

Notes:
[a] IPJ is the interphalangeal joint, i.e. the articulations between the two segments of the thumb;
[b] PIPJ is the proximal interphalangeal joint, i.e. the finger articulation nearest to the hand;
[c] as for dimension 12, except that the palm is contracted to make it as narrow as possible;
[d] measured by sliding the hand down a graduated cone until the thumb and middle fingers only just touch;
[e] measured by gripping a flat wooden wedge with the tip end segments of the thumb and ring fingers;
[f] the side of the smallest equal aperture through which the hand will pass.

Table 4. Anthropometric estimates for the hand (all dimensions in mm) (Pheasant, 1996).

As discussed in Chapter 2, muscles atrophy with age, and the atrophy will contribute to a decreasing in muscle mass (Saxon & Etten, 2002). Therefore, in the aging process, older people's hands become smaller than healthy adults' hands. When the length of a handle is greater than the sum of the maximum thumb breadth and hand breadth, the handle will be suitable for everyone, including elderly people. As shown in Table 4, the value of the sum of the maximum thumb breadth and hand breadth will be:

26+95=121mm (4.76")

3.1.2 Handle Design of Gripping and Squeezing Tools

To build an effective gripping and squeezing tools, Pheasant (1996) has defined two factors, which determined the effective cutting/crushing force:

An important group of cutting and crushing tools, from pliers and wire-cutters to nut- crackers and secateurs, are operated by a forceful squeezing action across two pivoting arms. The fingers curl around one arm and the heel of the palm butts against the other. The effective cutting/crushing force is determined by the mechanical advantage of the tool and the user's grip strength. The latter is determined inter alia by the distance across the two arms—as shown in Table 5. The optimal handle separation is 45–55 mm for both men and women（Pheasant, 1996）.

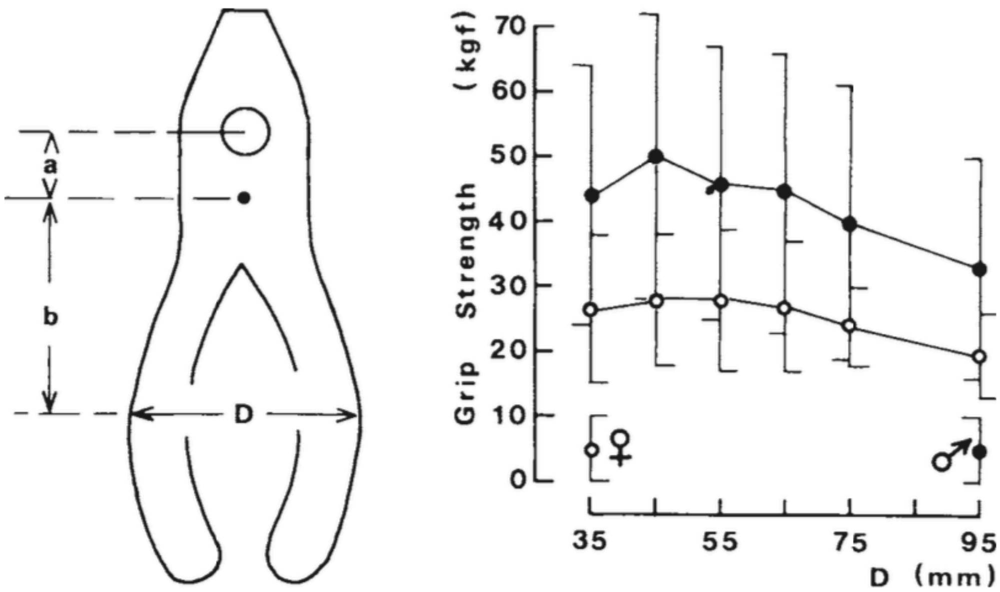


Table 5. Grip strength (G) as a function of the handle size (D). Vertical lines are 5th–95th percentile values in samples of 22 men and 22 women. The tool is a lever of the first class, the mechanical advantage=b/a. Hence, the effective cutting or crushing force = GB/A (Pheasant, 1996).

As mentioned above, in handle design, the effective cutting/crushing force is determined by the distance between two arms. Older people's hand strength decreases with age. As shown in Table 5 above, the decline of hand grip strength will start around age 40 to 44. However, even if one's grip strength decreases, the peak of grip strength will take place when the handle diameter is between 1.77" (45mm) and 2.16" (55mm). Table 6 shows the approximate change of grip strength with handle separation. Hence, the optimal handle separation for elderly users is 1.77" (45mm) and 2.16" (55mm).

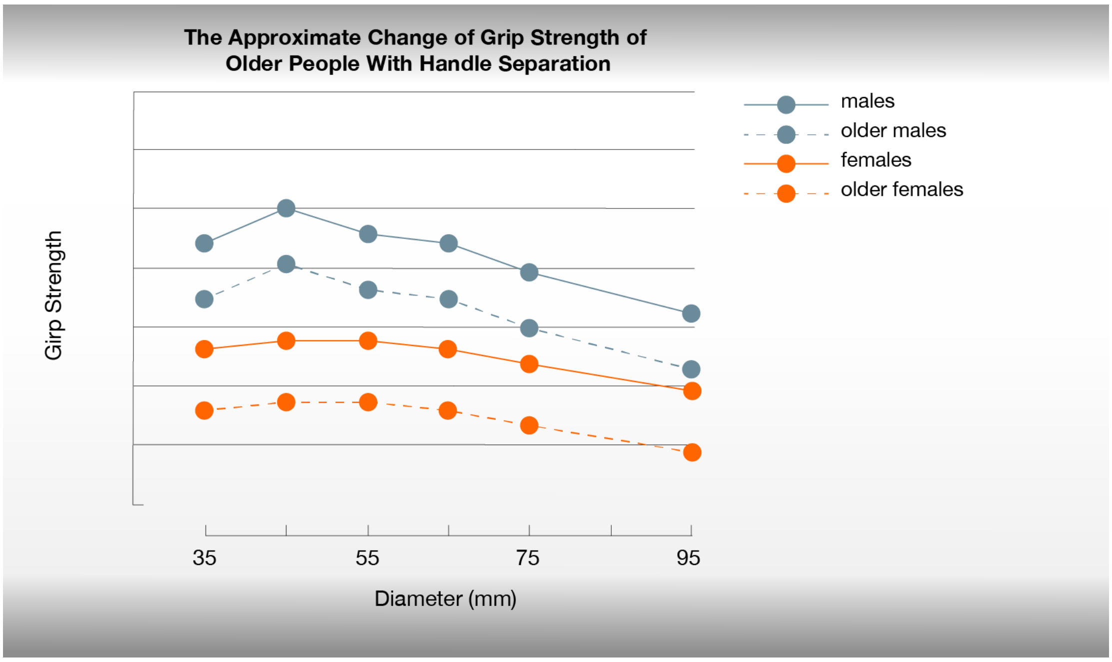


Table 6. The approximate change of grip strength of older people with handle separation (Pheasant, 1996).

3.1.3 Handle Design of Gripping and Turning Tools

In Pheasant's (1996) "Body space", he has talked what factors determine the strength of action when using gripping and turning tools (as a screwdriver):

> Consider a cylindrical handle as shown in Figure 11. It may be gripped and turned about its own axis A–A'. When the handle is

employed as a screwdriver (rotating about axis A–A') the strength of the action is no longer determined by the user's capacity to generate torque but by the ability to transmit it across the hand-handle interface. It is, therefore, strongly dependent upon handle design. Torque about axis A–A' is exerted by a shearing (frictional) action on the cylinder's surface, hence

$$T_a = G\mu D,$$

where G is the net compressive force (i.e., grip), D is the diameter of the cylinder, and μ is the coefficient of limiting friction between the hand and the handle. For any handle of circular cross-section (i.e., cylinder, sphere, or disc), T_a will increase with diameter. Table 7 summarizes the results of such an experiment.

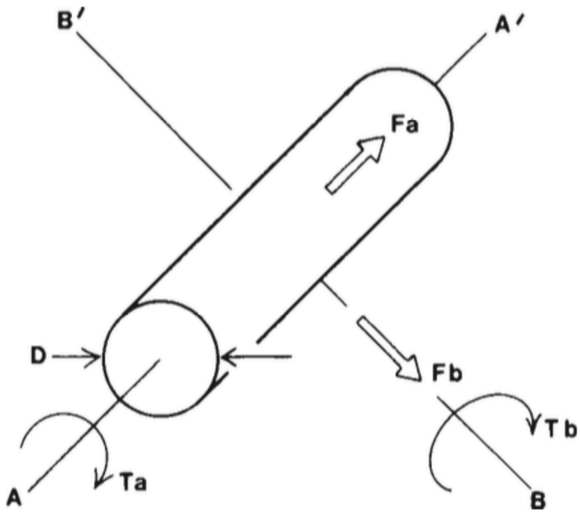


Figure 11. The cylindrical handle showing the long axis A–A' (Pheasant, 1996).

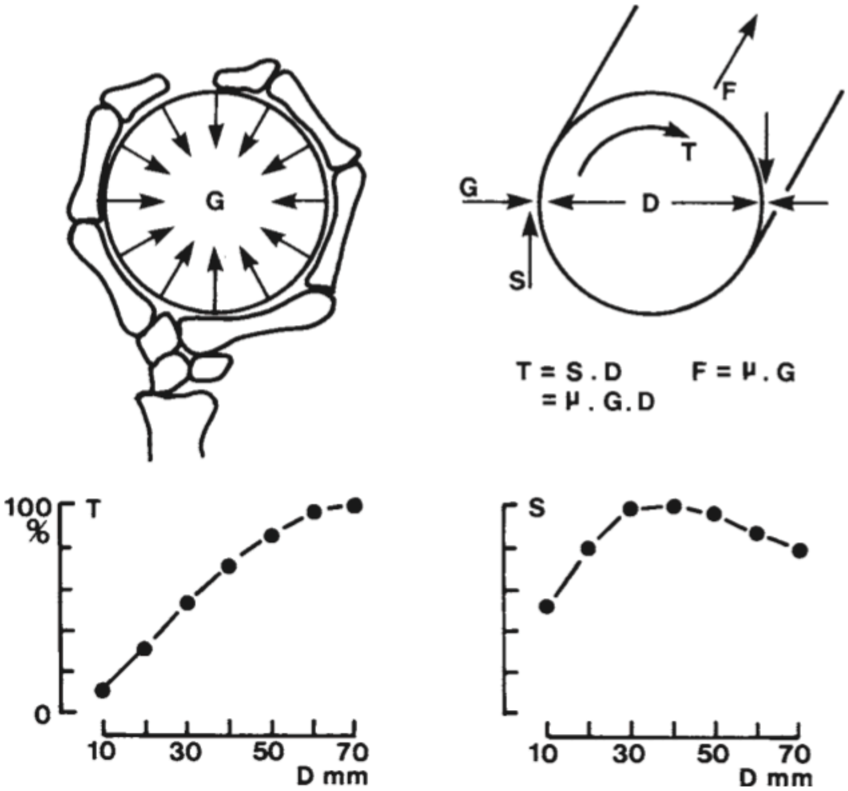


Table 7. The mechanics of the gripping and turning action, using a cylindrical handle. Note that torque (T) is the greatest on the 70-mm handle, whereas both shear (S=T/D=μG) and thrust (F, not plotted), are greatest on handles in the 30–50 mm range. (Pheasant, 1996)

Thrust shear (S) was measured directly (Pheasant & O'Neill, 1975), and the strength of a thrusting action along axis A-A' is given by

$F_a = G\mu,$

From Table 7 as shown, the force declines steeply when the handle diameter exceeds a certain value. It may be concluded that the strength of one's grip decreases when using large handles (Pheasant & O'Neill, 1975).

To figure out what reasons result in the declines of grip strength, Pheasant and O'Neill did another experiment:

To clarify this phenomenon, palm prints were taken of six subjects by wrapping photographic paper around each of the seven handles, prior to gripping with the greased hand. An example of such a set of prints is shown in Figure 12. The total contact areas were measured using a planimeter and the mean normalized values (± 1 SD) are shown in Table 8.

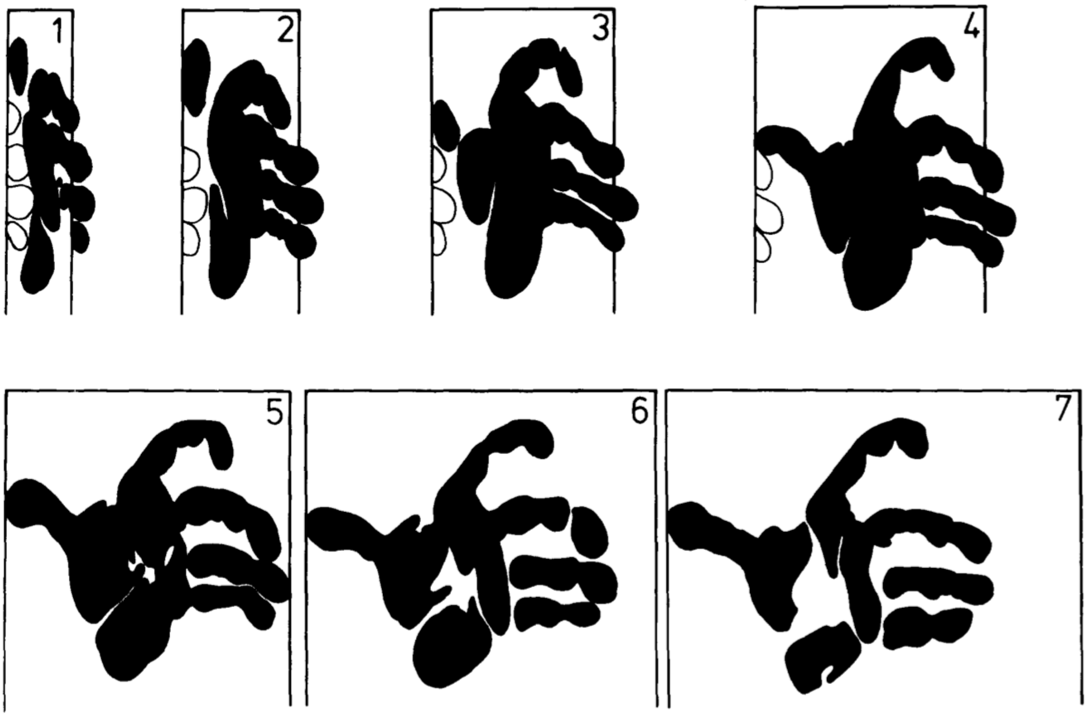


Figure 12. Sample set of the hand prints. (Pheasant & O'Neill, 1975).

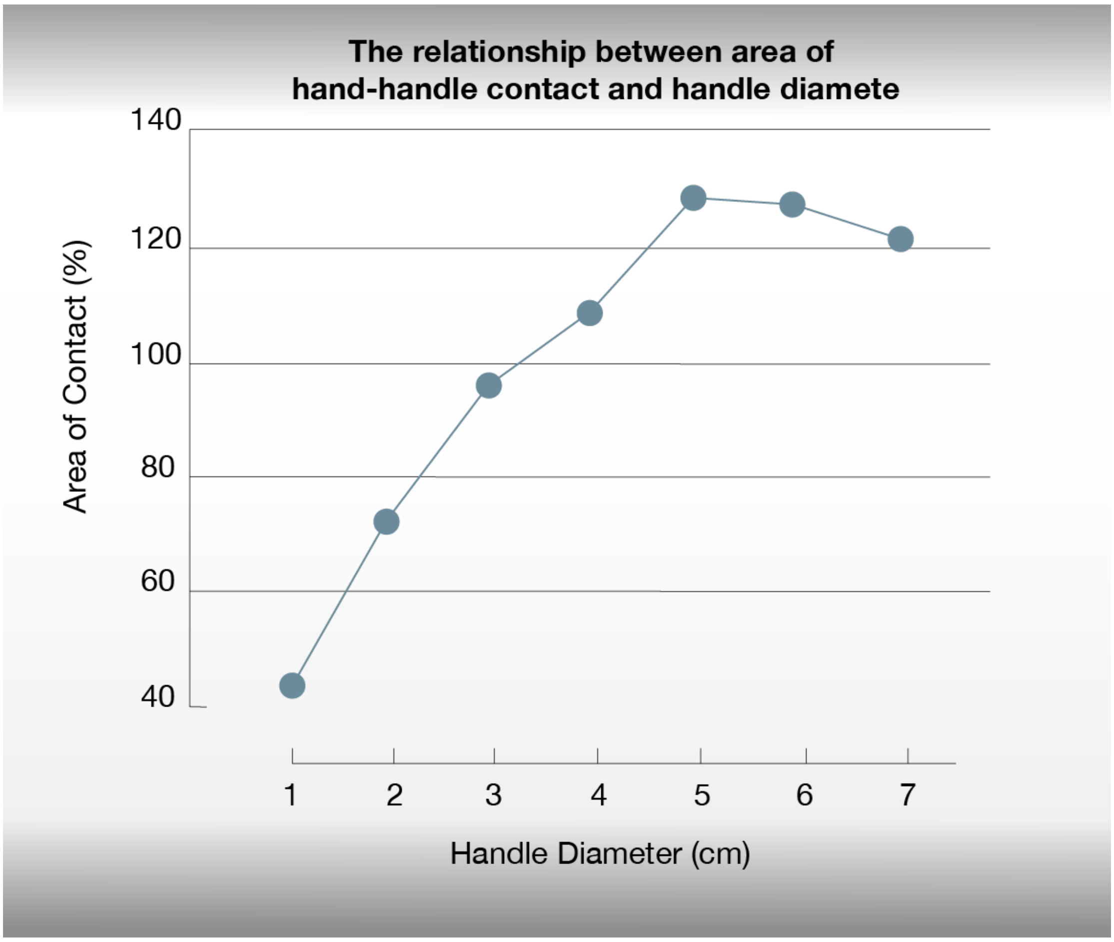


Table 8. The relationship between area of hand-handle contact and handle diameter (mean normalized values ± 1 standard deviation from six subjects). (Pheasant, 1996)

The comparison of this relation with that shown in Table 8 suggests that grip is weaker on smaller handles due to inadequate contact. The reduction in performance at greater than optimal diameters is much more marked than the reduction in contact area, and hence it is probable that in this range it is the muscles themselves that limit performance, although the possibility of other more complex interactions cannot be excluded (Pheasant & O'Neill, 1975).

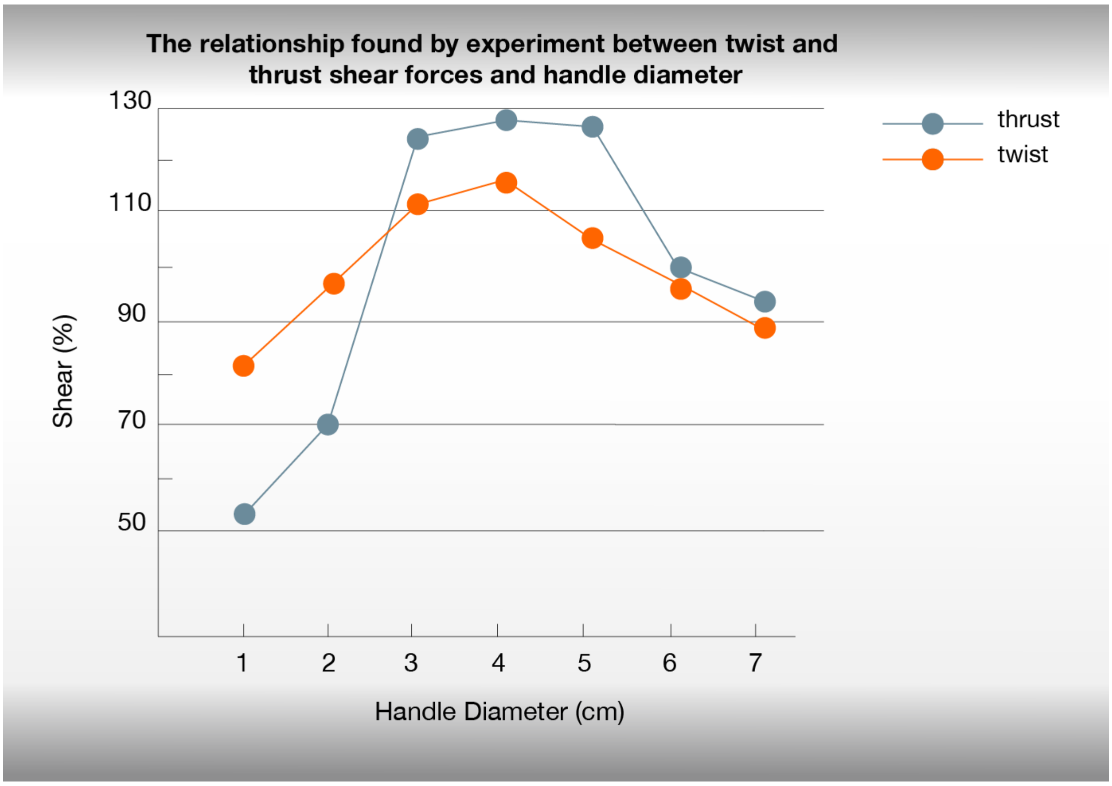


Table 9. The relationship found by experiment between twist and thrust shear forces and handle diameter (mean normalized values from 10 subjects) (Pheasant & O'Neill, 1975).

According to the inference discussed in the last section and the function: $F_a = G\mu$, we can know aging people have weaker grip strengths than young people, so their shear would be smaller than that of healthy adults. Moreover, the peak of shear will still take place when the handle diameter is between 1.18" (30mm) – 1.97" (50 mm). The palm prints experiment also proved this view. When the contact area is adequate, the grip strength will be greater than when less contact area is available. Therefore, the when the handle is employed as a screwdriver (rotating about axis A–A') or as held like a toothbrush, the optimal diameter for aging people is between 1.18" (30mm) – 1.97" (50 mm).

From the formula: $T_a = G\mu D$, to increase torque (T), we can also raise the coefficient of friction (μ). This issue involves material selection and handle grain, which are discussed in the following sections.

3.1.4 Material Selection for Handle

As previously mentioned, aging skin is logy in reception of senses, especially in perceiving temperatures. To avoid burns or any injuries caused by inappropriate temperatures, the material of the handle needs to have low thermal conductivity.

Table 10 (MidwayUSA, 2017) below shows frequently-used handle materials. A good material for elderly tools' handles should have low thermal conductivity, and the thermal conductivity should not change too much as temperature changes. The data from Table 10 (MidwayUSA, 2017) indicates that G-10, Noryl® GTX, Phenolic, Valox®, and Zytel® are good selections for tool handles for the elderly.

Material	Characteristics	Thermal Conductivity (W/(m K))
Carbon Fiber	This material is a woven composite of graphite fibers fused together with an epoxy resin. Providing ultra-light weight and extreme tensile strength, it most often has a visible weave-like pattern. The weave pattern can be varied, as can the color of the epoxy used.	21-180
Delrin®	This lightweight and durable polymer was engineered for excellent long-term wear characteristics. It can be molded to form, and is used in many industries.	31
G-10	G-10 is an epoxy filled woven "E" glass composite, reinforced with glass fibers for strength. Originally designed for circuit boards, it offers the knife industry a handle which is	0.1-0.6

	impervious to most elements like oils, water and acids. It can be made in many colors, and finished in a variety of ways, offering different amounts of texture matched to different end uses.	
Noryl® GTX	A modern, engineered plastic offering extreme durability. It is impervious to harsh environments and chemicals and is very strong. It offers no flexibility, but can be molded to any shape and in any color.	0.25
Phenolic	This hard, ebony-colored compound is almost impervious to heat cold and shock, making it practically indestructible.	0.25
Valox®	A reinforced resin with exceptional stiffness, Valox® offers strength and dimensional stability. It has outstanding chemical and flame resistance, and is molded to form.	0.19
Zytel®	Zytel® is a material made up of fiberglass and nylon. The two are combined and heated to near 600°F and then injection molded to the desired form. Strong and lightweight, it offers excellent surface grip.	0.16

Table 10. Frequently-used handle materials (MidwayUSA, 2017)

3.2 Controls

3.2.1 Press-Buttons

Press-buttons are widely used in hand tools. They are suitable for starting and stopping or for switching on or off (Ivergard, 1989). When we design hand tools for older people, press-buttons are important parts that need to be considered.

Buttons should be designed with appropriate sizes and placed properly so they are easy for older people to use. To improve operation accuracy, the sum of the button semidiameter and the distance between two buttons should be greater than the half of the finger's breadth (Figure 13). For example, when people are using their index finger operate on a press-bottom, the minimum sum of button semidiameter and the distance between two buttons should be 0.45" (11.5mm). When adjacent buttons are in different size, the semidiameter will be defined by the smaller one. In this way, elderly people can avoid misoperation when they are using hand tools.

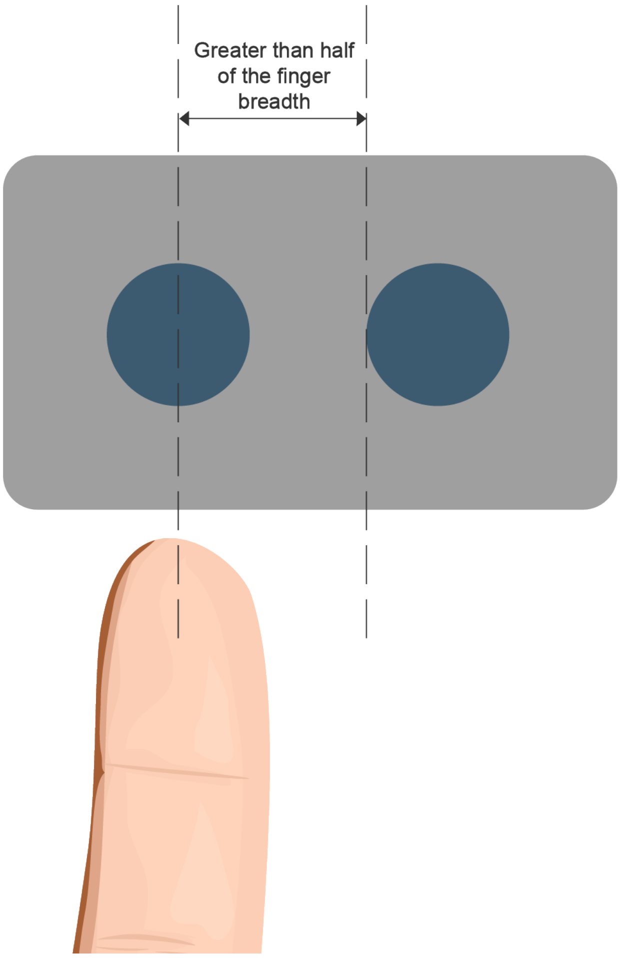


Figure 13. The sum of the button semidiameter and the distance between two buttons should be greater than the half of the finger's breadth.

Dimension	Men 5th %ile	Men 50th %ile	Men 95th %ile	Men SD	Women 5th %ile	Women 50th %ile	Women 95th %ile	Women SD
1. Hand length	173	189	205	10	159	174	189	9
2. Palm length	98	107	116	6	89	97	105	5
3. Thumb length	44	51	58	4	40	47	53	4
4. Index finger length	64	72	79	5	60	67	74	4
5. Middle finger length	76	83	90	5	69	77	84	5
6. Ring finger length	65	72	80	4	59	66	73	4
7. Little finger length	48	55	63	4	43	50	57	4
8. Thumb breadth (IPJ)[a]	20	23	26	2	17	19	21	2
9. Thumb thickness (IPJ)	19	22	24	2	15	18	20	2
10. Index finger breadth (PIPJ)[b]	19	21	23	1	16	18	20	1
11. Index finger thickness (PIPJ)	17	19	21	1	14	16	18	1
12. Hand breadth (metacarpal)	78	87	95	5	69	76	83	4
13. Hand breadth (across thumb)	97	105	114	5	84	92	99	5
14. Hand breadth (minimum)[c]	71	81	91	6	63	71	79	5
15. Hand thickness (metacarpal)	27	33	38	3	24	28	33	3
16. Hand thickness (including thumb)	44	51	58	4	40	45	50	3
17. Maximum grip diameter[d]	45	52	59	4	43	48	53	3
18. Maximum spread	178	206	234	17	165	190	215	15
19. Maximum functional spread[e]	122	142	162	12	109	127	145	11
20. Minimum square access[f]	56	66	76	6	50	58	67	5

	5^{th}	50^{th}	95^{th}
Man	0.75"	0.83"	0.9"
Woman	0.63"	0.71"	0.79"

Notes:
[a] IPJ is the interphalangeal joint, i.e. the articulations between the two segments of the thumb;
[b] PIPJ is the proximal interphalangeal joint, i.e. the finger articulation nearest to the hand;
[c] as for dimension 12, except that the palm is contracted to make it as narrow as possible;
[d] measured by sliding the hand down a graduated cone until the thumb and middle fingers only just touch;
[e] measured by gripping a flat wooden wedge with the tip end segments of the thumb and ring fingers;
[f] the side of the smallest equal aperture through which the hand will pass.

Table 11. Anthropometric estimates for the hand (all dimensions in mm) (Pheasant, 1996).

The press-button is a control that can transfer a decision from a human to a machine.

It needs to hold the user's resistance and increase little by little and then disappear suddenly to let the human know that the button has been activated (Ivergard, 2009). However, how much resistance elderly people can comfortably handle needs to be discussed. In Chapter 2, it was determined that many physical functions of the hand decline with age. The data from an experiment in which the pushing force of the index finger of 148 people aged from 2 to 90 was measured. The results are that one's pushing force declines by 20% after age 50 (Table 12). For normal users, the average resistance of a press-button is between 10 and 20 oz. of force (Denno et al., 1992). Therefore, the resistance of a press-button should be between 8 and 16 oz. to accommodate elderly people.

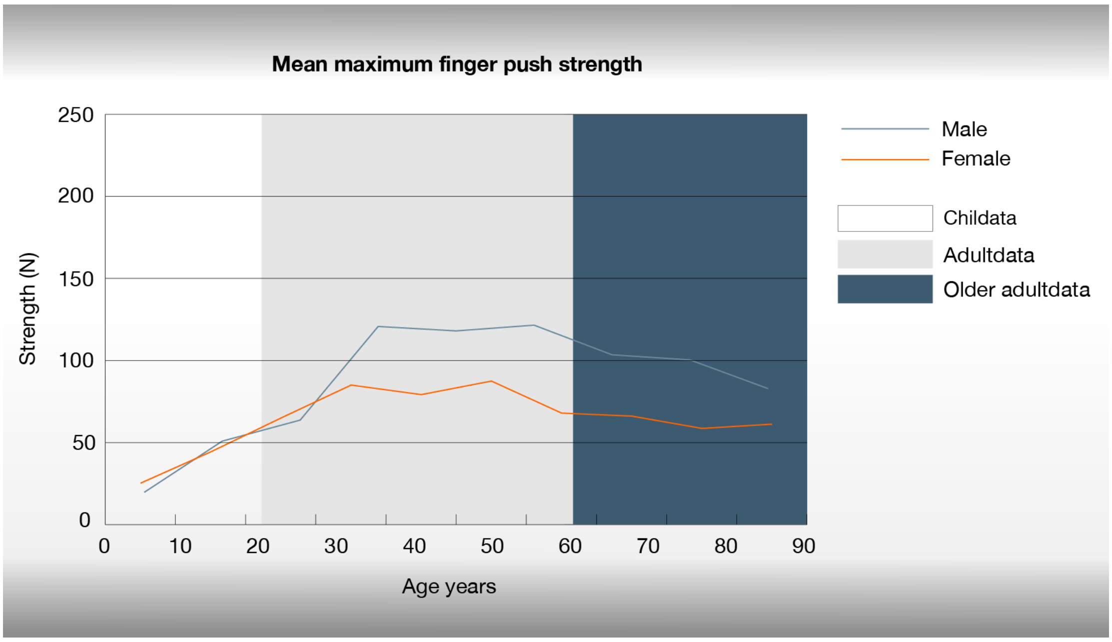


Table 12. Mean maximum finger push strength (Nottingham University, 2000)

3.2.2 Rotary Switches

3.2.2.1 Cylindrical

Rotary switches can be widely used in hand tools. Push-buttons and toggle switches will occupy more spaces than rotary switches and can be used to for the same function (Ivergard & Hunt, 2009). Mostly, there are two groups of rotary switches: cylindrical and winged (Ivergard & Hunt, 2009). Cylindrical rotary switches are shown in Figure 14.

The size of a cylindrical rotary switch should be from 0.5 to 1.0" high and from 1.0 to 1.5" in diameter to satisfy most user's needs (Denno et al., 1992). The turning resistance should sustainably increase and suddenly disappear as the next position is approached (Ivergard & Hunt, 2009). When designing tools for elderly users, the resistance of rotary switches needs to be considered.

Table 13. Mean maximum circular knob wrist-twisting strength (Nottingham University, 2000)

There is an experiment on the mean maximum circular knob wrist-twisting strengths of people in different age groups (Nottingham University, 2000) Subjects exert a static twisting force with their dominant hand in a clockwise direction on a circular knob, and the experiment results are shown above (Table 13). As shown in Table 13, after age 50, one's wrist-twisting strength decreases by around 20%. For common users, the torque of a cylindrical knob is between 20 and 50 in-oz (Denno et al., 1992). Therefore, the maximal turning resistance of a cylindrical rotary switch should be between 16 and 40 in-oz. to accommodate elderly users.

To prevent the user's hand from sliding off, the surface of a rotary switch should have a sufficient coefficient of friction (Ivergard & Hunt, 2009) Additionally, as mentioned in Chapter 2, pinch strength declines with age. There is only one way to increase the coefficient of friction, which is to increase the roughness of the surface (Figure 14).

Figure 14. Increasing the Roughness of the Surface (Kufatec, 2017).

Furthermore, rotary switches' scales should always increase clockwise and a sound should be made to denote that the switch has been activated (Ivergard & Hunt, 2009). This is discussed in the next section

3.2.2.2 Winged

Another kind of rotary switch is a winged rotary switch. There is a pair of wings above the cylindrical part, and the wings function both as positional markers and as finger grips (Ivergard & Hunt, 2009). For a majority of users, the size of a winged rotary switch should be from 0.625" to 3.0" high and 1.0" to 4.0" long, and 1.0" wide (Denno et al., 1992).

In addition to these recommendations for rotary switches, the scale arrangement should be considered for winged rotary switches design. From the mean maximum ridged knob wrist-twisting strength experiment data list below (Table 14), it is easy to figure out that the strength required to turn the knob is greater than the ridged knob placed vertically when the ridged knob is placed horizontally.

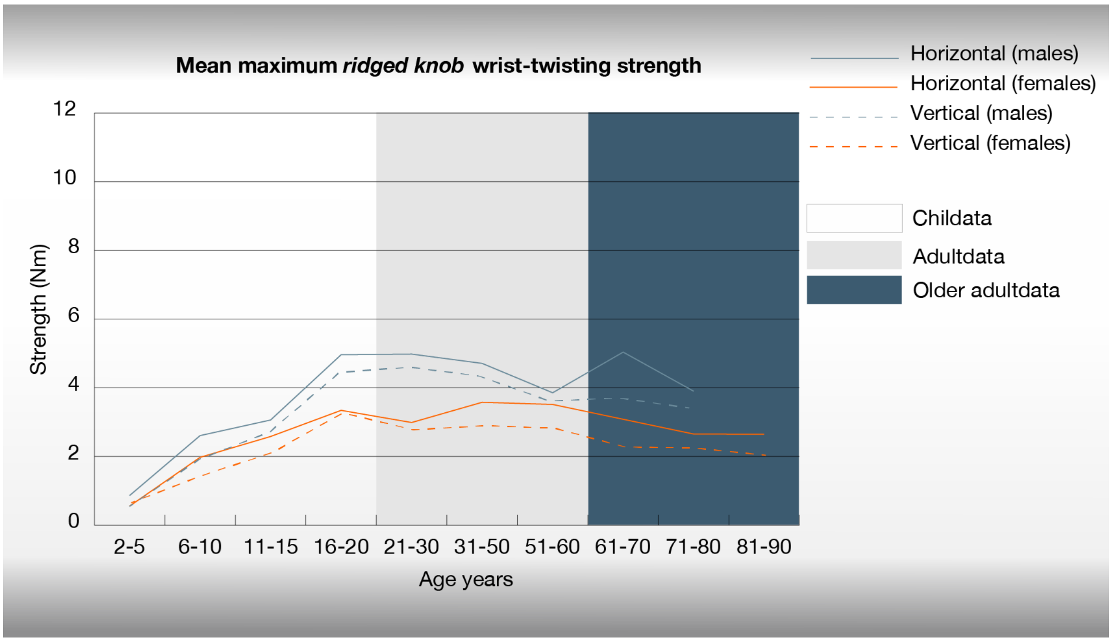
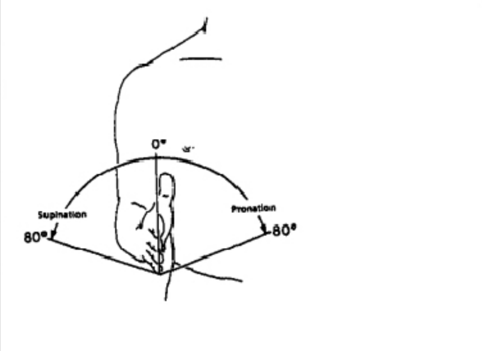


Table 14. Mean maximum ridged knob wrist-twisting strength (Nottingham University, 2000)

From research, the forearm ROM (range of motion) (pronation-supination) is pronation 80° and supination 80° with both hands (Washington State Department of Social & Health Services, 2014) (Figure 15). Moreover, no significant differences were found in the elbow and wrist joint ROMs between people in different age groups

(Doriot &Wang, 2006). However, as Chapter 2 mentioned, degenerative arthritis and osteoarthritis are the most common form of arthritis in people over the age of 50. These chronic diseases will definitely influence their ROM in pronation-supination. Regarding this situation, there is study that measured older peoples' ROM of pronation-supination (Sacco et al., 2015). There are 77 participants in the experiment, whose age is from 77 to 90 years old, and the result is shown in Table 15.



Left	
Pronation 80°	Supination 80°
Degrees	Degrees
Right	
Pronation 80°	Supination 80°
Degrees	Degrees

Figure 15. Normal Adults' Wrist ROM (Washington State Department of Social & Health Services, 2014)

Movement	Date range
Pronation	79.1-110.1
Supination	57.9-86.7

Note: Data is measured in degrees.

Table 15. The Wrist ROM of Elderly People (Sacco et al., 2015)

Based on the discusses above, the winged rotary switch scale for elderly hand tools should be designed like that in Figure 16. The scale should be placed horizontal and the range of angle will not be over 80° on left side and 57° on right side (for people who use right hand as dominance).

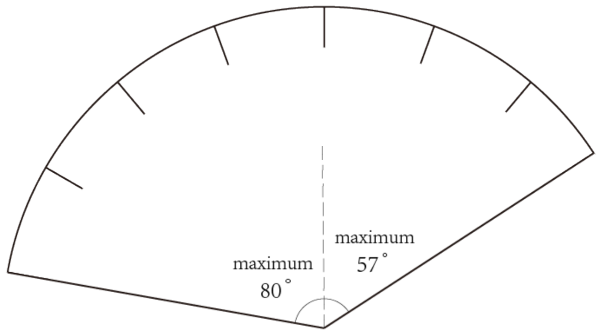


Figure 16. Scale of Rotary Switches for Elderly People

Moreover, the normal resistance of a winged rotary switch is between 12 and 48 oz. (Denno, et al., 1992). Table 14 indicates that people's wrist-twisting strength on a ridged knob will drop by around 17% after they reach the age of 50. Therefore, for older people to use winged rotary switches, the maximum turning resistance should be between 9.96 and 39.84 oz.

3.2.3 Rocker Switches

Usually, the function of a rocker switches is confined to on/off or start/stop controls (Weinger, et al., 2010). They are widely used in hand tools as control switches. Rocker switches normally maintain positions until they are actuated again.

Rocker switch size recommendations need be designed to accommodate the index fingers of the largest men, which also accommodates elderly users by offering a large contact surface area (Weinger, et al., 2010). Table 16 shows that the largest man's index finger breadth is 0.9". The length and width of a rocker switch needs be greater than 0.9".

	5^{th}	50^{th}	95^{th}
Man	0.75”	0.83”	0.9”
Woman	0.63”	0.71”	0.79”

Table 16. Anthropometric estimates for index finger breadth

(Pheasant, 1996)

For normal users, the resistance of rocker switch is from 10 to 40 oz. (Denno et al., 1992). As with press-buttons, one’s pushing force declines by 20% after they reach the age of 50. Therefore, for older users, the recommended resistance is 8 to 32 oz.

A 30° angle of travel is recommended, along with a level of resistance that does not require prolonged exertion by elderly users (Weinger, et al., 2010).

3.3 Feedback

3.3.1 Sounds

When people use hand tools, a sound signal is an important communicative method between the user and the tool. In addition to being timekeepers when people are using hand tools, a sound can also be made to denote that the switch has been activated. As mentioned in Chapter 2, most elderly people have presbycusis, which causes them to be unable to hear high-frequency sounds. To enable older people to receive sound signals clearly, designers need to find a proper sound frequency range.

Table 17 shows hearing loss in a population between 0 and 100 years old. Table 18 shows the cumulative percentage distribution of hearing levels at different frequencies. This data was compiled from the Health and Nutrition Examination Survey (1971–1975) (Denno, et al., 1992).

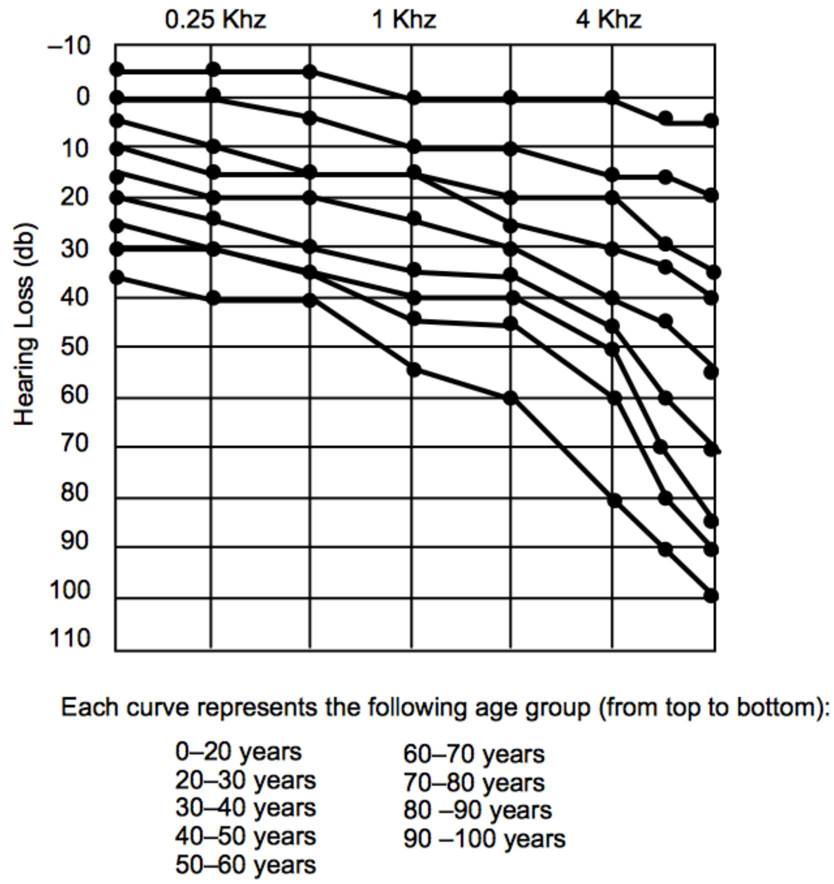


Table 17. Decade Audiogram Illustrating the Audiometric Patterns of Normal Aging (Denno, et al., 1992)

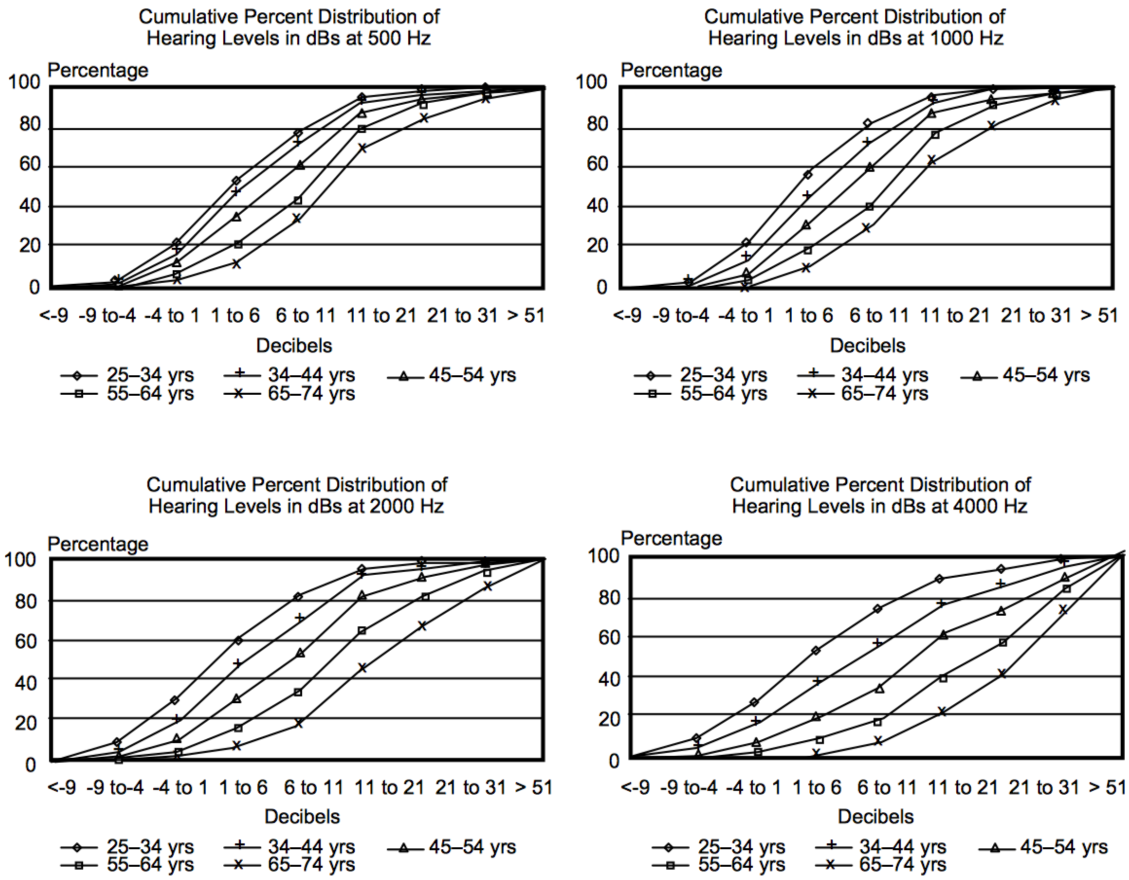


Table 18. Percentage Hearing Loss by Age and Frequency (Denno, et al., 1992)

The main frequency range for human hearing is from 300 to 3000Hz. This is also the range of frequencies that must be heard for the perception of speech (Sound Engineering Academy, 2017). Table 17 indicates that the hearing loss of elderly will increases sharply if the frequency of sound is greater than 625Hz. Thus, the best range of sound frequency for old people is 300 to 625Hz.

A safe and proper sound decibel range for normal humans is 0 to 85dB (WIDEX 2017). As shown in Table 18 above, elderly people can completely perceive sounds at around 51dB. Therefore, for older users, the recommended decibel range for sound indicators on handheld tools is 51 to 85dB.

3.4 Displays

As discussed in Chapter 2, many people over the age of 40 get presbyopia, which is caused when the lens of the eye begins to harden in the natural aging process. Presbyopia makes people unable to focus on small objects well and results in reading disorders. Beyond that, color vision also reduces with advancing age. Older people cannot distinguish between blue, green, and purple well. In particular, the color blue appears to be washed out. Therefore, in this section, the author focuses on the colors and fonts used in hand tool design.

3.4.1 Fonts

For normal healthy adults, the recommended focus distances of reading are between 15 to 25 inches from the eyes (Dhir Hospital, 2017). However, the elderly people who have presbyopia will move the reading material farther away than the ideal reading distance mentioned above, when they are reading. That is because their lens has changed shape and only when they are looking at something far away will the object be clearly focused on their retina.

In order to have older people reading at an ideal reading distance, the font size and shape need to be considered. There is a study in which differences in legibility and perceptions of font legibility are studied (Bernard, Liao, & Mills, 2001). Table 19 shows different font types and sizes. The serif fonts used are Georgia and Times New Roman, and the sans serif fonts Arial and Verdana, at both 12- and 14-points. Font conditions were compared by having participants read eight passages and the text of each passage comprised of a font from one of the eight type/size font conditions.

There were 27 participants aged from 62 to 83 in this experiment. Participants were asked to read passages that contained ten randomly-placed substitution words as quickly and accurately as possible. The substitution words varied grammatically from the original words, for instance the noun "lake" was switched with the verb "make" (Bernard, Liao, & Mills, 2001).

Serif Fonts	Sans Serif Fonts
Times New Roman	Arial
Georgia	Verdana
Times New Roman	Arial
Georgia	Verdana

Table 19. Example of the eight size/type font combinations studied (Bernard, Liao, & Mills, 2001).

"As a result, in assessing font legibility by means of reading efficiency, a main effect for size was found, where the 14-point font size had significantly greater reading efficiency than the 12-point font size" (Bernard, Liao, & Mills, 2001). The results of the experiment reveal that the 14-point font was significantly more legible than the 12-point font (Bernard, Liao, & Mills, 2001). Furthermore, Table 20 indicates that 14-point fonts were significantly preferred to 12-point fonts size. Moreover, the Arial fonts were significantly preferred over other fonts (Bernard, Liao, & Mills, 2001).

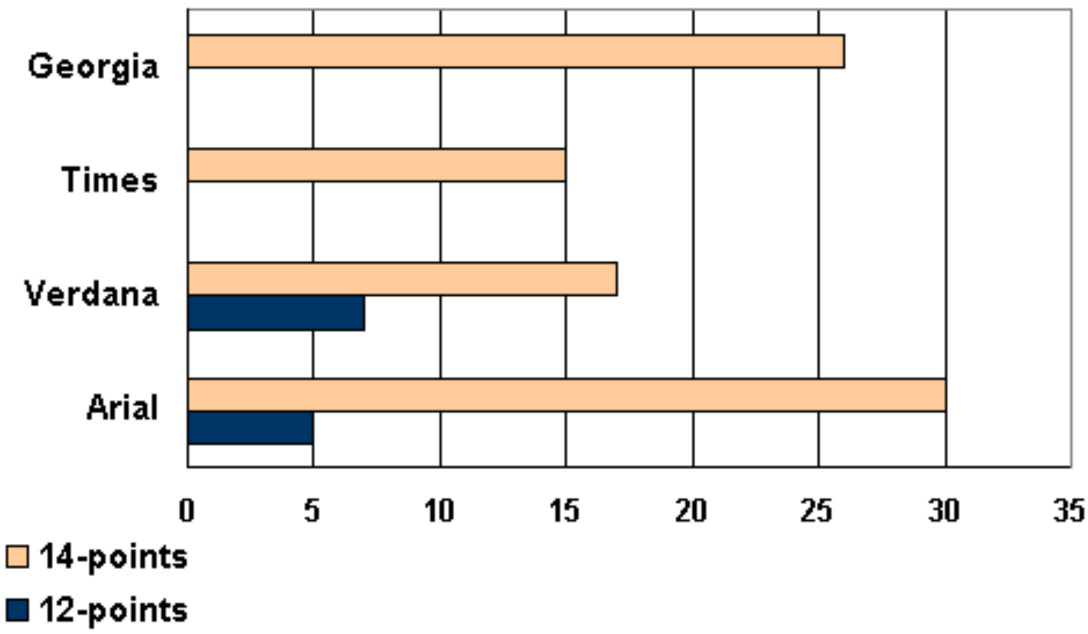


Table 20. The Reading Efficiency of Each Font in Different Size

(Bernard, Liao, & Mills, 2001)

In conclusion, hand tools always have words and characters in the instructions. For elderly users, 14-point Arial fonts are recommended.

3.4.2 Colors

a. Physical Aspect

From the physical side, color vision also reduces with advancing age. In hand tool design, the designer needs to avoid using blue because the color blue appears faded to elderly people. Moreover, old people have difficulties distinguishing between blue, green, and purple. Therefore, avoiding the use of these three colors together is necessary.

In addition to know which color needs to be avoided, designer also needs to know how to use colors. In order to make elderly people feel at ease when they are reading, contrast between the foreground and background is one of the most important factors. When the contrast is weak, it is illegible, for instance, when a white text is used on a pink background.

In Arthur and Passini's (2002) book, there is a decent calculating method to count the contrast between two colors. Subtracting the darker color's light reflectance (LR) from the lighter color's, and be divided by the lighter color's LR, and multiplying by 100:

$$\frac{K1-K2}{K1} * 100\% = H$$

*K1= Highest color value

K2= Lowest color value

H=Contrast value

When the contrast value is 70% or higher, elderly people can read easily.

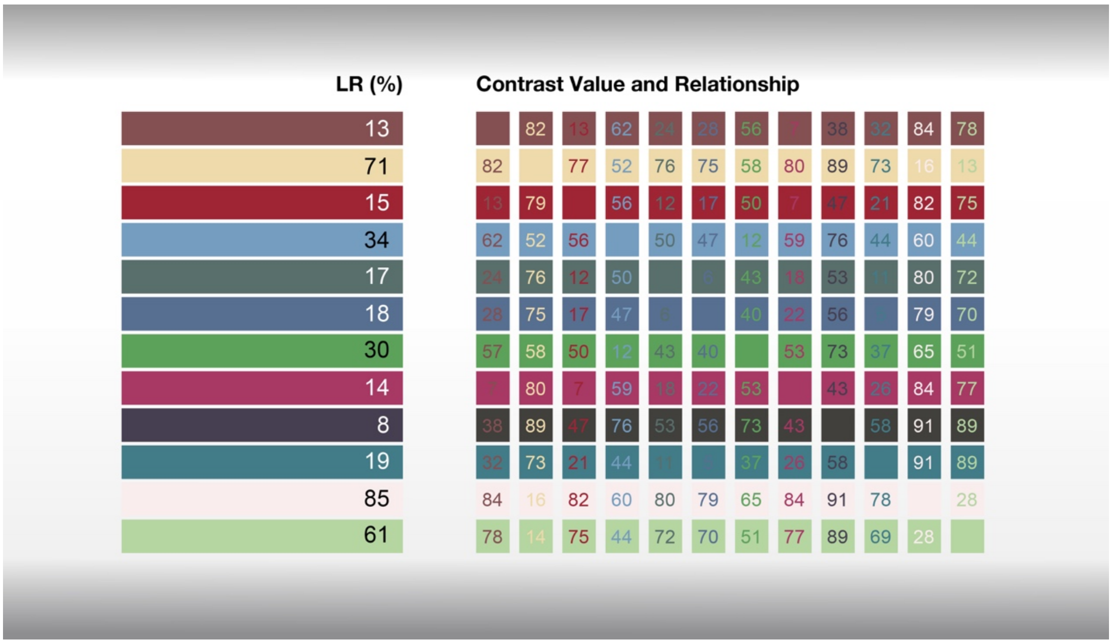


Figure 17. The Contrast Value and Relationship (Arthur & Passini, 2002)

b. Psychological Aspect

"Becoming old can bring about a sense of loneliness and fear so decorating with the elderly in mind needs to address warmth, security and harmony" (Atkinson, 2004). An effective color can impart a pleasant mood and keep one's cognitive function alive. It is important to identify the psychological hint of each color to use effective color schemes on products designed for elderly users.

Following is a guide to color:

Color	Description
White	In its natural form, it is daylight. It helps the mind to be open, clear, and receptive. Not good if feeling isolated or cut off.
Red	Reds tend to have the ability to over-stimulate and are very warming.
Oranges	Bright oranges are very social and gregarious.
Golds	They fall between yellows and oranges. Less irritating to the nervous system than yellow.
Yellows	Bright sharp yellows are very tiring and can trigger migraines and travel sickness. Soft yellows used with bright blues are good for mental stimulation and growth in children.
Bright Greens	Kelly greens are found to energize. Used with clear blues and pure white, this type of green encourages physical activity.
Dark Greens	Works well in areas where you need to concentrate for long periods.

	Think of the 'green room' used by an actor prior to a performance.
Pale Greens	Very soothing
Pale Blues	Cooling and helps encourage rest Balance for over-activity
Indigos	Useful where fear is stopping activity
Mauves	Mix of violet and red Nurturing, promotes intuition, meditative and insightful
Grays	Blending of two neutrals As a mid-tone color, it has been used to denote cool, rational thinking. Too much of this color is demotivating.
Browns	Earthy blend of orange, ochre yellow, and black Denotes dependability Can make a space feel secure and stable Darkest form of orange
Black	Black equates to lack of light—night—and is used to rest the mind and body.

Table 21. A guide to colors (Atkinson, 2004)

From the guide above, deep oranges and golds, soft yellows, bright and pale greens, mauves, and browns are recommended for use in elderly hand tool designs.

3.5 Summary of Design Guidelines

To make the design guidelines easy for users to use, a booklet (Figure 18, Figure 19, Figure 20, Figure 21) is developed. Designer just need to check with the booklet when they design handheld tools for elderly people.

Summary of Design Guidelines

GUIDELINES FOR DESIGNING HANDHELD TOOLS FOR THE ELDERLY

1

Handle Design

- Handle length should be greater than 4.76”.
- Handle seperation of gripping and squeezing tools should be between 1.77” to 1.97”.
- Handle diameter of gripping and turning tools should be between 30-50
- Material Selection for Handle

Material	Thermal Conductivity (W/(m K))
G-10	0.1-0.6
Noryl® GTX	0.25
Phenolic	0.25
Valox®	0.19
Zytel®	0.16

Figure 18. Booklet First Page

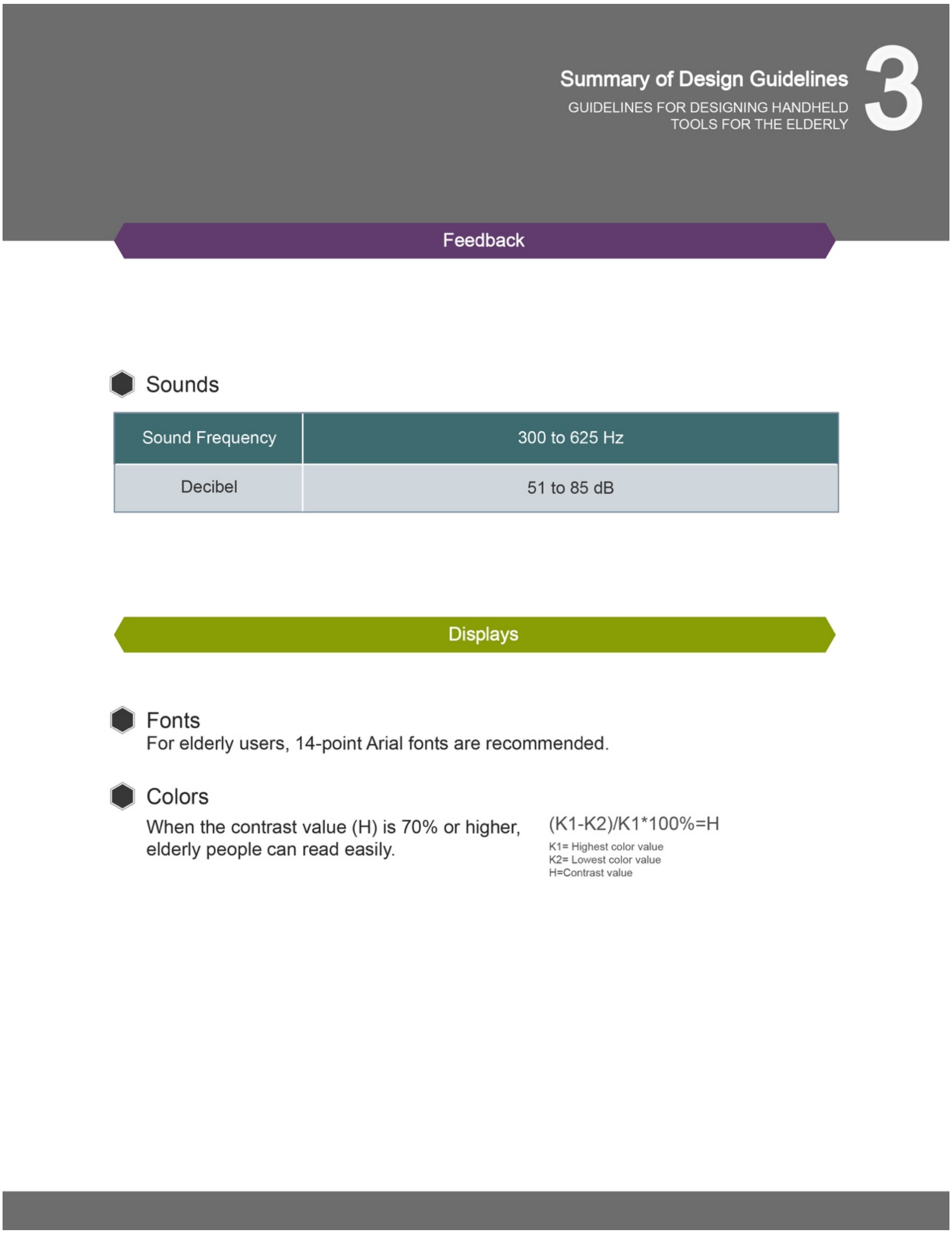
Summary of Design Guidelines
GUIDELINES FOR DESIGNING HANDHELD TOOLS FOR THE ELDERLY

2

Controls

		Size/Layout	Resistance	Special notes
Press-buttons		The minimum sum of button diameter and the distance between two buttons should be 0.9".	Adults: 10 - 20 oz.	
			Elderly: 10 - 20 oz.	
Rotary Switches	Cylindrical	High: 0.5"- 0.9" Diameter: 1.0"- 1.5"	Adults: 20 - 50 in-oz.	The scale should be placed horizontal and the range of angle will not be over 80° on left side and 57° on right side (for people who use right hand as dominance).
			Elderly: 16 - 40 in-oz.	
	Winged	High: 0.625"- 3.0" Length: 1.0"- 4.0" Width: 1.0"	Adults: 12 - 48 oz.	Increasing the roughness of the surface to increase the coefficient of friction.
			Elderly: 9.96 - 39.84 in-oz.	
Rocker switches		Length: >0.9" Width: >0.9"	Adults: 10 - 40 oz.	A 30° angle of travel is recommended.
			Elderly: 8 - 32 oz.	

Figure 19. Booklet Second Page



Summary of Design Guidelines

GUIDELINES FOR DESIGNING HANDHELD TOOLS FOR THE ELDERLY

3

Feedback

Sounds

Sound Frequency	300 to 625 Hz
Decibel	51 to 85 dB

Displays

Fonts

For elderly users, 14-point Arial fonts are recommended.

Colors

When the contrast value (H) is 70% or higher, elderly people can read easily.

(K1-K2)/K1*100%=H

K1= Highest color value
K2= Lowest color value
H=Contrast value

Figure 20. Booklet Third Page

Summary of Design Guidelines
GUIDELINES FOR DESIGNING HANDHELD TOOLS FOR THE ELDERLY 4

Displays

Colors - Psychological Aspect

Colors	Description
White	• In its natural form, it is daylight. • It helps the mind to be open, clear, and receptive. • Not good if feeling isolated or cut off.
Red	•Reds tend to have the ability to over-stimulate and are very warming.
Oranges	• Bright oranges are very social and gregarious.
Golds	• They fall between yellows and oranges. • Less irritating to the nervous system than yellow.
Yellows	• Bright sharp yellows are very tiring and can trigger migraines and travel sickness. Soft yellows used with bright blues are good for mental stimulation and growth in children.
Bright Greens	• Kelly greens are found to energize. • Used with clear blues and pure white, this type of green encourages physical activity.
Dark Greens	• Works well in areas where you need to concentrate for long periods. • Think of the 'green room' used by an actor prior to a performance.
Pale Greens	• Very smoothing.
Pale Blues	• Cooling and helps encourage rest. • Balance for over-activity.
Indigos	• Useful where fear is stopping activity.
Mauves	• Mix of violet and red. • Nurturing, promotes intuition, meditative and insightful.
Greys	• Blending of two neutrals • As a mid-tone color, it has been used to denote cool, rational thinking. • Too much of this color is demotivating.
Browns	• Earthy blend of orange, ochre yellow, and black. • Denotes dependability. • Can make a space feel secure and stable.
Black	• Black equates to lack of light—night—and is used to rest the mind and body.

Figure 21. Booklet Fourth Page

3.6 Conclusion

The guidelines developed in Chapter 3 can be applied to any handheld tools design. The guidelines are specific about each component of handheld tools. The rest of the thesis will explain and demonstrate how to use the guidelines to design an electric toothbrush for the elderly population.

Chapter 4

An Application of the Design Guidelines

This chapter will show designers how to use the design guideline developed in Chapter 3 through an electric toothbrush design application.

4.1 Handle development

4.1.1 Diameter of an electric toothbrush handle

According to the research results of Chapter 3, we can know that the handle length should be greater than 4.76” (121mm) and the applicable range of handle diameter of an electric toothbrush should be between 1.18” (30mm) to 1.97” (50mm) for both normal adults and elderly people to hold. However, the author found that the diameters of the majority of electric toothbrushes in today’s market are too thin to hold. In the current market, the range of diameter of electric toothbrush is between 0.98” to 1.14”, which is even improper for a normal adult to hold.

In the concepts of a handle shown below (Figure 22), the diameters of all handles are around 1.77” (45mm). And the length of all handle concepts are around 5.9” (150mm) which is greater than 4.76” (121mm). In this range of size, the handle of an electric toothbrush will be suitable for elderly people to hold.

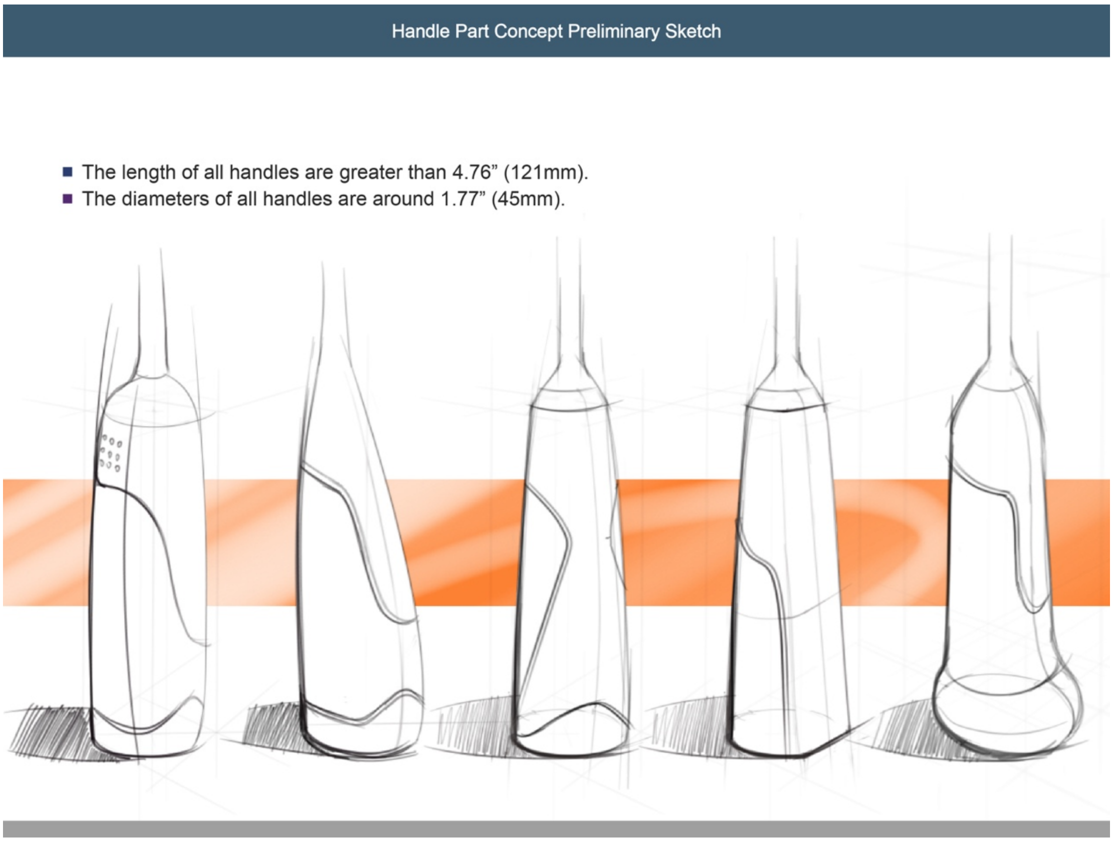


Figure 22. Handle part concept preliminary sketch

4.1.1 Material selection for electric toothbrush handle

The electric toothbrush will be used in the bathroom, which is a moist environment with a variety of temperatures. Therefore, the material of electric toothbrush handle need to be waterproof. Furthermore, Chapter 3 also mentioned that elderly people are logy in perceiving temperatures. In order to avoid burns or any injuries in such an environment, the material of the handle needs to have a low thermal conductivity. According to the above concerns, the author chose Noryl® GTX for the electric toothbrush handle.

4.2 Button development

The author mentioned in chapter 3 that the sum of the button semidiameter and the distance between two buttons should be greater than the half of the finger's breadth (the sum will be defined by the smaller size button when adjacent buttons are different sizes). As we know, when people are using toothbrushes, they will use thumb to operate on the press button (Figure 23). Pheasant has mentioned in his book “Body Space” in 1996, the maximum anthropometric estimates for thumb breadth is 1.02” (26mm). To satisfy most users’ requirement, the sum of the button semidiameter and the distance between two buttons should be greater than the half of the thumb’s breadth, which is 0.51” (13mm). In the author’s design project, the sum of the button semidiameter and the distance between two buttons is 0.64” (16.22mm).

Chapter 3 also mentioned that, to accommodate elderly people, the resistance of a press-button should be between 8 and 16 oz. And in this design project, the resistance of these buttons is 12 oz.

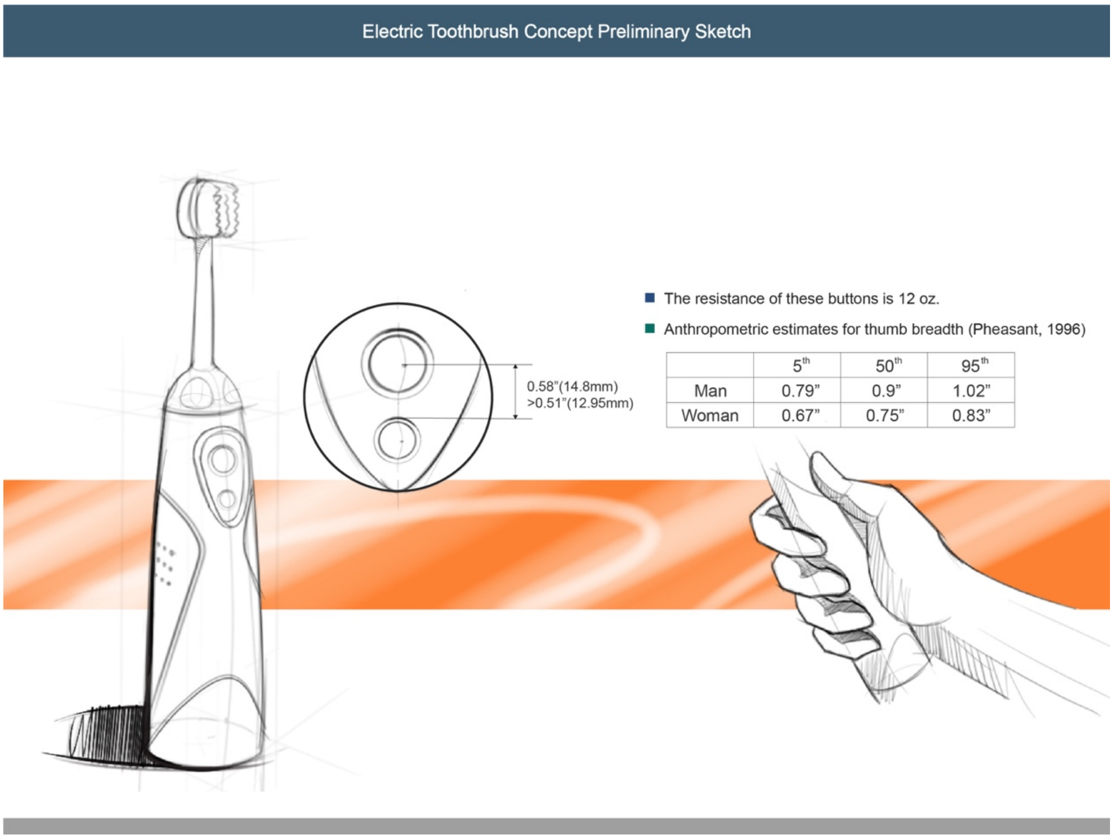


Figure 23. Button part concept preliminary sketch

4.3 Toothbrush head Replacement

As we know, electric toothbrush heads need to be changed regularly. In today's market, there are two ways to change the toothbrush head: pull out the head from the handle or twist it off. The first kind of toothbrush needs more friction to keep the head on the handle when people are using it, so it will have more resistance to pulling it out. As the author talked about in the Chapter 2, the force of the hand will decline with aging, due to the aging process of musculoskeletal system of hand. Therefore, the second way is more appropriate for elderly users. Many twisting electric toothbrush products on the market need users to twist it over 360° to replace toothbrush head, like unscrewing a cap. However, as Chapter 3 mentioned, the elderly people have limited ROM (range of motion) in twisting. The minimum forearm ROM of elderly people is pronation 79.1° and supination 57.9°. In order to satisfy elderly users, the screwing range should be less than the minimum forearm ROM of elderly people. In the author's design work (Figure 24), the ribbed ring on the bottom of the brush head can increase friction which will helps users' hold their left hand there. Users need to twist the toothbrush handle by the right hand clockwise and anticlockwise, both 30°, to screw on and screw out the head.

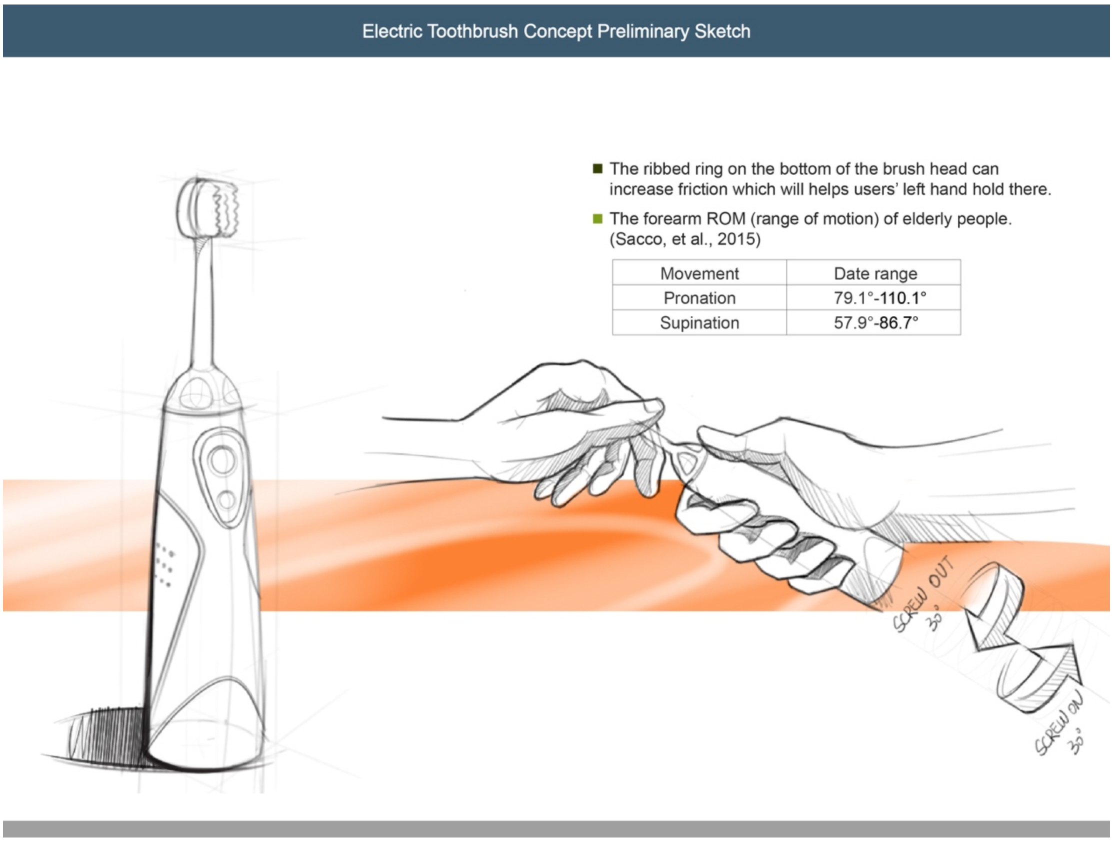


Figure 24. Electric toothbrush concept preliminary sketch

4.4 Feedback

4.4.1 Sounds

According to Chapter 3, for older people the best range of sound frequency is 300 to 625Hz and the recommended decibel range for sound indicators on handheld tools is 51 to 85dB. The author takes the sound which is 550Hz and 60dB as the indicator sound in the electric toothbrush design project.

Figure 25. Demonstration of 3D Electric Toothbrush Model

4.4.2 Font

As Chapter 3 recommended, all the fonts which are used in the author's project are 14-point sans serif fonts. (Figure 26)

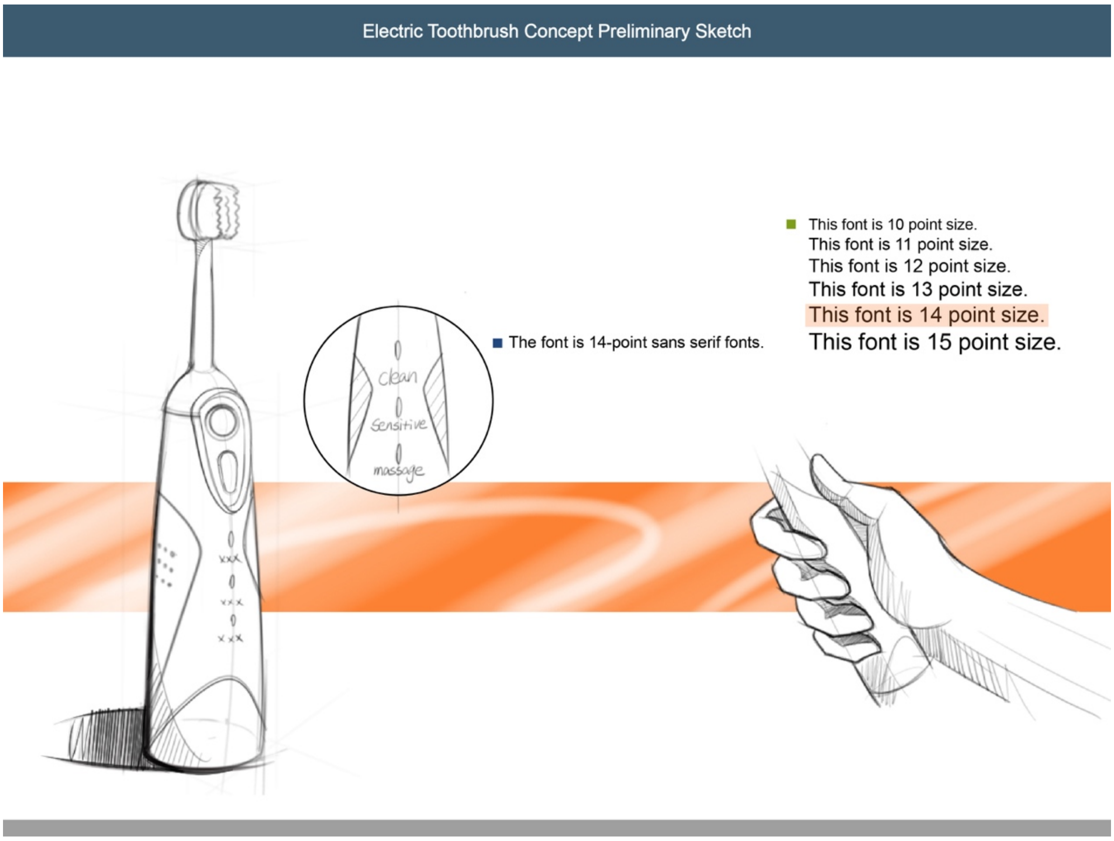


Figure 26. Electric toothbrush concept preliminary sketch

4.5 Color selection

The author used white and red in the design project (Figure 27). As Chapter 3 mentioned, "Becoming old can bring about a sense of loneliness and fear so decorating with the elderly in mind needs to address warmth, security and harmony" (Atkinson, 2004). The white is a very clear and receptive color, which is suitable for personal care products. And red is a very warming color, which can help the elderly alleviate loneliness and bring to them a sense of warmth and harmony.

Figure 27. Color selection and details

4.6 Toothbrush head for elderly people

As an aging process, the gingiva tends to become fragile; the common age-related disorders are bleeding gums and gingival atrophy (Zhao, 2017). The suitable length of a toothbrush head for elderly people should be smaller than 32mm (1.26in) (360 Jiankang, 2017). In my design work, the length of the toothbrush head is 0.95" (24.22mm) (Figure 28). Nylon is a good material selection for elderly toothbrush head, because it is soft which can reduce damage to aging gingiva.

4.7 Summary

Chapter 4 has given an example successfully following the design guidelines and showing explorations of the design guidelines. The author used these guidelines to build an electric toothbrush for elderly population. Other designers could use the guidelines to explore other handheld tool products for elderly users.

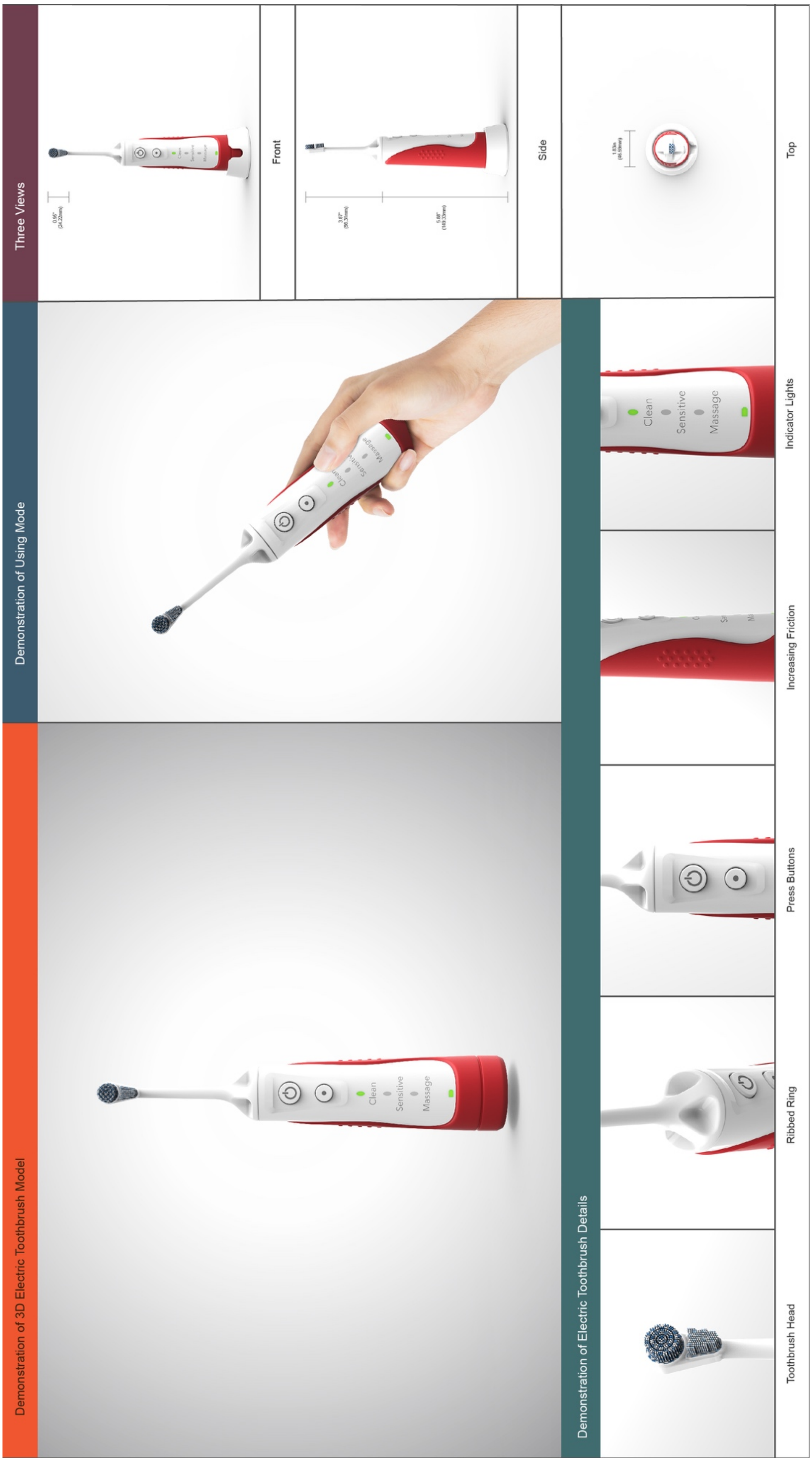


Figure 28. Demonstration of 3D Electric Toothbrush Model

Chapter 5

Conclusions

The intention of the thesis was to develop guidelines for designers to use when they are designing handheld tools for elderly people. The guidelines have been drawn from study of both physical and psychological characteristics of the aging process and defined standards on handheld tools for elderly population. The guidelines created can be applied to any handheld tools. Even though the guidelines have detailed and specific standards in each unit of handheld tools, designers still can use it to create many different designs.

In this thesis, an electric toothbrush was created according to the guidelines. However, this is not the only possible solution of the guidelines; it simply illustrates how the guidelines are used.

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