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# A Review on Design Parameters of Hand-operated Product that Influence Hand Grip of Senior Citizen

**Isa Halim[1*], Radin Zaid Radin Umar[1], Adi Saptari[2], Vinothini Padmanathan[1,3]**

[1]Human-Machine Interaction System Research Group, Fakulti Kejuruteraan Pembuatan, Universiti Teknikal MalaysiaMelaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, MALAYSIA

[2]Department of Industrial Engineering, President University, Jl. Ki Hajar Dewantara, Kota Jababeka, Cikarang Baru,Bekasi 17550, INDONESIA

[3]Department of Physiotherapy, Universiti Tunku Abdul Rahman, Sg. Long Campus, Bandar Sg. Long,43000 Cheras, Selangor, MALAYSIA

*Corresponding Author

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**Abstract:** The number of senior citizens worldwide is growing and therefore ergonomically designed hand-operated products are necessities and play a vital role in their everyday lives. However, designing hand-operated products for senior citizen users pose distinct challenges because the design parameters are different from the young adults' requirements. Some senior citizens are vulnerable to hand-related diseases such as arthritis, stroke or impairment of the motor and Parkinson that can limit them to carry and hold hand-operated products. The aim of this paper is to present a comprehensive overview of design parameters of hand-operated products that influence hand grip of senior citizens. The authors searched the information of design parameters from journal articles, conference proceedings, doctoral dissertations and guidelines from online databases such as Google Scholar, ScienceDirect and Pubmed. The following keywords were used throughout the search: hand-operated products; hand grip; hand dexterity; product weight; product shape; product contact surface; grip span; force and torque requirements; handle diameter, length and orientation; product size; product materials; spring stiffness. Based on review of 140 journal articles, six main design parameters of hand-operated products were identified to influence hand grip of senior citizens. The design parameters can be categorized as: 1) weight; 2) shape, grip span, size; 3) materials, contact surface, friction coefficient; 4) force, torque and spring stiffness; 5) diameter, length and orientation of handle; 6) clearance or allowance. These parameters met the principles of ergonomic designs that allow senior citizens to operate hand-operated products with neutral wrist posture, less muscle effort and ease of use.

**Keywords:** Hand-held products, design parameters, ergonomics, elderly, hand grip, hand dexterity

## 1. Introduction

The demand for ergonomically designed hand-operated products for senior citizens continues to increase in tandem with significant growth of senior citizens population around the world. The terms senior citizen, elderly and older adults have been used interchangeably [1]. A recent literature pointed that there is a lack of definitive classification of the word 'elderly' as this term is differently perceived in different cultures and generations [2]. For example, in the UK, male and female aged over 65 years old are classified as senior citizen [3]. Japanese researchers proposed to redefine the elderly as those over 75 years of age [4]. However, the United Nations Population Funds describes that elderly is referred to citizens with the age of 60 years and above [5]. A study pointed that by 2060, the population of senior

*Corresponding author: isa@utem.edu.my
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citizens aged over 65 years old in the United States will be expected to double in size [6]. According to the Department of Economic and Social Affairs of United Nations in the World Population Prospects 2019 Report, the number of citizens aged 65 years and above has increased substantially in the recent years. As tabulated in Table 1, in 2019 the citizen aged 65 years old and above is approximately 9.1 % of the whole population and it is projected to reach nearly 12 % in 2030, 15.9 % in 2050 and up to 22.6 % by 2100. Currently, Europe and Northern America have the largest proportion of senior citizens (18 % of the total population) and projected to increase to almost 30 % by 2100 [7].

**Table 1 - Percentage of population aged 65 years old and above**

| Regions | 2019 | 2030 | 2050 | 2100 |
|---|---|---|---|---|
| World | 9.1 | 11.7 | 15.9 | 22.6 |
| Eastern and South-Eastern Asian | 11.2 | 15.8 | 23.7 | 30.4 |
| Australia/ New Zealand | 15.9 | 19.5 | 22.9 | 28.6 |
| Europe and Northern America | 18.0 | 22.1 | 26.1 | 29.3 |

Physical strength is the ability of a muscle to produce force to perform activities which require effort. A contemporary study suggested that human strength is low at child age, greatest during the young adults of 35 to 50 years old range [8], and return to child strength at older age. A study pointed that an average 70 years old has comparable strength to a 10 years old child [9]. In female senior citizens aged 75 years old, their torque mean strength is less than 3.2 Nm - the mean jar opening torque [9]. Due to decline in physical capabilities, the senior citizens may be facing difficulties and limitations in performing daily living activities such as setting up the car seat for an optimal driving position [10], holding a handrail [11] and toileting [12]. Low force exertion may result in inadequate hand grip ability, while maintaining exertion may lead to faster rate of muscle fatigue.

The strength of a senior citizen may declines due to aging factors and health problems. A decrease in muscle strength with aging has been well documented [11, 13-18]. As the age increases, the muscle strength deteriorates significantly, especially among men [19-21]. Consequently, the hand grip strength also decreases [17, 22-26] as well as a decline of abilities to maintain a steady finger posture, handling speed and hand sensation [27]. A study reported that a person of above 65 years old can attain only about 75 % of their young age capacities in grip strength and endurance [28]. The aging process has been recognized to induce muscle wasting (or sarcopenia) whereby the muscle decreases in size, strength and physical performance [29-30]. Due to this phenomenon, senior citizen's hands are relatively smaller, weaker and slower movement than healthy adults. Beside physical strength deficiencies due to age, some senior citizens are also prone to have hand related diseases [28] such as arthritis [31], stroke or motor impairments of the upper extremities and can cause loss of arm function [32] and Parkinson disease [33]. These diseases cause limitation in strength, functional and range of motion of hand and wrist which result to difficulty to operate hand-operated products. A cross-sectional study pointed that senior citizens aged 81 years and older experienced difficulty in opening medicine containers due to hand functional deficiencies [34].

A hand-operated product can be referred as a hand-held tool or device which uses hand to operate, examples include computer input devices such as mouse and keyboard, food packages [35], can opener and handsaw. In designing a hand-operated product, end-users' age is one of the characteristics which requires careful attention from the designers. A hand-operated product such as a smartphone may work well to a dexterous-fingers youth but it is likely to pose physical challenges to a senior citizen with hand arthritis. Fig. 1 shows posterior and anterior views of hand arthritis experienced by a senior citizen. The ability of muscle to generate adequate force and maintaining body balance is a must to enable senior citizen to operate any product or object without triggering further health risk such as muscle sprain. Manipulating hand-operated products are highly influenced by users' physical capacities such as muscle and sensorimotor which is likely to decline with age. Many senior citizens utilize hand-operated products such as walking sticks, tin/ can openers and wheelchairs to compensate for their deteriorating physical capacities and sensorimotor functions, and to practice independent lifestyle. Operating the hand-operated products is one of activities of daily living (ADL) which requires hand grip strength and dexterity. Studies revealed that the following hand-operated products and activities cause pain in the hand: holding a reading tablet, ironing clothes, using vacuum and holding razor for shaving [36], activating fire extinguisher [37], pressing remote control units [38], operating vehicle interior switches [39], using inhaler devices [40], gripping handle of pans and kettles, opening jar lids and turning taps [41].


**Fig. 1 - Hand with arthritis: Posterior (A), Anterior (B)**

As depicted in Fig. 2, among common physical deficiencies experienced by senior citizens can be classified into four impairments: vision deficit, hearing loss and motion problem, muscle wasting (sarcopenia). Abundant literature already described vision impairment in senior citizens [42-47]. The review on hearing loss been performed by former studies [42, 48-54]. The limitation on motion and activities of daily living been reviewed by past researches [55-58]. Meanwhile the hand grip and dexterity was reviewed by previous articles [59-61]. A recent systematic review by Carli and Hellström [62] focusing on physical functionality and user capability studies of packaging products which addressing child-resistant containers and opening the medication. Even though the published review articles have reported the effects of aging on vision, hand grip and dexterity, hearing and motion; however, collective and comprehensive information on the design parameters of hand-operated product that can influence the hand grip strength and dexterity of senior citizens is still lacking. Due to this limitation, the product designers, researchers and manufacturers acquire inadequate information to design and manufacture ergonomic products for the use of senior citizen. For this reason, this paper is presented to review specific parameters of hand-operated products that can affect hand grip and dexterity which consequently causing difficulty to senior citizen users to operate them.

The aim of this article was to review the literature about design parameters of hand-operated products in relation to hand grip of senior citizens. The question explored through this study was "what are design parameters of hand-operated products that can influence hand grip and dexterity of senior citizens?"

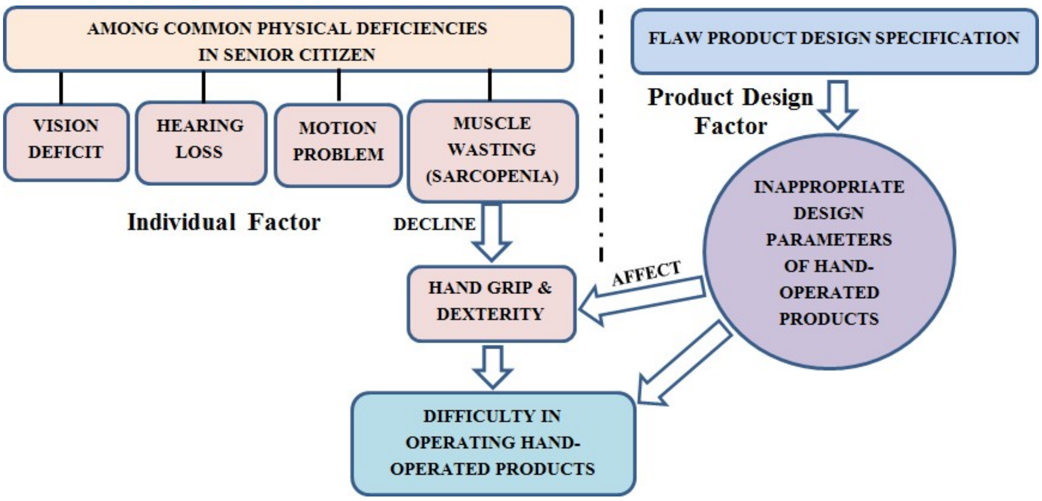


**Fig. 2 - Individual factor (decline in hand grip and dexterity) and product design factor (flaw product design specification) cause difficulty to senior citizens for operating hand-operated products**

## 2. Methodology

The authors searched relevant articles from the electronic databases such as PubMed, Scopus, Web of Science, and Google Scholar for the publication period 2005 to November 2019. The following keywords were typed throughout the search: hand-operated products; hand grip; hand dexterity; product weight; product shape; product contact surface; grip span; force and torque requirements; handle diameter, length and orientation; product size; product materials; spring stiffness. Then the full texts of journal articles include original research and review article which written in English were downloaded. The authors examine and comprehend the title and the abstract whereby any article with unclear title and abstract was excluded. Additionally, the authors examined the reference lists of all articles to find additional relevant articles. To justify the relevancy of studies, articles will be included in the further review if they meet the following inclusion criteria: at least 80% of the participants or subjects in the study were elderly aged 60 years old and above; hand grip strength, hand dexterity or both were the variables of the study; hand-operated products were used as a sample (object) in the study. The journal name, authors, and institution were not considered as criteria to minimize bias in selection of the articles. Quality of the selected articles was assessed by fulfilling these requirements: was the method of hand grip strength and hand dexterity measurement is reliable (this is to ensure data validity)? Were the subjects participated in the studies are given suffice time to familiarize the experimental setup and procedures (this is to ensure data reliability)? Were the statistical tools to analyze the data are correct? Finally, 140 journal articles, 6 conference proceedings, 2 doctoral dissertations, 1 ergonomics guideline and 1 statistical report were included in the paper writing. Preparation of this manuscript was started by identifying the key features of hand-operated products that can influence hand grip and dexterity of senior citizen users. Six design parameters identified: 1) lightweight; 2) shape, span, size; 3) materials, contact surface, friction coefficient; 4) force, torque and spring stiffness; 5) diameter, length and orientation of handle; 6) clearance or allowance. Key findings of previous research works pertaining to identified design features were then reviewed and summarized in form of table. Additionally, relevant pictures were attached to support explanation.

## 3. Results

This section presents the design parameters of hand-operated products that can influence hand grip and dexterity of senior citizens users.

### 3.1 Weight

The weight refers to the amount of gravitational force acting on the product held by a person. A study pointed that repetitive holding of a 2 kg object was perceived to be strenuous to senior citizens and may lead to significant fatigue in the hand muscles [63]. Muscle fatigue occurs when the person is unable to generate suffice force or power capacity in response to muscular contraction [64]. Senior citizens with arthritis in their hands refuse to use hand-operated products which designed in heavy weight [65]. Additionally, a continuous gripping or high repetitive of handling of a heavy product can increase muscle effort which accelerating muscle fatigue rate. Senior citizen users might be prefer to utilize a light product (e.g. a light walking stick) as it can lessen the effort to operate and easy to use. As an impact of lightweight, the senior citizen can avoid strenuous muscle effort and energy drain while using the product. Table 2 summarizes key findings of previous studies related to weight of hand-operated products.

**Table 2 - Studies related to weight of hand-operated products**

| Studies | Product studied *weight in the bracket | Key findings |
|---|---|---|
| [66] | Pruner | Pruner's weight of less than 250 g is recommended. Pruner's weight of greater than 250 g should be avoided for senior citizen with weak hand. |
| [67] | Blood pressure monitor (270 g)<br>Blood glucose monitor (55 g)<br>Pulse oximeter (28 g)<br>Spirometer (35 g)<br>Electronic fever thermometer (50 g)<br>Portable heart scan (130 g) | Hand-operated products used by senior citizen should be designed with low physical effort to avoid discomfort, fatigue or strain. |
| [68] | Four blender models with different materials (glass, plastic and combination of aluminum and plastic) | The most preferred feature is light weight blender jars. |
| [37] | Portable fire extinguisher | A portable fire extinguisher with a total weight of 2 kg (when full) would be a good target weight to be tested. |

### 3.2 Shape, Grip Span, Size

The shape, grip span and size of hand-operated products influence the ability of senior citizens for gripping activities. Shape defines the form and geometry of product or part of the product. Shape is crucial because it is intimately related to grip function. As shown in Fig. 3, water containers with taper shape allow better grip and would not slip easily. Vertical computer mouse promotes neutral wrist posture compared to horizontal mouse (Fig. 3). Another example a pencil is designed in hexagonal to ease grip and can prevent from rolling. Another function of shape is to support the wrist torque strength. Previous studies pointed that rectangular and triangular handle shapes were most favorable to acquire greater torque exertion [69-70]. An experimental work tested grasped spherical surfaces varied from concave with radius of 20 mm to convex with radius of 5 mm. It was proved that there is a correlation between shape and grip force during object manipulation - more convex the curvature, the higher the applied grip force [71]. Table 3 tabulates key findings related to shape of hand-operated products.


**Fig. 3 - Tapered containers (A) for better grip. Vertical mouse (B) allows neutral posture, but not horizontal mouse (C)**

**Table 3 - Studies related to shape of hand-operated products**

| Studies | Product studied *shape in the bracket | Key findings |
|---|---|---|
| [72] | Food jars (circular and square) | The square shape allowed more torque exertion than the circular. |
| [73] | Handles (A, D, I, and V) | Older subjects exerted largest grip force with I-shape handle and the smallest with V-shape handle. |
| [74] | Jar lids (circular, square, hexagonal and combination of circular and rectangular) | The more favored designs for the smaller lids were the ones with non-circular top shapes, or a concave side shape. |
| [75] | Sun spray bottle (oval cylindrical), tablet sweetener bottle (cylindrical), a deodorant bottle (cylindrical) and shower gel bottle (cylindrical). | The shape needs to be carefully considered with older people as it influences the grip strength and dexterity. |
| [76] | Jar lids (cone, concave, reverse cone, convex, octagonal, hexagonal, circular ) | Preferred shapes for smaller diameter lids were non-circular and concave. Traditional circular shape was the less preferred. |
| [77] | Jar lids (circular, flat, hexagonal and convex) | Taller height, hexagonal top shape and convex side shape were the best designs for 42 mm diameter jar lids. Taller height and hexagonal top shape were the best designs for 28 mm diameter jar lids. |

The grip span (Fig. 4) is the inter distance of two handles of a hand-operated product. Food tongs, pliers and tweezers are examples of hand-operated product which designed with two handles to ease tasks associated with gripping, cutting and crushing. To operate these products, a user has to exert a forceful squeezing action across two pivoting handles. An appropriate grip span allows senior citizens to hold the handles firmly thus generate maximum force for gripping. On the other hand, too large grip span results in stress in the flexor tendons consequently affect the grip strength. Similarly, if the span is too small then the force that can be applied by the hands decreases. Optimum grip spans for senior citizens are given in Table 4.


**Fig. 4 - Grip span (A)**

**Table 4 - Grip span for senior citizens**

| Studies | Grip span studied | Key findings |
|---|---|---|
| [78] | 51, 76 and 102 mm | Grip span of 51 mm produced greater hand grip strength. Increasing the grip span resulted in decline of grip force. |
| [79] | 35, 45, 55, 75, 95 mm | Maximum grip strength was obtained between 45 to 55 mm for both men and women. |

The size of a hand-operated product can be measured through its dimensions include the height, width, length and circumference. The products should be designed in appropriate size (neither too small nor too big), so that the senior citizen can grip them easily with one hand and can operate any control of the product using the thumb or fingers of the same hand. In scooping soup, spoon handles which designed with small and medium sizes allowed senior citizens with Parkinson’s disease to move faster and smoother than the large size spoon. Moreover, small and medium sizes of spoon gained higher subjective comfort than the large-handled spoon [80]. In other study of consumer products, Yoxall [81] observed that senior citizens will struggle to open the closure of a large jar size. Fig. 5 shows a senior citizen with hand arthritis having difficulty to rotate a large diameter of power cable drum. Table 5 presents the existing size of several hand-operated products.

**Fig. 5: Senior citizen with hand arthritis having difficulty in rotating cable drum**

**Table 5 - Studies related to size of various hand-operated products**

| Studies | Product studied | Size in mm (height x width x length) |
|---|---|---|
| [67] | Blood pressure monitor | 157 x 74 x 34 |
| | Blood glucose monitor | 96 x 52 x 22 |
| | Pulse oximeter | 58 x 32 x 34 |
| | Spirometer | 73 x 53 x 16 |
| | Electronic fever thermometer | 94 x 45 x 58 |
| | Portable heart scan | 121 x 67 x 24 |
| [82] | Pharmacy container (tablets bottles) | 28 (top diameter)<br>32 (body diameter)<br>48 (height) |
| [83] | Jar lids | diameter around 73 mm is easy to open |
| [76] | Jar lids | Lids smaller than 40 mm need to increase their height and diameter. |

## 3.3 Materials, Friction Coefficient, Contact Surface

Materials used in the construction of a hand-operated product determine its ability to resist slippage, weight, strength and life span [84]. The presence of water, moisture and oil between the hands and the handle can cause slippage when opening bottles, cans and jars or holding handrails. This can be avoided by applying anti-slip materials between the hand and the contact area to ensure a secure grip and to avoid slippage [36]. A soft material such as rubber can provide a firm grip, averts the handle from slipping out of the hand and minimizes contact stress in skin and soft tissue of the palm when holding the handle. Slippery or low-friction materials such as plastics and smooth-surface steels should be avoided.

The contact surface plays a vital role in operating and manipulating a hand-operated product. The contact surface characteristics such as surface roughness, texture and hardness determine effortlessness and comfort level in gripping the products. Industrial designers should pay special attention on the surface texture to allow senior citizens to hold the products with a firm grip. Adequate friction on the product surface plays a significant role in grip function [85]. Many senior citizens with arthritis in their hands struggle to hold firmly the frictionless products such as a wet glass. The condition worsens when the contact surface does not have adequate friction property, for example, opening or gripping product with damp or oily hands may reduce the friction coefficient between the hands and the product such that senior citizens may not have sufficient strength to hold firmly [86]. Application of a low-friction handle would result in a 16 – 42 % reduction in grip force compared to high-friction handle [87].

Additionally, senior citizens tend to have skin-dryness which predominantly leads to insecure grasping of hand-operated products due to a reduced coefficient of friction [88]. Textured surface on the handle might be may be helpful to avoid slippery and where high grip forces need to be exerted. Textured surface functioned as slip resistant and the senior citizens do not have to grip the handle hardly because the texture provides a good friction for better grip. A study pointed that surface texture could influence the energy consumption in gripping. A handle without texture causes slip, consequently consume more force and energy for senior citizens to hold [65]. Imrhan and Loo [89] in their experimental study observed that jar lids with rough texture increases wrist-twisting strength (average of 5.01 Nm), in contrast, jar lids with smooth texture decreases the wrist torque strength (average of 0.6 Nm). A recent study on jar lid usability concluded that lid diameter of 28 mm, flat shape and serrate surface texture offered some benefits, particularly for older women with more severe hand dysfunction [77]. Table 6 provides key findings of previous studies related to friction coefficient.

**Table 6 - Key findings of previous studies related to friction coefficient**

| Studies | Gender and age group | Key findings |
|---|---|---|
| [90] | 51 to 60 years, males and females | Gloves (kitchen and latex) increased coefficients of friction. Friction coefficient for kitchen glove and latex glove is 0.72 and 0.57 respectively. |
| [83] | Males, 60 years and above | Recommended friction coefficient is 0.20 |
| | Females, 60 years and above | Recommended friction coefficient is 0.41 |
| [91] | Males, 81 years and above | Friction coefficient for bamboo viscose is 0.38, polytetrafluoroethylene is 0.31, mix of cotton and polyester is 0.42 |
| | Females, 82 years and above | Friction coefficient for bamboo viscose is 0.37, polytetrafluoroethylene is 0.30, mix of cotton and polyester is 0.43 |

## 3.4 Force, Torque, Spring Stiffness

The amount force and torque that a human can exert to tighten or loosen any hand-operated product is greatly influenced by the age. Torque is a rotational force required to twist the cap or part of a product, for instance, tightening or loosening a jar lid (Fig. 6). Senior citizens demonstrated poor control of finger forces in gripping and manipulating hand-operated objects due to decline in dexterous behavior [92-93]. The human strength starts to decrease enormously when the age more than 60 years old [94]. It was found that the peel force of senior citizens aged over 65 years was generally lower than the young adults [95]. Voorbij and Steenbekkers [96] performed a study on wrist torque among senior citizens whom over 50 years old. Their study suggested that the required torque for opening a 66 mm diameter jar lid should be limited to 2 Nm for senior citizens. A study suggested that medicine containers with child resistant closure (CRC) require torque of 0.5 Nm to ease senior citizens to open them [82]. Notenboom [97] observed that breaking scored tablets by hand is less successful in senior citizens compared to youngsters. Another study pointed that there is a fair relationship between grip strength and the forces used to open the large prescription medicine bottle and to operate the aerosol spray can performed by senior citizens. Table 7 provides key findings of previous studies related to torque needed to operate hand-operated products.

**Fig. 6 – Applying torque to rotate the bottle closure**

**Table 7 - Key findings of previous studies related to torque needed to operate products**

| Studies | Product studied | Measured torque (Nm) | Participants |
|---|---|---|---|
| [72] | Pickled onions | 4.52 | Males (69 – 81 yrs) and females (60 – 72 yrs) |
| | Peanut butter | 1.79 | |
| | Lemon juice | 2.06 | |
| | Beetroot | 6.13 | |
| | Marmalade | 6.16 | |
| | Ketchup | 1.69 | |
| | Jam | 3.25 | |

| | | | |
|---|---|---|---|
| | Coffee | 1.29 | |
| | Mustard | 1.49 | |
| [98] | Door lever | 6.6 – 32.3 | |
| | | 14.5 – 29.5 | |
| | Door knob | 2.4 – 4.9 | |
| | | 5.2 – 7.8 | |
| | Tap | 3.5 – 7.4 | |
| | | 8.0 – 8.6 | Female (61 – 70 yrs) |
| | Circular knob | 1.6 – 3.4 | Male (61 – 70 yrs) |
| | | 2.3 – 5.3 | |
| | Ridged knob | 1.6 – 2.9 | |
| | | 3.1 – 5.0 | |
| | Butterfly nut | 2.0 – 3.3 | |
| | | 2.7 – 3.6 | |
| [89] | 31 – 55 mm lid | 1.9 – 3.9 | Male (60 – 97 yrs) |
| | 74 – 113 mm lid | 5.0 – 6.0 | |
| | 31 – 55 mm lid | 1.5 – 3.0 | Female (60 -87 yrs) |
| | 74 – 113 mm lid | 3.7 – 4.4 | |
| [99] | Faucet handles | 2.7 – 10.0 | Female (65 -90 yrs) |
| [96] | Jar lid | 4.0 | Female (65 -69 yrs) |
| | | 6.5 | Male (65 -69 yrs) |
| | | 3.7 | Female (70 - 74 yrs) |
| | | 5.4 | Male (70 - 74 yrs) |
| | | 3.5 | Female (75 - 79 yrs) |
| | | 5.0 | Male (75 - 79 yrs) |
| [9] | 75 mm diameter jar and lid | 3.2 | Female (8 - 95 yrs) |
| | | | Male (8 - 93 yrs) |
| [100] | 113 mm diameter rough lid | 5.01 | Male and female (60 – 97 yrs) |
| | 74 mm diameter rough lid | 4.20 | |
| | 55 mm diameter rough lid | 3.30 | |
| | 31 mm diameter rough lid | 1.62 | |
| | 113 mm diameter smooth lid | 3.29 | |
| | 74 mm diameter smooth lid | 4.19 | |
| | 55 mm diameter smooth lid | 3.25 | |
| | 31 mm diameter smooth lid | 1.53 | |
| [101] | Peanut butter, 123 mm lid diameter | 4.41 | Female (62 - 92 yrs) |
| | | 7.94 | Male (62 - 91 yrs) |
| | Peanut butter, 103 mm lid diameter | 4.41 | Female (62 - 92 yrs) |
| | | 7.53 | Male (62 - 91 yrs) |
| | Instant coffee, 86 mm lid diameter | 4.12 | Female (62 - 92 yrs) |
| | | 6.91 | Male (62 - 91 yrs) |
| | Tomato juice, 67 mm lid diameter | 3.62 | Female (62 - 92 yrs) |
| | | 6.50 | Male (62 - 91 yrs) |
| | Olives, 48 mm lid diameter | 2.47 | Female (62 - 92 yrs) |
| | | 3.89 | Male (62 - 91 yrs) |
| | Salad dressing, 40 mm lid diameter | 1.58 | Female (62 - 92 yrs) |
| | | 2.33 | Male (62 - 91 yrs) |
| | Nyquil, 29 mm lid diameter | 1.05 | Female (62 - 92 yrs) |
| | | 2.04 | Male (62 - 91 yrs) |
| | Coca-cola, 27 mm lid diameter | 0.92 | Female (62 - 92 yrs) |
| | | 1.51 | Male (62 - 91 yrs) |

Some hand-operated products such as car's door handle, rollator's hand brake and car's hand brake switch use a spring to operate them. An example of spring application in the hand-operated products (pruner) is shown in Fig. 7. The spring is used to enable handles or switches to return to their original position in response to the grip or push actions. Sometimes senior citizen users may encounter considerable difficulties to operate the hand-operated products (e.g. clamping cutting tools such as pruning shears) due to hard spring. This is due to mechanical properties of the spring called as stiffness (measured in N/m). The spring stiffness refers to magnitude of force required to compress or stretch a spring by unit distance. The force and spring stiffness is positive correlated, means that high stiffness requires high effort (force) to operate the hand-operated products. You [102] highlighted the use of spring represented a tradeoff effect on handle operation. The negative effect of spring might be due to an additional effort required against the spring force. Meanwhile the positive effect could be due to assistance of releasing the handles. Dayanidhi [103] in their study applied a helical compression spring (stiffness = 0.86 N/cm) to measure pinch strength and strength–dexterity in a cross-sectional population of 98 participants (aged 18 to 89 years old). The study found that the poorest hand manipulation ability occurred among individuals older than 65 years. This is due to deterioration of neuromuscular control over the age. Selection of spring stiffness is crucial in designing a hand-operated product, however, very minimal studies been performed to investigate appropriate stiffness of spring for senior citizen users. Table 8 lists the key findings of previous studies related to spring stiffness.

**Fig. 7 - Spring is used in operating a pruner**

**Table 8 - Key findings of previous studies related to spring stiffness**

| Studies | Key findings |
|---|---|
| [103] | A decline of neuromuscular associated with age can be detected by fingertip force dynamics during spring compression (stiffness = 0.86 N/cm). |
| [88] | Lack of tactile feedback leads to a constant or even increasing grip force for the elderly. |
| [24] | Spring stiffness should not exceed 11 kg for products related to gripping task. |
| | Spring stiffness should not exceed 4 kg for products related to pinching task. |

## 3.5 Diameter, Length and Orientation of Handle

Handle is one of the important parts in the design of hand-operated products. The handle acts as an interface between the user's hand and the product which enable his/ her to hold the product firmly. The design of handle including diameter, length and orientation can influence the grip strength while users manipulating a hand-operated product. Handgrip diameter can be defined as diameter of a round handle that a user can grasp with contact between the middle finger and thumb. A study confirmed that the handle diameter is one of significant factors to influence grip strength [104]. Inappropriate diameter such as too small or too large handle results in discomfort and less grip force. Edgren [105] observed that the hand grip strength increased 34.8 N when the handle diameter increased from 25.4 to 38.1 mm and then monotonically declined 103.8 N as the handle diameter increased to 76.2 mm. Based on a study by Saran [106], a 25 mm handle diameter is most preferred than 19 mm or 32 mm. Other study found that a 38 mm diameter of handle is optimum size based on the ratio between force and muscle activity [107]. Drury [108] recommended that the handle should be designed with a range of 25 – 40 mm diameter rather than a single optimum size. However, the abovementioned handle diameter studies were conducted among young adults, hence, their findings might not be suitable for senior citizens due to weaker muscle strength and smaller palm size.

Based on a literature [67], the grip diameter of senior citizens varies in terms of gender and dexterity impairment. The 50th percentile grip diameters of male and female without dexterity impairment are 52 mm and 48 mm respectively. On the other hand, the grip diameter of both genders with dexterity impairment is 40 mm (50th percentile). Cylindrical handrails between 28 mm diameter to 32 mm are more suitable for a bathroom to enable senior citizens to apply high forces on [109]. There is a study concerning to handle diameter among 61 to 90 years old Malaysian whereby three diameters (32 mm, 34 mm and 38 mm) of walking stick handle were studied. The study found that walking stick handle with a diameter of 34 mm is more suitable to apply high grip force on [110]. Due to growing of senior citizens, extensive studies on handle diameter are needed to satisfy both males and females. Fig. 8 shows an arthritis hand performing a pinch grip of three different handle diameters.

Fig. 9 shows the position of palm (hand) and fingers when gripping the handle of a hand-operated product. An appropriate handle length can be obtained by measuring the palm breadth (a). Population (or ethnics) and gender factors should be taken into account when designing a handle for hand-operated products for senior citizens. This is due to different population (or ethnics) and gender has different anthropometry dimension [111]. For example, Haitao [112] showed that the anthropometry dimensions differences were found between Chinese (Beijing) and Japanese senior citizens. Rosnah [113] observed that the hand length of Malay ethnic senior citizens has a significant difference with non-Malays. Another study pointed that there is a significant correlation between the hand size and grip strength of senior citizens [26]. In product design, anthropometry dimensions measured from young adults or children may not be accurate to design handle length for senior citizens. Very few studies reported the palm breadth dimension (Table 10) even though a lot of studies have been conducted on anthropometry of senior citizens. This indicates further study is needed to establish a comprehensive database of hand anthropometry of senior citizens. As an alternative to determine the handle length, the palm breadth of senior citizen can be estimated based on the palm breadth of young adults (95th percentile). Using this estimation, it will results in longer handle length, but it can accommodate everyone including senior citizens. Table 9 tabulates recommended handle length for senior citizens based on palm breadth.

**Fig. 8 - Gripping of three different handle diameters**


**Fig. 9 - Handle length follows the palm breadth (a)**

**Table 9 - Recommended handle length for elderly based on palm breadth**

| Studies | Population | Gender | Handle length = palm breadth |
|---|---|---|---|
| [114] | British | Male | 90 mm (95$^{th}$ percentile) |
| | | Female | 80 mm (95$^{th}$ percentile) |
| [114] | American | Male | 100 mm (95$^{th}$ percentile) |
| | Aged 19-65 | Female | 85 mm (95$^{th}$ percentile) |
| [115] | Australian | Male | 92 mm (95$^{th}$ percentile) |
| | | Female | 81 mm (95$^{th}$ percentile) |
| [116] | Malaysian | Male | 94 mm (95$^{th}$ percentile) |
| [117] | Malaysian | Male and female | 89.9 mm (50$^{th}$ percentile) |

Handle orientation is the angular position of the handle measured from the horizontal surface to the handle axis. A proper handle orientation allows user to maintain wrist in neutral posture. On the other hand, improper handle orientation leads to awkward posture in the wrist and can cause compression of nerves and blood vessels in the hand. This condition may also detriment the grip strength. Handle orientation can be found in horizontal, vertical, rotated and tilted to ease user for gripping a product. Horizontal handle orientation is effective for product which lifting is needed, for example kettle or iron. Young [118] found that grip strength is greatest in horizontal orientation. In general, vertical handle orientation is recommended for hand-operated products which require precise manipulation such as pen and screwdriver. Combination of 45° handle rotation and 15° handle tilt allows highest push force when pushing a trolley at elbow height [119].

## 3.6 Clearance or Allowance

Clearance is a gap or space provided to allow hand or fingers for accessing handles or openings so that the hand can have a certain degree of freedom for movement. As illustrated in Fig. 10, anthropometry dimensions of hand such as palm breadth (a), hand thickness (b) and maximum hand thickness (c) are crucial in providing clearance to the hand, for example, the width (a1) and the height (b1) of a drawer latch. A handle which is designed in adjustable (can move in and out) allows a better clearance; consequently accommodate different sizes of palm. In designing a rectangular opening, Delphi suggested minimum height of 5 cm and minimum width of 10 cm to permit the hand to enter.

Moreover, 2 cm should be added for each dimension when wearing hand gloves [120]. Suffice clearance around the handle and opening promotes better grip (d) and can avoid the hands or fingers from contact stress (e) and feeling of discomfort (Fig. 11). Table 10 provides handle clearance of door knob, handrail and toilet grab bar.

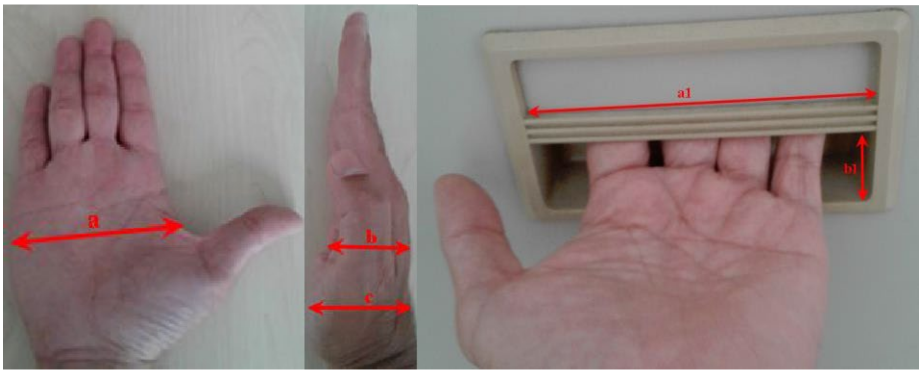


**Fig. 10 - Palm breadth (a), hand thickness (b) and maximum hand thickness (c) and relevant clearance**


**Fig. 11 – Good clearance around the handle (d) and contact stress due to insufficient clearance (e)**

**Table 10 – Minimum clearance of handle**

| Studies | Products | Minimum clearance |
|---|---|---|
| [121] | Door knob | 2.54 cm (between knob and door) |
| | Handrail | 3.8 cm (between wall and railing) |
| [122] | Handrail | 86 cm to 96 cm (between handrails for a wheelchair) |
| [123] | Toilet grab bar | 2.54 cm (between armrest and grab bar) |

## 4. Discussion

This study aimed to review the design parameters of hand-operated products that can influence hand grip and dexterity of senior citizens. Based on the literatures studied, the major findings can be summarized as follow:

1) Weight – A lightweight hand-operated product is meaningful for preventing strenuous muscle effort and ease of use. A hand-operated product weighed over 2 kg object was regarded as strenuous for seniors and can lead to significant fatigue in the hand muscles [63].
2) Shape, span and size – A hand-operated product with a taper shape handle allows for better grip and greater grip strength. The grip span between 45 to 55 mm allowed the senior to grip the hand-operated product with maximum strength [79]. Meanwhile product lids about 73 mm in diameter are regarded as easy to open [83].
3) Materials, contact surface, friction coefficient - A soft material such as rubber can provide a firm grip, avoid slipping the handle out of the hand and reduce contact stress in the palm's skin and soft tissue while holding the product handle. Among males and females over 60 years of age, the suggested coefficient of friction is 0.20 and 0.41 respectively [83].
4) Force, torque and spring stiffness – It is recommended that senior citizens exert very minimal force to grip, rotate and push the hand-operated products. To make seniors feel comfortable, any product’s cover such as jar lid should be lower than 2 Nm of torque to open [96]. Additionally, product manufacturers are suggested to apply spring stiffness less than 11 kg in designing hand-operated products [24].

5) Handle diameter, length and orientation – To provide comfort and greater grip power, handle diameter of 52 mm and 48 mm is suggested for male and female seniors respectively [67]. It is recommended that the length of handle for males between 90 and 100 mm and for females between 80 and 89.9 mm [114 – 117]. Young et al. [118] proposed horizontal orientation of handle for greater grip strength.
6) Clearance or allowance – A rectangular opening with minimum height of 5 cm and minimum width of 10 cm can allow the hand to reach comfortably [120].

Before incorporating the above values in the hand-operated products, however, it is recommended that designers consider human variability such as population or ethnicity, body dimension, gender and health status, as they determine the strength of the hand grip.

Extensive studies have been conducted regarding the relationship between age, hand grip and dexterity among senior citizens, in which the increase in age directly related to reduce in muscle strength, poor hand coordination and lack of smooth performance [124–126]. In addition, arthritis is one of the most prevalent medical conditions among senior citizens, whereby most of the senior citizens who suffered from the arthritis will experience clinical symptoms such as joint pain, limited range of movement and reduce muscle strength especially in small joints such as hand and fingers [127-128]. The above-mentioned issues may cause the senior citizens to have difficulty in using the available hand-operated tools which require certain amount of grip force to perform instrumental activities of daily living (IADL). A heavy product requires the hand to exert more force and torque into the affected arthritic joints and muscles thus indirectly increases the clinical symptoms such as pain [129-130].

Designing hand-operated products for senior citizens requires knowledge from multiple engineering fields such as ergonomics (e.g. body dimension and physical strength), manufacturability, maintenance and services, aesthetics, hygiene, affordability, ease of storage and transportation for greater user experience and better usability. Application of universal design principles such as low physical effort to use the product would be appreciated by the senior citizens [131]. In addition, hand-operated tools should consider ergonomics design principles to meet physical dimension and capabilities of senior citizens. Some examples include proper handle to allow wrist stays in its neutral posture [132], handhold to minimize exertion of the hands while lifting a heavy bucket, cushioned and contoured grip handle to minimize contact pressure and slippage, and sufficient clearance between hand and openings. Design information such as gripping force which measured by hydraulic gauge (Fig. 12a) and dexterity test using peg-board (Fig. 12b) will certainly support designers to deploy appropriate force exertion and to study finger motor coordination when designing hand-operated products for senior citizens use [133-135].


**Fig. 12 - Grip strength measurement (a) [110]. Dexterity test using grooved peg-board (b) (Lafayette Instrument, USA)**

Nowadays, with the advancement of digital product and technology, the application of hand-operated products not only relies on physical efforts, but cognitive functions as well. An abundance of digital mobile devices and mobile health applications (apps) in market today is rapidly rising among senior citizens. For instances, smartphones and tablets are popularly used by senior citizens to enable them to find information, updating events in the community, to enjoy hobbies such as mobile games [136] and to stay communicated with the love ones. Furthermore those devices are installed with helpful apps to take care the senior citizens [137-138], for examples, medication assistance [139], mobile health monitoring [140-142], well-being checking [143] and diet and lifestyle monitoring [144]. Besides physical efforts (e.g. holding or gripping the device and touching the screen) senior citizens need cognitive functions (mental processing such as thinking, remembering and decision making) to use these devices. Similar to physical strength, reduce in cognitive functions are prevalent concomitants among senior citizens [42, 145-147]. According to Rodríguez [148] the existing digital products require further consideration on cognitive study to benefit senior citizens. For example, one of the common issues associated with mobile devices among senior citizen users is usability of the devices and mobile health apps [149]. In the devices, they may have difficulty to press button for adjusting screen brightness and sound volume. Meanwhile, in the mobile health apps, senior citizens are facing understandability problems [150]. A usability study on congestive heart failure management apps observed that senior citizen users struggling to understand the graphical information because the graphs contain numerous features such as grid lines, multiple data points and different factors [151]. During the design stage, usability study on the hand-operated product is highly recommended in order to maximize satisfaction and acceptance levels of senior citizen users. Additionally, providing a hands-on training and a user manual guide to potential users could enhance product usability [152]. These efforts can make the senior citizen users to operate the products and complete the task accurately with a pleasant state both physical and mental.

In this paper, the authors have reviewed a substantial volume of research work on design parameters of hand-operated products which focusing on ergonomics requirements of hand grip to facilitate senior citizens in executing their IADL. The outcomes of this study will certainly benefit to industrial designers to develop a hand-operated product for senior citizens which known to have hand grip and dexterity deterioration compared to young adults.

## 5. Conclusion

The major discovery in this study was a series of key design parameters of hand-operated products, focusing on a consideration of how the products fit the capabilities of senior citizens so that grip force and dexterity can be enhanced. The key parameters highlighted by this study meet the principles for good ergonomic designs which rely on six fundamental requirements that can be applied to any hand-operated product. Based on a comprehensive review from 140 journal articles, this study concluded that the following design parameters of hand-operated products can influence hand grip and dexterity of senior citizens: 1) weight; 2) shape, grip span, size; 3) materials, contact surface, friction coefficient; 4) force, torque and spring stiffness; 5) diameter, length and orientation of handle; 6) clearance or allowance.

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