**PRODUCT PHYSICAL INTERFACE DESIGN CHARACTERISTICS
FOR OLDER ADULTS WITH HAND USE LIMITATIONS**

DISSERTATION

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By

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ABSTRACT

Older people often experience difficulties in performing the activities of daily living. There are two knowledge gaps associated with the problem. First, there is a research void in understanding the relationship between product interface design characteristics and hand dysfunction levels in older populations. Taking jar lids as an example of the product interface as the focus of this study, associations between jar lid design characteristics and the user experiences of older people with hand disability were explored. When investigating jar lid design characteristics, to the best of our knowledge, no prior published research specifically studied older people who were known to have difficulties opening or closing jar lids or who reported experiencing hand pain around the time of their study participation.

Second, methods and tools for making it easier for industrial designers to produce inclusive designs during product design processes are still insufficient. Although there are many Human Factors design assist tools available for designers to use, it has been found that designers seldom consult these established resources. It was recognized that a gap still exists between Human Factors information explorers (e.g. engineering researchers) and information users (e.g. designers).

Therefore, the aim of the study was to address knowledge limitations in two important areas by applying Ergonomics and product design research methodologies, in concert, to (1) discover what lid design features can improve the user experience of older people with

hand impairment, and (2) discover what concepts of Human Factors design assist tools can satisfy the practical needs of industrial designers when solving design problems, such as jar lids that facilitate opening and closing by a wide range of potential users.

Accordingly, there were three phases of research activities included: Phase 1 (“Exploration”) – Exploring different levels of user experiences when interacting with product interfaces; Phase 2 (“Evaluation”) – Evaluating product interface design characteristics through controlled experimental tests; and Phase 3 (“Communication”) – Investigating industrial designers’ needs when using an electronic Human Factors design assist tool during the product design process. For Phase 1 and 2, older females (65 years of age or older) with declined hand function, and for Phase 3, industrial designers who had at least one year of work experience in industry were recruited into the study.

According to the lid design evaluation results, lid height was the strongest factor associated with the levels of perceived effort when turning a lid. For both medium lids (e.g. 42 mm in diameter) and small lids (e.g. 28 mm in diameter), the design that was rated the lowest in perceived effort to turn was the one with a tall height and a hexagonal top shape.

As to the investigation of designer’s usage of Human Factors information during the design process, the result showed that most of designers used Human Factors information in the beginning (e.g. “Information Gathering”) and the end (e.g. “Evaluating and Refining Prototype”) of the design process. If compared with designers with less years of work experience, a higher percentage of designers with more than 20 years of experience would use Human Factors information to support their ideation. In addition, they tended to start their concept evaluations earlier in the design process.

The study identified barriers to use of Human Factors information by designers. In addition, it demonstrated how participatory design can be applied to learn about needs of designers and features for a design assist tool that designers would find useful, usable and desirable.

Dedicated to
my parents and my wife Katharine

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CHAPTER 1

1 INTRODUCTION

In the United States, the proportion of the population aged ≥ 65 years is projected to increase by 48%, from 13% in 2010 to 19.3% in 2030 (U.S. Census Bureau, 2008b). As shown in the Figure 1.1, the number of people aged ≥ 65 years is expected to increase from approximately 40.2 million in 2010 to an estimated 72 million in 2030 (U.S. Census Bureau, 2008a). This demographic shift brings with it certain challenges with regard to whether the society is ready to meet the special needs of these older individuals.

Figure 1.1: Population pyramids for United States in 2010 and 2030 (U.S. Census Bureau, 2008a)

The effect of aging is associated with marked decline in motor functions including weaker muscle strength, impaired mobility, lack of independence in activities of daily living (ADL), and gait-relevant problems (Hunter *et al.*, 1998). In addition, aging affects hand functions. The decline in hand functions has been postulated to be due to the deterioration in muscle coordination, finger dexterity, hand sensation, and the degeneration of the central nervous system (Hunter *et al.*, 1998). In addition, it has been concluded that not only the aging effect but also chronic diseases, for example hand osteoarthritis (OA), hand rheumatoid-arthritis (RA), or Parkinson's disease, are reflected in the decrease of the

effectiveness of hand use (Carmeli *et al.*, 2003). Most of the older individuals with hand use limitations experience increased difficulties in performing everyday tasks such as opening a new jar (92%), carrying a full pot (80%), fastening jewelry (78%), turning faucets on or off (76%), and doing up buttons (72%) when interacting with products in their living environments (Bellamy *et al.*, 2002a).

It has been well known that product physical interface design is highly associated with the levels of product usability, especially for the older people who have hand problems. For example, opening a new jar has been identified as one of the most difficult ADLs for older people with hand dysfunction (Bellamy *et al.*, 2002a). However, there is a research void in understanding the relationship between product interface design characteristics and hand dysfunction levels in older populations. When investigating the product interface design characteristics, none of those studies specifically included older people who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation.

In addition, the adoption of the Human Factors knowledge in product design may be another problem. It has been found that many product designers have difficulty in considering the special needs of older people when producing inclusive designs (Goodman *et al.*, 2006a). As reported, designers lack either the relevant Human Factors knowledge or well-developed assistive tools, which can productively provide information about target users and their needs of using products (Goodman *et al.*, 2006b). Most design resources were not available in formats suitable for practical use because they were not developed with industrial designers' perspectives in mind (Choi *et al.*, 2006; Law *et al.*, 2010; Law *et al.*, 2008b).

As such, the current study addressed knowledge limitations in two important areas by applying ergonomics and product design research methodologies, in concert, to (1) discover what interface design features can improve the user experience of older people with hand impairment, and (2) discover what design concepts of Human Factors resource tools can satisfy the practical needs of industrial designers when solving design problems. The long-term goal of this line of inquiry is to bridge the gap between Human Factors researchers (e.g. knowledge discoverers) and industrial designers (e.g. knowledge users) so that new research knowledge is made useful and usable to help industrial designers make design decisions during design processes. Both of these problems are examples of research to improve the design of interfaces for users – at its heart, this is the objective of most ergonomics research.

A theoretical model that illustrates the interaction between users and product physical interfaces was proposed in this study (Figure 1.2). As indicated in the figure, different user characteristics, e.g. gender, age, or health condition, will be associated with varied abilities of motor or sensory functions due to the physiological differences in biomechanics, anthropometry, and so on. It can explain why older people with hand impairment, the special population focus of this study, may have decreased hand performance when interacting with products. Conversely, different interface designs of products may be associated with different performance levels of users, as well. Therefore, how a product's physical interface design characteristics can influence the performance of older people with hand use limitations was what was explored in this research.

Figure 1.2: Theoretical model that illustrates the interaction between user and product physical interface

Figure 1.3 illustrates graphically the research structure. It further shows the theorized relationship between product interfaces, ADLs, users, and user experience. The whole study was divided into two parts represented by grey-solid lines and black-dashed lines. Firstly, the grey-solid lines represent the user experience analysis for different product interface designs when performing ADLs. Taking jar lids as the example of a product interface as the focus of this study, the associations between jar lid design characteristics, e.g. diameter, height, shape, and texture, and the user experiences of older people with hand use limitations were explored. In addition, several new lid design features that could possibly improve user performance were proposed and assessed. The hypothesis was that certain design characteristics could be found to enhance user performance, and that features could be identified that enhance performance of people with hand dysfunction while not disadvantaging people without hand dysfunction. It was

similar to one of the central tenets of universal design which is that design that benefits people with physical disabilities should also benefit able-bodied users.

Secondly, the black-dashed lines illustrate the construction that begins on a new bridge between the disciplines of Human Factors and product design, in the form of concepts for new design assist tools that will facilitate use, by industrial designers, of knowledge discovered by Human Factors researchers. Ultimately, this should lead to improvement in designs of products for use by a wide range of users, including people with hand use limitations due to pain from OA and other problems.

Figure 1.3: Research structure of the study. The grey-solid lines represent the user experience analysis for different product interface designs when performing ADL. The black-dashed lines illustrate how Human Factors knowledge found in the grey-solid route can be available in formats to facilitate industrial designers' use

In order to achieve the two goals indicated above, older females who were 65 years of

age or older with declined hand function, and industrial designers in industry were recruited in the study. As shown in the Figure 1.4, there were three phases included in the study:

- Phase 1 (“Exploration”) – Exploring different levels of user experiences when interacting with product interfaces;
- Phase 2 (“Evaluation”) – Evaluating product interface design characteristics through controlled experimental tests; and
- Phase 3 (“Communication”) – Investigating industrial designers’ needs when using an electronic Human Factors design assist tool during the product design process

Figure 1.4: Research phases included in the study

The details of the three research phases are described in the following chapters. To accomplish the three phases, the ergonomics and product design research methodologies used in the study included direct observation, questionnaire, focus groups, participatory design methods, and controlled laboratory test.

If it is agreed that making a theoretical contribution means that people now see things differently than they were seen before the research was proposed or conducted, two theoretical contributions stem from this research. First, the study demonstrates the

omission and need for the inclusion of older adults with hand pain and disability in the area of interface design in ergonomics research. Second, but equally important, the gap between the production of Human Factors research-based knowledge and the application of that knowledge can be bridged, by reconciling the format of that research-based knowledge with the needs of product design users for that knowledge to be in a format that is useful, usable, and desirable to them.

CHAPTER 2

2 BACKGROUND

The knowledge and methods used to solve Human Factors problems in the field of product interface design is interdisciplinary, including Physiology, Biomechanics, Ergonomics / Human Factors, Design, and so on. The focuses of this study were (1) jar lid design for older people with hand problems, and (2) design assist tools for industrial designers. Therefore in this chapter, first, in order to have a better understanding about older populations, their background information regarding hand disability and the associated factors is summarized. In addition, the pros and cons of current established hand dysfunction assessment techniques are discussed; a relevant method of assessing research participants was needed for the study.

Following the background information about older people, second, the methods or tools in ergonomics and design areas that could be used as means to explore the user needs of using products are discussed. In addition, previous research studies that focused on how varied jar lid design characteristics could affect usability of lids are introduced. The relevant torque models in Biomechanics are also described.

Industrial designers' needs related to using design assist tools during the design

process are the focus of the study, as well. Therefore, in the latter part of the chapter, the development of current published design assist tools and their limitations of use are discussed.

2.1 Summary

Hand disability in older populations is associated with difficulties in performing the activities of daily living. The ability of using hands effectively relies on muscle strength, absence of chronic pain, anatomical integrity, mobility, sensation, and coordination (Dellhag & Bjelle, 1999). It has been found that the hand disability in older populations is related with not only aging effects, but also chronic diseases. However, according to Dahaghin's study (Dahaghin *et al.*, 2005b), the determinants that were associated with hand disability in older populations were still unclear because only 25.2% of hand disability could be explained. Thus, instead of focusing on any specific hand pathology and its relevant effects on hand use, comprehensive hand function ratings have been commonly used as the criterion for identifying levels of hand dysfunction in older populations.

Different design methods or tools can be used to document different levels of user experiences in the early stages of design processes (Sleeswijk Visser *et al.*, 2005). Individual surveys, (e.g. questionnaire and interview), group surveys (e.g. focus group) and field methods (e.g. behavior observation) were the most frequently used methods or tools to collect user needs. As to the deeper level of user experience, the application of

design toolkits, for example MakeTools®, can be very helpful (Sanders, 1999).

In addition to the design methods or tools indicated above, there have been several other studies using controlled experimental tests to quantitatively document the usability levels of different lid designs, e.g. the wrist-twisting torque a person can exert on a jar lid with different design characteristics. Imrhan and Loo (1988) investigated the maximum voluntary torques (MVTs) of healthy older subjects when opening rough and smooth circular jar lids with four different diameters. They found that the main effects of lid diameter and surface texture on the hand torques of older people were significant. Crawford et al. (2002) found that diameter, height, and shape of lid were associated with MVTs a user can apply. They also pointed out that there was a significant difference in hand strength between older and younger people. However, only a few studies explicitly included older populations with hand problems as participants. Even so, the comprehensive understanding of the main effects of various lid design characteristics, e.g. diameter, height, shape, and texture, and the interactions between them are still limited.

Previous studies have proposed a couple of biomechanical models to explain the association between human hand performance and product interface design characteristics, for example handle diameter and surface texture. An early model developed by Pheasant and O'Neill (1975) predicted torque as a product of the handle diameter, friction coefficient between skin and handle surface, and grip force on cylindrical handles. Seo et al. (2007) proposed a modified torque model that was applicable to irregularly shaped objects. She found that the grip force should be considered as the resultant of normal forces from all the contact segments of a hand or fingers when acting on the object's surface. Therefore, these established biomechanical models may be used to further

examine the findings of the current study and explain how older people's hands can interact with different lid designs when applying torques.

Many design assist tools have been developed to help industrial designers to solve design problems during the product development process. However, it has been found that most of the published design assist tools, for example Human Factors resource tools, were not always useful, usable, or desirable for industrial designers (Burns & Vicente, 1996; Burns *et al.*, 1997; Choi *et al.*, 2006; Law *et al.*, 2008a). Although some solutions and tool development recommendations have been discussed, only a few of them explicitly explored how the resource tools can be designed to map designers' behaviors during the different phases of the product design processes. In addition, the methodologies used to probe the user needs of designers could be another limitation of the previous studies. There is still a research void here, a limited understanding of the latent needs of designers as to how they use Human Factors information and resources to solve design problems in their designs.

2.2 Hand disability in older population

Hand disability is associated with the difficulties in performing ADL (Dahaghin *et al.*, 2005b). The ability of using hands effectively relies on muscle strength, absence of chronic pain, anatomical integrity, mobility, sensation, and coordination (Dellhag & Bjelle, 1999). It has been found that hand disability in older populations is related with not only aging effects, but also chronic diseases.

2.2.1 Aging effect

Aging is one of the factors associated with impaired hand mobility and lack of independence in ADL. Ranganathan et al. (2001) examined age-induced changes quantitatively in hand function in an older population. The maximum handgrip, 2-finger pulp pinch strength, control ability in maintaining a steady sub-maximal finger pinch force, and the speed in relocating small objects with a 2-finger pulp pinch were investigated. As indicated in the study, if compared with young subjects (20-35 years), the older group's (65-79 years) handgrip and 2-finger pulp pinch strength were 30% and 26% weaker, respectively. The results also showed that the force control ability of the older group was significantly less than the younger group. It was concluded that the decline of the force control ability to maintain steady grip and pinch force was more significant in women than men in the older population. In addition, Ranganathan et al. found that the time taken to relocate small objects with a 2-finger pulp pinch increased significantly with age. Accordingly, the similar trend could be found when examining the distance needed to discriminate two identical mechanical stimuli on finger tips. It was pointed out that the sensation function of hands was reduced in older populations, as well.

Carmeli et al. (2003) investigated the anatomical and physiological changes in aging hands to examine the hand function deterioration. They pointed out that the worsening in hand function was one of the primary age-related changes in the older population. As indicated in the article, the decline of hand function in older adults was an aggregation of

changes in local body structures, including joint, muscle, tendon, bone, nerve and receptor, skin, and fingernail. In addition, they concluded that these age-related changes were usually occurring along with other underlying pathological conditions, which included osteoarthritis (OA), rheumatoid arthritis (RA), and Parkinson's disease.

2.2.2 Chronic disease

It has been concluded that not only the aging effect but also chronic diseases, for example hand OA, hand RA, and Parkinson's disease, are associated with degeneration of hand function (Carmeli et al., 2003). For example, hand OA is one of the most common health problems among elderly people. Some previous studies pointed out that hand OA could result in enormous socioeconomic impacts because it affected 67% of the women and 54.8% of the men in the population over 55 years old (Dahaghin *et al.*, 2005a). In a Tasmanian study of 522 subjects, whose average age was 57 years for females and 53.2 years for males, the prevalence of hand OA was documented as 44% to 71% depending on different compartments of hand OA. It was concluded that pain and dysfunction involved with hand OA increased with age, whereas grip strength decreased (Jones *et al.*, 2001). Another study also found that hand OA was frequent in a study of 253 elderly patients. The occurrence of hand OA was found in 77% of the entire cohort on clinical examination and in 83% on radiologic examination (Caspi *et al.*, 2001). Dreiser et al. (1995) further observed that the most symptomatic joints within 261 hand OA patients (239 females and 22 males) were the distal interphalangeal joints (68%), first trapezometacarpal joints

(62%), and proximal interphalangeal joints (48%).

Since hand OA has been known as a very common disease in older populations, the relationship between hand OA and corresponding hand dysfunction levels has been explored. Kjekken et al. (2005) pointed out that if compared with the people without hand OA, the grip strength of people with hand OA was reduced to less than 60% of normal. Another recent study also found that hand OA would lead to (1) reduction of grip strength, (2) increased difficulties in performing ADLs, (3) loss of productive work time, and (4) decreased ability to perform manual activities (Stamm *et al.*, 2007). Bagis et al. (2003) pointed out that hand OA may cause a significant functional disability. As indicated in Bagis's study, since the people with hand OA had significantly lower grip and pinch strength, and both characteristics were the important components of the functional integrity of hands, the hand functional levels would be affected. Bellamy's study (2002a) supported this statement. Bellamy et al. pointed out that hand OA has been associated with considerable functional consequences to joint pain, reduced hand mobility, reduced grip force, and difficulties in performing daily activities.

2.2.3 Determinants of hand disability

The determinants that are associated with hand pain and hand disability are complicated. Dahaghin et al. (2005a) investigated the association between radiographic hand OA and hand pain/disability in a population based study (ages over 55 years). Accordingly, only a modest to weak relationship was found, varying with the site of

involvement. It was pointed out that not only hand OA, but also hand RA, Parkinson's disease, age, genders and so forth were all potentially associated with hand pain or hand disability (Dahaghin et al., 2005b).

Dahaghin et al. (2005b) investigated the prevalence of hand pain and hand disability in an older population, which include 7983 participants (61% female) aged 55 years and above, to explore the potential determinants associated with their hand problems. A home interview technique was applied to determine (1) the occurrence of hand pain during the previous month, (2) RA, OA, diabetes, stroke, neck/shoulder pain, fracture in the past 5 years, and (3) Parkinson's disease. The age, gender, and occupation of participants were documented, as well. In addition, the hand disability was assessed using the mean score of the Stanford Health Assessment Questionnaire Disability Index (HAQ-DI). As concluded in the study, by the univariate analysis for hand pain, RA showed the highest odds ratio and the highest explained variance, followed by pain in neck/shoulder, OA, and female gender. Dahaghin et al. also pointed out that age (> 70 years) had the highest explained variance with hand disability, followed by RA, stroke, female gender, and hand pain. However, Dahaghin et al. concluded that all determinants together could only show an explained variance of 19.8% for hand pain and 25.2% for hand disability in the multivariate logistic regression models.

Therefore, it can be concluded that instead of focusing on any specific hand pathology and its relevant effects on hand use, future studies should apply comprehensive hand function ratings as the criterion to identify the levels of hand dysfunction in older populations.

2.3 Hand dysfunction assessment techniques

According to the previous studies, the comprehensive hand function ratings can be estimated by direct hand function tests and self-report instruments (Hochberg *et al.*, 2000). The pros and cons of the techniques are discussed below.

2.3.1 Direct hand function test

Direct hand function tests are defined as the techniques measuring the hand performance directly when performing specific assigned hand tasks. Jebsen et al. (1969) proposed a comprehensive generic testing protocol called Jebsen-Taylor Hand Function Test (JTHFT) to measure hand functions. As indicated in Jebsen's article, JTHFT contained seven subtests, including writing, turning cards, picking up small objects, simulated feeding with beans and a spoon, stacking checkers upon each other, and placing light and heavy large objects on a board. All the seven subtests were timed with a stopwatch and both hands were measured separately. The total scores of JTHFT were calculated by summing up the scores of all the subsets from both hands.

JTHFT was categorized as an "*etiologically neutral technique*" because it did not bridge to the health conditions that were directly related to the disease perspective. Instead, it provides a broad understanding of hand function (Stamm et al., 2007).

In addition to JTHFT, Backman et al. (1991) proposed an arthritis-specific testing protocol, the Arthritis Hand Function Test (AHFT), to estimate people's hand function

levels. Backman et al. pointed out that AHFT was a performance-based instrument for measuring hand strength and dexterity of adults with RA and OA. As described in the study, AHFT consisted of eleven items, which included grip strength, pinch strength, the time used to insert and remove nine pegs from a pegboard, five timed items (e.g. buttoning, lacing a shoe and tying a bow, putting coins into a slot, opening and closing safety pins, and cutting putty with a knife and fork), the total number of tin cans lifted (0–12), and the total amount of water lifted in the pitcher (0–2000 ml). The scores of the four subscales, e.g. strength, applied strength, dexterity, and applied dexterity, were documented on a hand function profile sheet sorted by age and gender. The profile sheet could then provide a summary and score comparison with healthy people.

There were other direct hand function tests found to be more feasible in busy clinical settings because of their relatively shorter administration time, for example Moberg Picking-Up Test (MPUT) and Grip Ability Test (GAT) (Stamm et al., 2007). The short hand function tests were different from those comprehensive tests because they estimated the hand function in only a few aspects (Amirjani *et al.*, 2007; Poole *et al.*, 2006). Moberg (1958) proposed MPUT to quantify the hand function levels in sensibility and dexterity. According to the article, twelve different objects, including a wing nut, screw, safety pin, paper clip, large and medium-sized hexagonal nut, and small square nut, were spread randomly on an 11.5x17.5 inch wooden platform, next to a 6-inch-wide round container. Subjects were instructed to pick up the items one at a time and place them into the container as fast as they could (Figure 2.1). They were also told that they could only use the first 3 fingers, e.g. thumb, index finger, and middle finger, and were not allowed to slide the objects on the platform. The function levels of hand sensibility and dexterity

were then referred to an individual's performance timed with a stopwatch. The test was performed in two phases: (1) with eyes open, and (2) with eyes closed, to assess the sensory acuity at the fingertips. In addition, the dominant hand was always tested first. Amirjani et al. (2007) examined how age, gender, and handedness could affect people's performance in MPUT. As mentioned in the study, only healthy subjects were recruited and the results are shown in the Table 2.1. Amirjani found that women performed the MPUT faster than men. Additionally, the dominant hand was also faster in executing the test than the non-dominant hand.

Figure 2.1: Materials of MPUT (Stamm et al., 2003)

Table 2.1: Normative values (seconds) for MPUT based on age and gender (abstracted from Amirjani et al., 2007)

	Young (20-39 years)		Middle-aged (40-59 years)		Old (60+ years)	
	Female	Male	Female	Male	Female	Male
Eyes open						
Dominant hand	12.0	12.3	12.6	16.5	16	16.8
Nondominant hand	12.5	14.0	13.3	18.0	18.0	15.4
Eyes closed						
Dominant hand	23.8	22.5	23.0	30.6	27.8	29.9
Nondominant hand	23.6	21.6	24.1	31.6	31.5	31.2

Values represent the upper bound of 95% confidence interval

Dellhag and Bjelle (1995) developed GAT to examine people's hand function based on the performance of doing ADLs. Subjects were instructed to complete three tasks one at a time, e.g. (1) putting a 25-cm elasticized tubular bandage (7.5-cm wide for female and 10-cm wide for male) over one hand, (2) putting a metal paper clip (30x10 mm) clip in an envelope (115x160 mm), and (3) pouring water from a one-liter jug, and their performance was based on how much time they used to complete the three tasks. The authors pointed out that if an individual's total time of completing the tasks is less than 20 seconds, his or her hand function will be considered as normal; otherwise, higher scores mean declined hand function.

The details of JTHFT, AHFT, MPUT, and GAT are summarized in Table 2.2. Since the dependent measures for all the four tests are how much time it takes to complete the assigned tasks, the trainings to rate the scores and interpret the outputs were not required (Poole et al., 2006). If compared with the comprehensive tests (e.g. JTHFT and AHFT), the short tests (e.g. MPUT and GAT) were very easy and quick to use and cost less money for administration. The comprehensive tests could provide more detailed information since they included more components of hand function. In other word, if the detailed

information of the people's hand function is not critical, but the administration time is, for example for quicker screening for purposes not associated with medical diagnosis, the short tests can be justified.

If comparing JTHFT and AHFT within the comprehensive tests subgroup, JTHFT was more generic than AHFT because it has been used to measure the hand function of people with a wide range of diagnoses, from normal aging to arthritis and stroke. In the short tests subgroup, the application of GAT was relatively limited, because its reliability and validity had been examined previously only on people with RA. Since the validated populations' characteristics of MPUT included not only hand arthritis but also aging effects, MPUT would have a wider range of applications.

Table 2.2: Comparison of current direct hand function tests: JTHFT, AHFT, MPUT, and GAT (abstracted from Poole et al., 2003)

Test	Content	Outputs	# of items	Response format	Time	Cost for admin.	Validated populations
JTHFT	Hand daily tasks	7 subscales that can be compared to normative data	7	Performance time	10-20 minutes	~\$210	Aging, OA, RA, Stroke
AHFT	Hand strength, dexterity, and daily tasks	4 subscales that can be compared to normative data	11	Grip/pinch strength; Performance time; Total amount of cans/water	20 minutes	~\$500	OA, RA
MPUT	Pick-up tasks	1 score that can be compared to normative data	12	Performance time	2~3 minutes	<\$50	Aging, OA, RA
GAT	Hand daily tasks	3 subscales that can be compared to normative data	3	Performance time	2~3 minutes	~\$55	RA

JTHFT = Jebsen-Taylor Hand Function Test; AHFT = Arthritis Hand Function Test; MPUT = Moberg Picking-Up Test; GAT = Grip Ability Test

2.3.2 Self-report instruments

The self-report instruments used to measure hand dysfunctions have been proposed by several authors. They are briefly summarized below. For example, Fries et al. (1980) developed the Health Assessment Questionnaire Disability Index (HAQ-DI) to assess the outcome of hand disability in arthritis by eight domains, including dressing, arising, eating, walking, hygiene, reach, grip, and activities. A mean score of 0.5 or greater was defined as the presence of hand disability, which means moderate to complete hand disability (Dahaghin et al., 2005b).

Another self-report instrument is the Arthritis Impact Measurement Scales (AIMS) proposed by Meenan et al. in 1980. It is a multidimensional health status index for use with various arthritis patients. The AIMS is a 56-item questionnaire with nine different dimensions, which included mobility, physical activity, dexterity, activities of daily living, social role, social activity, anxiety, depression, and pain. Ren et al. (1999) published a revised and short-form version (AIMS2-SF) to improve its simplicity and ease of application.

The Australian/Canadian Osteoarthritis (AUSCAN) Hand Index was presented by Bellamy et al. in 2002 (Bellamy et al., 2002a; Bellamy *et al.*, 2002b). Bellamy et al. pointed out that the AUSCAN was developed jointly between Australia and Canada to provide a multi-cultural assessment of hand physical function (nine items), pain (five items), and stiffness (one item) in hand OA. The 15 items contained in the AUSCAN

were designed to document a combination of common symptoms that were important to symptomatic hand OA individuals.

Duruoz et al. (1996) developed the Cochin scale to assess the functional disability for RA and hand functions in France. Although the Cochin scale was not a hand OA specific tool, Duruoz et al. pointed out that Cochin would also be valid and reliable for hand function assessments for hand OA patients. There were 18 questions included in the Cochin to assess ADLs in kitchens, dressing, hygiene, and offices.

Dreiser et al. (1995) published the Functional Index of Hand Osteoarthritis (FIHOA) for evaluating the follow-up symptoms of patients with digital OA in clinic settings. As indicated, the index was based on a physician-administered questionnaire with 10 items about doing ADLs with hands.

The Michigan Hand Outcomes Questionnaire (MHQ) was proposed by Chung et al. in 1998. It included 37 questions that measure the 6 scales of interest, including (1) overall hand function, (2) ADLs, (3) pain, (4) work performance, (5) aesthetics, and (6) patient satisfaction with hand function. The MHQ was constructed of items that were included in other existing assessment tools. As mentioned in Chung's article, for example, some items of the AIMS were incorporated into the sections of hand-related work performance and physical hand function, and the McGill Pain Scale and the Carpal Tunnel Questionnaire were used as the guides for developing the questions to quantify hand pain. Chung et al. found that the pain scale of MHQ was the strongest predictor of physical hand function ($p=0.001$), whereas the aesthetics scale is the weakest ($p=0.993$). Therefore, they concluded that the patients who reported less pain would have better physical hand function.

Different self-report instruments have different features and validated target populations. Dziedzic et al. (2005) discussed which self-report hand assessment questionnaire could best estimate the levels of hand disability in older populations in UK. Four review criteria, e.g. reliability, validity, conceptual model, and measurement model, were discussed in the article. Dziedzic et al. concluded that the AIMS2 and AUSCAN were the most highly rated tools across the four main criteria of all the instruments (AIMS2, HAQ-DI, AUSCAN, Cochin, and FIHOA). They concluded that the FIHOA and Cochin, which were investigator administered-based questionnaire, were less useful than the self-completion ones for a population survey. In addition, Dziedzic et al. pointed out that the main disadvantage of HAQ-DI was that its hand pain subscale has not been validated yet.

However, Stamm et al. (2007) tended to have different conclusions. Stamm et al. discussed which published self-report instruments could best describe the real hand dysfunction levels of patients with hand OA. As described in the study, a generic comprehensive hand function test, which was JTHFT, was used as the benchmark. Stamm et al. found that without age correction, the total score of the AIMS2-SF had the highest raw correlation coefficient (0.672) to the JTHFT, followed by AIMS2-SF upper body limitation subscale (0.448). However, after including age correction, the HAQ-DI had the highest correlation coefficient (0.763), followed by the Cochin scale (0.739), and the AIMS2-SF total score (0.689).

Thus, it can be concluded that if with age correction, the HAQ-DI was the best self-report instrument to assess hand dysfunction levels. However, the main limitation was that the correlation coefficient between HAQ-DI and real hand dysfunction levels of

patients with hand OA was only 0.763. In addition, its hand pain subscale has not been validated yet (Dziedzic et al., 2005).

Due to a need for accurate tests that could be performed with minimal specialized equipment and in a field setting, which could be used to categorize research participants, one of the research activities of the current study was to propose a comprehensive hand function assessment method for older people with hand problems. Similar to Chung's approach which pieced together different assessment scales and tests from a variety of sources when developing the MPQ (1998), in addition to HAQ-DI, the current study would include other assessment tools and techniques, for example the pain scale of MHQ that was designated for quantifying hand pain, or short hand function tests, if the administration time and cost could be well managed.

2.3.3 Direct hand function tests VS. Self-report instruments

Both direct hand function tests and self-report instruments have been validated to assess hand dysfunction levels. However, each of them may have different advantages and disadvantages if compared to the other. For example, although direct comprehensive hand function tests, e.g. JTHFT and AHFT, could examine the hand function levels from different aspects, the main disadvantage was that the presence of professionally trained investigators and the allocation of testing space were required (Poole et al., 2006). Therefore, Stamm et al. (2007) concluded that compared with direct hand function tests, self-report instruments were more feasible in busy clinical settings. However, it was

found that some clinicians would prefer objective hand function tests to subjective questionnaires because they thought that the responses from a questionnaire were, to some degree, relying on patients' educational levels and motivations. In addition, the person who was answering the questions "*might think about his or her ability to perform the particular task in daily life as influenced by environmental and personal factors and not about a standardized task, which is commonly used in a test*" (Stamm et al., 2007). This bias might result in the underestimations of their hand dysfunction levels (Hochberg et al., 2000).

According to the discussions indicated above, the use of the direct hand function tests, for example JTHFT, will be a good choice if a detailed hand function test is required, such as in a clinic setting. For research purposes, where there is only a need to categorize individuals based on extent of hand dysfunction and hand pain, and where the duration of the test time must be limited, a combination of self-report instruments and short hand function tests may provide the most feasible and still highly informative assessment method.

2.4 Participatory product design methods

2.4.1 Changes of needs in older populations

The differences between older and younger populations in terms of their needs for products can be explained by not only physiological changes, but also psychological changes triggered by aging.

Hirsch et al. (2000) investigated the influences of user emotion when designing products for older populations. They pointed out that a product designed for older people should not pose a “*stigmatizing aesthetic*” or make them feel ashamed. Therefore, Hirsch et al. concluded that in addition to product function, the factor of aesthetic, for example size, materials, and “*look and feel*”, was equally important for older people who have physical problems. Chung et al. (1997) made similar conclusions in a design study when discussing handle design of canes for older people with hand arthritis.

According to the findings from the previous studies, the products designed for older populations that were only useful and usable were not good enough to be truly accepted by users unless the desirability criterion could be satisfied emotionally. Thus, it could be concluded that the integration of different design methods or tools to collect different levels of user experience and needs is required.

2.4.2 Design methods to document user experience

Different levels of user experience will reveal different stories or pictures of user needs (Sanders, 1999) (Figure 2.2). According to Sanders (2002), in order to comprehensively understand what people really want, in addition to the explicit knowledge that can be learned from listening and the observed information that can be understood from watching, it is necessary to access people’s latent needs – what they feel, dream, and imagine, that something they cannot express in words. Sanders concluded that when all three levels of user experience are explored simultaneously, researchers can more readily

understand and develop empathy with users of the target products.

Figure 2.2: Different levels of user experience (Sanders, 1999)

Different methods or tools can be used to document different levels of user experience in the early stages of design processes. As shown in the Figure 2.3 (Sleeswijk Visser et al., 2005), individual survey (e.g. questionnaire and interview) (say methods), group survey (e.g. focus group) (say methods) and field methods (e.g. behavior observation) (do methods) are the mostly commonly used methods or tools to collect user needs. As to the deeper level of user experiences, the application of the new design toolkits, for example Inspiration & Assessment Cards (Figure 2.4) and MakeTools® (make methods) could be very helpful.

Figure 2.3: Different levels of knowledge about experience are accessed by different techniques (Sleeswijk Visser et al., 2005)

Figure 2.4: Inspiration & Assessment Cards. Top left: Set with 100 abstract images; Top right: a designer's selection of cards expressing the experience the product should evoke; Bottom left: a graphical overview of the answers (keywords & images) of 100 subjects, clustered by 7 main topics. The size of the circles represents the number of similar answers. Bottom right: IA cards of different sets with different themes, such as people, products, environments and abstract images (Abstracted from the Design and Emotion Society Website, <http://www.designandemotion.org/>, 2011)

The MakeTools® is a method used in the generative phase of a participatory design process. There are many different types of MakeTools® that could facilitate different expressions of needs. It has been found that the MakeTools® method was effective in accessing end-users' unspoken feelings and ideas (Sanders, 1999, 2002). According to Sanders (1999), MakeTools® can be roughly classified into two types. With “emotional toolkits”, people can use their artifacts, for example collages or diaries, to show or tell their stories, dreams, happiness, and worries about their current lives. With “cognitive toolkits”, people could describe how they understand or misunderstand things through artifacts they created, such as maps, 3D functional models, relationship diagrams, or process flowcharts. Sanders also pointed out that the cognitive toolkits could be applied as a means to explore relationships between the components of a product or system.

According to the previous paragraphs, integrating different design methods or tools to explore different levels of user experience, e.g. say, do, and make, in the product design and development process might be a valuable approach to adopt when investigating questions related to product design for an older population. Therefore, the individual questionnaire, focus group, behavior observation, and MakeTools® were applied together in the current study.

2.5 Jar lid design characteristics

In the past, food packaging was only designed to satisfy the needs of manufacturers, which was preserving and protecting the food contents. However, it has been found that

some people experience significant difficulties in using and opening some food containers (Yoxall *et al.*, 2006). Opening a new jar or bottle is a good example. Jar opening has been reported as one of the most difficult ADLs for older populations, especially those who have hand problems (Bellamy *et al.*, 2002a; Voorbij & Steenbekkers, 2002; Yoxall *et al.*, 2006). In recent years, some studies have discussed improvements in the “*Openability*” of jars or bottles, e.g. “*how easy it is for the consumer to access a product*” (Langley *et al.*, 2005). Most of these studies were interested in investigating how different jar lid design characteristics, such as size, surface texture, and shape, could affect the performance of users.

2.5.1 Size

The diameter of lids is the most common lid design characteristic discussed in previous studies. Voorbij and Steenbekkers (2002) investigated the MVTs of older populations when opening a 66 mm diameter lid. Seven hundred and fifty participants (123 of them were aged from 20 to 30 years and the other 627 were over 50 years of age) were recruited into the study. All the participants had abilities to live independently and none of them had needed to consult a medical specialist in the three months preceding the experiments. Voorbij and Steenbekkers found that if the opening torque of 66 mm diameter jar lids can be reduced to 2 Nm, 97.6% of the users from 50 to 94 years old and 100% of the 20-30 years old users would have no difficulty in opening a jar. By using a similar research protocol, Yoxall *et al.* (2006) examined the differences in MVTs between

the different ages of healthy people when opening a 75 mm diameter jar. As described in the article, 235 participants (138 males and 96 females) aged from 8 to 95 years were recruited. According to the result, they found that the mean MVT of 75-year-old females was significantly below 3.2 Nm, which was the mean torque level required to open the 75 mm diameter jar lids on a variety of products. Yoxall et al. concluded that only 15% of the 75 mm diameter lids could be opened by an average 85-year-old woman.

In addition to MVTs, Yoxall et al. (2007) discussed how users would select their grip types when interacting with jar or bottle lids with different diameters. As listed in the article, four different types of packaging – three jars (85 mm lid diameter gherkin jar, 75 mm lid diameter curry jar, and 60 mm lid diameter olive jar) and one water bottle (28 mm lid diameter plastic beverage closure) were tested. Fifty healthy participants from 18 to 63 years old were recruited in the study. The results of the study are shown in the Figure 2.5. Yoxall et al. concluded that the most popular grip type for the larger lids was a spherical grip; for the medium lids, the spherical and box grips were equally popular; as to the smaller lids, a lateral grip was the most popular. The authors found that the trends in grip type selection were based on which grip type provided easier access to the given lids. They also pointed out that the strength of the grips would be another factor associated with their grip type selections.

(a) Grip classification

Grip type	Number of subjects observed (total = 50)					
	Gherkin jar (85 mm)	Curry jar (75 mm)	Olive jar (60 mm)	Water bottle (28 mm)	Yoghurt pot	Crisps
Spherical	24	19	13			
Box	18	19	8	1		
Lateral	5	7	20	27		
Cylindrical	3	2	9	9		
Pulp				9		
Cylindrical with ring finger		2		2		

(b) Ethnography study results summary

Figure 2.5: Frequency recorded for grip types on various packaging designs (Yoxall et al., 2007)

2.5.2 Surface texture

The relationship between applied grip force, applied frictional force, lid diameter, and resulting torque has been discussed in recent studies. Yoxall and Janson (2008) proposed a simple model (Figure 2.6) to explain how the static coefficient of friction

(COF) between human finger skin and lid surface texture could affect the turning torques when opening a circular shaped lid. As explained in the study, based on simplified assumptions of friction calculations and point applications of force, the value of friction force was the product of the maximum hand grip force applied to the lid and the maximum value of the COF between finger skin and lid surface. And then the torque was developed by the product of the friction force and the radius of the lid. Yoxall and Janson concluded that the model could be applied to predict the maximum torques an older female (aged over 60 years) could produce when turning a circular shape lid, by simply measuring her grip force, lid diameter, and the relevant COF.

Figure 2.6: Model of how the torques can be produced by hands on a circular shape lid. N_H is the grip force applied by the user. F_H is the friction force resulting from N_H and the COF between finger skin and lid surface texture. T_H is the resulting torque given by F_H and lid radius r_c . (Yoxall and Janson, 2008)

However, it has been found that the optimal diameter for producing the largest turning torque could not be determined simply by the force model described above, because there was no strong indication of an optimal lid diameter for generating the maximum grip force, not to mention the relationship between the given grip force and resulting torque was found to be not always linear. Imrhan and Loo (1988) investigated

the relationship between grip force, resulting torque, lid diameter, and COF by measuring the maximum grip force and MVTs of older people when opening rough and smooth circular lids of four different diameters. The result is illustrated Figure 2.7. As indicated in the study, 42 subjects (16 males and 26 females) between the ages of 60 and 97 years who were capable of using their preferred hand for grasping and turning lids were recruited in the study. Lids with two types of surface texture, e.g. rough and smooth, and four diameters, e.g. 31, 55, 74, and 113 mm, were tested (eight testing conditions). According to the results, Imrhan and Loo concluded that both diameter and surface texture were important characteristics for lid design. When comparing the differences between smooth and rough surface lids, Imrhan and Loo pointed out that for smooth surface lids, the 74 mm diameter lid would be optimal for older people to produce torques. However, on the other hand, the torques produced from turning the rough texture lids were monotonically increasing along with the diameter, which had different patterns if compared with the corresponding grip forces. In addition, Imrhan and Loo pointed out that it was very likely that alternative lid shapes, e.g. non-circular, could provide greater torques because they might eliminate the slippage. Imrhan and Loo concluded that this design feature was particularly important for older people since their declined grip strength was one of their disadvantages for exerting wrist-twisting torques.

Figure 2.7: Grip force and torque trends for smooth (S) and rough (R) lids in varied lid diameters. M and F represent males and females. (a) Force-diameter trends in wrist-twisting grip force. The trends were all slightly quadratic. The grip forces in 31-74 mm diameters were not significantly different for rough and smooth lids within the same gender. (b) Torque-diameter trends in wrist-twisting torque. The data of males and females followed the similar pattern and were different only in magnitude. (Imrhan and Loo, 1988)

2.5.3 Shape

The research focused on investigating the relationship between lid shapes and applied turning torques is relatively limited. Most studies have examined the lids with circular shapes, whereas only a few of them included alternative top shapes.

Crawford et al. (2002) examined the influences of lid shape, diameter, and height on MVTs of younger and older adults. Forty participants were recruited in the study and divided into four groups: younger males, younger females, older males and older females. All the participants had no medical history of joint problems or symptoms in fingers and wrists, and were able to participate while standing. Twelve lids that were composed of three diameters (20 mm, 50 mm, and 80 mm), three heights (10 mm, 20 mm, and 30 mm) and two shapes (circular and square) were tested (only the lids with 50 mm in diameter and 20 mm in height were tested in not only circular shape but also square shape).

According to the testing result and consistent with other studies, there was a significant difference between older and younger people in MVTs. As indicated, the participants could exert greater torques with square lids if compared with circular lids in the same diameter. In addition, Crawford et al. found that the surface area of some of the test lids, e.g. the six circular lids with 20 and 50 mm in diameter, and 10, 20, and 30 mm in height, was calculated to be highly correlated with the MVTs. They pointed out that it could be because the surface area of the lids in contact with hands and the torque strength exerted there was highly correlated. However, the similar findings could not be found in 80 mm circular lids because different grips were used for larger diameter lids.

2.5.4 Conclusions

There have been a number of jar lid design studies conducted within the last two decades. Most of them focused on the association between lid design characteristics, e.g. diameter, height, surface texture, and shape, and the hand performance of users when turning the lids of jars or bottles. However, although the special needs and difficulties of older populations were emphasized in most of the previous studies, to our best knowledge, none of those studies specifically included older people who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation. Even though they were recruited, there was still a research void in comprehensively exploring how the variant of lid design characteristics together, e.g. the major effects of the design characteristics and the interactions between them,

could affect the lids' usability levels.

2.6 Biomechanical models of applied torque

Several biomechanical models have been developed to explain the association between various handle design characteristics and hand performance. A very early model proposed by Pheasant and O'Neill (1975) concluded that the turning torque applied to a cylindrical handle was the product of the handle diameter, the COF between the hand and handle surface, and the hand grip force (Figure 2.8). By adopting the similar concept, some lid design studies have shown that the selection of surface textures and resulting MVTs are associated (Imrhan & Loo, 1988; Yoxall & Janson, 2008).

Figure 2.8: Early torque model proposed by Pheasant and O'Neill (1975)

Pheasant and O'Neill's biomechanical model was modified by Seo et al. (2007) to account for the distribution of grip force (Figure 2.9). They pointed out that the grip force should be considered as a set of normal forces acting on the object surface, instead of one single scalar value, since the grip force of a hand or fingers varied over the object surface. Therefore, the torque T of the modified model could be re-written as shown in

Equation 1.

Figure 2.9: Modified torque model proposed by Seo et al. (2007)

$$T = \sum_{i=1}^n r_i \times \mu_i \times F_{ni} \quad (\text{Equation 1})$$

where T is the torque, n is the number of hand segments touching the object, r is the moment arm between the object's center of mass and point where friction force is applied, μ is the COF between the hand and object, and F_n is the normal force (Seo et al., 2007).

If compared with the Pheasant and O'Neill's model, Seo et al. pointed out that the modified model was applicable to not only circular shaped objects, but also irregularly shaped ones. Seo et al. concluded that each contact segment could have a different COF depending on the selection of material, surface texture, and applied grasp.

While considering the goals of the current jar lid design study indicated in the Chapter 1, it has been found that Seo's torque model was more suitable to illustrate how people's hands interact with lids when applying torques. Therefore, the primary concept of the model could be further adopted to not only explain the hypothesized research findings,

but also assist Human Factor researchers or designers to build up new ideas for lid designs.

2.7 Design assist tools for industrial designers

The development of design assist tools to help industrial designers create designs during product development processes have been discussed in many studies.

Accordingly, the design assist tools could be categorized by different characteristics, including designated application purposes, carried information contents, visual representations of information, and corresponding support design activities. Various types of tools have been created for designers to solve different types of design problems.

However, existing design assist tools are not always useful, usable, or even desirable for industrial designers. It has been found that designers seldom consult established design tools in their work. Recent studies have concluded that some of the design resources or tools fail to meet the needs of their end users, e.g. industrial designers, without carefully and systematically studying their needs or behaviors (Burns et al., 1997; Choi et al., 2006; Law et al., 2008a). Some reasons associated with the problem have been discussed and are discussed below.

2.7.1 Developed design assist tools

The applications of current design assist tools for industrial designers working in the product design process can be roughly divided into three different categories. They are (1) Provide information, (2) Assist in collaboration, and (3) Facilitate design activities.

2.7.1.1 Provide information

According to the definitions of the term Industrial Design (a.k.a. Product Design) and roles of industrial designers, “*Industrial design is a combination of applied art and applied science, whereby the aesthetics, ergonomics and usability of products may be improved for marketability and production...(and) The role of an industrial designer is to create and execute design solutions towards problems of form, usability, physical ergonomics, marketing, brand development and sales.*”(de Noblet & Palais, 1993) Therefore, it could be concluded that industrial designers or industrial designers would need to look for different types of information during the design process in order to solve various design problems.

The types of information that the developed design assist tools could provide to designers include product data and user data. The product data could contain component replacement suggestions, manufacturer’s standards in industry and so on; whereas user data could be targeted user needs, physical/cognitive characteristics and capacities, behaviors, subjective preferences, and user-product interactions. Keeping in

mind the main objective of the current study, the design assist tools that convey information concerning user data will be the focus of this section.

The user data provided by design assist tools or guidance could be collected through research, laboratory controlled studies, field studies, case studies, and other collected experience. According to Law's classifications (2008), the current guidance could be divided into two different types: (1) well-defined guidance and (2) fuzzy or poorly-defined guidance. *"A well-defined guidance can be described as one that is specific, measurable, agreed to, realistic, and time/cost-framed; whereas a fuzzy or poorly-defined guidance can be described as the opposite, i.e., vague, un-measurable, born in disagreement, unachievable with available resources, or having unclear requirements in terms of time and cost."*(Law et al., 2008a) He also pointed out that many of the human sciences fell into the second category because human behaviors were dynamic and often highly varied by nature.

Some design assist tools are capable of providing user data, including user preferences, physical and mental capacities, anthropometry data, dynamic motion, human performance and so on, for designers to use. For example, Tsai and Chou (2007) created design support software (Figure 2.10) to map the association between the color schemes of two-colored products and consumer perceptions. They concluded that the software could help designers to decide which color combinations to use on a product to fit the preferences of diverse consumer groups.

Figure 2.10: Design support software for mapping the association between the color schemes of two-colored products and the likely consumer perceptions (Tsai and Chou, 2007)

Gyi et al. (2004) explored the development of a computer-based design tool (HADRIAN) to support designers in evaluating the usability of new designs during early prototyping. As described in the article, the user data used in the study was collected from various types of individuals, particularly older people and people with certain disabilities. Gyi et al. pointed out that, for each participant, 27 different anthropometry measurements, maximal comfortable joint ranges of upper arm movements, boundary of grip reach volumes, postures of performing bend-lift-reach activities, and the abilities of accessing in/out different heights of chairs were investigated. By utilizing the collected data, Gyi et al. concluded that HADRIAN was able to estimate the percentage of individuals that could be accommodated for a proposed design. They also concluded that HADRIAN could help designers to understand the difficulties experienced by older people and people with certain disabilities in the early stages of design processes.

In addition to the user information about static postures such as provided by Gyi et

al. (2004), some other computer-based design assist tools have been developed to simulate dynamic human motions. Chaffin (2007) discussed the application of Digital Human Models (DHMs) when simulating human motions in vehicle and workplace design. He pointed out that DHM software, for example Jack¹, SAFEWORK², RAMSIS³, SAMMIE⁴, and UM 3DSSPP⁵, could assist designers in the early phase of the design process when developing the physical designs of vehicle interiors and manufacturing workplaces. In addition, he found that one of the most important features of DHMs was that human motion simulations allowed industrial designers to have a better understanding about potential problems and associated risks a particular population could have. However, as indicated in the article, the most common difficulty for designers when using DHM software was that it was very challenging for them to predict how a person with certain anthropometric characteristics should be positioned in a virtual workplace or dynamically interacting with objects. Chaffin pointed out that it could be because designers usually did not have a profound understanding of and training in biomechanics. Practically, this may be a primary barrier for designers that precludes their use of simulation software.

Some studies have focused on general ergonomic guidance for the design of hand tools. Patkin (1997) investigated a set of general-purpose handle design principles for designers of hand tools. According to that study, a checklist was proposed with 13

¹ Developed at the Centre for Human Modeling and Simulation, University of Pennsylvania, Philadelphia, Pennsylvania, United States

² Developed at Dassault Systemes, Vélizy-Villacoublay, France

³ Developed at Tecmath and the Technical University, Munich, German

⁴ Originally developed at the University of Nottingham, United Kingdom and subsequently at Loughborough University, United Kingdom

⁵ Developed at the University of Michigan, Ann Arbor, Michigan, United States

principal headings, including size, shape, surface, security, stiffness, sitting, surroundings, signify function, sensing features, storage, special other features, skill needed, and validating design. The guidance of hand tool design was mostly focusing on power grips of hands. For example, in the “size” criterion, the design principles were described and shown as below: *“Length at least 10 to 15 centimeters, to fit the width of the palm, longer for large-handed population, shorter if the butt end of the handle is to fit into the palm, when it should be rounded. Allow for the thickness of working gloves. The length of the shaft of the tool has to be looked at separately.”* And in the “stiffness” criterion, one of the principles was *“The force needed to use a handle occasionally should be less than one-third of average possible maximum for the user population.”* As indicated in the article, all the contents were described in words.

Similar to Patkin’s study, Woodson (1981) also explored general principles and recommendations for hand tool design. In addition to the checklist-type guidelines in words, Woodson presented accompanying sketches to graphically illustrate how users would interact with hand tools and explain how various factors, including mechanical factors, anthropometric factors, anatomical considerations, physical characteristics of the tool, ergonomic considerations, and work environments, could be comprehensively considered when creating the design (Figure 2.11). Woodson also applied sketches to describe a number of typical problematic scenarios of using hand tools (e.g. examples of bad designs) to provide readers some ideas regarding how to prevent operation injuries.

Figure 2.11: Guidelines for tool design and selection (Woodson, 1981)

Computer technology has been applied in a couple of studies to organize and present existing knowledge to facilitate the decision-making process for designers. Kayis and Charoenchai (2004) developed a computer knowledge-based software system (TOOL-EXPERT) to assist the design of non-powered hand tools. They pointed out that despite investigations in previous studies of the interactions between human capabilities, task requirements, working situations, and the design characteristics of hand tools, there appear to be several limitations to utilizing research knowledge in practical use. One of the main barriers indicated in the study was that knowledge was not integrated into the format that can practically support decision-making processes. Therefore, by using the TOOL-EXPERT, Kayis and Charoenchai pointed out that users would have an option to choose to use either the knowledge of a particular consideration itself (e.g. Task, User, Tool, Grip and handle, Injury risk, and Gloves use) or, furthermore, the relation of that knowledge to other considerations. As indicated, the TOOL-EXPERT would search for

the related knowledge and eventually compile the recommendations for the users.

2.7.1.2 Assist in collaboration

Nowadays, a new product development team is usually composed of team members with different expertise (Edmondson and Nemhard, 2009). Therefore, from the “macro” perspective of new product development processes, some design assist tools have been developed to facilitate the collaborations within the multi-disciplinary product development teams.

Pei et al. (2010) investigated the use of design representation cards, e.g. iD Cards, for assisting the collaborations between industrial designers and engineers (Figure 2.12). According to the study, Pei et al. found three problems from previous collaborative design activities, including conflicts in values and principles, differences in design representations, and education differences. For example, drawing sketches was one of the most common techniques used by industrial designers in the early phases of design process when embodying their ideas. However, Pei et al. pointed out that since the sketches were sometimes “*ill-defined, inaccurate, and inconsistent*”, the communications between designers and engineers in a product development team would be harmed. Therefore, Pei et al. developed a design collaboration assist tool, e.g. iD Cards, to facilitate the communications, by providing a “*uniform definition of design representations with common vocabularies*” on the cards for both industrial designers and engineers. Accordingly, the authors concluded that all the stakeholders in a design

team would be able to develop a common understanding regarding the working processes, which could make the design collaboration more effective and efficient.

(a) Card layout

(b) Examples

Figure 2.12: iD Cards (Pei et al., 2010)

2.7.1.3 Facilitate design activities

Some design assist tools have been developed for supporting design activities and enhancing designers' working efficiency. Generally speaking, the most common design feature of this category of tools is the application of new computer technologies. The 3D Sketching device developed by Diehl et al. (2004) is a good example (Figure 2.13). They investigated a new design assist device for industrial designers that could transfer sketches and drawings into 3D computer models. Diehl et al. concluded that the device could save a lot of time and thinking for designers when they embody the raw sketches into CAD systems during the product design process.

Figure 2.13: 3D-Sketching device (Diehl et al., 2004)

Bryant et al. (2006) explored a web-based design tool that could automatically generate the variants of feasible design concepts for designers. As indicated in the study, the software-based design tool could abstract the historical design data from an existing product knowledge repository, and use the matrices of products' sub-functions and

components' compatibilities to generate and rank new design concepts. Bryant et al. pointed out that designers could then explore and evaluate the returned concepts to further solidify their design solutions. As concluded in the study, the authors found that this design assist tool could specifically help novice designers take advantage of previous design knowledge and experience during the ideation phase of the design process.

2.7.2 Problems with current design assist tools

While there are many design assist tools available for designers to use, it has been found that designers seldom consult these established resources when developing designs (Burns & Vicente, 1996; Burns et al., 1997; Choi et al., 2006; Law et al., 2008a).

Although the barriers for designers in using established design resources and tools have been discussed in many articles (some of which are more than ten years old), the problems still exist. Due to the focus of the current study, design assist tools that were primarily developed for providing Human Factors knowledge to designers are the focus of this section.

It is recognized that a gap exists between Human Factors information explorers, meaning engineering researchers, and information users, meaning designers. (Burns & Vicente, 1996). As indicated in Burns and Vicente's article (1996), *"In the field of Human Factors engineering, it has been noted that a gap exists between the worlds of the Human Factors researcher and the Human Factors designer. The problem is not that Human Factors information is not available to designers – in fact, Human Factors*

researchers have gone to great efforts to produce large compilations of Human Factors data and information for designers. But despite these efforts, Human Factors information has had very little impact on design.” The reasons associated with the problem have been generally discussed in some studies. For example, Law et al. (2008) examined published universal design resources (UDRs) to measure how effectively they could support typical design processes and design psychology. Law et al. found that although the aim of developing the UDRs was to improve the lives of people, the needs of the recipients of UDRs, e.g. industrial designers, were usually not well considered. It may be that the Human Factors researchers who created guidelines may easily overlook the needs of designers (Norman, 2002). Burns et al. (1997) pointed out that the reasons why designers rarely consult established Human Factors resources include (1) lack of contextual information, where the relation to the target product is unclear, and (2) having negative perceptions, which means that based on negative past experiences in trying to use Human Factors resources, designers would rather spend time working on design solutions on their own.

Rouse (1986) proposed a theoretical model to explain designers' information search behaviors. He found that the designers' information accessing behavior was a function of (1) perceived importance, (2) perceived relevance, and (3) perceived cost. However, Burns and Vicente (1996) came to different conclusions. They indicated that designers were not always capable of differentiating between what is relevant and what is important. They concluded that designers consistently overestimated the cost of obtaining information. Burns and Vicente pointed out that this may be because designers are not familiar with the information resources that have been developed and are readily available for them to

use.

Burns et al. (1997) proposed a framework to illustrate the factors that could impact the transfer of Human Factors research findings to designers (Figure 2.14). According to the article, the framework introduced the concept that Human Factors guidance or tools could be defined as the interface between designers and Human Factors research findings. Burns et al. pointed out that to be “effective”, the values of designers, e.g. the end users of this particular interface, and the constraints of designers’ working environments must be adequately considered when designing the interface. As indicated, the design of the interface should address four factors: (1) provide good match between the forms of guidance and the designers’ questions, (2) the amount of effort in retrieving different forms of guidance, (3) designers’ subjective values, and (4) designers’ information search strategies.

Figure 2.14: Framework to illustrate the factors that could impact the transfer of Human Factors research findings to designers. The right side dealt with Human Factors research, whereas the left side dealt with Human Factors design. The area below the dotted line showed how the Human Factors research and design activities interacted with each other when one attempts to transfer research findings to designers in paper or computer-based forms. (Burns et al., 1997)

The criteria associated with the term “effective” that an information interface should strive to satisfy were also addressed in Burns’s study (1997). They conducted experimental testing to evaluate published Human Factors handbooks. The three information interface design criteria they examined were usability, usefulness, and

viability. As indicated in the article, “*Usability refers to ease of use, which is determined by the extent to which a design is consistent with the features of human information processing (e.g. working memory, long-term memory). Usefulness focuses on domain-specific semantic features and required that a design has the functionality required to accomplish work domain objectives (as opposed to just being easy to use). Viability refers to the extent to which the design is consistent with users’ values and needs, which determines whether the design will actually be used or not.*” They concluded that most of the Human Factors information resources did not meet the needs of designers.

Other studies have made similar conclusions. Goodman et al. (2006) investigated how different formats of end user information can fit with designers’ work practices. The pros and cons of them, including personas, detailed disability information, and capability simulators, were discussed. For instance, as indicated in the article, personas could be used informally as the means to encourage designers to explore potential needs of varied users. However, it might take much time to create really reliable and representative personas. In addition, Goodman et al. pointed out that personas were not useful for presenting detailed technical information about end users, e.g. about disability. Tables and charts were usually used to present detailed information and could support designers in making detailed decisions. But Goodman et al. found that most of the designers thought the format was too dry. As indicated, designers needed the data about product use to be transformed and communicated in a way that they feel they can easily use. They also wanted the key points to be “*vividly and memorably presented to carry out the information*” (Black, 2003). Accordingly, reports and guidelines were not enough for designers. They needed the information in such a form and at the moments that they

could easily use it during the design process (Boess, 2009).

The differences in mindsets between designers and engineers can be another factor associated with the problem. The primary goal of developing Human Factors information guidance is to provide Human Factors data and information to designers for embodying their design ideas. However, previous studies have determined that engineers (e.g. guidance developers) and designers (e.g. guidance users) were different in thinking about “problems” and work approaches (Law et al., 2010; Persson & Warell, 2003). Industrial designers usually view “problems” as ill-defined. They prefer open-ended solutions, adopt a trial-and-error approach, and use intuition to solve design problems; whereas engineers usually view “problems” as well-defined, which are specific, measurable, and realistic (Persson & Warell, 2003). The quote from a designer when illustrating the need for guidance may be able to explain the conflicts: *“(Designers) want to know what current best practice and thinking is and stay abreast of new developments, and they want to know more about the what, how, and why of inclusive design. The problem is they have very little time in which to do this, and no way of sifting out the nuggets of valuable information and guidance from a great mass of material. Someone has to do that for them, but they do not want the resulting information delivered in prescriptive form. They want to develop their own ways of working and be able to incorporate information and methods into that, not to be told how to go about designing.”*

The differences between designers themselves in terms of individual styles of problem-solving could be another factor which may be associated with each designer’s skills in dealing with largely unstructured and ill-defined design problems. However, it has been found that although previous studies have addressed the cognitive actions taken

by designers when solving problems, the individualities within the process were not addressed during the analysis (Coley *et al.*, 2007). De Jong and Boess (2007) investigated how user data can be communicated and engaged by designers and, if possible, used as an ideation inspiration source in the product design process. As indicated in the study, designers were included in the design workshops and a set of information cards about target users was provided. De Jong and Boess pointed out that although some designers used the information cards during their design work because they felt the information could contribute to their ideas, one designer could not make any use of them since he felt what he saw on the cards only reflects “*little things*” about the users, which may limit his imagination. The designer suggested that he would prefer to receive the cards later where he would use the user information to refine the final ideas. The authors also concluded that in addition to the photos, quotes about users, and the interactions between users and products, a video clip might be helpful to clarify how people actually do things.

2.7.3 Conclusions

While the problems of designers when utilizing current Human Factors information resources or guidance have been explored, some solutions and design recommendations for producing better design resources have been also discussed. They are summarized in the Table 2.3.

Table 2.3: Design recommendations for developing Human Factors information resources proposed by previous studies

Author (year)	Design recommendations for developing Human Factors information resources
Rouse, 1986	<ol style="list-style-type: none"> 1. All information to be presented should be valuable in the sense of reducing uncertainty and being task relevant and having an appropriate form 2. Types of information should include facts, fantasies, and feedback, with content and forms consistent with current tasks and individual differences 3. The system should be interactively adaptive and provide support ranging from aiding to embedded training
Burns and Vicente, 1996	<ol style="list-style-type: none"> 1. Provide on-line references which provide for quick search and access 2. Create reference information that is closely matched with the context and form of actual design problems
Law et al., 2010	<ol style="list-style-type: none"> 1. Explicitly define the target user groups of the guidance, research their needs 2. Clearly define “accessible” and/or “universal design” and gain the consensus 3. Publish the testing method for measuring conformance with the requirements 4. Work together with the appropriate authorities 5. Conduct user testing on the guidance throughout its development

According to the articles, most of the design recommendations were acquired by the need to create new resource tools to aid designers, and they seem to be able to bridge the gap between the Human Factors information developers, e.g. engineers or researchers, and the information users, e.g. designers. However, it is still not very clear whether the needs of designers were fully explored, not to mention how the “general” recommendations can be used to really solve the problems in depth. Only a few studies so far have focused on understanding and modeling how resource tools can be mapped with designers’ behaviors during the different phases of the product design process.

The methodologies applied to explore the user needs of designers can be another limitation of these studies. As indicated in Sander’s article (1999), different levels of user experience, e.g. *say*, *do*, and *make*, can reveal different stories or pictures about the users, and only when all the three perspectives are explored simultaneously, can people’s needs be readily understood. However, as indicated in previous Human Factors

resource tool design studies, only *say* (e.g. questionnaire, survey, and focus groups) and *do* (e.g. observations) methods were applied. There was still an opportunity to investigate the latent needs of designers when they use Human Factors information resources to solve design problems in their designs.

2.8 Conclusions

This literature review shows (1) a need for further investigation and identification of product physical interface characteristics that facilitate use by older people with hand disabilities, (2) a need for a simple, accurate, and comprehensive assessment method to categorize hand dysfunctions, and (3) a need for additional ideas regarding ways to bridge the gap between Human Factors researchers and industrial designers. All three of these voids are addressed, at least in part, by the research described in the remaining chapters of this document.

CHAPTER 3

3 PHASE 1: EXPLORATION – EXPLORING DIFFERENT LEVELS OF USER EXPERIENCES WHEN INTERACTING WITH PRODUCT INTERFACES

3.1 Introduction

Usefulness, usability, and desirability are three criteria required for successful products (Sanders, 1992). The statement is also supported by previous studies when designing product interfaces for older populations (K. C. Chung et al., 1998; Hirsch et al., 2000). Thus, how human factor researchers and designers can gain deeper insight into the user needs has become a big challenge.

According to previous studies, focus groups and surveys have been the most common methods used to collect user needs. For example, Demirbilek and Demirkan (2004) discussed how older users can be involved in the design process through focus groups. Three groups (3-6 people in each) of older people participated in the user-centered design process, e.g. (1) concept development phase in the very beginning, (2) concept refinement phase in the middle, and (3) user trial phase near the end. As concluded in the article, the authors pointed out that the quality of the design solutions could be enhanced by directly involving older people in the design process. They also

found that during the focus group sessions, older people were very good at not only expressing themselves freely but also explaining their positive and negative ideas about the design.

However, as indicated in the Chapter 2, the focus group method alone is not enough to explore all the contexts of what older people really want and need. Since user experience can be classified into three different levels, e.g. what they say/think, what they do/use, and what they make/know (Sleeswijk Visser et al., 2005), in addition to the focus group technique, e.g. *say* method, applying other design methods or tools together, for example MakeTools® (*make* method), would be more applicable to document deeper levels of user needs.

Since the user experience of older people with hand use limitation was the focus of the current study, it would be important that their hand dysfunction levels could be objectively defined in advance. Factors associated with the hand function deterioration include aging effect, chronic disease, female gender, and so on. However, previous research had shown that the determinants of hand disability or hand pain in older populations were complicated and still unclear. Studies that examined numerous factors still could only show an explained variance of 19.8% for hand pain and 25.2% for hand disability in the multivariate logistic regression models (Dahaghin et al., 2005b).

Therefore, instead of focusing on any specific hand pathology and its relevant effects on hand use, an integrated hand function assessment method was used in the study to comprehensively examine the status of hand dysfunction in the study participants, who were drawn from a population of community dwelling older adults.

3.2 Goal

While taking jar lid design as the demonstration of this product interface design research, the primary goal of Phase 1 was to preliminarily explore how the lids that were composed of various design characteristics, e.g. size, shape, and texture, could be associated with different levels of user experience. Additionally, the secondary goal was to further determine what lid design features could be included and examined in the next phase of the study “Phase 2: ‘Evaluation’ – Evaluate the product interface design characteristics through controlled experimental tests” presented in Chapter 4.

Unlike most of the previous jar lid design research, older people with hand problems were expressly recruited in the study. Both Ergonomics and product design research methodologies were adopted as the means to explore the different levels of user experience.

Thus, the necessary research activities of Phase 1 included –

- (1) Propose a new comprehensive method to assess the hand dysfunction levels of older people
- (2) Evaluate current and new lid designs through questionnaire and focus group methods
- (3) Explore the deeper levels of user needs about desirable jar lid designs by the means of participatory product design process

3.3 Methods

3.3.1 Design of experiment

There were two steps included in the study. The research procedure is outlined in Figure 3.1. They were Step 1 – Hand function assessment and Step 2 – Focus group event. The protocol was approved by the university’s IRB and all participants provided informed consent prior to starting each step of the study. The details of each step are described below.

Figure 3.1: Research protocol of Phase 1: Exploration – Exploring different levels of user experiences when interacting with product interfaces

3.3.1.1 Step 1 – Hand function assessment

The primary purpose of this step was to determine the focus group eligibility by estimating the hand dysfunction levels of voluntary participants. The comprehensive hand function assessment method used in the study was composed of six different techniques that were proposed by previous research. They were the Patient Reported Outcome Measurement Information System Health Assessment Questionnaire (PROMIS HAQ), Michigan Hand Outcomes Questionnaire Pain section (MHQ Pain), Moberg Picking-Up Test (MPUT), maximum voluntary exertion test of key pinch (MVE KP) and chuck pinch (MVE CP) tested by a pinch gauge, the observation of metacarpophalangeal joint hyperextension (MPH), and the range of motion examination of thumb palmar abduction (ROM Thumb). The time needed to administrate this series of tests was less than 30 minutes. The hand dysfunction characteristics and the corresponding assessment methods mentioned above are summarized in Figure 3.2 and Table 3.1. The description of each hand dysfunction assessment method is described in the following sections.

Figure 3.2: Structure of the comprehensive hand function assessment method

Table 3.1: Hand dysfunction characteristics and corresponding assessment methods

Hand dysfunction characteristics	Assessment techniques	Defined as abnormal
Self-report difficulties of ADL	PROMIS HAQ	> 0.5 points
Self-report presence of chronic pain	MHQ Pain	< 4 points
Sensibility	MPUT (eyes closed section)	> 28 seconds
Dexterity	MPUT (eyes open section)	> 16 seconds
Strength	MVE KP	< 4.5 kg (10 lb)
	MVE CP	< 4.5 kg (10 lb)
Anatomical integrity	MPH (during key pinch)	Concave
Mobility	ROM Thumb	< 30 degree

After the hand function assessment, the evaluation of current lid designs was then conducted. The lids on a selection of 24 current food containers found in grocery stores in Columbus, Ohio were examined (Figure 3.3).

The current lid designs were separated into two testing groups – “Small” (Group A: 15 - 39 mm in diameter) and “Medium” (Group B: 41 mm - 64 mm in diameter). For

example, the lids of water bottles, soft drink bottles, and juice were categorized in the group “Small”. The details of the current lid designs evaluated in the study are described in the Appendix A. The distribution of the lids by the sizes, e.g. diameter and height, is shown in Figure 3.4. Only the lids that were smaller than 65 mm in diameter were included in the study, because it was assumed that large-portioned food products could be less and less commonly used by older people since most of them would live alone and independently.

(a) “Small” lids (Group A: 15 ~ 39 mm in diameter)

(b) “Medium” lids (Group B: 41~64 mm in diameter)

Figure 3.3: Current lid designs evaluated in Phase 1

Figure 3.4: Size distribution of the current lids evaluated in Phase 1. A1 ~ A12 represents the 12 lids in the group “Small” (15 ~ 39 mm in diameter), and B1-B12 represents the other 12 lids in the group “Medium” (41 ~ 64 mm in diameter). The lids with underlined labels mean their surface texture is rough. Otherwise, it is smooth.

Each participant was asked to evaluate the two lid groups one at a time. The evaluation orders of the lid groups between participants, and the orders of the lids within each group were both randomized. All the testing lids were glued tightly to their original containers so as to simulate the difficulties participants may experience when opening the jars or bottles for the first time. After a couple of trials of performing jar-opening tasks with the lids in the same group, the participant was asked to evaluate each lid design by filling out an evaluation form (Appendix B). The evaluation form was designed for systematically documenting each participant’s preferences for the lid design characteristics. Therefore, for each lid, the participant was asked how they felt about the diameter (“Too small”, “OK”, or “Too large”), the height (“Too short”, “OK”, or “Too

high”), the texture as it affected turning (“Helpful” or “Not helpful”), and the texture as it affected comfort (“Comfortable” or “Not comfortable”). In addition, an overall preference rating for the lid was also requested; participants could select “Hate it”, “Dislike it”, “Like it”, or “Love it”.

The current lid evaluations in Step 1 were also used as a means to probe the cognitive status of participants. If a participant has significant cognitive difficulties in understanding or completing the whole current lid design evaluation in a set period of time (e.g. 30 minutes), the participant would not be further recruited to the focus group event in Step 2, as well.

- Patient Reported Outcome Measurement Information System Health Assessment Questionnaire (PROMIS HAQ)

Similar to the HAQ-DI described in 2.3.2 Self-report instruments, the PROMIS HAQ is the improved version of HAQ-DI that used five-point response scale to reduce floor and ceiling effects, used present tense without a time frame, and improved questions in aids and devices (Fries *et al.*, 2005). A mean score of 0.5 or greater was defined as the presence of hand disability, which means moderate to complete hand disability (Dahaghin *et al.*, 2005b).

- Michigan Hand Outcomes Questionnaire Pain section

As indicated in Chung's study (1998), the pain scale of MHQ was the strongest predictor of physical hand function. Therefore, the pain scale of MHQ was selected to quantify participants' hand pain. If a participant's mean score of the MHQ Pain is 4 or below based on a five-point response scale, the participants will be defined as having hand pain.

- Moberg Picking-Up Test (MPUT)

The purpose of applying the MPUT was to quantify the functional values of hands in terms of sensibility and dexterity (Moberg & Gothenburg, 1958). The test was performed in two phases: (1) with eyes open, and (2) with eyes closed, to assess the sensory acuity and precision grip at fingertips. Each phase of the test was repeated three times to obtain an average. In this study, only the dominant hand was examined; the participants were asked to hold the container with the non-dominant hand. In addition, when less than four objects were left on the platform, they were verbally informed of the number of remaining items by the researcher. It was thought that this could help to avoid the tendency of participants being distracted and count the objects while performing the task. The same protocol was also adopted in Amirjani's study (2007).

The normative values (seconds) that showed how age, gender, and handedness can affect the MPUT results in an older female population (60 years and above) were listed in Amirjani's study (2007) (Table 2.1). Accordingly, if the performance value of a female

participant in the current study is below the population average, which is over 16 seconds in the eyes open section or over 28 seconds in the eyes closed section, the participant will be categorized with the presence of hand abnormality in dexterity or sensitivity, respectively.

- Maximum voluntary exertion tests of key pinch (MVE KP) and chuck pinch (MVE CP)

The MVE KP and MVE CP (e.g. 3-finger pinch) were measured with a portable pinch gauge (PG-30, B & L Engineering, Santa Ana, California). The order of the two types of pinch strength tests was randomized between participants in order to minimize the individual variances of fatigue effects. The participants were specifically instructed to ramp up to their voluntary peak capacity, sustain the effort for a brief time (about two seconds), and then ramp down.

All the exertions were performed by participants' dominant hands while seated. The participants were required to have upright posture with the feet on the floor, shoulder adducted, elbow flexed at 90 degree, and forearm and wrist in a neutral position. In addition, both the dominant and non-dominant arms were well supported. During the measurement, no verbal encouragement was given to the participants. In addition, 2-minute breaks were allowed between the three trials. During the break periods, the participants were asked to rest their fingers on the gauge to make sure the finger postures and the contact segments of fingers between trials were consistent. They were also encouraged to request more rest if the symptoms of fatigue were felt at any point during the

assessment. The average reading from the three repetitions was defined as the individual's maximum voluntary exertion of key pinch or chuck pinch. The testing protocol was also adopted in DiDomenico and Nussbaum's study (2003).

Right after each pinch exertion, the question "Is there any reason you can not pinch any harder?" was given. The question was used to probe for potential confounding factors that may have been associated with a decrease of their maximum pinch strength.

According to previous studies regarding the maximum chuck pinch strength in female populations (Table 3.2), for older people (60 years old and above) with hand OA, the mean was 1.98 kg (4.4 lb) and the standard deviation was 1.07 kg (2.36 lb) (Kjeken et al., 2005); for younger healthy people (20-30 years old), the mean was 6.35 kg (14 lb) and the standard deviation was 1.11 kg (2.45 lb) (Fernandez *et al.*, 1992). In addition, it has been found that the key pinch and chuck pinch were not significantly different in the natural wrist position for healthy people (DiDomenico & Nussbaum, 2003; Fernandez et al., 1992; Imrhan, 1991). Therefore, it was decided in the current study that if the participant's maximum strength of chuck pinch or key pinch is lower than 4.5 kg (10 lb), the participant will be classified with the presence of hand impairment in strength.

Table 3.2: Maximum pinch strength of female populations measured in previous studies

Author (year)	Participants	Pinch type	Maximum pinch strength*
DiDomenico et al., 2003	Healthy females; 33.2 (11.4) yr; Seated	Key pinch Chuck pinch	Key pinch: 6.61 (1.79) Chuck pinch: 6.54 (1.42)
Fernandez et al. 1992	Healthy females; mean 21.5 yr; Seated	Key pinch Chuck pinch	Key pinch: 6.39 (0.65) Chuck pinch: 6.34 (1.11)
Kjeken et al., 2005	Female with hand OA; 62.7(5.4) yr; Seated	Chuck pinch	1.98 (1.07)

*Mean (Standard deviation); Unit: kg

- Observation of metacarpophalangeal joint hyperextension (MPH)

The presence of the hyperextension of a participant's first metacarpophalangeal joint was observed when performing MVE KP. If the metacarpophalangeal joint extension angle was over 180 degree and appeared as a concave shape, it was classified as the abnormality of hand anatomical integrity.

- Range of motion examination of thumb palmar abduction (ROM Thumb)

As shown in Figure 3.5, the ROM Thumb was measured by a goniometer. If a participant's maximum thumb palmar abduction was less than 30 degrees, the mobility of the hand was classified as abnormal.

Figure 3.5: Thumb palmar abduction (Smith et al., 1996)

3.3.1.2 Step 2 – Focus group event

In the second step, focus group events with identical process were conducted. Different participants were recruited for each group. Only the participants with the presence of hand disability based on the outcome of the hand function assessments in Step 1 and without apparent cognitive limitations were eligible to participate in the Step 2.

There were two sections included in the focus group activity. The first section involved evaluations of the new lid designs proposed by the investigators. The second section was a participatory design process in which participants could freely explore their ideal lid designs by using designated design tool kits. The details are described below. The focus group events were audio- and video- recorded for later data analysis.

- Section 1 – Evaluation of new lid designs

Forty-two prototype models of lids with two diameters (25 mm and 40 mm), two heights (10 mm and 15 mm), and thirteen shapes were evaluated. The new lid designs tested in the focus groups were developed based on two different sources. First, according to the lids found in stores, the lid sizes tested in the current study can include the majority of small and medium lids currently in the market (Figure 3.6). Second, based on the biomechanics model proposed by Seo et al. (2007) regarding the theoretical mechanism of how hands apply torque to an object (Figure 2.9 in Chapter 2), there were four ways that could facilitate the increase of the turning torque T : (1) increase the coefficient of friction μ , (2) apply higher grip force F_{ni} , (3) lengthen the moment arm r_i , or (4) increase the number of segments n that can contact the object. The proposed new lid design features that can possibly improve the hand performance of users are listed in Table 3.3.

Figure 3.6: Size distribution of the current lids found in stores. The four circles represent the lid sizes tested in Phase 1, e.g. two diameters (25 mm and 40 mm) and two heights (10 mm and 15 mm).

Table 3.3: New lid design features proposed in Phase 1

Ways to increase torque T	Corresponding new lid design characteristics
(1) Increase coefficient of friction μ	Because the material used for making lid models was wood, the evaluations of lid surface texture were not included in Phase 1.
(2) Apply higher grip force F_{mi}	<p>A lid design to which users could apply higher grip force might have compound design features. It could be because of (1) better lid shape that users feel more comfortable (because of less pain at finger joints), or (2) better lid size that older people with hand problems can grasp it well.</p> <p>[Side shape] Increase contact surface to enhance comfort levels</p> <div style="display: flex; justify-content: space-around; align-items: center;"> </div> <div style="display: flex; justify-content: space-around; align-items: center;"> Concave Cone Reverse cone </div>
(3) Lengthen the moment arm r_i	<p>[Size] Increase diameter – two diameters (25 mm and 40 mm)</p> <p>[Top Shape] Increase leverage -</p> <div style="display: flex; justify-content: space-around; align-items: center;"> </div> <p style="text-align: center;">(Alternative top shapes: generic shapes)</p>
(4) Increase the number of segments n	<p>[Size] Increase height – two heights (10 mm and 15 mm)</p> <p>[Side Shape] Increase contact segments on hand/fingers</p> <div style="display: flex; justify-content: center; align-items: center;"> </div> <p style="text-align: center;">Convex</p> <p>[Top Shape] Increase contact segments on hand/fingers</p> <div style="display: flex; justify-content: space-around; align-items: center;"> </div> <p style="text-align: center;">(Alternative top shapes: generic shapes)</p> <div style="display: flex; justify-content: space-around; align-items: center;"> </div> <p style="text-align: center;">(Alternative top shapes : two-layered shapes)</p>

All the prototype lid models were covered with gray color (e.g. neutral color) spray paint to avoid any subjective color preferences. Each model was glued to its corresponding jar or bottle and then weighted by sand according to the weight of matched food/drink products found in grocery stores, in order to simulate realistic jar opening tasks. The 42 lids were then randomly divided into three groups (14 lids in each). The groups of lids were discussed one at a time in the focus group to minimize the potential difficulty older people might have when recalling using short-term memory.

During the lid design evaluations, the participants were strongly encouraged to spend some time exploring the given lids before writing down their opinions on evaluation forms. The evaluation forms used here were similar to the ones in the Step 1, which included diameter (“Too small”, “OK”, or “Too large”), height (“Too short”, “OK”, or “Too high”), shape for turning (“Helpful” or “Not helpful”), shape for comfort (“Comfortable” or “Not comfortable”), and the overall 4-level preferences (“Hate it”, “Dislike it”, “Like it”, or “Love it”) (Appendix C). For each lid group, participants were asked to complete the evaluation forms individually first. After that, they were then interviewed as a group and were asked to talk about why they liked/disliked or loved/hated the lid designs. They did not need to come to an agreement in the discussions. During the activity, the participants were constantly encouraged to share different opinions from their personal aspects, particularly in relation to their hand use limitations and discomfort they may have.

- Section 2 – Participatory design process

The second section was to let participants design their own best lids. Taking the MakeTools® technique proposed in Sanders’ article (1999) as the core concept that can be applied in user experience studies, the aim of this section was to further access end-users’ unspoken feelings and ideas. By providing the participants proper tool kits, they could then make their own dream lids through a participatory design process.

The tool kits used in the section contained air-dry modeling clay, e.g. Crayola Model Magic®, clay modeling tool sets, and empty containers (Figure 3.7). The participants were instructed to work individually to create the “best” lid designs, particularly in relation to any hand use limitations or discomfort they may have, with favorite sizes, shapes or surface textures by adding the clay to the containers as caps and then shaping them.

(a) Air-dry modeling clay

(b) Clay modeling tool sets

(c) Empty containers

Figure 3.7: Design tool kits used in participatory design process in Phase 1

In order to stimulate the capacity of the participants to produce various levels of design ideas, they were asked to complete two design tasks one at a time: (1) Task 1 –

Incremental design ideas, and (2) Task 2 – Blue-sky design ideas. In task 1, the instruction “*The best lid design that you might see in the market within a couple of years*” was given. In the task 2, the instruction was “*Your craziest or blue-sky idea for a new lid. It could be any shape, any size, or any type of lids in the future*”. After the design workshop activity, each participant was then invited to present and explain the primary design concepts of her artifacts lids to the rest of group. They were instructed to pretend that they were selling their new ideas to a company who might be a likely future product seller.

3.3.2 Participants

3.3.2.1 Eligibility determination

Since the user needs of older people with hand use limitations was the focus of the study, a process to determine the eligibility of participants was applied (Figure 3.8). The recruitment of participants was conducted in the Central Ohio area. The initial eligibility criteria including being female, at least 65 years of age, and having difficulty in opening jars or bottles with twist-off lids.

Next, according to the testing results from the Step 1 – Hand function assessment, a weighted rating system was then applied as the methodology to determine the hand dysfunction levels for each participant. The subjects without any assessed hand dysfunction or with cognitive issues were not eligible to participate in the focus group events.

Figure 3.8: Participants' eligibility determination process in Phase 1

The details of the weighted rating system are shown in Table 3.4. Participants were determined to either be within (score of 0) or outside (score of 1) the limits of normal performance on each item. That 0 or 1 score was then multiplied by the weight contribution of the characteristic to the total assessment score from 0 to 10. The weight factor of most of the hand dysfunction characteristics was 1. However, since the “Self-reported presence of chronic pain”, “Strength” (which was divided into two parts: key pinch and chuck pinch), and “Anatomical integrity” had stronger associations with the performance of jar opening tasks, their given weight factors were designated to be doubled, that is 2. For example, if a participant’s PROMIS HAQ final score is 3, which is larger than 0.5 and will be defined as abnormal, the participant will get 1 (1 for abnormal times 1 for weight) weighted score in the item “Self-reported difficulties of ADL”. Similarly, if the participant’s MHQ Pain score is less than 4, its weighted score will be 2 (1 for abnormal times 2 for weight). Otherwise, it is 0. Therefore, the total score of 10 was defined as the worst hand function level; whereas 0 was defined as no hand problems.

Table 3.4: Weighted rating system of the hand function assessment method

Hand dysfunction characteristics	Assessment techniques	Defined as abnormal	Weight
Self-reported difficulties of ADL	PROMIS HAQ	> 0.5 points	<i>1</i>
Self-reported presence of chronic pain	MHQ Pain	< 4 points	<i>2</i>
Sensibility	MPUT (eyes closed section)	> 28 seconds	<i>1</i>
Dexterity	MPUT (eyes open section)	> 16 seconds	<i>1</i>
Strength	MVE KP	< 4.5 kg (10 lb)	<i>1</i>
	MVE CP	< 4.5 kg (10 lb)	<i>1</i>
Anatomical integrity	MPH (during key pinch)	Concave	<i>2</i>
Mobility	ROM Thumb	< 30 degree	<i>1</i>

3.3.2.2 *Sample size*

Thirty-seven participants from five different retirement facilities in and around Columbus, OH were recruited in the beginning of the study and 34 of them completed the research activities in Step 1 – Hand function assessment. After accounting for some dropouts and participants who decided not to participate in the focus group events due to time conflicts, twenty-six female participants were included in the focus group events (Step 2). Accordingly, eight focus groups were conducted.

The numbers of participants of both steps are described in Figure 3.9. It is worthy to address that no participants were dropped out because of their healthy hands.

Figure 3.9: Number of participants in Phase 1

3.3.3 Data analysis

The data collected in Phase 1 could be classified into two parts. The first part was the quantitative data about participants' subjective preference ratings when interacting with the current lid designs found in the market and the new lid designs proposed by the researchers. Since the distribution of their preference ratings was not normal, non-parametric statistical methods, e.g. Friedman two-way analysis and Wilcoxon signed-rank test, were applied to analyze which jar lid design characteristics were found to be significantly associated with participants' preference ratings.

The other part of the results was the lids proposed by participants through the participatory design process. These artifacts were treated as the expressed needs of users about their desirable lid designs. The re-occurring design features found in

participants' design artifacts were counted and qualitatively summarized.

As to the audio and video data recorded during group discussions and individual presentations, they were viewed as supplemental information when analyzing their expressed needs.

3.4 Results

3.4.1 Participant demographics

Twenty-six female participants who were over 65 years old and had hand problems were included in the focus group events in Step 2 (Figure 3.10). The mean of their ages was 84.8 years and the standard deviation was 4.96 years. They were living independently and were residents of various local retirement facilities in and around Columbus, OH. All of them had experienced difficulties opening jars and about 80% of the participants reported experiencing hand pain in the past month on a screening questionnaire. The demographics details of the participants are summarized in Table 3.4 (Appendix D).

Figure 3.10: Distribution of participants by age in the focus group events in Phase 1

Table 3.5: Demographic details about participants in Phase 1

Gender			
	Male	0 people	(0%)
	Female	26 people	(100%)
Age			
	Mean	84.8 years	
	SD	4.96 years	
Have hand pain in the past month (self-report)?			
	Yes	21 people	(80.8%)
	No	5 people	(19.2%)
Have difficulty opening jars (self-report)?			
	Yes	26 people	(100%)
	No	0 people	(0%)
Live independently (self-report)?			
	Yes	26 people	(100%)
	No	0 people	(0%)
Hand used opening jars (self-report)?			
	Right	23 people	(88.5%)
	Left	3 people	(11.5%)

3.4.2 Hand function assessment

The testing results of the hand function assessment techniques are summarized in Table 3.5. According to the cut-off points decided for defining the normality of hand function characteristics, most of the participants had difficulties on MPUT, which refers to the hand dysfunction in sensibility and dexterity. Conversely, when examining their hand mobility, only 1 participant had problems abducting her thumb over 30 degrees and reported having muscular dystrophy. In addition, if comparing the maximum strength of key pinch and chuck pinch given by the participants, their key pinch was significantly stronger (Paired-samples t-test, $p = 0.021$). This was different from the findings of previous studies, which indicated that for healthy people, the key pinch and chuck pinch were not significantly different in the neutral wrist position (DiDomenico & Nussbaum, 2003; Fernandez et al., 1992; Imrhan, 1991).

Table 3.6: Phase 1 participants' hand function assessments results

Hand dysfunction characteristics (Assessment technique)	Testing results		Abnormality determination	
	Mean	Standard deviation	Normal (# of ppl)	Dysfunctional (# of ppl)
Self-reported difficulties of ADL (<i>PROMIS HAQ</i>)	0.95	0.7	11	15
Self-reported presence of chronic pain (<i>MHQ Pain</i>)	3.85	0.89	12	14
Sensibility (<i>MPUT – eyes closed section</i>)	45.17 sec	17.63 sec	0	26
Dexterity (<i>MPUT – eyes open section</i>)	21.68 sec	8.37 sec	2	24
Strength (<i>MVE KP</i>)	4.12 kg (9.08 lb)	1.02 kg (2.26 lb)	10	16
Strength (<i>MVE CP</i>)	3.71 kg (8.17 lb)	1.34 kg (2.96 lb)	8	18
Anatomical integrity (<i>MPH during key pinch</i>)	Yes: 8 ppl	No: 18 ppl	18	8
Mobility (<i>ROM Thumb</i>) (degree)	< 30: 1 ppl	>=30: 25 ppl	25	1

The details of the testing results from each hand function assessment technique (Appendix E) are illustrated in Figure 3.11 to Figure 3.18.

Figure 3.11: Phase 1 participants' PROMIS HAQ scores

Figure 3.12: Phase 1 participants' MHQ Pain scores

Figure 3.13: Phase 1 participants' MPUT (eyes open session)

Figure 3.14: Phase 1 participants' MPUT (eyes closed session)

Figure 3.15: Phase 1 participants' maximum voluntary exertion of key pinch

Figure 3.16: Phase 1 participants' maximum voluntary exertion of chuck pinch

Figure 3.17: Phase 1 participants' occurrence of metacarpophalangeal joint hyperextension

Figure 3.18: Phase 1 participants' thumb palmar abduction's range of motion

According to the weighted rating system shown in Table 3.3, the distribution of the scores that represented the comprehensive hand dysfunction levels of the participants are shown in Figure 3.19. As expected, all 26 participants' scores were larger than 0. From the chart, it shows that the distribution of the scores of the 26 participants was a normal distribution (Kolmogorov-Smirnov Test, $p = 0.493$). The mean was 5.54, median was 5.50, and the standard deviation was 1.97.

Figure 3.19: Number of participants in Phase 1 by hand function assessment total weighted scores. Score 10 was defined as the worst hand function level; whereas 0 is defined as no hand problems.

3.4.3 Evaluation of current lid design

Figure 3.20, Figure 3.21 and Table 3.7 describes the evaluation results of the current lid designs ordered by preference ratings. The current lid designs were analyzed separately by diameter (e.g. “Small” and “Medium” lids) through Wilcoxon signed-rank test (Appendix F). The brackets in Figure 3.20 mean the preference ratings of the lids contained in the same bracket were not significantly different in Wilcoxon signed-rank test. For example, A7 was significantly different from all other small lids except A6, and B12 was significant different from the rest on the high end. Accordingly, the lids can be classified to four levels that are displayed with different filling colors and textures in Table 3.7 and Figure 3.21.

(a) Group "Small" (15 ~ 39mm in diameter)

(b) Group "Medium" (41~64mm in diameter)

Figure 3.20: Preference ratings of the current lids evaluated in Phase 1. The bar of each lid design is the mean of the preference rating given by the participants plus and minus one standard deviation. The brackets mean the lids' preference ratings were not significant different in Wilcoxon signed-rank test.

Table 3.7: Evaluation results of the current lid designs in Phase 1 ordered by identified preference level

Preference levels		Lids with the same preference levels in Statistics					
Highest
	<u>B12</u>

	<u>A1</u>	<u>A2</u>	<u>A3</u>	<u>A4</u>	<u>A5</u>	<u>A12</u>

	B1	B2	<u>B6</u>	<u>B7</u>	<u>B10</u>

	A8	<u>A9</u>	A10	A11

	B3	B9	B11				
Lowest
	A6	<u>A7</u>

	B4	B5	B8				

* The lids with underlined labels mean their surface finish is rough. Otherwise, it is smooth.

Figure 3.21: Distribution of the current lids evaluated in Phase 1 by size. A1-A12 represents the 12 lids in the group "Small" and B1-B12 represents the other 12 lids in the group "Medium". The lids with underlined labels mean their surface finish is rough. Otherwise, it is smooth surface. Different filling colors and textures mean their preference ratings are significantly different in Wilcoxon signed-rank test.

According to the analysis results, some trends were found. First, the lids with taller height and larger diameter were more desirable for participants. Second, the lids with rough texture were more preferred than those with smooth surface. In addition, the texture feature seemed to compensate for some disadvantages of the shorter and smaller lids.

3.4.4 Evaluation of new lid design

Forty-two new lid designs that were composed of two diameters (25 mm and 40 mm), two heights (10 mm and 15 mm), and thirteen shapes (Figure 3.22) were evaluated. The results of the new lid design evaluation are shown in Figure 3.23. The histogram describes the preference ratings for different lid designs.

Figure 3.22: Thirteen lid shapes (A~M) evaluated in Phase 1

(a) Group "Small" (25mm diameter lids)

(b) Group "Medium" (40mm diameter lids)

Figure 3.23: Preference ratings of the new lid designs evaluated in Phase 1. S1-S21 represents the 21 small size lids (25 mm in diameters) and M1-M21 represents the 21 medium size lids (40 mm in diameter). The bar of each lid design is the mean of the preference ratings given by the participants plus and minus one standard deviation. "Short" and "Tall" refer to two heights of lids, e.g. 10 mm or 15 mm. The alphabet letters A-M represent 13 different lid shapes.

The statistical comparisons of the preference ratings between the lid designs were completed (Appendix G). First, the preference ratings of the lid designs were compared based on diameters (Figure 3.24). It was found that for seven (lids 2,5,6,8,9,16, and 17) of the twelve shorter lids (lids 1-9 and 15-17), the participants preferred the lids with larger diameters. However, this diameter preference was only seen for two of the nine taller lids (lids 10-14 and 18-21), these were the circular and reverse-cone shape lids (lids 13 and 19, respectively).

* $p < 0.05$, the preference ratings are significantly different based on Wilcoxon signed-rank test

Figure 3.24: Preference ratings of new lid designs compared by diameter. The bar of each lid design is the mean of the preference ratings given by the participants plus and minus one standard deviation.

The comparisons of the new lid designs by different top shapes, side shapes, and heights are illustrated from Figure 3.25 to Figure 3.29. The bar of each lid design is the mean of the preference ratings given by the participants plus and minus one standard deviation. A couple of trends in their preferences were identified. First, it was found

that the participants were more sensitive to the changes of the lid designs that had a smaller diameter or shorter height. Second, the participants tended to like the taller lids more than the shorter ones, especially for the lids with smaller diameters. Third, among the alternative top shapes, the hexagon shape lid got significantly higher ratings than the octagon one, but this statement was only true in the group of short-medium lids. Otherwise, the preference ratings of the four alternative top shapes were the same. Fourth, the circular shape lid, e.g. the most common lid design in the market, was the least preferred design among all the tested top shapes. However, for the circular shape lid with a larger diameter and a taller height, its preference rating was not significantly different from any other top shape lids. Last, among all the alternative side shapes, only the preference ratings of convex shape lids were changed with lid heights.

Figure 3.25: Preference ratings of new lid designs with two-layered shapes.

*: $p < 0.05$; +: $p < 0.01$; x: $p < 0.005$; the preference ratings were significantly different in Wilcoxon signed-rank test

Figure 3.26: Preference ratings of new lid designs with alternative top shapes grouped by height

(a) 25mm diameter lids

(b) 40mm diameter lids

*: $p < 0.05$; +: $p < 0.01$; x: $p < 0.005$; the preference ratings were significantly different in Wilcoxon signed-rank test

Figure 3.27: Preference ratings of new lid designs with alternative top shapes compared by height

*: $p < 0.05$; +: $p < 0.01$; x: $p < 0.005$; the preference ratings were significantly different in Wilcoxon signed-rank test

Figure 3.28: Preference ratings of new lid designs with alternative side shapes grouped by height

(a) 25mm diameter lids

(b) 40mm diameter lids

* $p < 0.05$, the preference ratings are significantly different based on Wilcoxon signed-rank test

Figure 3.29: Preference ratings of new lid designs with alternative side shapes compared by height

Overall, the more favored designs for the smaller lids were the ones with a tall height, non-circular top shapes, or a concave side shape; whereas for the larger lids, all the designs with a tall height were preferred, regardless their top shapes or side shapes (except the ones with a reverse-cone side shape). The least preferred design for both smaller and larger lids was the traditional circular shape lid with a short height.

3.4.5 Comparison between hand-dysfunctional and healthier groups

Lids were also compared based on dividing the participants into two groups, according to the extent of their hand dysfunction. The criterion of classifying the participants was based on their hand function assessment total weighted scores. As indicated in Figure 3.30, the cut-off point was set in 5.5 (e.g. the median). It meant that for the participants whose hand function assessment total weighted scores were over 5.5, they were categorized into the hand-dysfunctional group, otherwise, the hand-healthier group.

Figure 3.30: Criterion of classifying hand-dysfunctional and hand-healthier participants in Phase 1

The preference ratings of the new lid designs evaluated by the two groups are compared in Figure 3.31 based on Wilcoxon signed-rank test (Appendix H). According to the charts, first, there were more divergences between the participant groups when evaluating the smaller diameter lids – the preference ratings of nine of the 21 lid designs were significantly different (the ratings from the hand-dysfunctional participants were all lower), whereas only two lid designs’ ratings were different for the medium diameter lids. In other words, it could be concluded that the participants in the hand-dysfunctional group seemed to be more sensitive to the change of lid diameters. Second, the two-layered lids with smaller diameter were more disfavored for the hand-dysfunctional participants. However, for most of the two-layered lids with medium diameter (except C), the preference ratings between the two participant groups were the same based on Wilcoxon signed-rank test. Third, it seemed that the participants with more severe hand problems had a stronger negative experience with the traditional circular shape lids. Last but not the least, as to the side shapes, the medium-tall lid with convex side shape

was one of the favorites for the participants in the hand-dysfunctional group.

* $p < 0.05$, the preference ratings are significantly different in Statistics

Figure 3.31: Preference ratings of lid designs compared between hand-dysfunctional and hand-healthier groups. S1-S21 represents the 21 small size lids (25 mm in diameters) and M1-M21 represents the other 21 medium size lids (40 mm in diameter). "Short" and "Tall" mean 2 heights of lids, e.g. 10 mm or 15 mm. The alphabet letters A-M represent 13 different lid shapes. The two bars of each lid design are the means of the preference ratings given by the hand-dysfunctional and hand-healthier groups. The cells with dark filling color (or having a star sign) mean the lids' preference ratings given by the two groups are significantly different based on Wilcoxon signed-rank test.

3.4.6 Participatory design process

Thirty-six designs were generated by the participants from the MakeTools® session. These were collected and analyzed qualitatively in order to identify common or unique design features. By reviewing the contents of presentations made by the participants along with their design artifacts, the found design features were treated as alternative forms through which participants expressed their latent needs about desirable lid designs, which they may not have been able to express in words. The analysis of the design artifacts is detailed in Table 3.8 below.

Table 3.8: Analysis of participants' design artifacts collected from participatory design process in Phase 1

Lid #	Design artifacts	Add texture	Increase leverage	Increase contact surface (shape)	Increase contact surface (height)	Facilitate other grip types	Additional features indicated by subjects
1		X	X	X	X		Modified from M5 (square)
2		X	X	X	X		Modified from M6 (triangle)
3		X			X		
4		X			X		Modified from S14 (circular)
5		X		X			Modified from M21 (concave side shape)
6		X	X		X		Modified from S13 (octagon)
7			X		X		Large ridges

(Table 3.8 continued on the next page)

(Table 3.8 continued from the previous page)

Lid #	Design artifacts	Add texture	Increase leverage	Increase contact surface (shape)	Increase contact surface (height)	Facilitate other grip types	Additional features indicated by subjects
8		X	X		X		Modified from S5 (square)
9			X	X	X		
10		X	X		X		Square top shape
11		X		X	X		Cone side shape
12			X				
13				X	X	X	Use power grip
14					X	X	Use key pinch

(Table 3.8 continued on the next page)

(Table 3.8 continued from the previous page)

Lid #	Design artifacts	Add texture	Increase leverage	Increase contact surface (shape)	Increase contact surface (height)	Facilitate other grip types	Additional features indicated by subjects
15				X	X		Ball shape
16		X		X			Modified from M20 (convex side shape)
17			X		X		Modified from S5 (square)
18		X	X		X		Modified from M10 (square)
19		X	X		X		Modified from M13 (octagon)
20		X		X			Cone side shape
21		X	X		X		Octagon top shape
22			X			X	Use key pinch

(Table 3.8 continued from the previous page)

Lid #	Design artifacts	Add texture	Increase leverage	Increase contact surface (shape)	Increase contact surface (height)	Facilitate other grip types	Additional features indicated by subjects
23		X		X			
24			X				Faucet-like lid
25			X	X		X	Bar shape, use power grip
26		X	X		X		Indentation + Texture
27			X		X		Indentation
28			X	X		X	
29		X	X				Modified from M7 (hexagon)

(Table 3.8 continued on the next page)

(Table 3.8 continued from the previous page)

Lid #	Design artifacts	Add texture	Increase leverage	Increase contact surface (shape)	Increase contact surface (height)	Facilitate other grip types	Additional features indicated by subjects
30		X		X			Modified from S21 (concave side shape)
31		X			X	X	Use power grip
32		X		X			Convex side shape
33			X		X	X	Can use 2 grip types + indentation
34		X			X		
35			X		X		
36			X				

The re-occurring design features found in the participants' design artifacts or mentioned in their presentations were counted and qualitatively summarized. As listed in Table 3.9, four primary design features were found and were consistent with the characteristics identified by Seo et al. (2007). They were (1) add texture onto lid surface, (2) increase leverages by changing lid top shapes or diameters, (3) increase contact segments or surface area with palm/fingers by redesigning the lid side shapes or heights, and (4) propose brand new lid designs to facilitate alternative grip types. After counting the numbers of the re-occurring design features, both "Increase leverage" and "Increase contact surface with palm/finger by changing lid heights" can be found in 61% of all the 36 design artifacts, followed by "Add surface texture" (58%), "Increase contact surface with palm/finger by changing lid shapes" (39%), and "Facilitate alternative grip types" (19%).

Table 3.9: User needs expressed through the participatory design process in Phase 1

Expressed needs	Found in participants' design artifacts (Lid #)
(1) Add surface texture	1, 2, 3, 4, 5, 6, 8, 10, 11, 16, 18, 19, 20, 21, 23, 26, 29, 30, 31, 32, 34 (21 lids; 58%)
(2) Increase leverage by changing lid top shapes or diameters	1, 2, 6, 7, 8, 9, 10, 12, 17, 18, 19, 21, 22, 24, 25, 26, 27, 28, 29, 33, 35, 36 (22 lids; 61%)
(3a) Increase contact segments or surface with palm/fingers by changing lid side shapes	1, 2, 5, 9, 11, 13, 15, 16, 20, 23, 25, 28, 30, 32 (14 lids; 39%)
(3b) Increase contact segments or surface with palm/fingers by changing lid heights	1, 3, 4, 6, 7, 8, 9, 10, 11, 13, 14, 15, 17, 18, 19, 21, 26, 27, 31, 33, 34, 35 (22 lids, 61%)
(4) Facilitate alternative grip types	13, 14, 22, 25, 28, 31, 33 (7 lids; 19%)

3.5 Discussion

The aim of the study was to preliminarily explore, in broader range, the potential design solutions for better lid designs. Twenty-six older females who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation were included in the study. The study applied Ergonomics and product design research methodologies, including questionnaires, focus groups, and a participatory design process, to explore the different levels of user experience when the older people with hand problems interact with various jar lid designs. Accordingly, twenty-four current lid designs found in the market and forty-two new lid designs proposed by the researcher, which were composed of two diameters (25 mm and 40 mm), two heights (10 mm and 15 mm), and thirteen shapes, were evaluated. In addition, a participatory product design process was applied to access the participants' unspoken feelings and ideas about their desirable lid designs. Their expressed user preferences and needs regarding the current and new lid design features could further provide future research directions for the latter phase of the study.

3.5.1 Hand function assessment method

The hand function assessment method used in the study integrated both published self-reported instruments and short duration hand tests to comprehensively examine the participants' hand function from several perspectives. The researcher received training

for conducting the assessment methods prior to the use in the study. The practical benefits of this were that the testing was conducted at locations convenient to the participants (their own residential retirement facilities) and the time required of them was limited to at most 30 minutes, which include the informed consent process, explanation, and testing.

As for the weighted rating system applied to quantitatively interpret the testing results of hand function assessments, to our best knowledge, the relevant examinations regarding the sensitivity and specificity are still limited for the individual components of the assessment, and no validation of the combined method was performed. However, it demonstrated the concept that the weighted rating system of a comprehensive hand function assessment could be customized and adapted according to different application purposes. Taking the current jar lid design study as an example, the hand strength, joint anatomical integrity, and the presence of hand pain were designated to have heavier weights since they have stronger associations with the performance of jar opening tasks. Nevertheless, if a study's focus is the design of a product interface that needs accurate operations and controls, the testing results of hand characteristics "dexterity" and "sensibility" could have stronger influences on the final weighted score.

According to the testing results of the hand function assessment method MPUT, almost all the participants were categorized as having dysfunction on dexterity (24 out of 26) and sensibility (26 out of 26) (Table 3.5). Despite the extreme trends, it might truly reflect the real hand conditions of older female populations who have had hand problems. According to Amirjani's study (2007), they examined the effects of age, gender, and handedness on the MPUT. As concluded, for the older females (at least 60 years of age)

with their dominant hands, the median values of MPUT eyes-open and eyes-close sessions were 16.0 and 27.8 seconds (Table 2.1), respectively; whereas the testing results of the current study were 18.24 (mean = 21.68, standard deviation = 8.37) and 38.58 (mean = 45.17, standard deviation = 17.63) seconds. It should be noted that the subjects recruited in Amirjani's research were all healthy without any hand problems, which may account for differences in performance results between participants in that study and the current study. Accordingly, those who had (1) sensory or motor complaints, (2) hand deformities, (3) movement disorders such as Parkinson's disease, (4) neuropathies, (5) hypothyroidism and diabetes, or (6) arthritis, neurologic diseases, and neurologic sequelae, were all excluded (Amirjani et al., 2007). The current study explored, at a macro level, jar lid preferences of older females with hand problems based on their hand function status. Future studies may further explore explicitly how each of the hand disorders listed above can affect the levels of deterioration in hand dexterity and sensibility.

3.5.2 Lid design evaluation method

The lid design evaluation method used in the study was developed to document the subjective preference ratings of older people for not only the current lids found in the market, but also some new lid design concepts proposed by the researchers. The primary advantage of the preference rating method used in this study was that it was usable by older people; they found it quick, easy, and understandable to use. It was

found that only one out of the 34 participants had difficulty completing the lid design evaluation activity in Step 1 within the set period of time (e.g. complete the evaluations of 24 current lid designs in 30 minutes).

The rating method had a high degree of content validity, in that it evaluated several aspects and features of jar lid design and the user's interaction with the lids. The rating method was pilot tested prior to its use in the study. The rating method's reliability was, however, not assessed, and that is a limitation of the study. However, it should be noted that despite this limitation, when compared with the conclusions of previous lid design studies within controlled laboratory settings, the trends of the findings were consistent (Table 3.10). The patterns of the preference ratings (e.g. dependent variable of the current study) and MVTs (e.g. dependent variable of previous studies in laboratory settings) that were associated with the main effects of lid design characteristics, for example diameter, height, and shape, were generally in agreement.

Table 3.10: Testing results of current and previous lid design studies

Author (yr)	Participants	Dependent variables	Independent variables	Primary findings relevant to the current study
Imrhan and Loo (1988)	Older (65+); Male + Female; Capable of using preferred hand for grasping and turning lids	Grip force MVT	(1) Four diameters: <i>31, 55, 74, 113 mm</i> (2) Two textures: <i>Rough, Smooth</i>	(1) Torque levels were monotonically increasing with lid diameters before 75mm (2) Grip forces and torques were not significantly different in 31-74 mm diameter lids for rough and smooth lids
Crawford et al. (2002)	Young (22-39); Older (60+); Male + Female; No medical history of joint problems in fingers/wrists; No current symptoms of joint problems	MVT	(1) Three diameters: <i>20, 50, 80 mm</i> ; (2) Three heights: <i>10, 20, 30 mm</i> (3) Two top shapes: <i>Circular, Square</i>	(1) Only for the 20 and 50 mm diameter pieces, torque levels were increasing with diameter and height, but no interaction between them was found (2) Torque levels were larger with square lids compared to circular lids
Current study (Phase 1)	Older (65+); Female only; Have hand pain and difficulties in opening jar lids	Four-level Preference ratings by survey	(1) Two diameters: <i>25, 40 mm</i> (2) Two heights: <i>10, 15 mm</i> (3) Nine top shapes: <i>Four two-layered shapes, Triangle, Circular, Square, Hexagon, Octangle</i> (4) Five side shapes: <i>Cylinder, Convex, Concave, Cone, Reverse cone</i>	(1) Prefer taller lids than the shorter ones, especially for the 25 mm diameter lids (2) Lids with alternative top shapes were generally more preferred than circular ones. However, for the circular shape lid with larger diameter (40 mm) and taller height (15 mm), no significant difference was found if compared with other top shape ones (3) For most of the 10 mm height lids, the participants preferred the lids with larger diameters. However, this diameter preference was not significant in the group of 15 mm height lids except the ones with circular and reverse-cone shapes. (4) Ratings for the lids with alternative side shapes were not changed with lid heights, except convex shape ones

3.5.3 Study limitations

By design, only older females were recruited for the study. This could be viewed as a limitation. However, there were two reasons for this choice of subjects. First, according to Dahaghin's study in 2005 (Dahaghin et al., 2005a; Dahaghin et al., 2005b), the female gender has been identified as one of the highest explained determinants of hand disability in an older population, in addition to aging, rheumatoid arthritis, stroke, and hand pain. Second, since females have been shown to have lower hand pain threshold (referring to the pain caused by contact stress)(Buchanan & Midgley, 1987), they were expected to be more sensitive to the various characteristics of jar lid designs. Future studies should include other groups of users to see if the same lid characteristic could also be favored by them.

Another limitation was the potential selection bias that may have been inherent in the participant recruitment process. It is possible that older people with severe hand problems would not volunteer for the study; they might be reluctant to expose their hands to any additional use. For that reason, the distribution of hand dysfunction level found in the study represents the study participants and may underestimate the population of over age 65 females who are living independently in the community.

The third limitation was that because of the constraints of resource and time, only a part of current and new lid designs was evaluated. The selection of the lid designs tested in the study was based on three criteria: (1) Less than 65 mm in diameter, (2)

Representative of the most common designs currently in the market, and (3) Generic shapes, e.g. square, hexagonal, cone, convex, etc. Further studies would be able to expand the current knowledge base by including more types of lid designs in the future.

The last limitation of the study was that in addition to the main effects, how the interactions between the lid design characteristics, for example height and side shape together, can affect the usability of lids was still unclear. More studies would be necessary to systematically examine not only the main effect of each lid design characteristic, but also the interactions between them by the means of controlled laboratory testing.

3.6 Conclusion

There is a research void in understanding the relationship between product interface design characteristics and hand dysfunction levels in older populations, which this study began to address. Taking jar lids as the example of the product interface as the focus of this study, the study applied Ergonomics and product design research methodologies in concert, including questionnaires, focus groups, and a participatory design process, to explore the different levels of user experience when the older people with hand problems interact with various jar lid designs. In addition, a comprehensive hand dysfunction assessment method was proposed and used as the means to explain inclusively the older people's resulting hand dysfunction from different functional aspects.

The current lid designs found in the market and the new lid designs proposed by the

researcher that could possibly improve users' hand performance were assessed.

According to the evaluation results, some trends were identified: (1) the participants were more sensitive to the changes of the lid designs that have a smaller diameter; (2) the participants preferred the taller lids more than the shorter ones, especially for the lids with smaller diameters; (3) for most of the shorter lids, the participants would prefer the ones with larger diameter. However, this diameter preference was not significant in the group of taller lids, except for the circular and reverse-cone shape ones; (4) the preference rating of the traditional circular shape lid was mostly worse than any other top shapes, unless they have larger diameters and taller heights; (5) the preference ratings of the new lid designs that have alternative side shapes were not changed with lid height, except the convex shape ones; (6) the texture feature seemed to compensate for certain levels of disadvantages associated with shorter and smaller circular shape lids.

In addition, there were four users' latent needs expressed through the participatory design process and which were consistent with the characteristics identified by Seo et al. (2007). They were (1) add texture onto lid surface, (2) enlarge leverages by changing lid shapes or diameters, (3) increase contact segments or surface area with palm/fingers by redesigning lid side shapes or heights, and (4) propose brand new lid designs to facilitate alternative grip types.

The study was the first phase of a larger research project addressing several outstanding questions concerning product interface design. The role was to search, in macro view, the potential solutions of better lid designs. Future studies would be required to systematically examine the research findings through controlled experimental testing.

CHAPTER 4

4 PHASE 2: EVALUATION – EVALUATING PRODUCT INTERFACE DESIGN CHARACTERISTICS THROUGH CONTROLLED EXPERIMENTAL TESTS

4.1 Introduction

There have been many studies focusing on investigating Human Factors knowledge for product interface design. Most of them were interested in exploring the association between interface design characteristics and the corresponding performance of users.

Langley et al. (2005) proposed the term “Openability”, e.g. *“how easy it is for the consumer to access a product”*, when discussing human strength capabilities in packaging design research. Opening a new jar or bottle has been determined as one of the most difficult ADLs for older populations, especially for those who have hand problems (Bellamy et al., 2002a; Voorbij & Steenbekkers, 2002; Yoxall et al., 2006). Some studies have been conducted in laboratory settings to examine how users’ physical performance can be associated with different jar lid design characteristics, e.g. size, surface texture, and shape.

Yoxall et al. (2006) examined the MVT of 235 subjects of different ages (8-95 yrs) when turning a 75 mm diameter jar lid. They pointed out that the MVT of 75 year-old

females was found to be below 320 Ncm, which was the mean of the opening torques measured from several 75 mm jars of various products found in UK. They also found that an average 85 year-old woman can open only 15% of the current 75 mm diameter jars. Crawford et al. (2002) found that the lid diameter, height, and shape were associated with the MVT that healthy people can apply. They pointed out that the torque levels were larger with square lids compared to traditional circular lids. Imrhan and Loo (1988) investigated the MVTs and grip strength of elderly subjects when opening rough and smooth circular lids of four different diameters, e.g. 31, 55, 74, and 113 mm. They pointed out that for smooth surface lids, the 74 mm diameter lid would be optimal for older people to produce torques. However, on the other hand, the torques produced from turning the rough texture lids were monotonically increasing along with the diameter. Therefore, according to the previous studies, it can be concluded that not only the main effects of those lid design characteristics, but also some interactions exist between the characteristics that could be associated with users' hand performance when opening a lid.

Although the special needs and difficulties of older people have been addressed in most of the prior jar lid design studies, when investigating jar lid design characteristics, prior research has focused on healthy study participants. To our best knowledge, no prior published research specifically studied older people who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation. Even when including older study participants, the number and interaction of jar lid design characteristics explored in previous studies was limited. There is still a research void in comprehensively exploring how all the lid design

characteristics together, e.g. the major effects of the design characteristics and the interactions between them, can affect the usability levels of jar or bottle lids.

Therefore, by the means of controlled laboratory testing, a subjective evaluation process was applied in the current study to quantitatively examine the effects of lid design characteristics on a user's perceptions of effort and discomfort. Similar to Phase 1, the population of interest for Phase 2 consisted of females who were over 65 years of age and had hand problems. The main effect of each lid design characteristic and the interactions between them were explored.

4.2 Goal

Phase 2 could be defined as the design concept evaluation phase of this product interface research study. The primary goal was to evaluate the new lid design concepts initially explored in Phase 1, through controlled experimental tests. In accordance, the associations between jar lid design characteristics and older people's perceptions of effort and discomfort when using the test lids were systematically investigated.

Therefore, the necessary research activities of Phase 2 included –

- (1) Propose a subjective evaluation process for older people with hand dysfunctions to quantitatively examine the usability levels of different lid designs
- (2) Examine the main effect of jar lid design characteristics and the interactions between them in terms of the influences on a user's perceptions of effort and

discomfort

- (3) Determine whether older people with and without severe hand dysfunctions could both derive benefits from new lid designs

4.3 Methods

4.3.1 Design of experiment

A controlled experiment was conducted to systematically examine how the various lid design characteristics could be associated with the usability levels of product interfaces, e.g. jar lids. When reviewing the research methods of prior jar lid design studies, it was found that most of them used participants' resulting MVTs as the indicator to examine the usability levels of lid designs (Crawford et al., 2002; Imrhan & Loo, 1988; Voorbij & Steenbekkers, 2002; Yoxall et al., 2006). In contrast to these previous studies, a subjective evaluation process was employed in the current study. Instead of using participants' MVTs, the usability levels of different lid designs were examined subjectively by participants through their perceived ratings of effort and discomfort.

The concept of this usability testing method is illustrated in Figure 4.1. The subjective evaluation process required subjects to perform only two or three repetitions of their MVT at the very beginning of the experiment, while the remaining exertions were all sub-maximums. There were two reasons why this subjective evaluation process was more viable than the MVT-testing protocol used by previous studies. First, the participants in the current study were older adults age 65 years old and above who had

hand problems. Therefore, asking these participants to provide their MVTs repetitively within a short period of time was very likely to cause significant hand pain or discomfort. Second, there were 32 testing conditions (e.g. combinations of two diameters, two heights, two top shapes, two side shapes, and two surface textures) included in the study. If the experiments were conducted with the MVT-testing protocol, significant fatigue effects would be confounded in the results.

Figure 4.1: Comparison of lid design evaluation process between previous and current studies

4.3.1.1 Independent variables

There were 32 lid designs tested in the study. The tested prototype models were made by a 3D CAD system and composed of five lid design characteristics: diameter, height, texture surface, top shape, and side shape, and each has two levels (Table 4.1).

The selections of lid shapes and surface texture tested in the study were based on the testing results in Phase 1. As to sizes, the testing lids were (1) 28 mm and 42 mm in diameter, and (2) 9 mm and 17 mm in height, which represented smaller and medium sizes of common beverage bottles, water bottles, and sauce/dressing containers currently in the market. The lids with larger diameters were excluded, because, as indicated in Phase 1, it was assumed that large-portioned food products will be less and less commonly used by older people since most of them will live alone when living independently.

Table 4.1: Lid design characteristics tested in Phase 2

Lid design characteristics	Two levels	
Diameters (d)	[Small] (28 mm)	[Medium] (42 mm)
Heights (h)	[Short] (9 mm)	[Tall] (17 mm)
Top shape

[Circular]	[Hexagonal]
Side shape

[Flat]	[Convex]
Surface texture of sides

[Smooth]	[Serrate]

4.3.1.2 Dependent variables:

The dependent variables were the levels of perceived effort and discomfort. The perceived effort levels were verbally reported by participants according to the Borg CR10 Scale (Borg, 1998)(Figure 4.2) from 0 to 10, where 0 means “*nothing at all*” and 10 means “*extremely strong (almost maximal)*” or “*maximal*”, when performing jar opening tasks with given lid designs. The discomfort ratings were based on a 5-level scale – “Not uncomfortable”, “Somewhat uncomfortable”, “Pretty uncomfortable”, “Very uncomfortable”, and “Painful”.

0	Nothing at all
0.5	Extremely easy (just noticeable)
1	Very easy
2	Easy (light)
3	Moderate
4	Somewhat difficult
5	Difficult
6	
7	Very difficult
8	
9	
10	Extremely difficult (almost maximal)
*	Maximal

Figure 4.2: Borg CR10 Scale (modified from Borg, 1998)

4.3.1.3 Subjective evaluation process

The subjective evaluation process was divided into two stages (Figure 4.3). The instruments necessary for the experimentation and the set-up are shown in Figure 4.4 and

Figure 4.5. As illustrated, a tested lid was mounted on a bottle held in a closure torque sensor (STBA50, MARK-10, Copiague, NY; Capacity: 570 Ncm; Resolution: 0.5 Ncm) prior to the evaluation process. In the Stage 1, participants were instructed to apply a twisting force to turn the lid with an applied torque that matched the target torque displayed on the screen of an oscilloscope (2245A, Tektronix, Beaverton, OR). The target torque for each participant was defined as a proportion of the participant's MVT measured in the beginning of Phase 2.

The wrist twisting during the tests was an isometric exertion. The more torque the subject applied to the lid, the farther the dashed line on the oscilloscope display, which represented the applied torque, moved upward. The participants were asked to hold the applied torque for four seconds.

Figure 4.3: Subjective evaluation process in Phase 2

(a) Digital torque gauge
(BGI, MARK-10, Copiague, NY)

(b) Closure torque sensor
(STBA50, MARK-10, Copiague, NY)
(Capacity: 570 Ncm; Resolution: 0.5 Ncm)

(c) Lid on torque sensor

(d) Oscilloscope
(2245A, Tektronix, Beaverton, OR)

(e) Screen of oscilloscope covered by a
transparency card with thin color tapes
(which represent target torques)

Figure 4.4: Experimentation instruments used in Phase 2

Figure 4.5: Set-up of instruments in Phase 2

After the four-second exertion, the subject was asked to rate her levels of effort and her discomfort while applying torque to the lid she just experienced. The first question, “*According to the scale, how difficult was it for you when turning the lid?*”, was given in order to document the participants’ perceived effort quantitatively when applying torque to the given lid design. Next, the second question, “*How uncomfortable did your hand feel?*”, was asked to explore discomfort. While asking the questions, the researcher also pointed to the corresponding scale boards with his finger simultaneously to provide visual indications to the participants which rating scale was being used.

4.3.1.4 Experimental design

In order to minimize the fatigue and discomfort associated with hand conditions of older participants, a complete block design was adopted in the study and the lid diameter was defined as the block factor (e.g. two blocks), which allowed for testing the blocks on two different days. In each block, sixteen lid designs that were composed of two top shapes, two side shapes, two heights, and two surface textures were tested (Table 4.2).

Table 4.2: Complete block design for lid design evaluations in Phase 2

Block #	Lid design characteristics	# of testing conditions
Block 1 – Small diameter lids	2 heights, 2 textures, 2 top shapes, and 2 side shapes	16
Block 2 – Medium diameter lids	2 heights, 2 textures, 2 top shapes, and 2 side shapes	16

It should be noted that in the complete block design, the target torques used for testing

small (28 mm) and medium (42 mm) diameter lids were different. For each participant, the target torque used in each block of tests was based on the participant's MVT when turning a prototype model of a current jar lid design matched in diameter. The design characteristics of the prototype models are described in Table 4.3.

Table 4.3: Design characteristics of prototype models for MVT testing in Phase 2

Block #	Design characteristics of the prototypes for MVT testing
Block 1 – Small diameter lids (28 mm in diameter)	28 mm in diameter, 17 mm in height, Circular top shape, Flat side shape, and Smooth surface texture
Block 2 – Medium diameter lids (42 mm in diameter)	42 mm in diameter, 17 mm in height, Circular top shape, Flat side shape, and Smooth surface texture

4.3.1.5 Testing Protocol

All the lid-twisting exertions were performed by the participant's dominant hand when seated. As shown in Figure 4.5, the height of the testing lids was adjusted according to the participant's elbow height prior to the research activities. The participants were required to sit comfortably upright with their feet on the floor, shoulder adducted, elbow flexed at about 90 degree, forearm pronated, and wrist in a neutral position. No specific lid grasp type was suggested during the experiments. The participants were encouraged to position each lid (along with the bottle) in the torque sensor by themselves, especially for the non-circular shaped lids, so that it felt most comfortable for their hands as they applied a twisting force to the lid.

The testing order of the 16 lid designs within each block was randomized. All the lids within a block were tested in the same test session, for a given subject. The lids

were made from the same plastic material with the same color (white) and were glued to identical bottles to minimize any subjective appearance preferences. In addition, the testing order of the two testing blocks between participants was randomized, as well.

Participants were tested one at a time. The research protocol was pilot tested and a few amendments were made (see details in Chapter 4.5 Discussion). The flow chart of the current research protocol per participant's test session is illustrated in Figure 4.6 (one block of lids per test session). First, the participant's MVT was tested in order to determine the target torques, which were proportional to the measured MVT, required for the later activities of lid design evaluations. During the MVT measurement, the participant was specifically instructed to ramp up to her peak capacity, sustain the effort for a brief time, and then gradually ramp down. No verbal encouragement was given during the tests. In addition, 2-minute breaks were allowed between at most three trials – if the first two trials were within 10% of each, the third one was not collected. Out of the two or three consecutive measurements, the maximum reading was defined as the individual's MVT.

Figure 4.6: Research protocol of Phase 2

Next, two levels of target torques, e.g. “Medium” (50% of MVT) and “High” (70% of MVT), were calculated. A customized transparency card that fit the oscilloscope’s screen was made and marked with three horizontal lines: (1) a baseline, which represented zero Ncm of applied torque, and (2) two target lines, which represent “Medium” target torque (white tape) and “High” target torque (red tape) (Figure 4.4 (e)). The distances between the baseline and the two target lines were calculated according to the pre-determined “shift distance per torque” ratio, for example 0.5 mm per Ncm. For example, if the target torques are 100 Ncm (“Medium”) and 140 Ncm (“High”), then the locations of the white and red tapes will be 50 mm and 70 mm from the baseline, respectively. So when participants were instructed to match an applied torque to the target torque with a lid, the instruction would be as simple as *“Lifting the flashing line to the red line (or white line) by twisting the lid”*

After the MVT was determined, participants were given a chance to practice with the subjective evaluation process to let them become comfortable with the usability testing method. After that, the participants were asked to apply torques twice to each testing lid. The first was a Trial phase, wherein they applied the “Medium” target torque, to tryout a proposed lid design. The second was an Evaluation phase, wherein they applied the “High” target torque, for the real usability testing.

In order to minimize fatigue, a 30-second break was given between torque exertions. The participants were encouraged to request more rest if any symptoms of fatigue were felt at any point during the experiment. The anthropometric data of participants’ dominant hands, including the hand breadth, hand length, finger breadth, and finger

length were measured during the breaks.

4.3.2 Participants

4.3.2.1 Eligibility determination

The subject recruitment was conducted in the Central Ohio area. The initial eligibility criteria included being female, at least 65 years of age, and having had difficulty in opening jars or bottles with twist-off lids. The hand function assessment used in Phase 1 was applied as the means to determine the hand dysfunction levels for each participant. Individuals without any assessed hand dysfunction or with cognitive issues were not eligible to participate in the current experimentation.

4.3.2.2 Sample size

The opportunity to participate in this second phase of the research was made known to the subjects who participated in Phase 1 previously and several of them volunteered for Phase 2. In total, nineteen female subjects who completed the hand function assessment in Phase 1 participated in Phase 2. They were capable of living independently at the time of participation and according to their hand function assessment results, all participants' scores were larger than 0, which means at least one hand function characteristic was outside the limit of normal performance.

However, according to the measurement results, not all the participants' data were included in the later data analysis process. It was found that the MVTs of one of the participants (e.g. 56 Ncm and 15 Ncm when turning 42 mm and 28 mm diameter lids, respectively) were less than the group mean (155 Ncm for 42 mm lids; 72.05 Ncm for 28 mm lids) minus two standard deviations (48.34 Ncm for 42 mm lids; 22.09 Ncm for 28 mm lids). In addition, the perceived difficulty ratings given by this participant when testing various lid designs were significantly lower than ratings of the other participants. For example, her ratings of smaller lids were all between 1 and 4 and the mean was 2.75, which was significantly below ratings for the rest of the group, which ranged from 3.11 to 5.47 with a mean of 4.2. It was possible that the participant did not give us her MVTs in the beginning of Phase 2. Therefore, by the current study design, the participant was excluded and only eighteen participants' data were analyzed.

4.3.3 Data analysis

The perceived effort and discomfort ratings collected from the experimentations were analyzed quantitatively through statistical analysis by using SPSS software (version 19, IBM, Armonk, New York). For the perceived effort ratings, the Kolmogorov-Smirnov Test was applied in advance to test the hypothesis that the distribution of the data was normal. Linear Mixed Model Analysis (Dependent variable: perceived effort ratings based on Borg CR10 Scale; Fixed factors: all other factors; Random factor: subject ID; Repeated covariance type: compound symmetry) was applied after that to test the fixed

effects of not only each jar lid design characteristic but also the interactions between them. Associated pairwise comparisons (e.g. comparing estimated marginal means) were made if any significant effects were found. In addition, the relationship between perceived effort and discomfort ratings were examined by Pearson Correlation Coefficient.

4.4 Results

4.4.1 Participant demographics

Eighteen female participants who were over 65 years old and had had hand problems were included in the study (Figure 4.7 and Table 4.4). All the participants were able to live independently and were residents of various retirement facilities located in and around Columbus, Ohio at the time of participation. According to the pre-screen survey and self-report questionnaire, the mean age of the participants was 85.4 years and the standard deviation was 5.4 years. All the participants were used to using their right hands to turn lids when performing jar opening tasks and about 89% of them reported that they had hand aches or pain in the past month prior to the study.

Figure 4.7: Distribution of participants by age in Phase 2

Table 4.4: Demographic details about participants in Phase 2

Gender			
	Male	0 people	(0%)
	Female	18 people	(100%)
Age			
	Mean	85.4 years	
	SD	5.4 years	
Have hand pain in the past month (self-report)?			
	Yes	16 people	(88.9%)
	No	2 people	(11.1%)
Have difficulty opening jars (self-report)?			
	Yes	18 people	(100%)
	No	0 people	(0%)
Live independently (self-report)?			
	Yes	18 people	(100%)
	No	0 people	(0%)
Hand used opening jars (self-report)?			
	Right	18 people	(100%)
	Left	0 people	(0%)

Since all the participants were used to using their right hands to open jar lids and the lid design evaluation process in Phase 2 were performed by right hands only, only the dimensions of their right hands were measured (Appendix I). The anthropometric data are listed in Figure 4.8. In addition to hands, specifically, the sizes of the first three fingers: thumb, index finger, and middle finger were documented, as well. It was

because the lids tested in the study were smaller in diameter (e.g. 28 mm and 42 mm) and according to Yoxall's study (2007), the most popular grip types selected by people when turning smaller lids were lateral grip, cylindrical grip, and pulp grip (Figure 2.5).

(Only right hands are measured)

	Right hand breadth	Right hand length	Thumb length	Index length	Middle length
Mean	74.64	168.25	55.61	64.94	71.06
SD	4.88	9.73	3.48	4.11	3.97
	Thumb 1 breadth	Thumb J1 breadth	Thumb 2 breadth		
Mean	14.42	18.47	15.17		
SD	1.22	1.61	1.25		
	Index 1 breadth	Index J1 breadth	Index 2 breadth	Index J2 breadth	Index 3 breadth
Mean	14.00	17.58	13.39	15.08	12.06
SD	1.82	1.78	1.58	1.31	1.56
	Middle 1 breadth	Middle J1 breadth	Middle 2 breadth	Middle J2 breadth	Middle 3 breadth
Mean	12.97	17.56	12.97	15.14	12.06
SD	1.54	2.07	1.48	1.75	1.36

(SD = Standard deviation; Unite: mm)

Figure 4.8: Anthropometric data about participants' hands in Phase 2

To our best knowledge, anthropometric data explored in previous studies that explicitly included older people or older people with certain hand disabilities only focused on subjects' hand or finger strength, for example grip force and pinch force. As to the subjects' hand dimensions, they were not specifically documented.

Therefore, according to the general anthropometric data provided by Pheasant (1996) for British adults aged 19-65 years, the mean of females' hand breadth and hand length were 75 mm (standard deviation: 4 mm) and 175 mm (standard deviation: 9 mm), respectively. If compared with the current study, the group mean of participants' hand breadth was very close to the population mean; whereas the mean hand length of the participants was 7 mm shorter than the 50th percentile for British females.

4.4.2 Hand function assessment

All eighteen participants recruited in the current study had completed the hand function assessment in Phase 1. The testing results of their hand function characteristics (Appendix J) are summarized in Table 4.5 and were used as the criteria again in Phase 2 to divide the participants into two groups – hand healthier group and hand dysfunctional group. The details about each hand dysfunction characteristic's assessment technique, criteria of defining abnormality, and the weighted rating system used to calculate a participant's comprehensive hand dysfunction level are described in Chapter 3.3.1.1 Step 1 – Hand function assessment and Chapter 3.3.2.1 Eligibility determination.

Table 4.5: Phase 2 participants' hand function assessment results

Hand dysfunction characteristics (Assessment technique)	Testing results		Abnormality determination	
	Mean	Standard deviation	Normal (# of ppl)	Dysfunctional (# of ppl)
Self-reported difficulties of ADL (<i>PROMIS HAQ</i>)	1.11	0.64	5	13
Self-reported presence of chronic pain (<i>MHQ Pain</i>)	3.63	0.82	5	13
Sensibility (<i>MPUT – eyes closed section</i>)	47.05 sec	19.83 sec	0	18
Dexterity (<i>MPUT – eyes open section</i>)	22.63 sec	9.75 sec	2	16
Strength (<i>MVE KP – 2-finger pinch</i>)	4.43 kg	0.98 kg	8	10
Strength (<i>MVE CP – 3-ringer pinch</i>)	4.04 kg	1.31 kg	5	13
Anatomical integrity (<i>MPH during key pinch</i>)	Yes: 3 ppl	No: 15 ppl	15	3
Mobility (<i>ROM Thumb</i>) (degree)	< 30: 1 ppl	>=30: 17 ppl	17	1

According to the cut-off points decided for defining the abnormality of hand function characteristics, the majority of the participants in Phase 2 reported the presence of chronic pain (72.2%) and had difficulties on sensibility (100%), dexterity (88.9%), strength (77.8%), and performing ADL (72.2%). The details of the testing results from each hand function assessment technique are shown in Figures 4.9 to 4.16.

Figure 4.9: Phase 2 participants' PROMIS HAQ scores

Figure 4.10: Phase 2 participants' MHQ Pain scores

Figure 4.11: Phase 2 participants' MPUT (eyes open session) results

Figure 4.12: Phase 2 participants' MPUT (eyes closed session) results

Figure 4.13: Phase 2 participants' maximum voluntary exertion of key pinch

Figure 4.14: Phase 2 participants' maximum voluntary exertion of chuck pinch

Figure 4.15: Phase 2 participants' testing results of the occurrence of metacarpophalangeal joint hyperextension

Figure 4.16: Phase 2 participants' range of motion of thumb palmar abduction

According to the weighted rating system, the calculated total weighted scores used to define the hand dysfunction levels of the participants are shown in Figure 4.17. Following the classification criterion used in Phase 1, e.g. set score 5.5 as the cut-off point, in Phase 2, eleven participants were categorized into the hand dysfunctional group and seven participants were in the hand healthier group.

Figure 4.17: Phase 2 participants' hand function assessment total weighted scores. Score 10 is defined as the worst hand function level; whereas 0 is defined as no hand problems.

The MVTs given by the participants are shown in Figure 4.18. When turning medium lids (e.g. 42 mm in diameter), the MVTs between hand healthier group and hand dysfunctional group were significantly different in One-way ANOVA test ($p = 0.015 < 0.05$); whereas their MVTs were not significantly different ($p = 0.092$) when turning small lids (e.g. 28 mm in diameter) (Appendix K). If considering the removal torques required to open the current jar products in the market (Reliable Caps LLC, 2011), the participants in the hand dysfunctional group can open only about a half of current jar products with medium lids. (The process used in this study for assessing removal torque requirements for jar lids on products commonly found in stores today is described in Appendix L.) On the other hand, hand healthier people did not seem to have significant difficulties with that. However, regardless of hand dysfunction level, it was found that all the older participants would have significant difficulties to open most of the jars with small lids.

	42 mm diameter lid			28 mm diameter lid		
	Hand dysfunctional group (Score > 5.5)	Hand healthier group (Score < 5.5)	All participants	Hand dysfunctional group (Score > 5.5)	Hand healthier group (Score < 5.5)	All participants
MVT[†]	138.1 (25.1)	195.7 (38.9)	160.5 (43.19)	68.1 (14.0)	86.4 (15.9)	75.22 (17.74)

[†]Mean (Standard deviation) (Unit: Ncm)

Figure 4.18: Maximum voluntary torque given by participants in Phase 2. The * indicates a statistically significant difference ($p = 0.011 < 0.05$) between hand healthier group's and hand dysfunctional group's MVTs when turning a 42 mm diameter lid. (Estimated removal torque requirements for current products were based on Reliable Cap, LLC, 2011)

4.4.3 Examination of lid design characteristics

The perceived effort ratings of medium and small lids are summarized in Figure 4.19. According to the design of the experiment (e.g. complete block design), the tests

of fixed effects of lid design characteristics were divided by the block factor – lid diameter. Therefore, the medium lids (42 mm in diameter) and small lids (28 mm in diameter) will be discussed separately.

The distributions of the perceived effort ratings for both medium and small lids were Normal, except for one dataset ($p = 0.035$) in Kolmogorov-Smirnov Test (Appendix M), as such Mixed Model Analysis and Post Hoc Tests were applied.

Figure 4.19: Perceived effort ratings of the testing lids in Phase 2

4.4.3.1 Medium lid group

According to the testing results (Appendix N), the lid design characteristics of medium lids that have significant effects on perceived effort ratings are summarized and illustrated in Table 4.6 and Figures 4.20 to 4.22. The analyses were also conducted for each hand function group to examine if there were any differences in preferred lid designs between them.

Table 4.6: Summary of lid design characteristics in medium lid group that have significant effects on perceived effort ratings (grouped by hand dysfunction level)

Medium lids (42mm in diameter)		
● All subjects		
Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
Top shape * Side shape (p = 0.023)	●	If [Flat]), [Hexagonal] = [Circular] ● If [Convex], [Hexagonal] < [Circular] (p = 0.019) ● [Flat] = [Convex]
Top shape * Height (p = 0.031)	●	[Tall] < [Short] (p < 0.001) ● If [Short], [Hexagonal] = [Circular] ● If [Tall], [Hexagonal] < [Circular] (p = 0.024)
Side shape * Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001) ● If [Short], [Flat] < [Convex] (p = 0.008) ● If [Tall], [Convex] < [Flat] (p = 0.007)
● Hand healthier subjects		
Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
Side shape * Height (p = 0.008)	●	[Tall] < [Short] (p = 0.033 in [Flat]; p < 0.001 in [Convex]) ● If [Short], [Flat] < [Convex] (p = 0.003) If [Tall], [Flat] = [Convex]
● Hand dysfunctional subjects		
Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
Top shape * Height (p = 0.014)	●	[Tall] < [Short] (p < 0.001) ● If [Short], [Circular] = [Hexagonal] If [Tall], [Circular] = [Hexagonal]
Side shape * Height (p = 0.018)	●	[Tall] < [Short] (p < 0.001) ● If [Short], [Flat] = [Convex] ● If [Tall], [Convex] < [Flat] (p = 0.004)

("<" means "significant lower perceived effort rating"; "=" means "No significant difference")

(a) Height

(b) Top shape * Side shape

(c) Top shape * Height

(d) Side shape * Height

(* = $p < 0.05$; + = $p < 0.01$; x = $p < 0.001$)

Figure 4.20: Significant effects of lid design characteristics on perceived effort rating in medium lid group for all subjects regardless hand dysfunction levels

(a) Height

(b) Side shape * Height

(* = $p < 0.05$; + = $p < 0.01$; x = $p < 0.001$)

Figure 4.21: Significant effects of lid design characteristics on perceived effort rating in medium lid group for hand healthier subjects

(a) Height

(b) Top shape * Height

(c) Side shape * Height

(* = $p < 0.05$; + = $p < 0.01$; x = $p < 0.001$)

Figure 4.22: Significant effects of lid design characteristics on perceived effort rating in medium lid group for hand dysfunctional subjects

The analysis results were re-organized by lid design characteristic to develop concrete design knowledge for practical use (Table 4.7). Overall, lid height played the most important role in determining the usability levels of medium lids. The medium lid designs that got the lowest perceived ratings were the ones with a tall height, a hexagonal top shape, and a convex side shape, which were especially beneficial to hand dysfunctional group. As to the change of lid texture (e.g. smooth and serrate), however, no significant effect was found on the participants' perceived efforts.

Table 4.7: Summary of lid design characteristics in medium lid group that have significant effects on perceived effort ratings (grouped by lid design characteristic)

Medium lids (42mm in diameter)	
● Top shape	
If lids are [Short]...	
→ [For all subjects]	No difference on perceived effort between [Circular] and [Hexagonal]
If lids are [Tall]...	
→ [For all subjects]	[Hexagonal] is easier than [Circular] to turn
If lids are [Flat]...	
→ [For all subjects]	No difference in perceived effort between [Circular] and [Hexagonal]
If lids are [Convex]...	
→ [For all subjects]	[Hexagonal] is easier than [Circular] to turn
● Side shape	
If lids are [Short]...	
→ [For hand healthier group]	[Flat] is easier than [Convex] to turn
→ [For hand dysfunctional group]	No difference on perceived effort between [Flat] and [Convex]
If lids are [Tall]...	
→ [For hand healthier group]	No difference on perceived effort between [Flat] and [Convex]
→ [For hand dysfunctional group]	[Convex] is easier than [Flat] to turn
● Height	
	[For all subjects] [Tall] is easier than [Short] to turn
● Texture	
	[For all subjects] No significant difference on perceived effort between [Smooth] and [Serrate]

4.4.3.2 Small lid group

The testing results of the lid design characteristics in small lids (Appendix O) that have significant effects on perceived effort ratings are summarized in Table 4.8 and Figures 4.23 to 4.25. Again, the data was analyzed separately with and without considering participants' hand dysfunction levels.

Table 4.8: Summary of lid design characteristics in small lid group that have significant effects on perceived effort ratings (grouped by hand dysfunction level)

Small lids (28mm in diameter)		
● All subjects		
Top shape (p < 0.001)	●	[Hexagonal] < [Circular] (p < 0.001)
Side shape (p < 0.001)	●	[Flat] < [Convex] (p < 0.001)
Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
Side shape*Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
	●	If [Short], [Flat] < [Convex] (p < 0.001) If [Tall], [Flat] = [Convex]
● Hand healthier subjects		
Side shape (p = 0.002)	●	[Flat] < [Convex] (p = 0.002)
Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
Side shape*Height (p = 0.009)	●	[Tall] < [Short] (p < 0.001)
	●	If [Short], [Flat] < [Convex] (p < 0.001) If [Tall], [Flat] = [Convex]
Top shape* Side shape*Height (p = 0.006)	●	[Tall] < [Short], EXCEPT [Hexagonal]+[Flat] lids
	●	If [Hexagonal], then Case [Short], [Flat] < [Convex] (p < 0.001) Case [Tall], [Flat] = [Convex] If [Circular], [Flat] = [Convex]
	●	If [Convex], then Case [Short], [Circular] = [Hexagonal] Case [Tall], [Hexagonal] < [Circular] (p = 0.017) If [Flat], [Circular] = [Hexagonal]
● Hand dysfunctional subjects		
Top shape (p < 0.001)	●	[Hexagonal] < [Circular] (p < 0.001)
Side shape (p < 0.001)	●	[Flat] < [Convex] (p < 0.001)
Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
Side shape*Height (p < 0.001)	●	[Tall] < [Short] (p < 0.001)
	●	If [Short], [Flat] < [Convex] (p < 0.001) If [Tall], [Flat] = [Convex]
Side shape*Texture (p = 0.023)	●	If [Flat], [Serrate] < [Smooth] (p = 0.008) If [Convex], [Smooth] = [Serrate]
	●	If [Smooth], [Flat] = [Convex] If [Serrate], [Flat] < [Convex] (p < 0.001)

("<" means "significant lower perceived effort rating"; "=" means "No significant difference")

(a) Top shape

(b) Side shape

(c) Height

(d) Side shape * Height

(* = $p < 0.05$; + = $p < 0.01$; x = $p < 0.001$)

Figure 4.23: Significant effects of lid design characteristics on perceived effort rating in small lid group for all subjects regardless hand dysfunction levels

(a) Side shape

(b) Height

(c) Side shape * Height

(d-1) (Side shape * Height) – Circular

(d-2) (Side shape * Height) – Hexagonal

(* = $p < 0.05$; + = $p < 0.01$; x = $p < 0.001$)

Figure 4.24: Significant effects of lid design characteristics on perceived effort rating in small lid group for hand healthier subjects

(* = $p < 0.05$; + = $p < 0.01$; ^x = $p < 0.001$)

Figure 4.25: Significant effects of lid design characteristics on perceived effort rating in medium lid group for hand dysfunctional subjects

The testing results were re-sorted by lid design characteristic to explore whether any patterns or trends of preferred lid design features can be found (Table 4.9). Generally speaking, for the hand dysfunctional group, the small lid designs that got the lowest perceived effort ratings were the ones with a tall height and a hexagonal top shape, and there was no significant difference between the side shapes in this case. However, if lids have a flat side shape, the serrate surface texture may provide an advantage. As to the hand healthier group, taller lid height was also important except the ones with a hexagonal top shape and a flat side shape. In addition, hexagonal top shape was better only on tall-convex lids; otherwise, no significant effect was found. The change of lid texture was not important for them.

Table 4.9: Summary of lid design characteristics in small lid group that have significant effects on perceived effort ratings (grouped by lid design characteristic)

Small lids (28mm in diameter)			
● Top shape			
For hand healthier group			
If lids have...		Better top shape?	
Side shape	Height		[Circular] or [Hexagonal]?
[Flat]	[Short]	→	Does not matter
[Flat]	[Tall]	→	Does not matter
[Convex]	[Short]	→	Does not matter
[Convex]	[Tall]	→	[Hexagonal]
For hand dysfunctional group			
[Hexagonal] is easier than [Circular] to turn			
● Side shape			
For hand healthier group			
If lids have...		Better side shape?	
Top shape	Height		[Flat] or [Convex]?
[Circular]	[Short]	→	Does not matter
[Circular]	[Tall]	→	Does not matter
[Hexagonal]	[Short]	→	[Flat]
[Hexagonal]	[Tall]	→	Does not matter

(Table 4.9 continued on the next page)

(Table 4.9 continued from the previous page)

For hand dysfunctional group

If lids are [Short]...

→ [Flat] is easier than [Convex] to turn

If lids are [Tall]...

→ No difference on perceived effort between [Flat] and [Convex]

If lids are [Smooth]...

→ No difference on perceived effort between [Flat] and [Convex]

If lids are [Serrate]...

→ [Flat] is easier than [Convex] to turn

● **Height**

For hand healthier group

If lids have...			Better height?
Top shape	Side shape		[Short] or [Tall]?
[Circular]	[Flat]	→	[Tall]
[Circular]	[Convex]	→	[Tall]
[Hexagonal]	[Flat]	→	Does not matter
[Hexagonal]	[Convex]	→	[Tall]

For hand dysfunctional group

[Tall] is easier than [Short] to turn

● **Texture**

If lids are [Flat]...

→ **For hand healthier group** No difference on perceived effort between [Smooth] and [Serrate]

→ **For hand dysfunctional group** [Serrate] is easier than [Smooth] to turn

If lids are [Convex]...

→ **For hand healthier group** No difference on perceived effort between [Smooth] and [Serrate]

→ **For hand dysfunctional group** No difference on perceived effort between [Smooth] and [Serrate]

4.4.4 Perceived discomfort rating

The relationship between perceived effort and discomfort ratings were illustrated in Figure 4.26. According to the testing results in Pearson Correlation (Appendix P), the relationship between the two ratings were linear on both medium ($p = 0.000$) and small lids ($p = 0.000$). The Pearson Correlation Coefficient was 0.593 and 0.479 when testing medium and small lids, respectively.

(a) Medium lids (42 mm in diameter) (Person Correlation Coefficient = 0.593; $p = 0.000$)

(a) Small lids (28 mm in diameter) (Person Correlation Coefficient = 0.479; $p = 0.000$)

Figure 4.26: Linear relationship between perceived effort and discomfort ratings (jittered scatter plots)

The perceived discomfort ratings on medium and small lids by different design characteristics are shown in Figures 4.27 and 4.28. According to the charts, it was observed that for both medium and small lids, lid height was the strongest main factor associated with participants' perceived discomfort ratings, which is consistent with the perceived effort ratings. However, all other design characteristics did not seem to make significant effects to alleviate participants' discomfort on hands.

Figure 4.27: Perceived discomfort ratings on medium lids by design characteristics. The bar is the mean rating plus and minus one standard deviation.

Figure 4.28: Perceived discomfort ratings on small lids by design characteristics. The bar is the mean rating plus and minus one standard deviation.

4.5 Discussion

The aim of the study was to evaluate new lid design concepts by means of controlled experimentation. Based on the lid design concepts explored in Phase 1, thirty-two lid designs that were composed of two diameters, two heights, two top shapes, two side shapes, and two surface textures were proposed and tested through a subjective evaluation process. Eighteen people participated in the study; eleven people of them were placed in the hand dysfunctional group and seven were placed in the hand healthier group. The results showed that lid height was the strongest factor associated with the levels of perceived effort and discomfort when turning a lid. The medium lid design (e.g. 42 mm in diameter) that received the lowest perceived effort rating was the one with a tall height, a hexagonal top shape, and a convex side shape, which could be in particular advantageous for older people with dysfunctional hands. When turning small lid designs (e.g. 28 mm in diameter), the one rated lowest in perceived effort was also the design with a tall height and a hexagonal top shape. And if small lids have a flat side shape, the serrate surface texture may provide an advantage.

4.5.1 Effects of lid design characteristics

The effects of lid design characteristics on perceived effort ratings were examined via statistical analysis using Mixed Model Analysis and estimated marginal means comparison. However, it was found that the “significant” effects identified through the

statistical analyses might not be always considerable from a practical perspective. For example, if the ratings of two lid designs are 3.3 and 3 in Borg CR10 Scale (rating 3 means “Moderate” and rating 4 means “Somewhat difficult”), even though they are statistically different with each other, the 0.3 difference between them might not be meaningful for practical uses.

The mean differences on the perceived effort rating of the statistically significant effects are listed in Table 4.10. According to the table, if the rating difference of and about 1 on Borg CR10 Scale is defined as the criteria of being a “meaningful” effect, two highlighted design recommendations for 28 mm and 42 mm diameter lids will be: (1) Regardless of the lid diameter, a tall lid height (17 mm) is strongly suggested, and (2) Regardless of the lid diameter, for shorter lids (9 mm), generally speaking, a flat side shape is more favorable than a convex design.

Table 4.10: Real difference on perceived effort rating of the statistically significant effects

Statistically significant effects			Diff on rating*
Medium lids (42mm in diameter)			
Top shape	All subjects	If lids are [Tall], [Hexagonal] is better than [Circular]	0.354
Top shape	All subjects	If lids are [Convex], [Hexagon] is better than [Circular]	0.368
Side shape	Healthier group	If lids are [Short], [Flat] is better than [Convex]	0.946 ←
Side shape	Dysfunctional group	If lids are [Tall], [Convex] is better than [Flat]	0.545
Height	All subjects	[Tall] is better than [Short]	1.128 ←
Small lids (28mm in diameter)			
Top shape	Healthier group	If lids are [Convex]+[Tall], [Hexagonal] is better than [Circular]	0.786
Top shape	Dysfunctional group	[Hexagonal] is better than [Circular]	0.557
Side shape	Healthier group	If lids are [Hexagonal]+[Short], [Flat] is better than [Convex]	1.393 ←
Side shape	Dysfunctional group	If lids are [Short], [Flat] is better than [Convex]	0.920 ←
Side shape	Dysfunctional group	If lids are [Serrate], [Flat] is better than [Convex]	0.750
Height	All subjects	[Tall] is better than [Short], EXCEPT [Hexagonal]+[Flat] lids	1.313 ←
Texture	For hand dysfunctional group	If lids are [Flat], [Serrate] is better than [Smooth]	0.477

(*It is perceived effort ratings based on Borg CR10 Scale)

4.5.2 Experimental design

For practical purposes, no specific grasp type was given to the participants during the experiments. The participants were asked to adopt any grasp types they used normally for opening jars or bottles. Similar research protocols were used in a couple of previous studies, as well (Crawford et al., 2002; Voorbij & Steenbekkers, 2002; Yoxall et al., 2006). There were primarily two advantages. First, it can make sure that the participants' grasp types used in the test would be similar to their possible real behaviors when interacting with real products. Second, in addition to the ratings given by the participants between the lid designs, their grasp types observed during the experiments can be used as the research materials of future studies. It would be worthwhile to further explore alternative biomechanical models to explain how the specific types of users, e.g. older people with hand problems, use their hands to interact with products.

The comparison of the testing results between the current and previous studies was difficult, because no prior published research specifically studied older people who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation (Table 4.11). If comparing the lid design evaluation results between Phase 1 and Phase 2, the findings were quite similar. For example, both studies found that taller lids were more preferred. However, in addition to the main effect of each lid design characteristic, the interactions between them were examined in Phase 2. Therefore, if compared with Phase 1, the testing results of Phase 2 were mostly conditional. For instance, a hexagonal top shape was found to be more

preferred than traditional circular design in Phase 1; whereas in Phase 2, it was concluded that only the medium lids with a convex side shape or a tall height could get benefits from adding a hexagonal top shape. For small lids, a hexagonal shape was mainly beneficial to the older participants with dysfunctional hands, though subjects with healthier hands were not disadvantaged by this design. As to the subjects with healthier hands, a hexagonal design was better only on tall-convex lids; otherwise, no significant effect was found.

Table 4.11: Testing results of current and previous lid design studies (extended from Table 3.9)

Author (yr)	Participants	Dependent variables	Independent variables	Primary findings relevant to the current study
Imrhan and Loo (1988)	Older (65+); Male + Female; Capable of using preferred hand for grasping and turning lids	Grip force MVT	(1) Four diameters: <i>31, 55, 74, 113 mm</i> (2) Two textures: <i>Rough, Smooth</i>	(1) Torque levels were monotonically increasing with lid diameters before 75mm (2) Grip forces and torques were not significantly different in 31-74 mm diameter lids for rough and smooth lids
Crawford et al. (2002)	Young (22-39); Older (60+); Male + Female; No current symptoms and medical history on joint problems in fingers/wrists	MVT	(1) Three diameters: <i>20, 50, 80 mm;</i> (2) Three heights: <i>10, 20, 30 mm</i> (3) Two top shapes: <i>Circular, Square</i>	(1) Only for the 20 and 50 mm diameter pieces, torque levels were increasing with diameter and height, but no interaction between them was found (2) Torque levels were larger with square lids compared to circular lids
Current study (Phase 1)	Older (65+); Female only; Have hand pain and difficulties in opening jar lids	Four-level Preference ratings by survey	(1) Two diameters: <i>25, 40 mm</i> (2) Two heights: <i>10, 15 mm</i> (3) Nine top shapes: <i>Four 2-layered shapes, Triangle, Circular, Square, Hexagon, Octangle</i> (4) Five side shapes: <i>Cylinder, Convex, Concave, Cone, Reverse cone</i>	(1) Prefer taller lids than the shorter ones, especially for the 25 mm diameter lids (2) Lids with alternative top shapes were generally more preferred than circular ones. However, for the circular shape lid with larger diameter (40 mm) and taller height (15 mm), no significant difference was found if compared with other top shape ones (3) For most of the 10 mm height lids, the participants preferred the lids with larger diameters. However, this diameter preference was not significant in the group of 15 mm height lids except the ones with circular and reverse-cone shapes. (4) Ratings for the lids with alternative side shapes were not changed with lid heights, except convex shape ones
Current study (Phase2)	Older (65+); Female only; Have hand pain and difficulties in opening jar	Controlled experiments: Subjective evaluation process	(1) Two diameters: <i>28, 42 mm</i> (2) Two heights: <i>9, 17 mm</i> (3) Two top shapes:	(1) Height is the strongest factor associated with lids' perceived effort ratings. (2) The medium lid design that got the lowest perceived effort

(Table 4.11 continued on the next page)

(Table 4.11 continued from the previous page)

lids	Circular, Hexagonal (4) Two side shapes: Flat, Convex (5) Two texture: Smooth, Serrate	rating was the one with a tall height, a hexagonal top shape, and a convex side shape, which were especially beneficial to hand dysfunctional group. As to the surface texture (e.g. smooth and serrate), no significant effect was found (3) For the hand dysfunctional group, the small lid design that was rated lowest in perceived effort was also the one with a tall height and a hexagonal top shape, and there was no significant difference between the side shapes in this case. However, if lids have a flat side shape, the serrate surface texture will be preferred. For hand healthier group, lid height did not make any significant difference for them if a lid has a hexagonal top shape and a flat side shape. In addition, hexagonal top shape was better only on tall-convex lids; otherwise, no significant effect was found. The change of lid texture was not important for them, either.
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The research protocol applied in the current study (Figure 4.6) was actually partially different from the one planned in the beginning of the study. According to the original study design, participants were asked to apply torques to each testing lid for three times (not two times in the current protocol). They were (1) (Trial phase) “Medium” target torque (e.g. 50% of MVT) to tryout a proposed lid design, (2) (Evaluation 1) “Medium” target torque again (e.g. 50% of MVT; weaker stimulus) for first usability testing, and (3) (Evaluation 2) “High” target torque (e.g. 70% of MVT; stronger stimulus) for second usability testing. The reason why two levels of usability testing (50% and 70% of MVT) were planned was because, as a secondary goal of the study, it could examine whether the lower level of sub-maximal exertion (e.g. weaker stimulus) was strong enough for older

participants to differentiate the variance between the lid designs tested in the subjective evaluation process. The original research protocol was pilot tested before the data collection activities. However, unexpectedly, it was found that even though the exertions were all sub-maximums, noticeable fatigue still developed after repetitive exertions and was reported by the first two older subjects who had hand problems. In addition, since the lid design ratings given by the participants in the “Medium” target torque session were mostly lower on the Borg CR10 Scale (e.g. between 1 and 3), it was decided that the activity “Evaluation 1” (with a “Medium” target torque) should be excluded and only the lid design evaluations with a “High” target torque were performed. The result showed that all the participants could complete all the lid design evaluation activities without suffering significant fatigue or discomfort.

4.5.3 Study limitations

By the research design, again, only older females were recruited in the study and it could be considered as one of the study limitations. In addition, since all the participants were right handed and the lid designs were tested with their right hands only, future studies should include left-handed and male participants to see if the current research findings can be also beneficial to other user groups.

Older people who participated in Phase 1 and completed the hand function assessment before were recruited into the current study. Due to the limit of time, their hand function assessment scores concluded in Phase 1 were used again as the criterion to

determine their current hand dysfunction levels. The time between Phase 1 and Phase 2 was about a year and if considering the deterioration of hand functions in older populations, their hand dysfunction levels might be underestimated at the time of their participation in Phase 2.

The effects of varied lid design characteristics on participants' perceived effort and discomfort ratings were examined in the current study. The preferences of the 32 lid designs that were composed of five different design characteristics were compared comprehensively with older people with hand dysfunction. However, how the differences on the scale can be mapped to real improvements of participants' hand physical performance was not clear. Future studies would be required to explore the relationship between Borg CR10 Scale and real hand performance for this special population.

4.6 Conclusion

Although the special needs and difficulties of older populations in performing jar opening tasks have been highlighted in many previous studies, when investigating jar lid design characteristics, none of them specifically studied older people who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation.

Phase 2 could be defined as the design concept evaluation phase of this product interface research study. The study applied a subjective evaluation process to

quantitatively examine the perceived effort ratings of different lid designs through controlled experimental tests. The older females who were over 65 years old and had hand problems were included. The main effects of varied jar lid design characteristics and their interactions were examined to see how older people's perceived effort and discomfort can be affected.

Thirty-two lid designs that were composed of two diameters (28 mm and 42 mm), two heights (9 mm and 17 mm), two top shapes (circular and hexagonal), two side shapes (flat and convex) , and two surface textures (smooth and serrate) were tested in the study. According to the results, lid height was the most important design characteristic associated with a lid's perceived effort rating. The medium lids (42 mm in diameter) designs that were rated lowest in perceived effort to turn were the ones with a tall height (17 mm), a hexagonal top shape, and a convex side shape, which were especially beneficial to older people who have dysfunctional hands. As to smaller lids (28 mm in diameter), designs with a tall height and a hexagonal top shape also got the lowest effort rating for hand dysfunctional participants. And if smaller lids have a flat side shape, the serrate surface texture could be helpful. As to older people with healthier hands, taller lid height was also important, but the lids with a hexagonal top shape and a flat side shape were the exceptions. In addition, the change of surface texture does not matter for them.

CHAPTER 5

5 PHASE 3: COMMUNICATION – INVESTIGATING INDUSTRIAL DESIGNERS’ NEEDS OF USING AN ELECTRONIC HUMAN FACTORS DESIGN ASSIST TOOL DURING THE PRODUCT DESIGN PROCESS

5.1 Introduction

The development of design assist tools that are capable of providing user data to help product designers create designs during the product design process has been discussed in many studies. For example, Tsai and Chou (2007) created design support software to map the association between the color schemes of two-colored products and consumer perceptions. They concluded that the software could help designers to decide which color combinations to use on a product to fit the preferences of diverse consumer groups. Gyi et al. (2004) explored the development of a computer-based design tool (HADRIAN) to support designers in evaluating the usability of new designs, particularly focusing on the needs of older people and people with certain disabilities. Chaffin (2007) discussed the application of Digital Human Models (DHMs) when simulating human motions in vehicle and workplace design. Focusing on handle design, Patkin (1997) proposed a checklist to convey general-purpose handle design principles for

designers of hand tools. Woodson (1981) used not only checklist-typed guidelines in words, but also sketches to graphically illustrate how users would interact with hand tools and explain how various factors, including mechanical factors, anthropometric factors, anatomical considerations, physical characteristics of the tool, ergonomic considerations, and work environments, could be comprehensively considered when creating the design.

While there were many design assist tools available for designers to use, it has been found that designers seldom consult these established resources when developing designs (Burns & Vicente, 1996; Burns et al., 1997; Choi et al., 2006; Law et al., 2008a). Although the barriers for designers in using established design resources and tools have been discussed in many articles, some of which are more than ten years old, the problems still exist.

It was recognized that there was a gap between Human Factors (HF) information explorers, meaning engineering researchers, and information users, meaning designers (Burns & Vicente, 1996). Burns et al. (1997) pointed out that the reasons why designers rarely consult established HF resources include (1) lack of contextual information, where the relation to the target product is unclear, and (2) having negative perceptions, which means that based on negative past experiences, designers would rather spend time working on design solutions on their own. Goodman et al. (2006) discussed the formats of end user information that fit with designers' work practices. It has been found that designers need the data about product use to be transformed and communicated in a way that they feel they can easily use during the design process.

Some general solutions and design recommendations for producing better design

resources have been proposed in some previous studies (Burns & Vicente, 1996; Law et al., 2010; Rouse, 1986). For example, Rouse (1986) suggested that *“The system should be interactively adaptive and provide support ranging from aiding to embedded training”* and Law et al. (1996) advised that *“Create reference information that is closely matched with the context and form of actual design problems.”* However, it was still not very clear whether the needs of designers were comprehensively explored. First, to our best knowledge, there was no study so far focusing on understanding and modeling how designers’ use of HF information can be mapped with their current design behaviors, in detail, during the different phases of the product design process. Second, the capabilities of the methodologies applied to explore the needs of designers have been limited. As indicated in Sander’s article (1999), different levels of user experience, e.g. say, do, and make, can reveal different stories or pictures about the users, and only when all the three perspectives are explored simultaneously can people’s needs be readily understood. However, as indicated in previous HF resource tool design studies, only say (e.g. questionnaire, survey, and focus groups) and do (e.g. observations) methods were applied. There was a research void to investigate the latent needs of designers about HF design assist tools that they would desire to use to solve design problems during the product design process.

5.2 Goal

Phase 3 was viewed as the “communication” phase of this product interface research

study. After creating the new research-based HF knowledge about the lid design characteristics, the aim of the current study was to further investigate how the explored knowledge can be useful, usable, and desirable for real knowledge users, e.g. industrial designers, in a format of electronic design assist tool.

Following the concepts of traditional test-and-evaluation product design process, in which new HF design assist tools can be viewed as “products” being designed and industrial designers are viewed as “users” who use the products, a multi-stage development process for HF design assist tools is illustrated in Figure 5.1. Since there was still a research void understanding the real needs of target users, e.g. industrial designers in industry, regarding HF design assist tools, Phase 3 was focused on the first step of the development process – “Collect and analyze user needs”. The goal was to comprehensively explore industrial designers’ needs regarding the applications of HF information resources during the product design process.

Figure 5.1: Multi-stage development process for Human Factors design assist tools. The focus of the current study was the first step “Collect and analyze user needs”

Accordingly, the necessary research activities included –

- (1) Investigate current situations to learn how industrial designers in industry use HF information during the product design process
- (2) Through a participatory design process, explore latent needs of designers

concerning desirable electronic HF design assist tools

5.3 Methods

5.3.1 Design of experiment

Focus group events were conducted using a participatory design process in Phase 3. The research protocol is outlined in Figure 5.2; the protocol was approved by the university's IRB and all participants proved informed consent prior to participating. An individual survey was given to each participant at the beginning of the research activities to document the background information about the subject's work experience in the industrial design area, including years of working, specialties and so forth (Appendix Q).

Figure 5.2: Research protocol of Phase 3

Following the individual survey, there were two research activities included in each focus group event. The aim of the first design activity, Product physical interface design, was to investigate how participants, e.g. industrial designers in industry, currently seek out and utilize HF information during the different phases of the product design process. The second design activity, Design assist tool conceptualization, was a participatory design process. The aim was to further explore designers' latent needs concerning the

most desirable designs for a new HF design assist tool, by inviting participants to become involved in a design procedure directly.

The details of both design activities are described below. Microsoft PowerPoint slides were used as a visual aid during the focus group events. In addition, the entire sessions were audio- and video- recorded, in order to be able to perform qualitative analysis of the contents of discussions and presentations during these focus group events.

5.3.1.1 Design activity 1 – Product physical interface design

The goal of the first design activity was to explore current situations with regards to how industrial designers in industry use HF information during the product design process. Therefore, in order to understand participants' real problem-solving behaviors when they create designs in industry, a scenario involving a design project requested from a beverage company was described at the beginning of the design activity. The project required the redesign of the lid for a current coffee product of Starbucks®. The details of the design project and this “problematic” product are listed in Table 5.1. The designers were asked to redesign the lid while specifically considering the needs of older consumers, especially those who have experienced pain when using their hands to open jars and bottles.

Table 5.1: Details of the design project in design activity 1 in Phase 3

Company name:	Starbucks®
Product:	9.5 oz Frappuccino bottle coffee

Current lid design:	44 mm in diameter; 9 mm in height; Circular top shape; Smooth surface texture (metal material)
Current problem*:	Many older consumers complain that it is very difficult for them to open
Design goal:	Older people, especially those who have experienced pain when using their hands, can open new lids easily
Design requirements / limitations:	(1) Starbucks® plans to use plastic materials on new lids (2) The diameter of lids (44 mm) cannot be changed
Budget:	Reasonable amount of budget, meaning although it is not unlimited, it is quite enough for designers to conduct all the necessary research or design activities during the product design process

* The scenario was designed for research purposes only

After explaining the goals, requirements and limitations of the design project to the designers, the research activities in the design activity 1 were divided into three steps (Figure 5.2). In the Step 1 “Complete an assigned design project”, a “Design Timeline Sheet” (Figure 5.3) was handed out to each participant to help them understand the design phases of interest in the current study. They were (1) information gathering, (2) ideation and sketching, (3) modeling, and (4) evaluating and refining prototypes. Step 1 was an individual assignment and the participants were instructed to describe on the

Design Timeline Sheet what they would like to do when embodying their new lid design concepts along the design process. They were encouraged to use either drawings or word descriptions on the sheet to indicate what methods, tools, or information they would like to apply to solve this design problem. The designers were told that the focus of the study was the procedures they used to solve design problems during the product design process, not an actual design of a jar lid.

Figure 5.3: Design Timeline Sheet used in Phase 3 (Original size: 17"x11")

After the designers completed the design process on the Design Timeline Sheet, in Step 2 “HF” stickers, which represented HF information, and sticky notes were handed out to each participant (Figure 5.4). The designers were instructed to put the stickers onto their Design Timeline Sheets to indicate where they searched and/or used HF information to solve design problems during the product design process. In addition, they were asked to explain the context of each HF sticker by writing on a corresponding

(number-matched) sticky note. Each sticky note included the following: (1) information contents you would look for (e.g. title of the information), (2) information resource you would use (e.g. reference books, journal articles, online search engines, etc.), and (3) information media you would prefer (e.g. tables, charts, photos, videos, etc.).

Figure 5.4: HF stickers and sticky notes used in Phase 3

Last, in the Step 3, the designers were interviewed as a group to discuss and exchange their thoughts about the usage of HF information in the product design process. They were invited to briefly summarize their HF stickers to the group. During the discussions, they did not need to come to an agreement. The designers were encouraged to share their thoughts from different aspects, particularly in relation to their professional working experiences and practical concerns in industry.

5.3.1.2 Design activity 2 – Design assist tool conceptualization

The aim of Design activity 2 was investigating designers' latent needs concerning the interfaces and content of a new HF design assist tool that could be used on electronic devices, including traditional screens like desktops and laptops, and mobile devices, such as tablets and smart phones. The MakeTools® technique (Sanders, 1999), which was previously used in Phase 1, was applied again in the current study to access participants' unspoken feelings and ideas. By providing the participants a proper tool kit, they could then create their own dream designs through a participatory design process.

The design tool kit used in Design activity 2 consisted of drawing materials and tools, such as large paper sheets and different colors of pens. The line frames that visually represented the contours of the electronic devices were printed on the paper sheets, in advance, to give the participants more ideas about the features and limitations of the different display areas (Figure 5.5). Participants could freely select any of the electronic devices, which they believed would be the most likely they would prefer the new electronic HF design assist tool to appear on for work. They then drew ideas directly on the sheets.

Figure 5.5: Visual representations of electronic devices used in Phase 3 (Original size: 11”x8.5”)

Taking a HF design assist tool for jar lid designs as the example, the participants were asked to work individually to create a desirable user interface that they thought would best assist them creating good designs. In order to stimulate the capacities of the participants to produce various complexity levels of design concepts, current research-based HF knowledge explored previously in Phase 2 was shown to them (Figure 5.6). The participants were asked to re-organize and present the given HF information when designing the new tool interface according to two separate usage scenarios. They were (1) Scenario 1 (e.g. basic search) – “You are designing the lids of bleach containers for older people. You are looking for the information about how the lid height can affect the usability of hexagon shaped lids”, and (2) Scenario 2 (e.g. advanced search) – “You are designing the lids of bleach containers for older people. You are looking for

the information about how the lid texture and side-shapes together can affect the usability of hexagon shaped lids”. After completing the designs, each participant was invited to present his or her design concepts to the rest of group. In addition, they were asked to describe where and how they would use the tool during the product design process, as well.

0	Nothing at all
0.5	Extremely easy (just noticeable)
1	Very easy
2	Easy(light)
3	Moderate
4	Somewhat difficult
5	Difficult
6	
7	Very difficult
8	
9	
10	Extremely difficult (almost maximal)
*	Maximal

Borg Scale

(Population: Older people with hand pain)

(a) Human Factors information given in Scenario 1

(Population: Older people with hand pain)

(b) Human Factors information given in Scenario 2

Figure 5.6: Human Factors information used in design activity 2 in Phase 3

The reason why the lids of bleach containers were selected as the product interface focused in the usage scenarios was based on what we learned in the first focus group.

The product interface focused in the first group was the lids of frappuccino bottles. However, it was observed that what designers were designing for mattered with regards to the extent of their needs for knowledge and looking for research. Therefore, in the remaining three focus groups, in order to address the importance and needs of searching critical HF information during the product design process, the lids of bleach containers were selected since a bad lid design may cause unwanted (and sometime dangerous) situations by accidentally spilling the liquid.

5.3.2 Participants

Designers who had at least one year of work experience in Industrial Design or Product Design and who worked in or around Columbus, OH were eligible to participate in the study. Four focus group sessions were conducted.

5.3.3 Data analysis

The data analysis in Phase 3 was divided into three parts. First, the HF stickers on the design timeline sheets and the contents on the sticky notes discussed during focus group events (e.g. video and audio recording) in design activity 1 were sorted qualitatively in order to investigate the trends and patterns in how the designers currently use HF information during the product design process. In addition, the barriers to using existing HF information were analyzed. Second, the participants' design artifacts in

design activity 2 were examined as expressions of the designers' latent needs. The participants' presentations were transcribed and reviewed along with the design artifacts to access the participants' needs for the user interface of new HF design assist tools. Last, according to what the participants said in the presentations, their preferences regarding where they would use the new tools during the design process were compared with their HF stickers on the design timeline sheets. The roles of the new tool, that is how the tool could practically help designers create designs were examined.

5.4 Results

5.4.1 Participant demographics

Sixteen industrial designers who had at least one year of work experience participated in the current study (Figure 5.7 and Table 5.3). They were recruited from three different design firms in and around Columbus, OH and four focus groups were conducted. According to the survey, the mean of their years of work experience was 13.5 years and the standard deviation was 10.2 years. Only one participant was a part-time employee (e.g. one year of work experience), whereas the other fifteen participants were full-time industrial designers working at design consulting firms at the time of participation (Table 5.2). The distribution of participants' specialties in Industrial Design is illustrated in Figure 5.8. Most designers marked design of housewares as one of their specialties (thirteen people), followed by consumer electronics (nine subjects), medical devices (five subjects) and hand tools (four subjects) (Appendix

R).

Figure 5.7: Distribution of participants' years of work experience in Phase 3

Table 5.2: Demographic details about participants in Phase 3

Gender			
	Male	15 people	(93.8%)
	Female	1 person	(6.2%)
Years of work experience			
	Mean	13.5 years	
	SD	10.2 years	
Employment status			
	Full-time	15 people	(93.8%)
	Part-time	1 person	(6.2%)
Design firm			
	Design firm 1	2 people	(12.5%)
	Design firm 2	10 people	(62.5%)
	Design firm 3	4 people	(25.0%)

Table 5.3: Distribution of participants' years of work experience and work companies in Phase 3

		Design firm 1	Design firm 2	Design firm 3
Years of work experience	0 ~ 4	2		2
	5 ~ 9		2	1
	10~14			1
	15~19			1
	20~24			5
	25~29		1	
	30~34			
	35~39		1

Figure 5.8: Distribution of participants' specialties in Industrial Design; Participants could describe more than one specialty area

5.4.2 Design activity 1

5.4.2.1 Design activities on design timeline sheets

Design activities the participants indicated on their design timeline sheets (Appendix S) are summarized in Table 5.4. Overall, it was observed that the boundaries between the four design phases were sometimes not very clear in terms of the design activities that were performed. For example, some designers did not stop collecting user information even after reaching the “Ideation and Sketching” phase. In addition, several designers indicated they made mockup foam models as early as the ideation phase for the purpose

of refining concepts. And the evaluations of prototypes with target users could be conducted earlier in “Modeling” phase (e.g. “informal test”).

Table 5.4: Summary of design activities shown on participants' design timeline sheets

Design phase	Summary
Information Gathering	The primary goals of designers in this phase were to define design problems and explore opportunities (or limitations) that they could use for later ideation phase. Therefore, designers might want to collect general information about the target product itself (materials, standards of manufacturing, etc.) and target users (if designers are not familiar with them). They would like to know how users talk about and interact with current similar products. In addition, designers would survey similar (or different products but sharing the similar function) products in the market to see what other solutions have been created or what problems have not been solved.
Ideation and Sketching	In the ideation phase, designers would focus on developing new design concepts or ideas. Techniques (e.g. brainstorming session) or information (e.g. design reference guide) that could expand or support new ideas generation would be used. After sketching the new ideas, some designers may make a few quick mockup foam models to initially refine concepts. In addition, some designers might start to discuss with their clients their new ideas at this phase.
Modeling	In the modeling phase, designers created functional prototypes or 3D computer models according to the developed ideas. A few designers would start to recruit target users to informally evaluate the prototypes in this phase.
Evaluating and Refining Prototypes	The main HF related design activity in this phase was to recruit target users to evaluate functional prototypes and determine the details of final designs.

5.4.2.2 Human Factors information used in product design process

The HF stickers that participants put on their design timeline sheets were reviewed and qualitatively sorted according to “goals” (or “categories”) (e.g. why did the participant want to use the information?) and “methods” (or “activities”) (e.g. how did

the participant achieve the goal?). The goal and method of each HF sticker was defined by the researcher, according to three sources of data: (1) contents participants wrote on the sticky notes, (2) context indicated on the design timeline sheets, and (3) discussions during the focus group events (Appendix T).

The usage of HF information in different design phases is summarized and illustrated in Figure 5.9. Most of the HF related design activities were performed in the Information Gathering phase at the beginning of the product design process (42 HF stickers), followed by the Modeling phase (14 HF stickers), Evaluating and Refining Prototypes phase (13 HF stickers), and Ideation and Sketching phase (6 HF stickers). As to the number of designers who used HF information in the design phases along the product design process, it formed a V-shape curve (Figure 5.10). It means most of the participants used HF information in the beginning (Information Gathering phase) and the end (e.g. Evaluating and Refining Prototype phase) of the design process, whereas fewer designers (5 out of 16) used HF information in the Ideation and Sketching phase. All the 16 designers who participated in the study put at least one HF sticker in the Information Gathering phase. Most of them (10 out of 16) would like to clarify design problems by interacting with target users directly, including survey / interview (e.g. “say” method) and observation (e.g. “see” method). They were interested in knowing what users thought about other current products in the market and would like to see how they interacted with the products. Only about half of the designers (8 out of 16) would like to collect background information about target users (e.g. in this case, older people who have hand problems) from previous research, including anthropometric data, health status, physical difficulties, etc. According to the discussions, it was found that in addition to

technical information, for example anthropometric data and disability status of target populations, the designers would strongly prefer to collect first-hand information by themselves. Some designers felt that the second-hand information, such as usability testing results from previous research articles, might be too specific, since they were exploring “opportunities” rather than “solutions” in the Information Gathering phase. In addition, they did not always trust the validity of existing user information. They wanted to know more details about how existing information had been collected – but they might not have access or were reluctant to spend extra effort to look into this. It was mentioned by the participants that videos about how users interacted with current products could be helpful as long as users were talking out loud about what they were thinking. But as indicated in a designer’s quote, *“It’s best to hear them in front of us so that we can see, feel, understand, and look at their faces and whole body and really have good interaction. We don’t want to bother to recruit people. But as far as videos, we don’t really have a good understanding and feeling what’s there in the room.”*

Figure 5.9: Designers' usage of Human Factors information during the product design process (data of all subjects). The connecting lines between goals (categories) mean that they were the same but in different design phases.

The Ideation and Sketching phase contained the least number of HF stickers among all the design phases on the design timeline sheet. Only five out of sixteen participants put HF stickers in this phase. The HF information used here was mainly applied to “support” ideation and sketching process, for example anthropometric data, design reference guidance, and anatomical drawings. It should be noted that there was one designer applying HF information in the ideation phase for the purpose of refining and evaluating design concepts.

In the phases of Modeling and Evaluating and Refining Prototypes, HF information was used primarily to evaluate design concepts or functional prototype models. However, according to the participants’ design timeline sheets, none of them would use previous HF research studies as an information resource here. The designers preferred first hand interaction with users as their information resource when performing concept evaluations. It should be pointed out that the information resources between the two phases could be slightly different. Some designers viewed the concept evaluations in the Modeling phase as “informal tests”. Therefore, instead of recruiting real users, they described using themselves, friends, or colleagues as an alternative information resource.

Based on the HF related activities indicated on the participants’ design timeline sheets, the reasons why designers use HF information can be further classified by the researcher into four categories, e.g. Research, Exploration, Support, and Evaluation. “Research” means the information was used to help designers clarify current design problems and identify existing solutions. “Exploration” means the information can be helpful for designers to explore opportunities or expand ideas. “Support” means the information can assist the ideation process by providing supplementary knowledge.

“Evaluation” means the information can be used to examine and refine design concepts.

The usage of HF information was also compared based on dividing the participants into two groups, e.g. highly-experienced designers and less-experienced designers, according to their years of work experience in industrial design. The criterion was determined based on the exploration of current data. Figure 5.10 shows different classifications of designers based on their years of work experience by three different criteria: 10, 15, and 20 years. It was observed that when using 20 years as the cut-off point, the difference between the two groups was mainly at the Ideation and Sketching phase, e.g. percentage of subjects who use HF information; when using 10 years as the cut-off point, the difference between the two groups in terms of the percentage of subjects who use HF information was at the Modeling phase. Therefore, since the Ideation and Sketching phase can be viewed as the “heart” of the product design process to create values, 20 years of work experience was selected in the current study as the criterion to classify subjects.

(a) Cut-off point: 10 years of work experience (nine subjects have 10+ years of work experience)

(b) Cut-off point: 15 years of work experience (eight subjects have 15+ years of work experience)

(c) Cut-off point: 20 years of work experience (seven subjects have 20+ years of work experience)

Figure 5.10: Classifying designers by different cut-off points of years of work experience

Figure 5.11 and Table 5.4 show the distribution of subjects in the two groups. It meant that for the designers whose work experience was less than 20 years, they were categorized as less-experienced designers (9 participants); otherwise, highly-experienced designers (7 participants). The applications of HF information during the product design process by less-experienced and highly-experienced designers are illustrated in Figures 5.12 and 5.13. The comparisons are made in Figures 5.14 and 5.15. It should be noted that although the sample size of the current study was not large, these comparisons can still provide some general ideas about the differences of using HF information in the product design process between the designers who have different levels of work experience.

Figure 5.11: Criterion of classifying designers was based on the years of work experience

Table 5.5: Number of participants in experienced group and less-experienced group in Phase 3

		Design firm 1	Design firm 2	Design firm 3	
Years of work experience	0 ~ 4	2		2	
	5 ~ 9		2	1	9 less-experienced designers
	10~14			1	
	15~19			1	
	20~24			5	
	25~29		1		7 highly-experienced designers
	30~34				
	35~39		1		

Human Factors Information Marked on Design Timeline Sheet (< 20 Years of Work Experience)

(a) HF stickers on design timeline sheets

(Figure 5-12 continued on the next page)

(Figure 5-12 continued from the previous page)

(b) Summary how Human Factors information was applied

Figure 5.12: Designers' usage of Human Factors information during the product design process (data of less-experienced designers)

Human Factors Information Marked on Design Timeline Sheet (20+ Years of Work Experience)

(a) HF stickers on design timeline sheets (Figure 5-13 continued on next page)

(Figure 5-13 continued on the next page)

(Figure 5-13 continued from the previous page)

(b) Summary how Human Factors information was applied

Figure 5.13: Designers' usage of Human Factors information during the product design process (data of highly-experienced designers)

Figure 5.14: Percentage of participants who used Human Factors information in the product design process

Figure 5.15: Average number of activities per subject when using Human Factors information

If comparing highly-experienced and less-experienced designers in terms of their usage of HF information, first, Figure 5.13 shows that the use was almost continuous for highly-experienced designers. As to less-experienced designers, Figure 5.12 shows that the use of HF information was focused primarily on the beginning (e.g. Information Gathering phase) and the end (e.g. Evaluating and Refining phase) of the product design process. Second, the highly-experienced designers tended to use HF information for Research and Exploration in not only the Information Gathering phase, but also part of the Ideation and Sketching phase. In addition, it was observed that a higher percentage of the highly-experienced designers (four out of seven) would use HF information to support their ideation process. On the contrary, only one less-experienced designer looked for HF information during the Ideation and Sketching phase. Third, highly-experienced designers tended to evaluate their concepts earlier in the design process. Almost all the highly-experienced designers (six out of seven) would start to evaluate their concepts in the Modeling phase; whereas less than 50% of less-experienced designers would do that. As to the average number of activities per designer when using HF information, overall, the patterns between both groups are similar.

5.4.2.3 Barriers to the use of existing Human Factors information

The barriers to using existing HF information resources that designers discussed in the focus group events are listed in Table 5.6. Accordingly, the reasons why the designers rarely use existing HF information resources can be discussed from two

perspectives. First, for the contents of the provided HF information, designers felt that the usage of the information may limit their abilities for creating new solutions. In addition, the provided information was sometimes too general so that they might not know how it could be related to real users or specific product types in practice. Videos could be helpful, but generally they lack contextual information about users. Second, as to the formats of provided HF information, they were too dry for designers to “read” and they usually did not fit designers’ cognitive processes.

Table 5.6: Barriers to the use of existing HF information identified in Phase 3

What participants said*	Interpretations (by researcher)
<i>"I think another advantage talking to people is...one of our goals is typically to provide our clients with the advantages of our arty place, differentiation, and if you are going out with the same data everyone else has, more than likely it comes out the similar solutions, may not be certain the advantage in the market place. So if you talk to people and gather new, fresh, and hopefully relevant information, that can help to lead to unusual solutions"</i>	<i>(Content)</i> Designers felt that the usage of existing HF information may limit their abilities of creating new solutions.
<i>"There is nothing I would trust that's written down that will tell me things because I want to experience it myself and see it through the eyes of other people because we are all different, right? (like this focus group) We are coming out of different answers to your questions. I think the same would be true with hand sizes and limits and so fourth. And I want to see that on my own eyes, I want to experience it 'where have you have problems?' really dial down deep, what is specifically you have troubles. I don't know what else I can get that kind of information without actually doing it and experiencing it. But even I did read that, it would be just the start point. I would want to test that to verify it by myself."</i>	<i>(Content)</i> The provided HF information was too general so that designers might not know how it could be practically related to real users in practice. <i>(Others)</i> Some designers did not trust the validity of second-hand HF information.
<i>"The problem what's out there (existing Human Factors resource) is not very easy to use. We go there and say it's not enough for us to do anything with that information. Sometimes the problem we are solving is not like a classic situation so that the information cannot be used."</i>	<i>(Content)</i> The provided HF information was too general and designers might not know how it could be practically related to specific types of products in practice
<i>"Because the success of the product is not if it's easy to open, it's success in a market place."</i>	<i>(Perceived importance)</i> Some designers might overlook the importance of HF information for a successful design
<i>"I don't want to READ data. That's not how I think."</i>	<i>(Format)</i> The formats of existing HF information were too dry and did not fit designers' cognitive process
<i>"Videos can be useful as long as the users are talking out loud. But it's best to hear them in front of us so that we can see, feel, understand, and look at their faces and whole body and really have good interaction. We don't want to bother to recruit people. But as far as video, we don't really have a good a understanding and feeling what's there in the room."</i>	<i>(Content)</i> The provided HF information, for example videos, lacked of contextual information about users

*Only representative comments are listed

5.4.3 Design activity 2

5.4.3.1 Expressed user needs about interface design

Fourteen participants completed the design activity 2 and fifteen design artifacts were collected. They were analyzed quantitatively to see whether any design trends could be found. The designers' presentations of their design tools were transcribed and reviewed along with the artifacts they created (Appendix U). The found design features were viewed as another form of user data through which the designers expressed their latent needs about desirable interfaces and contents for HF design assist tools.

According to their created artifacts, the selections of electronic devices, which the designers believed would be the most likely they would use a HF design assist tool on, are summarized in Figure 5.16. It was found that desktop/laptop was the most popular device the designers selected to create designs (seven designers), followed by tablets (six designers). Only two designers would like to use new a HF design assist tool on a smart phone.

Figure 5.16: Participants' selections of electronic devices for designing Human Factors design assist tools. There were 14 designers completing this design activity and one participant created designs on both tablet and smart phone.

The user needs, expressed through the participants' design artifacts, about Human Factors design assist tool interface design are listed in Table 5.7. The needs expressed in the presentations and design artifacts were interpreted and sorted by the researcher (Appendix V). In addition, the popularity (e.g. how many times a user need was expressed in the participants' design artifacts or presentations) of each user need was documented. It was found that most of the designers would prefer an interactive design assist tool. They wanted the search results (e.g. users' perceived effort ratings for a lid design) and the product (e.g. lid) shown on the screen to be visually and dynamically changeable as inputs were varied (e.g. varied lid design characteristics). They wanted to be able to explore how the varied lid design characteristics and the interactions between them could affect the difficulty ratings, similar to an interactive game. A designer talked about the use of the tool, *"And then by playing with these different parameters, I*

can actually see how I am either making it better or worse by changing it. You know as a designer, I think visually, so I think about objects and shapes and then that would, all that reference would make it easier for me to understand how I would change the design”

Therefore, they would like to have a “compare” function (or something similar) so that the design assist tool could compare the results from different searches and then list and summarize why they were different.

Table 5.7: User needs for Human Factors design assist tool interface design expressed through participants’ design artifacts

Popularity*	User needs about HF design assist tool interface design
● Output display	
High	Real-time users' perceived effort ratings
High	Compare different search results
Medium	Have result summary, e.g. trends, source of research, characteristics of target users etc.
Low	Predict the optimal and/or worst designs
● User control	
High	Everything on one page (input, output, and other info)
Low	Page-by-page linear information search process
● Visibility of input status - design characteristics	
High	Real-time visual representations of testing lid design
Low	Visual representations of texture (pictures, multiple views, etc.)
● Visibility of input status - target user	
Medium	Background info of target users, e.g. age, gender, health status
Low	Anthropometric data of target users, e.g. grip strength, finger dexterity, etc.
Low	Clips or photos how target users interact with products
● Minimize cognitive load	
Low	List search history
Low	Save search results
● Support and documentation	
Low	Provide source and details of referred research articles
● Assist work efficiency	
Low	Short-cut buttons for quick search

*Popularity = How many times a user need was expressed in subjects’ design artifacts or presentations. There were a total of 15 design artifacts created by the participants. “High” means a user need was expressed in over 9 out of 15 design artifacts; “Medium” means from 5 to 9; “Low” means from 1 to 4.

The layout designs of perceived difficulty ratings and controls of lid design characteristics are listed in Tables 5.8 and 5.9. It was observed that only two design artifacts used absolute numbers as search outputs. A designer talked about why he

disliked numbers, *“Maybe it would simplify things, but when you, it’s pretty weird, you know, I guess to get your head wrapped around it first. But you just start to think about it when you start to sketch things out. And really all the numbers go away, it’s just there is relative...you kind of mash thoughts together as you start to draw things.”* This may explain why the designers developed the ideas of scales with color coding, emoticons, and spectrum-like layouts for their interfaces. As to the design of tool controls, the most common designs were sliders and multiple graphics. The designers wanted visualized control designs for all the design characteristics, including not only size and shape, but also texture.

Table 5.8: Design of perceived difficulty scores as output from the design assist tool for a given combination of lid characteristics from participants' design artifacts. There were 15 design artifacts generated by the participants. Except S8, each participant created one design artifact.

Type	Designs of participants (Subject #)		
Number
	(S1)	(S4)	(S6)
Number
	(S7)		
Scale
	(S2)	(S10)	(S11)
Scale
	(S8)

	(S3)		

(Table 5.8 continued on the next page)

(Table 5.8 continued from the previous page)

Scale
with
color
coding

(S15)

(S5)

(S16)

Emoticon

(S8)

Spectrum

(S9)

(Table 5.8 continued from the previous page)

X-Y line
graph

(S13)

Table 5.9: Design of tool controls from participants' design artifacts. There were 15 design artifacts generated by the participants. Except S8, each participant created one design artifact.

Design characteristic	Design of controls (Subject #)	
Size	<div>● Slider</div> <div> </div> <div>(S1)</div>	<div> </div> <div>(S2)</div>
	<div> </div> <div>(S13)</div>	<div> </div> <div>(S16)</div>
	<div>● Multiple</div> <div> </div> <div>(S3)</div>	<div> </div> <div>(S5)</div>
	<div>● Arrow key</div> <div> </div> <div>(S8)</div>	
	<div>● Scale</div> <div> </div> <div>(S10)</div>	

(Table 5.9 continued from the previous page)

- Drag or pinch (for tablet)

(S4)

(S4)

(S11)

- Slider

(S1)

(S2)

(S16)

- Multiple

(S4)

(S4) and (S16)

(S5)

Shape

(S1)

(S11)

- Arrow key

(S8)

(Table 5.9 continued from the previous page)

Texture	<ul style="list-style-type: none"> Slider	<p>(S1)</p>	<p>(S2)</p>
		<p>(S13)</p>	<p>(S16)</p>
	<ul style="list-style-type: none"> Multiple	<p>(S8)</p>	<p>(S6)</p>
		<p>(S4)</p>
		<p>(S5)</p>	
Others	<ul style="list-style-type: none"> Short-cut buttons	<p>(S9)</p>	

5.4.3.2 *Use of new design assist tools during the product design process*

The question “*Where and how would you imagine using it (the new design assist tool) during the design process?*” was given to the participants during the presentations. Nine participants provided their responses. Each participant’s answer was compared with the HF stickers on their design timeline sheets, to examine how the new tools should be developed to practically assist designers creating designs during the process (Figure 5.17). The results are summarized in Table 5.10. It was concluded that the tool should be able to be used at many different points along the product design process and in different ways by different designers. Specifically, the tool should try to fill in the information gap between ideation and modeling so that designers could use it to refine their design concepts. Last but also important, the tool should be useful for both less-experienced and highly-experienced designers.

(a) Subject #4 (twenty years of work experience)

(b) Subject #7 (four years of work experience)

(Figure 5.17 continued on the next page)

(Figure 5.17 continued from the previous page)

(c) Subject #8 (twenty-two years of work experience)

(d) Subject #9 (six years of work experience)

(Figure 5.17 continued on the next page)

(Figure 5.17 continued from the previous page)

(e) Subject #10 (thirty-five years of work experience)

(f) Subject #11 (five years of work experience)

(Figure 5.17 continued on the next page)

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(g) Subject #13 (one and a half years of work experience)

(h) Subject #15 (twenty years of work experience)

(Figure 5.17 continued on the next page)

(Figure 5.17 continued from the previous page)

(i) Subject #16 (twenty years of work experience)

Figure 5.17: Usage of new Human Factors design assist tools

Table 5.10: Summary of how the new design tool could be used (ordered by participants' years of work experience)

Subject #	Years of work experience	Purpose of using new Human Factors design assist tools
13	1.5 years	Supplement for information gathering;
7	4 years	Supplement for determining design details (e.g. sizes)
11	5 years	Supplement for information gathering;
		Filling the gap between ideation and modeling
9	6 years	Supplement for information gathering;
		Filling the gap between ideation and modeling
4	20 years	Filling the gap between ideation and modeling
15	20 years	Supplement for information gathering and idea evaluations
16	20 years	Supplement for design reference guide
8	22 years	Supplement for clarifying design problems
10	35 years	Supplement for information gathering and ideation
		Filling the gap between ideation and modeling

5.5 Discussion

Phase 3 can be viewed as the “communication” phase of this product interface research study. The goal was to investigate how the research-based HF knowledge explored in the previous phases can be made useful, usable, and desirable for knowledge users, e.g. industrial designers, when presented in the form of an electronic design assist tool. Four focus group events with 16 practicing industrial designers were conducted as part of the study; each focus group included two design activities. The purpose of the first design activity, Product physical interface design, was to investigate how designers currently approach HF information during the different phases of the product design process. The purpose of the second design activity, Design assist tool conceptualization, was to further explore designers’ latent needs about their most desirable design features for new HF design assist tools. The result showed that most of the designers used HF information in the beginning (Information Gathering phase) and the end (e.g. Evaluating and Refining Prototype phase) of the product design process, whereas fewer designers used HF information in the Ideation and Sketching phase. However, designers with more years of work experience (e.g. ≥ 20 years) tended to use more HF information to support their ideation process. As to the expressed user needs about new HF design assist tools, the results suggest that the tool should be interactive. In addition, it should be able to be used in different ways by different designers, including those with different levels of work experience, different problem-solving skills, and different levels of interest in qualitative and quantitative information. There appeared to be a need to fill an

information gap between ideation and modeling, which could aid designers in refining their design concepts during the ideation process.

5.5.1 Barriers to the use of existing Human Factors information

The barriers for designers to use existing HF information during the product design process have been identified in the current study through the discussions in the focus group events. Since the barriers have been also discussed in some previous studies, the comparison of the results is listed in Table 5.11.

The relevant findings between the previous studies and current study were quite consistent. According to the findings of the study, it was found that designers thought if the provided HF information is too specific, they do not like to use it because their creativity could be limited. However, if the information is very general, it was reported that they might not use it either because they had no clue as to how they can apply the information in practice. This contradiction may be able to be explained by the current situation that designers would use different types of HF information in the different phases of the product design process. For example, designers may want to use general HF information to clarify design problems and most importantly, explore opportunities in the information gathering phase. After that, they may turn to other HF information resources that can provide more specific information to evaluate and refine their established ideas in ideation and modeling phases. Similar user needs were also expressed by the designers during the participatory design process.

Table 5.11: Barriers for designers to the use of existing Human Factors information identified in current and previous studies

Author (yr)	Found barriers for designers in using established HF information
Burns et al. (1997)	<ul style="list-style-type: none"> ● Most of the Human Factors information resources did not meet the needs of designers ● HF resources lack of contextual information, where the relation to the target product is unclear ● Based on negative past experiences, designers would rather spend time working on design solutions on their own
Norman (2002)	<ul style="list-style-type: none"> ● HF researchers who created guidelines may easily overlook the needs of designers
Persson and Warell (2003)	<ul style="list-style-type: none"> ● A quote from a designer “<i>They do not want the resulting information delivered in prescriptive form. They want to develop their own ways of working and be able to incorporate information and methods into that, not to be told how to go about designing.</i>”
Goodman et al. (2006)	<ul style="list-style-type: none"> ● Designers thought tables and charts are too dry
de Jong and Boess (2007)	<ul style="list-style-type: none"> ● Designers could feel that what they saw on existing HF information only reflects “<i>little things</i>” about users, which may limit the designers’ imagination ● In addition to the photos, quotes about users, and the interactions between users and products, a video clip might be helpful to clarify how people actually do things
Current study (Phase 3)	<p>About contents:</p> <ul style="list-style-type: none"> ● Designers felt that the usage of existing HF information may limit their abilities of creating new solutions ● The provided HF information, for example videos, lacked contextual information about users ● The provided HF information was too general so that designers might not know how it could be practically related to real users or specific product types in practice <p>About formats:</p> <ul style="list-style-type: none"> ● The formats of existing HF information were too dry and did not fit designers’ cognitive process <p>Others:</p> <ul style="list-style-type: none"> ● (<i>Perceived importance</i>) Some designers might overlook the importance of HF information for a successful design ● Some designers did not trust the validity of second-hand HF information ● Want to collect their own data

Future HF research studies should include industrial designers in research teams and involve them directly in the research process, so that the explored HF knowledge contents can really fit the practical needs of HF knowledge users (e.g. designers). Most importantly, involving designers in HF studies may also enhance their awareness about the importance of HF information for a successful design.

5.5.2 Development of new Human Factors design assist tools

The barriers for designers to use existing HF information have been discussed in many previous studies. However, most of them focused on the problems associated with the information content, not layout. Even though it has been found in some studies that designers dislike the way research-based HF information is presented currently, e.g. tables and charts, to our best knowledge, no studies explicitly investigated “how” the problem can be solved.

The user needs expressed by the designers regarding desirable design features for HF design assist tools were explored in the current study. If compared with the design recommendations proposed by other previous studies (Table 5.12), in addition to the information content, the current study addressed specifically designers’ needs regarding the design features for the interfaces of new design assist tools on electronic devices. The findings can be viewed as not only the latent needs expressed by the users, but also the possible directions of new designs for design assist tools in the future.

Table 5.12: Design recommendations for developing Human Factors information resources proposed by previous and current studies

Author (year)	Design recommendations for developing Human Factors information resources
Rouse, 1986	<ul style="list-style-type: none"> ● All information to be presented should be valuable in the sense of reducing uncertainty and being task relevant and having an appropriate form ● Types of information should include facts, fantasies, and feedback, with content and forms consistent with current tasks and individual differences ● The system should be interactively adaptive and provide support ranging from aiding to embedded training
Burns and Vicente, 1996	<ul style="list-style-type: none"> ● Provide on-line references which provide for quick search and access ● Create reference information that is closely matched with the context and form of actual design problems
Law et al., 2010	<ul style="list-style-type: none"> ● Explicitly define the target user groups of the guidance, research their needs ● Clearly define “accessible” and/or “universal design” and gain consensus ● Publish the testing method for measuring conformance with the requirements ● Work together with the appropriate authorities ● Conduct user testing on the guidance throughout its development
Current study (Phase 3)	<p>About content:</p> <ul style="list-style-type: none"> ● Be able to be used in different ways by different designers, including different levels of work experience, different problem-solving skills, and different levels of interest in qualitative and quantitative information ● Be able to be used at many different points along the product design process, including not only information gathering in the beginning, but also concept evaluations in the middle (e.g. ideation phase) and the end (e.g. modeling and prototypes evaluation phase) of the process. ● Can help designers explore opportunities of new ideas <p>About formats:</p> <ul style="list-style-type: none"> ● Have an interactive format ● Have visualized settings ● Everything on one page

The multi-stage development process for new HF design assist tools was outlined in Figure 5.1. While focusing on the first step, “Collect and analyze user needs”, the methods used in the current study were focus groups along with a participatory design process. Different levels of designers’ needs, e.g. what they “say” and what they “make”, regarding the use of new HF design assist tools were explored. Further studies could be conducted by exploring their needs from different perspectives, for example

field studies observing their behavior patterns how they practically deal with varied design projects in industry (e.g. “see” method). The evaluations of published design assist tools and the comparisons between them can be also useful because it can widen the area of search for solutions to a design problem. Other methods or techniques that can be applied to help to overcome design problems along the development process are listed in Table 5.13.

Table 5.13: Methods or techniques applied to develop electronic Human Factors design assist tools

Development phase	Methods / Techniques	Aim
Collect and analyze user needs	<ul style="list-style-type: none"> > Focus group events + Participatory design (<i>Already done in the current study</i>) > Questionnaire > Direct observations + Task analysis > Evaluations of current products (e.g. established design assist tools) 	<ul style="list-style-type: none"> > To investigate users’ opinions and latent needs regarding the usage of current HF information and new HF design assist tools > Following the focus group events, to refine and prioritize the collected user needs > To explore users’ behavior patterns of using HF information when doing varied design projects in working environments > To widen the area of search for solutions to design problems
Develop design concepts	<ul style="list-style-type: none"> > Brainstorming > Functional interface design > Graphic interface design 	<ul style="list-style-type: none"> > To stimulate the production of ideas > To create designs that can fit underlying cognitive models of target users > To create designs that can be perceived by target users
Develop prototype models	<ul style="list-style-type: none"> > Usability prototypes > Capability prototypes 	<ul style="list-style-type: none"> > To define, refine, and demonstrate user interface design usability, accessibility, look and feel > To develop, demonstrate, and evaluate the interface design concept
User trials and evaluations	<ul style="list-style-type: none"> > Heuristic analysis > Evaluations of user performance 	<ul style="list-style-type: none"> > To evaluate the usability > To evaluate the usability > To evaluate the usefulness

5.5.3 Study limitations

The study investigated how industrial designers use HF information during the product design process. In addition, the usage of HF information was compared based on dividing the designers into two groups according to their years of work experience. However, it was found that the differences between designers in terms of individual problem-solving styles could be associated with not only skill levels in dealing with unstructured and ill-defined design problems, but also individualities, meaning different levels of interest in qualitative and quantitative information. It could be a study limitation that the individualities were not explicitly addressed during the analysis. Further studies would be needed to explore how the HF design assist tools can be designed to fit the needs of different types of designers.

The differences between organizations where we recruited participants could be another factor associated with designers' individual problem-solving styles. Different design firms could have different management styles, atmosphere, working procedures, and hardware/software assistance. However, the examination of organization effects was not included in the current study because the numbers of participants recruited in the study were small and were not balanced between the different design firms. There were ten out of sixteen (62.5%) participants from larger design firms, whereas the participant numbers from the other two smaller design companies were only four (25%) and two (12.5%). Therefore, future studies would be required to examine how organizational factors could affect designers' individual styles of acquiring HF information to solve

design problems.

Last but also important, by the research design, in order to explore how designers use Human Factors information during the product design process, a design project (e.g. product physical interface design in design activity 1) was assigned to the participants along with two assumptions: (1) no time pressure from clients, and (2) enough budget. Future studies will need to investigate, by direct observations in the field, how those practical limitations could affect designers' decisions regarding the use of HF information during the design process.

5.6 Conclusion

It is recognized that there is a gap between HF information explorers, meaning engineering researchers, and information users, meaning designers. Although some general solutions and design recommendations for producing better design resources have been proposed in some of the previous studies, it is still not very clear whether the needs of designers were comprehensively explored.

Phase 3 could be viewed as the “communication” phase of this product interface research study. The goal was to investigate how the research-based HF knowledge explored in the previous phases can be made useful, usable, and desirable for industrial designers in the format of an electronic design assist tool. Therefore, industrial designers who had at least one year of work experience were included. Their needs regarding the usage of HF information during the product design process were explored.

Four focus group events with 16 practicing industrial designers were conducted as part of the study; each focus group included two design activities. The purpose of the first design activity, Product physical interface design, was to investigate how designers currently approach HF information during the different phases of the product design process. The purpose of the second design activity, Design assist tool conceptualization, was to further explore designers' latent needs about their most desirable design features for new HF design assist tools.

The results showed new findings that designers' usage of Human Factors information along the product design process was formed like a V-shape curve, meaning most of the designers used HF information in the beginning (Information Gathering phase) and the end (e.g. Evaluating and Refining Prototype phase) of the design process, whereas fewer designers used HF information in the Ideation and Sketching phase. Comparing the usage of Human Factors information based on participants' years of work experience in industrial design area, e.g. highly-experienced designers (≥ 20 years of work experience) and less-experienced designers (< 20 years of work experience), it was found that a higher percentage of the highly-experienced designers would use Human Factors information to support their ideation process. In addition, highly-experienced designers seemed to evaluate their design concepts earlier in the design process.

As to the expressed latent needs of designers about design features of new Human Factors design assist tools on electronic devices, it was found that most of the designers would prefer an interactive format with everything visualized, including settings for varying design characteristics, e.g. lid size, shape, and texture, so that they could "play" and explore by themselves how they could make better designs. It was also suggested

that the tool should be able to be used at many different points along the product design process and in different ways by different designers, which are consistent to Rouse's conclusions (1986). It is a new finding that specifically, the tool should be able to fill in the information gap between ideation and modeling phases so that designers could use it to refine their design concepts during the ideation process.

CHAPTER 6

6 CONCLUSION

The effect of aging is associated with marked decline in hand functions and, as a result, older people often experience increased difficulties in performing activities of daily living, such as opening a new jar (Hunter et al., 1998). However, there has been a research void in understanding the relationship between the product interface design characteristics and the hand dysfunction levels in older populations. Taking jar lids as the example of a product interface as the focus of the study, although older individuals have been included as participants in some prior jar lid design research, to our best knowledge, none of those studies specifically included older people who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation. Even when including older study participants, the number and interaction of jar lid design characteristics explored in previous studies was limited.

In addition, a related area of concern is how to make it easier for industrial designers to produce inclusive designs and persuade them to consider the special needs of older people during product design processes (Goodman et al., 2006a). While there are many

design assist tools available for designers to use, it has been found that designers seldom consult these established resources when developing designs (Burns & Vicente, 1996; Burns et al., 1997; Choi et al., 2006; Law et al., 2008a). It was recognized that there a gap still exists between Human Factors information explorers, meaning engineering researchers, and information users, meaning designers (Burns & Vicente, 1996). Some general solutions and design recommendations for producing better design resources have been proposed in some of previous studies (Burns & Vicente, 1996; Law et al., 2010; Rouse, 1986). However, it was still not very clear whether the needs of designers have been comprehensively explored.

Therefore, the current study addressed knowledge limitations in two important areas by applying ergonomics and product design research methodologies, in concert, to (1) discover what lid design features can improve the user experience of older people with hand impairment, and (2) discover what design concepts of Human Factors design assist tools can satisfy the practical needs of industrial designers when solving design problems.

In this chapter, the details about research activities, important findings, and results' applications are briefly summarized. In addition, suggestions that can be provided for future work are discussed.

6.1 Research Summary

There were three phases of research activities included in the study (Figure 6.1). For Phase 1 and 2, older females who were 65 years of age or older with declined hand

function, and for Phase 3, industrial designers who had at least one year of work experience in industry were recruited. The summaries of the three research phases are presented below.

Figure 6.1: Research phases included in the study

6.1.1 Phase 1 (“Exploration”) – Exploring different levels of user experiences when interacting with product interfaces

The aim of Phase 1 was to preliminarily explore, over a broader range, the potential design solutions for better lid designs. Twenty-six older females who were known to have difficulties in opening jar lids or who reported experiencing hand pain around the time of their study participation were included in this phase of the study.

The study applied ergonomics and product design research methodologies, including questionnaires, focus groups, and a participatory design process, to explore the different levels of user experience when the older people with hand problems interact with various jar lid designs. In addition, a comprehensive hand dysfunction assessment method was proposed and used as the means to explain inclusively the older people’s resulting hand dysfunction from different functional aspects.

The current lid designs found in the market and the new lid designs proposed by the

researcher that could possibly improve users' hand performance were assessed. Based on subjective preference ratings, some trends were identified in the evaluation results: (1) the participants were more sensitive to the changes of the lid designs that have a smaller diameter; (2) the participants preferred the taller lids more than the shorter ones, especially for the lids with smaller diameters; (3) for most of the shorter lids, the participants would prefer the ones with larger diameter. However, this diameter preference was not significant in the group of taller lids, except for the circular and reverse-cone shape ones; (4) the preference rating of the traditional circular shape lid was mostly worse than any other top shapes, unless they have larger diameters and taller heights; (5) the preference ratings of the new lid designs that have alternative side shapes were not changed with lid height, except the convex shape ones; (6) the texture feature seemed to compensate for certain levels of disadvantages associated with shorter and smaller circular shape lids.

In addition, according to the design features analyzed from the participants' design artifacts and their post-design presentations, there were four users' latent needs expressed through the participatory design process and which were consistent with the characteristics identified by Seo et al. (2007). They were (1) add texture onto lid surface, (2) enlarge leverages by changing lid shapes or diameters, (3) increase contact segments or surface area with palm/fingers by redesigning lid side shapes or heights, and (4) propose brand new lid designs to facilitate alternative grip types.

6.1.2 Phase 2 (“Evaluation”) – Evaluating product interface design characteristics through controlled experimental tests

Phase 2 could be defined as the design concept evaluation phase of this product interface research study. The aim was to further evaluate new lid design concepts by applying a subjective evaluation process to quantitatively examine the perceived effort ratings of different lid designs through a controlled experimental process

Eighteen females who were 65 years of age or older participated in the study. Based on the hand dysfunction assessment results, eleven of them were placed in a hand dysfunctional group and seven were placed in a hand healthier group. Through controlled experimental tests, the lid design concepts explored in Phase 1, e.g. thirty-two lid designs that were composed of two diameters (28 mm and 42 mm), two heights (9 mm and 17 mm), two top shapes (circular and hexagonal), two side shapes (flat and convex), and two surface textures (smooth and serrate), were tested in the study.

The results showed that lid height was the strongest factor associated with the levels of perceived effort when turning a lid. The medium sized lid design (e.g. 42 mm in diameter) that received the lowest perceived effort rating was the one with a tall height, a hexagonal top shape, and a convex side shape, which could be in particular advantageous for older people with dysfunctional hands. When turning small lid designs (e.g. 28 mm in diameter), the one associated with the least perceived effort for older people in the hand dysfunctional group was also the design with a tall height and a hexagonal top shape. And if small lids have a flat side shape, the serrated surface texture could be helpful. As to older people with healthier hands, lid designs with a taller height were

also rated lower in perceived effort, except the small lids with a hexagonal top shape and a flat side shape. In addition, the change of surface texture does not matter for them.

6.1.3 Phase 3 (“Communication”) – Investigating industrial designers’ needs when using an electronic Human Factors design assist tool during the product design process

Phase 3 could be viewed as the implement phase of this product interface research study. The goal was to investigate how the research-based Human Factors knowledge explored in the previous phases can be useful, usable, and desirable for industrial designers in a format of electronic design assist tool. Therefore, industrial designers who had at least one year of work experience were included. Their needs regarding the use of Human Factors information during the product design process were explored.

While applying the concepts of participatory design process, four focus group events with 16 industrial designers in industry were conducted in the study and two design activities were included. The purpose of the first design activity, Product physical interface design, was to investigate how designers currently approach Human Factors information during the different phases of the product design process. The purpose of the second design activity, Design assist tool conceptualization, was to further explore designers’ latent needs about their most desirable design features for new Human Factors design assist tools.

The results showed that designers’ usage of Human Factors information along the product design process was like a V-shape curve, meaning most of the designers used HF

information in the beginning (Information Gathering phase) and the end (e.g. Evaluating and Refining Prototype phase) of the design process, whereas fewer designers (5 out of 16) used HF information in the Ideation and Sketching phase. Comparing the usage of Human Factors information based on participants' years of work experience in industrial design area, e.g. highly-experienced designers (≥ 20 years of work experience) and less-experienced designers (< 20 years of work experience), it was found that a higher percentage of highly-experienced designers would use Human Factors information to support their ideation process. In addition, highly-experienced designers seemed to evaluate their design concepts earlier in the design process.

As to the expressed user needs about design features of new Human Factors design assist tools, it was found that most of the designers would prefer an interactive format with everything visualized, including settings for varying design characteristics, e.g. lid size, shape, and texture, so that they could “play” and explore how they could make better designs. It was also suggested that the tool should be able to be used at many different points along the product design process and in different ways by different designers. Specifically, the tool should be able to fill in the information gap between ideation and modeling phases so that designers could use it to refine their design concepts during the ideation process.

The user needs expressed by designers regarding their desirable design features for HF design assist tools were explored in the current study. If compared with the design recommendations proposed by other previous studies, in addition to the information contents, the current study addressed specifically designers' needs regarding the design features for the interfaces of new design assist tools on electronic devices. The findings

can be viewed as not only the latent needs expressed by the users, but also the possible directions of new designs for design assist tools in the future.

6.2 Study Limitations and Suggestions for Future Work

The main study limitations and relevant suggestions for future work are listed below. First, by the research design (Phase 1 and Phase 2), only older females were recruited in the study and it could be considered as one of the study limitations. In addition, since all the participants in Phase 2 were right handed and the lid designs were tested with their right hands only, future studies should include left-handed and include male participants to examine if the current research findings can be also beneficial to other user groups.

Second, only a limited number of lid designs and design features were evaluated in the study (Phase 1 and Phase 2). Future studies should expand the current knowledge base by including more types of lid designs.

Third, the study demonstrated the omission and need for the inclusion of older people with hand disability in the area of interface design in ergonomics research. Therefore, future work should include older people with hand problems when investigating not only jar lids, but also other categories of product interfaces.

Last, but not least, the study (Phase 3) investigated how the research-based Human Factors knowledge could be made useful, usable, and desirable for industrial designers in a format of electronic design assist tool. While the focus of the current study was to investigate designers' current usage of Human Factors information and their needs for the

new design tools, future research will be needed to collect and analyze designers' needs from different perspectives, for example observing designers' behaviors in using Human Factors information in the field. A process for developing new electronic HF design assist tools is outlined in Figure 6.2. Table 6.1 listed the examples of design methods or techniques that future studies can apply when developing new electronic Human Factors design assist tools.

Figure 6.2: Multi-stage development process for Human Factors design assist tools

Table 6.1: Methods or techniques applied to develop electronic Human Factors design assist tools

Development phase	Methods / Techniques	Aim
Collect and analyze user needs	<ul style="list-style-type: none"> > Focus group events + Participatory design <i>(Already done in the current study)</i> > Questionnaire > Direct observations + Task analysis > Evaluations of current products (e.g. established design assist tools) 	<ul style="list-style-type: none"> > To investigate users' opinions and latent needs regarding the usage of current HF information and new HF design assist tools > Following the focus group events, to refine and prioritize the collected user needs > To explore users' behavior patterns of using HF information when doing varied design projects in working environments > To widen the area of search for solutions to a design problems
Develop design concepts	<ul style="list-style-type: none"> > Brainstorming > Functional interface design > Graphic interface design 	<ul style="list-style-type: none"> > To stimulate the production of ideas > To create designs that can fit underlying cognitive models of target users > To create designs that can be perceived by target users
Develop prototype models	<ul style="list-style-type: none"> > Usability prototypes > Capability prototypes 	<ul style="list-style-type: none"> > To define, refine, and demonstrate user interface design usability, accessibility, look and feel > To develop, demonstrate, and evaluate the interface design concept
User trials and evaluations	<ul style="list-style-type: none"> > Heuristic analysis > Evaluations of user performance 	<ul style="list-style-type: none"> > To evaluate the usability > To evaluate the usability > To evaluate the usefulness

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APPENDIX A: LIST OF CURRENT LID DESIGNS IN PHASE 1

#	Pictures	Diameter (mm)	Height (mm)	Top Shape	Surface texture
A1		22	15	Round	Serrate
A2		39	9	Round	Serrate
A3		39	12	Round	Serrate
A4		30	16	Round	Serrate

(Appendix A continued on the next page)

(Appendix A continued from the previous page)

#	Pictures	Diameter (mm)	Height (mm)	Top Shape	Surface texture
A5		34	21	Round	Serrate
A6		15	11	Octagon	Smooth
A7		15	10	Round	Serrate
A8		26	23	Ball	Smooth
A9		28	11	Round	Serrate

(Appendix A continued on the next page)

(Appendix A continued from the previous page)

#	Pictures	Diameter (mm)	Height (mm)	Top Shape	Surface texture
A10		35	14	Round	Smooth
A11		33	12	Round	Smooth
A12		34	17	Round	Serrate

(Appendix A continued on the next page)

(Appendix A continued from the previous page)

#	Pictures	Diameter (mm)	Height (mm)	Top Shape	Surface texture
B1		43	16	Round	Smooth
B2		47	22	Round	Smooth
B3		41	15	Round (+tab on top)	Smooth
B4		44	9	Round	Smooth

(Appendix A continued on the next page)

(Appendix A continued from the previous page)

#	Pictures	Diameter (mm)	Height (mm)	Top Shape	Surface texture
B5		41	9	Round	Smooth
B6		41	12	Round	Serrate
B7		45	11	Round	Concave + Serrate
B8		49	10	Round	Smooth
B9		55	9	Round	Smooth

(Appendix A continued on the next page)

(Appendix A continued from the previous page)

#	Pictures	Diameter (mm)	Height (mm)	Top Shape	Surface texture
B10		54	11	Round	Serrate
B11		54	23	Round	Smooth
B12		64	18	Round	Serrate

APPENDIX B: EVALUATION FORM FOR CURRENT LID DESIGNS IN PHASE 1

A

Your name: _____

A 1		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Texture for turning Not helpful ☐ Helpful ☐	Texture for comfort Comfortable ☐ Not comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
<i>Any other reasons you love or hate this lid?</i>						
A 2		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Texture for turning Not helpful ☐ Helpful ☐	Texture for comfort Comfortable ☐ Not comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
<i>Any other reasons you love or hate this lid?</i>						
A 3		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Texture for turning Not helpful ☐ Helpful ☐	Texture for comfort Comfortable ☐ Not comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
<i>Any other reasons you love or hate this lid?</i>						
A 4		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Texture for turning Not helpful ☐ Helpful ☐	Texture for comfort Comfortable ☐ Not comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
<i>Any other reasons you love or hate this lid?</i>						

(Appendix B continued on the next page)

(Appendix B continued from the previous page)

A

Your name: _____

A 5		Diameter			Height			Texture for turning		Texture for comfort		Overall rating							
		Too small	OK	Too large	Too short	OK	Too tall												
		☐	☐	☐	☐	☐	☐	Not helpful	☐	Comfortable	☐	Hate it	☐	Dislike it	☐	Like it	☐	Love it	☐
Any other reasons you love or hate this lid?																			
A 6		Diameter			Height			Texture for turning		Texture for comfort		Overall rating							
		Too small	OK	Too large	Too short	OK	Too tall												
		☐	☐	☐	☐	☐	☐	Not helpful	☐	Comfortable	☐	Hate it	☐	Dislike it	☐	Like it	☐	Love it	☐
Any other reasons you love or hate this lid?																			
A 7		Diameter			Height			Texture for turning		Texture for comfort		Overall rating							
		Too small	OK	Too large	Too short	OK	Too tall												
		☐	☐	☐	☐	☐	☐	Not helpful	☐	Comfortable	☐	Hate it	☐	Dislike it	☐	Like it	☐	Love it	☐
Any other reasons you love or hate this lid?																			
A 8		Diameter			Height			Texture for turning		Texture for comfort		Overall rating							
		Too small	OK	Too large	Too short	OK	Too tall												
		☐	☐	☐	☐	☐	☐	Not helpful	☐	Comfortable	☐	Hate it	☐	Dislike it	☐	Like it	☐	Love it	☐
Any other reasons you love or hate this lid?																			

(Appendix B continued on the next page)

(Appendix B continued from the previous page)

A

Your name: _____

A 9		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Texture for turning Not helpful ☐ Helpful ☐		Texture for comfort Comfortable ☐ Not comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
Any other reasons you love or hate this lid?															
A 10		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Texture for turning Not helpful ☐ Helpful ☐		Texture for comfort Comfortable ☐ Not comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
Any other reasons you love or hate this lid?															
A 11		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Texture for turning Not helpful ☐ Helpful ☐		Texture for comfort Comfortable ☐ Not comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
Any other reasons you love or hate this lid?															
A 12		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Texture for turning Not helpful ☐ Helpful ☐		Texture for comfort Comfortable ☐ Not comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
Any other reasons you love or hate this lid?															

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B

Your name: _____

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APPENDIX C: EVALUATION FORM FOR NEW LID DESIGNS IN PHASE 1

Na

Your name: _____

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Your name: _____

M 1 2		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
<i>Any other reasons you love or hate this lid?</i>															
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<i>Any other reasons you love or hate this lid?</i>															
M 1 9		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
<i>Any other reasons you love or hate this lid?</i>															
S 1 6		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
<i>Any other reasons you love or hate this lid?</i>															

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(Appendix C continued from the previous page)

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Your name: _____

<p>M 9</p>	<p>Diameter</p> <p>Too small ☐ OK ☐ Too large ☐</p>	<p>Height</p> <p>Too short ☐ OK ☐ Too tall ☐</p>	<p>Shape for turning</p> <p>Not helpful ☐ Helpful ☐</p>	<p>Shape for comfort</p> <p>Not comfortable ☐ Comfortable ☐</p>	<p>Overall rating</p> <p>Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐</p>
<p>Any other reasons you love or hate this lid?</p>
<p>S 1 2</p>	<p>Diameter</p> <p>Too small ☐ OK ☐ Too large ☐</p>	<p>Height</p> <p>Too short ☐ OK ☐ Too tall ☐</p>	<p>Shape for turning</p> <p>Not helpful ☐ Helpful ☐</p>	<p>Shape for comfort</p> <p>Not comfortable ☐ Comfortable ☐</p>	<p>Overall rating</p> <p>Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐</p>
<p>Any other reasons you love or hate this lid?</p>
<p>S 1 8</p>	<p>Diameter</p> <p>Too small ☐ OK ☐ Too large ☐</p>	<p>Height</p> <p>Too short ☐ OK ☐ Too tall ☐</p>	<p>Shape for turning</p> <p>Not helpful ☐ Helpful ☐</p>	<p>Shape for comfort</p> <p>Not comfortable ☐ Comfortable ☐</p>	<p>Overall rating</p> <p>Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐</p>
<p>Any other reasons you love or hate this lid?</p>
<p>M 1 1</p>	<p>Diameter</p> <p>Too small ☐ OK ☐ Too large ☐</p>	<p>Height</p> <p>Too short ☐ OK ☐ Too tall ☐</p>	<p>Shape for turning</p> <p>Not helpful ☐ Helpful ☐</p>	<p>Shape for comfort</p> <p>Not comfortable ☐ Comfortable ☐</p>	<p>Overall rating</p> <p>Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐</p>
<p>Any other reasons you love or hate this lid?</p>						

(Appendix C continued on the next page)

(Appendix C continued from the previous page)

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Your name: _____

M 5		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
Any other reasons you love or hate this lid?															
M 3		Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
Any other reasons you love or hate this lid?															

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Your name: _____

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Nb

Your name: _____

S 1 7		Diameter Too small ☐ OK ☐ Too large ☐		Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐		
Any other reasons you love or hate this lid?												
S 1 0		Diameter Too small ☐ OK ☐ Too large ☐		Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐		
Any other reasons you love or hate this lid?												
M 1 3		Diameter Too small ☐ OK ☐ Too large ☐		Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐		
Any other reasons you love or hate this lid?												
S 1 5		Diameter Too small ☐ OK ☐ Too large ☐		Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐		
Any other reasons you love or hate this lid?												

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Nb

Your name: _____

S 1 9
Diameter		Height		Shape for turning		Shape for comfort		Overall rating				
Too small ☐	OK ☐	Too short ☐	OK ☐	Too tall ☐	Not helpful ☐	Helpful ☐	Not comfortable ☐	Comfortable ☐	Hate it ☐	Dislike it ☐	Like it ☐	Love it ☐
Any other reasons you love or hate this lid?												
M 4
Diameter		Height		Shape for turning		Shape for comfort		Overall rating				
Too small ☐	OK ☐	Too short ☐	OK ☐	Too tall ☐	Not helpful ☐	Helpful ☐	Not comfortable ☐	Comfortable ☐	Hate it ☐	Dislike it ☐	Like it ☐	Love it ☐
Any other reasons you love or hate this lid?												

Nc

Your name: _____

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Nc

Your name: _____

Diameter Too small ☐ OK ☐ Too large ☐				Height Too short ☐ OK ☐ Too tall ☐		Shape for turning Not helpful ☐ Helpful ☐		Shape for comfort Not comfortable ☐ Comfortable ☐		Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐			
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Any other reasons you love or hate this lid?														

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Nc

Your name: _____

S 6		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Shape for turning Not helpful ☐ Helpful ☐	Shape for comfort Not comfortable ☐ Comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
Any other reasons you love or hate this lid?						
S 8		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Shape for turning Not helpful ☐ Helpful ☐	Shape for comfort Not comfortable ☐ Comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
Any other reasons you love or hate this lid?						
M 1		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Shape for turning Not helpful ☐ Helpful ☐	Shape for comfort Not comfortable ☐ Comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
Any other reasons you love or hate this lid?						
S 2		Diameter Too small ☐ OK ☐ Too large ☐	Height Too short ☐ OK ☐ Too tall ☐	Shape for turning Not helpful ☐ Helpful ☐	Shape for comfort Not comfortable ☐ Comfortable ☐	Overall rating Hate it ☐ Dislike it ☐ Like it ☐ Love it ☐
Any other reasons you love or hate this lid?						

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(Appendix C continued from the previous page)

Nc

Your name: _____

M 2 0
Diameter		Height		Shape for turning		Shape for comfort		Overall rating				
Too small ☐	OK ☐	Too short ☐	OK ☐	Too tall ☐	Not helpful ☐	Helpful ☐	Not comfortable ☐	Comfortable ☐	Hate it ☐	Dislike it ☐	Like it ☐	Love it ☐
Any other reasons you love or hate this lid?												
M 6
Diameter		Height		Shape for turning		Shape for comfort		Overall rating				
Too small ☐	OK ☐	Too short ☐	OK ☐	Too tall ☐	Not helpful ☐	Helpful ☐	Not comfortable ☐	Comfortable ☐	Hate it ☐	Dislike it ☐	Like it ☐	Love it ☐
Any other reasons you love or hate this lid?												

APPENDIX D: QUESTIONNAIRE AND PHASE 1 PARTICIPANTS' BACKGROUND INFORMATION

Study Title: Jar lid design characteristics for older people
with hand use limitation

Researcher: Wei-Ting Yen and Dr. Carolyn Sommerich (PI)

Participant #: _____

Sign-up date: ____/____/____

Sign-up Sheet

The requirements of participating in this study are –

- Female; and
- 60 years old and above

Please answer the following questions to help me further determine your eligibility.

1. Have you had hand aches or pain in the past month?

☐ Yes ☐ No

2. Have you had difficulties in opening jars/bottles with twisting-off lids?

☐ Yes ☐ No

There are two phases to this study. The first phase is to determine whether or not you meet the inclusion criteria for the second phase of the study, which will be a focus group event.

If you would like to participate in this study, please leave your contact information below and give it to the researcher. The researcher will schedule an appointment for you now.

Your name: _____

Phone number: (____)____-_____

Study Title: Jar lid design characteristics for older people with hand use limitation

Researcher: Wei-Ting Yen and Dr. Carolyn Sommerich (PI)

Participant #: _____

Testing date: ____/____/____

Questionnaire

Section 1 – Background Information

1. What was your age on your last birthday? _____ years old
2. Do you live independently? ☐ Yes ☐ No
3. Would you describe yourself as
☐ Left-handed ☐ Ambidextrous ☐ Right-handed
4. Which hand do you use most often to open a lid on a jar or bottle?
☐ Left hand ☐ Right hand ☐ Either right hand or left hand
5. Do you currently have any hand pain or problem that limits how you use your hands, for example hand osteoarthritis? ☐ Yes ☐ No

If your answer is "Yes", please describe the hand pain or problem –

6. Are you currently undergoing any treatments to alleviate your hand pain?
☐ Yes ☐ No ☐ Not applicable

If your answer is "Yes", please specify _____

7. Using the hand diagrams below, please circle the region(s) where you experience significant pain.

Left hand

Right hand

Section 2 – Activity Assessment

Please tell us about your ability to carry out your daily activities by placing an “X” in the box which best describes your abilities:

Are you able to:	No difficulty	A little difficulty	Some difficulty	Much difficulty	Unable to do
Dress yourself, including shoelaces and buttons?	☐	☐	☐	☐	☐
Shampoo your hair?	☐	☐	☐	☐	☐
Stand up from an armless straight chair?	☐	☐	☐	☐	☐
Get in and out of bed?	☐	☐	☐	☐	☐
Cut your food using eating utensils?	☐	☐	☐	☐	☐
Lift a full cup or glass to your mouth?	☐	☐	☐	☐	☐
Open a new milk carton?	☐	☐	☐	☐	☐
Walk a block on flat ground?	☐	☐	☐	☐	☐
Climb up five steps?	☐	☐	☐	☐	☐
Wash and dry your body?	☐	☐	☐	☐	☐
Take a tub bath?	☐	☐	☐	☐	☐
Get on and off the toilet?	☐	☐	☐	☐	☐
Reach and get down a 5-pound object from above your head?	☐	☐	☐	☐	☐
Bend down to pick up clothing from the floor?	☐	☐	☐	☐	☐

Are you able to:	No difficulty	A little difficulty	Some difficulty	Much difficulty	Unable to do
Open car doors?	☐	☐	☐	☐	☐
Open previously opened jars?	☐	☐	☐	☐	☐
Turn faucets on and off?	☐	☐	☐	☐	☐
Run errands and shop?	☐	☐	☐	☐	☐
Get in and out of a car?	☐	☐	☐	☐	☐
Do chores such as vacuuming or yard work?	☐	☐	☐	☐	☐

For each of the following questions, please answer by placing an "X" in the appropriate box:

	YES	NO
To get around, do you usually need a cane, crutches, walker, wheelchair, or help from another person?	☐	☐
To stand up from a sitting position, do you usually need a special chair, a raised toilet seat, or help from another person?	☐	☐
To get dressed, do you usually need a buttonhook, zipper pull or other gadget, or help from another person?	☐	☐
To reach something, do you usually use long-handled appliances or help from another person?	☐	☐

Your ACTIVITIES: To what extent are you able to carry out your everyday physical activities such as walking, climbing stairs, carrying groceries, or moving a chair?

Completely	Mostly	Moderately	A little	Not at all
☐	☐	☐	☐	☐

Your PAIN: How much pain have you had IN THE PAST WEEK?

On a scale of 0 to 100 (where zero represents "no pain" and 100 represents "severe pain"), please record the number below.

--	--	--

Your HEALTH: Please rate how well you are doing on a scale of 0 to 100 (0 represents "very well" and 100 represents "very poor" health), please record the number below.

--	--	--

Section 3 – Pain Assessment

The following questions refer to how much **pain** you had in your hand(s)/wrist(s) **during the past week** (please answer by placing an "X" in the appropriate box)

	Always	Often	Sometimes	Rarely	Never
How often did you have pain in your hand(s)/wrist(s)?	☐	☐	☐	☐	☐

*If you answered **never** to the question above, please skip the following questions.

	Very mild	Mild	Moderate	Severe	Very severe
Please describe the pain you have in your hand(s)/wrist(s)?	☐	☐	☐	☐	☐

	Always	Often	Sometimes	Rarely	Never
How often did the pain in your hand(s)/wrist(s) interfere with your sleep?	☐	☐	☐	☐	☐

	Always	Often	Sometimes	Rarely	Never
How often did the pain in your hand(s)/wrist(s) interfere with your daily activities (such as eating or bathing)?	☐	☐	☐	☐	☐

	Always	Often	Sometimes	Rarely	Never
How often did the pain in your hand(s)/wrist(s) make you unhappy?	☐	☐	☐	☐	☐

- THE END OF QUESTIONNAIRE -

S#	sex	Age	Hand pain	Diff open	Live ind.	Handed	Hand used open jar	Hand pain limit ADL	Description	Trt	Trt to decrease pain
D5	F	84	Y	Y	Y	R	R	Y	Arthritis	N	-
D3	F	84	Y	Y	Y	R	R	Y	Numbness and stiffness in thumb, point finger, and 4th finger on R. hand. Little finger and ring finger on L.	Y	Joint exercise
D4	F	91	N	Y	Y	R	R	N	-	N	-
D6	F	79	N	Y	Y	R	R	N	-	N/A	-
D8	F	90	N	Y	Y	R	R	N	-	N	-
D14	F	88	Y	Y	Y	R	R	Y	Numb and painful	N	-
D17	F	84	Y	Y	Y	R	R	Y	Occasionally	N	-
D11	F	96	Y	Y	Y	A	L	Y	Hand (*stiffness, no pain)	N	-
D13	F	87	Y	Y	Y	A	R	N	(*pain years ago, no pain now)	N	-
D12	F	84	Y	Y	Y	A	L	N	CTS on right hand	N	-
T1	F	90	Y	Y	Y	R	L	N	-	N	-
T7	F	79	Y	Y	Y	R	R	Y	Also have muscular dystrophy	N	-
T8	F	83	Y	Y	Y	R	R	N	-	N	-
FC1	F	89	Y	Y	Y	R	R	Y	Pain in the joints when using hands	N	-
FC2	F	86	Y	Y	Y	R	R	Y	Pain in joints, not exercise, but joints are stiff	N/A	-
FC3	F	83	Y	Y	Y	R	R	Y	Arthritis in both thumbs and some weakness following bi-lateral CTS	N	-
FC4	F	75	N	Y	Y	R	R	Y	3 fingers very weak + lack of mobility	N/A	-
FC5	F	77	Y	Y	Y	R	R	Y	RA	Y	Drug for RA
FC6	F	85	Y	Y	Y	L	R	N	-	N	-
FC8	F	83	Y	Y	Y	R	R	Y	RA	Y	Treatment for RA
FVD2	F	83	Y	Y	Y	R	R	Y	OA	N	-
FVD3	F	87	Y	Y	Y	R	R	Y	Due to Guillain Barre Syndrome, my hand is very slow and weak	N	Tylenol and conjunction
FVD4	F	87	Y	Y	Y	R	R	N	-	N	-
FVD5	F	87	N	Y	Y	R	R	Y	OA	N	-
FVD6	F	74	Y	Y	Y	R	R	Y	Slight pain mostly from smaller fingers + Ranauuds syndrome	N	-
FVD7	F	89	Y	Y	Y	R	R	Y	Trigger finger numbness	N	-

APPENDIX E: PHASE 1 PARTICIPANTS' HAND FUNCTION ASSESSMENT

S#	PROMIS HAQ			MHQ Pain			MPUT Close			MPUT Open			MVE KP (lb)			MVE CP (lb)			MPH			ROM Thumb		Total Wt score
	Raw data	> 0.5	Wt scor	Raw data	< 4	Wt scor	Raw data	> 28	Wt scor	Raw data	> 16	Wt scor	Raw data	< 10	Wt scor	Raw data	< 10	Wt scor	Raw data	Con.	Wt scor	< 30	Wt scor	
D5	0.28	0	0	4.4	0	0	44.2	1	1	23.6	1	1	11.3	0	0	10.7	0	0	Y	1	2	0	0	4
D3	0.42	0	0	2.6	1	1	100.4	1	1	22.0	1	1	9.7	1	1	5.3	1	1	N	0	0	0	0	6
D4	0.00	0	0	5.0	0	0	41.8	1	1	16.4	1	1	9.7	1	1	11.3	0	0	N	0	0	0	0	3
D6	0.95	1	1	5.0	0	0	35.3	1	1	18.5	1	1	10.3	0	0	8.0	1	1	N	0	0	0	0	4
D8	0.25	0	0	4.8	0	0	42.6	1	1	17.6	1	1	12.0	0	0	13.0	0	0	N	0	0	0	0	2
D14	2.00	1	1	3.6	1	1	43.1	1	1	26.9	1	1	9.3	1	1	6.3	1	1	Y	1	2	0	0	9
D7	1.90	1	1	3.1	1	2	31.7	1	1	15.4	0	0	9.0	1	1	9.3	1	1	Y	1	2	0	0	8
D11	1.05	1	1	3.2	1	2	67.7	1	1	26.5	1	1	9.7	1	1	8.3	1	1	N	0	0	0	0	7
D13	0.21	0	0	4.6	0	0	69.9	1	1	32.1	1	1	7.0	1	1	4.0	1	1	N	0	0	0	0	4
D12	2.00	1	1	2.4	1	2	45.5	1	1	19.4	1	1	5.7	1	1	3.7	1	1	Y	1	2	0	0	9
T1	0.39	0	0	4.8	0	0	32.1	1	1	24.0	1	1	5.0	1	1	5.7	1	1	Y	1	2	0	0	6
T7	1.95	1	1	2.6	1	2	83.3	1	1	57.7	1	1	8.0	1	1	5.5	1	1	Y	1	2	1	1	10
T8	0.95	1	1	5.0	0	0	35.1	1	1	15.6	0	0	9.7	1	1	10.2	0	0	N	0	0	0	0	3
FC1	0.20	0	0	3.2	1	2	36.8	1	1	17.0	1	1	11.0	0	0	13.7	0	0	N	0	0	0	0	4
FC2	1.16	1	1	4.0	1	2	30.1	1	1	16.9	1	1	12.3	0	0	9.0	1	1	N	0	0	0	0	6
FC3	0.68	1	1	4.0	1	2	32.1	1	1	16.0	1	1	10.0	0	0	7.3	1	1	N	0	0	0	0	6
FC4	2.00	1	1	4.8	0	0	50.5	1	1	21.9	1	1	2.7	1	1	2.0	1	1	N	0	0	0	0	5
FC5	1.05	1	1	3.6	1	2	37.1	1	1	25.7	1	1	11.3	0	0	10.0	0	0	N	0	0	0	0	5
FC6	0.40	0	0	4.2	0	0	35.0	1	1	17.9	1	1	8.3	1	1	9.7	1	1	Y	1	2	0	0	6
FC8	1.42	1	1	2.7	1	2	34.2	1	1	16.6	1	1	8.3	1	1	6.3	1	1	N	0	0	0	0	7
FVD2	1.00	1	1	4.2	0	0	47.1	1	1	24.5	1	1	11.0	0	0	8.0	1	1	N	0	0	0	0	4
FVD3	0.45	0	0	3.8	1	2	35.1	1	1	17.0	1	1	8.3	1	1	7.0	1	1	N	0	0	0	0	6
FVD4	0.25	0	0	4.8	0	0	28.6	1	1	16.6	1	1	10.3	0	0	10.0	0	0	Y	1	2	0	0	4
FVD5	0.11	0	0	4.6	0	0	29.2	1	1	17.7	1	1	7.0	1	1	7.0	1	1	N	0	0	0	0	4
FVD6	1.60	1	1	3.0	1	2	66.2	1	1	22.1	1	1	11.7	0	0	14.0	0	0	N	0	0	0	0	5
FVD7	2.10	1	1	2.2	1	2	40.0	1	1	17.9	1	1	7.3	1	1	7.0	1	1	N	0	0	0	0	7
mean	0.95			3.85			45.17			21.68			9.08			8.17			Yes	8		< 30	1	5.54
SD	0.7			0.89			17.63			8.37			2.26			2.96			No	18		> =	25	1.97
median	0.95			4.00			38.58			18.24			9.67			8.00								5.50

**APPENDIX F: COMPARISON OF CURRENT LID
DESIGN'S PREFERENCE RATINGS IN PHASE 1 BASED
ON WILCOXON SIGNED-RANK TEST**

A	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12
A1	-	0.157	0.157	1	0.18	0*	0*	0.003*	0.005*	0.002*	0.001*	0.157
A2	-	-	1	0.317	0.059	0.001*	0*	0.008*	0.014*	0.005*	0.003*	1
A3	-	-	-	0.157	0.025*	0.001*	0*	0.008*	0.014*	0.005*	0.003*	1
A4	-	-	-	-	0.18	0*	0*	0.003*	0.005*	0.002*	0.001*	0.157
A5	-	-	-	-	-	0*	0*	0.001*	0.001*	0*	0*	0.025*
A6	-	-	-	-	-	-	0.083	0.025*	0.014*	0.046*	0.083	0.001*
A7	-	-	-	-	-	-	-	0.005*	0.003*	0.008*	0.014*	0*
A8	-	-	-	-	-	-	-	-	0.317	0.564	0.157	0.008*
A9	-	-	-	-	-	-	-	-	-	0.157	0.083	0.014*
A10	-	-	-	-	-	-	-	-	-	-	0.564	0.005*
A11	-	-	-	-	-	-	-	-	-	-	-	0.003*
A12	-	-	-	-	-	-	-	-	-	-	-	-

B	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
B1	-	0.157	0.02*	0*	0*	1	0.655	0*	0.005*	0.317	0.005*	0.014*
B2	-	-	0.059	0.001*	0.001*	0.157	0.564	0*	0.014*	0.083	0.014*	0.005*
B3	-	-	-	0.008*	0.008*	0.02*	0.014*	0.003*	0.564	0.011*	0.317	0*
B4	-	-	-	-	1	0*	0*	0.414	0.014*	0*	0.014*	0*
B5	-	-	-	-	-	0*	0*	0.157	0.014*	0*	0.014*	0*
B6	-	-	-	-	-	-	0.564	0*	0.005*	0.317	0.005*	0.014*
B7	-	-	-	-	-	-	-	0*	0.008*	0.317	0.008*	0.008*
B8	-	-	-	-	-	-	-	-	0.005*	0*	0.005*	0*
B9	-	-	-	-	-	-	-	-	-	0.003*	1	0*
B10	-	-	-	-	-	-	-	-	-	-	0.003*	0.025*
B11	-	-	-	-	-	-	-	-	-	-	-	0*
B12	-	-	-	-	-	-	-	-	-	-	-	-

**APPENDIX G: COMPARISON OF NEW LID DESIGN'S
PREFERENCE RATINGS IN PHASE 1 BASED ON
WILCOXON SIGNED-RANK TEST**

* P < 0.05

+ P < 0.01

x P < 0.005

S	1	2	3	4
1	-	0.001*	0.18	0.008*
2	-	-	0.011*	0.18
3	-	-	-	0.025*
4	-	-	-	-

M	1	2	3	4
1	-	0.008*	0.18	0.003*
2	-	-	0.157	0.564
3	-	-	-	0.157
4	-	-	-	-

S	5	6	7	8	9
5	-	0.059	0.059	0.014*	0.102
6	-	-	1	0.001*	0.317
7	-	-	-	0.001*	0.317
8	-	-	-	-	0.002*
9	-	-	-	-	-

M	5	6	7	8	9
5	-	1	0.157	0.002*	0.317
6	-	-	0.157	0.002*	0.157
7	-	-	-	0.005*	0.046*
8	-	-	-	-	0.001*
9	-	-	-	-	-

S	10	11	12	13	14
10	-	0.564	0.157	0.001*	0.083
11	-	-	0.083	0.002*	0.18
12	-	-	-	0*	1
13	-	-	-	-	0*
14	-	-	-	-	-

M	10	11	12	13	14
10	-	0.655	0.317	1	0.056
11	-	-	1	0.655	0.083
12	-	-	-	0.317	0.083
13	-	-	-	-	0.056
14	-	-	-	-	-

S	5	6	7	8	9
10	0.002*	-	-	-	-
11	-	0.083	-	-	-
12	-	-	0.005*	-	-
13	-	-	-	0.014*	-
14	-	-	-	-	0.002*

M	5	6	9	8	7
10	0.083	-	-	-	-
11	-	0.18	-	-	-
12	-	-	0.055	-	-
13	-	-	-	0*	-
14	-	-	-	-	0.056

S	15	16	17
15	-	0.025*	0.157
16	-	-	0.043*
17	-	-	-

M	15	16	17
15	-	0.18	0.564
16	-	-	0.157
17	-	-	-

S	18	19	20	21
18	-	0.003*	0.083	0.025*
19	-	-	0.001*	0*
20	-	-	-	0.317
21	-	-	-	-

M	18	19	20	21
18	-	0.043*	0.317	0.18
19	-	-	0.025*	0.014*
20	-	-	-	0.705
21	-	-	-	-

S	15	16	17
18	0.059	-	-
19	-	0.317	-
20	-	-	0.003*

M	15	16	17
18	0.059	-	-
19	-	0.317	-
20	-	-	0.005*

S	M	P value
1	1	0.157
2	2	0.025*
3	3	0.655
4	4	0.317
5	5	0.007*
6	6	0.046*
7	7	0.157
8	8	0.025*
9	9	0.008*
10	10	0.564
11	11	0.414
12	12	0.317
13	13	0.001*
14	14	0.157
15	15	0.414
16	16	0.046*
17	17	0.046*
18	18	0.317
19	19	0.046*
20	20	0.317
21	21	0.317

**APPENDIX H: COMPARISON OF NEW LID DESIGN'S
PREFERENCE RATINGS BETWEEN HAND FUNCTION
GROUPS IN PHASE 1 BASED ON WILCOXON
SIGNED-RANK TEST**

S	P value	M	P value
1	0.157	1	0.083
2	0.014*	2	0.564
3	0.046*	3	0.046*
4	0.083	4	0.317
5	0.046*	5	0.317
6	0.564	6	0.157
7	0.083	9	0.317
8	0.564	8	0.317
9	1	7	0.317
10	0.317	10	0.317
11	0.317	11	0.083
12	0.014*	12	0.083
13	0.046*	13	0.157
14	0.317	14	0.157
15	0.014*	15	0.157
16	0.083	16	0.083
17	0.157	17	1
18	0.025*	18	1
19	0.046*	19	1
20	0.025*	20	0.046*
21	0.157	21	0.073

APPENDIX I: PHASE 2 PARTICIPANTS' HAND DIMENSIONS

	Hand breadth	Hand length	Thumb length	Index length	Middle length	Thumb 1	Thumb J1	Thumb 2	Index 1	Index J1	Index 2	Index J2	Index 3
D3	75	155	58	68	72	14	18	17	13	16	13	14	11
D6	83	173	56	71	75	15	17	15	15	17	15	15	12
D7	73	170	60	69	73	15	16	14	15	16	13	14	11
D8	75	170	56	66	70	15	18	15	13	19	14	15	11
D10	73	172	60	64	69	14	18	16	15	18	14	15	12
D11	74	153	53	55	62	14	18	15	15	16	15	15	13
T1	70	155	48	61	68	12	16	14	12	15	12	14	11
T6	82	173	50	70	74	13	19	14	15	18	13	15	11
T7	76	181	59	65	77	15	18	15	14	18	12	15	12
T8	69	162	52	61	70	14	16	13	13	15	12	13	10
FC1	81	180	56	69	73.5	13.5	20	16	14.5	21	13	17.5	13.5
FC2	72	163	54	64	66.5	15	20	16	11.5	19	13	16	13
FC3	76	167	61	65	73	15	18.5	16	15	17.5	12	14	12
FC8	79	168	56	64	74	16	20	15	16	18	14	15	13
FVD1	75	170	56	66	70	15	18	15	13	19	14	15	11
FVD2	70	190	53	69	77	16	21	17	14	20	13	17	12.5
FVD3	63.5	157.5	56	61	69	12	20	13	10	15	11	14	11
FVD6	77	169	57	61	66	16	21	17	18	19	18	18	17

	Middle 1	Middle J1	Middle 2	Middle J2	Middle 3
D3	12	18	13	14	12
D6	14	17	13	14	11
D7	13	16	13	14	11
D8	12	18	14	14	11
D10	13	16	12	17	12
D11	14	16	13	15	13
T1	10	15	11	14	12
T6	14	18	13	15	12
T7	13	17	12	16	12
T8	11	14	12	13	10
FC1	13	22.5	13.5	18	13.5
FC2	15	17.5	12	16	13
FC3	14	17	14	13	11
FC8	14.5	18	14	16	12.5
FVD1	12	18	14	14	11
FVD2	12	22	13	17	13
FVD3	11	18	10	13.5	11
FVD6	16	18	17	19	16

APPENDIX J: PHASE 2 PARTICIPANTS' HAND FUNCTION ASSESSMENT

S#	PROMIS HAQ			MHQ Pain			MPUT Close			MPUT Open			MVE KP				MVE CP				MPH			ROM Thumb		Total Wt score	
	Raw data	> 0.5	Wt	Raw data	< 4	Wt	Raw data	>	Wt	Raw data	>	Wt	(lb)	(kg)	< 4.5	Wt	(lb)	(kg)	< 4.5	Wt	Raw data	Con.	Wt	< 30	Wt		
D10	1.72	1	1	3.4	1	2	58.8	1	1	29.8	1	1	9.7	4.38	1	1	7.7	3.48	1	1	1	1	0	0	0	0	7
D11	1.05	1	1	3.2	1	2	67.7	1	1	26.5	1	1	9.7	4.38	1	1	8.3	3.78	1	1	1	1	0	0	0	0	7
D3	0.42	0	0	2.6	1	2	100.4	1	1	22.0	1	1	9.7	4.38	1	1	5.3	2.42	1	1	1	1	0	0	0	0	6
D6	0.95	1	1	5.0	0	0	35.3	1	1	18.5	1	1	10.3	4.59	0	0	8.0	3.63	1	1	1	1	0	0	0	0	4
D7	1.90	1	1	3.1	1	2	31.7	1	1	15.4	0	0	9.0	4.08	1	1	9.3	4.23	1	1	1	1	1	2	0	0	8
D8	0.25	0	0	4.8	0	0	42.6	1	1	17.6	1	1	12.0	5.44	0	0	13.0	5.90	0	0	0	0	0	0	0	0	2
FC1	0.20	0	0	3.2	1	2	36.8	1	1	17.0	1	1	11.0	4.99	0	0	13.7	6.20	0	0	0	0	0	0	0	0	4
FC2	1.16	1	1	4.0	1	2	30.1	1	1	16.9	1	1	12.3	5.59	0	0	9.0	4.08	1	1	1	1	0	0	0	0	6
FC3	0.68	1	1	4.0	1	2	32.1	1	1	16.0	1	1	10.0	4.54	0	0	7.3	3.33	1	1	1	1	0	0	0	0	6
FC8	1.42	1	1	2.7	1	2	34.2	1	1	16.6	1	1	8.3	3.78	1	1	6.3	2.87	1	1	1	1	0	0	0	0	7
FVD1	2.55	1	1	3.0	1	2	49.0	1	1	31.3	1	1	6.0	2.72	1	1	7.7	3.48	1	1	1	1	0	0	0	0	7
FVD2	1.00	1	1	4.2	0	0	47.1	1	1	24.5	1	1	11.0	4.99	0	0	8.0	3.63	1	1	1	1	0	0	0	0	4
FVD3	0.45	0	0	3.8	1	2	35.1	1	1	17.0	1	1	8.3	3.78	1	1	7.0	3.17	1	1	1	1	0	0	0	0	6
FVD6	1.60	1	1	3.0	1	2	66.2	1	1	22.1	1	1	11.7	5.29	0	0	14.0	6.35	0	0	0	0	0	0	0	0	5
T1	0.39	0	0	4.8	0	0	32.1	1	1	24.0	1	1	5.0	2.27	1	1	5.7	2.57	1	1	1	1	1	2	0	0	6
T6	1.37	1	1	3.0	1	2	29.6	1	1	18.7	1	1	14.3	6.50	0	0	14.3	6.50	0	0	0	0	0	0	0	0	5
T7	1.95	1	1	2.6	1	2	83.3	1	1	57.7	1	1	8.0	3.63	1	1	5.5	2.49	1	1	1	1	1	2	1	1	10
T8	0.95	1	1	5.0	0	0	35.1	1	1	15.6	0	0	9.7	4.38	1	1	10.2	4.61	0	0	0	0	0	0	0	0	3

**APPENDIX K: COMPARISON OF PARTICIPANTS' MVTS
BETWEEN HAND FUNCTION GROUPS IN PHASE 2
BASED ON ONE-WAY ANOVA TEST**

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ONEWAY MVT_M MVT_S BY Hand_condition
/MISSING ANALYSIS
/POSTHOC=TUKEY ALPHA(0.05) .

```

One-way ANOVA

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
MVT_M	Between Groups	14204.162	2	7102.081	4.761	.015
	Within Groups	49224.838	33	1491.662		
	Total	63429.000	35			
MVT_S	Between Groups	1438.488	2	719.244	2.564	.092
	Within Groups	9255.734	33	280.477		
	Total	10694.222	35			

Post Hoc Tests

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Hand_condition	(J) Hand_condition	Mean Difference (I-J)	Std. Error
MVT_M	1	2	-57.623 [*]	18.674
		3	-22.409	14.781
	2	1	57.623 [*]	18.674
		3	35.214	17.204
	3	1	22.409	14.781
		2	-35.214	17.204
MVT_S	1	2	-18.338	8.097
		3	-7.131	6.409
	2	1	18.338	8.097
		3	11.206	7.460
	3	1	7.131	6.409
		2	-11.206	7.460

Multiple Comparisons

Tukey HSD

Dependent Variable	(I) Hand_condition	(J) Hand_condition	Sig.
MVT_M	1	2	.011
		3	.297
	2	1	.011
		3	.117
	3	1	.297
		2	.117
MVT_S	1	2	.075
		3	.513
	2	1	.075
		3	.303
	3	1	.513
		2	.303

**APPENDIX L: ESTIMATED REMOVAL TORQUE
REQUIREMENTS FOR JAR LIDS ON CURRENT
PRODUCTS IN PHASE 2**

Closure Diameter	Application torque				Estimated removal torque (40% ~ 60% of application torque)	
	(in-lb)		(N-cm)		(N-cm)	
	From	To	From	To	From	To
24 mm	10	18	113.0	203.4	45.20	122.04
28 mm	12	21	135.6	237.3	<u>54.24</u>	<u>142.38</u>
38 mm	17	26	192.1	293.8	76.84	176.28
43 mm	17	27	192.1	305.1	<u>76.84</u>	<u>183.06</u>
48 mm	19	30	214.7	339.0	85.88	203.40
53 mm	21	36	237.3	406.8	94.92	244.08
63 mm	25	43	282.5	485.9	11.30	291.54
70 mm	28	50	316.4	565.0	126.56	339.00
89 mm	40	70	452.0	791.0	180.80	474.60
110 mm	45	70	508.5	791.0	203.40	474.60

(Source: <http://www.reliablecap.com/torque.htm>)

**APPENDIX M: TESTS OF NORMAL DISTRIBUTION FOR
DATASETS IN PHASE 2 BASED ON
KOLMOGOROV-SMIRNOV TEST**


```

*Nonparametric Tests: One Sample.
NPTESTS
  /ONESAMPLE TEST (M1 M2 M3 M4 M5 M6 M7 M8 M9 M10 M11 M12 M13 M14 M15 M16)
  /MISSING SCOPE=ANALYSIS USERMISSING=EXCLUDE
  /CRITERIA ALPHA=0.05 CILEVEL=95.

*Nonparametric Tests: One Sample.
NPTESTS
  /ONESAMPLE TEST (S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15 S16)
  /MISSING SCOPE=ANALYSIS USERMISSING=EXCLUDE
  /CRITERIA ALPHA=0.05 CILEVEL=95.

```

Nonparametric Tests

(Medium lids)

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of M1 is normal with mean 4.11 and standard deviation 1.17.	One-Sample Kolmogorov-Smirnov Test	.175	Retain the null hypothesis.
2	The distribution of M2 is normal with mean 4.56 and standard deviation 1.29.	One-Sample Kolmogorov-Smirnov Test	.338	Retain the null hypothesis.
3	The distribution of M3 is normal with mean 4.25 and standard deviation 1.33.	One-Sample Kolmogorov-Smirnov Test	.565	Retain the null hypothesis.
4	The distribution of M4 is normal with mean 4.39 and standard deviation 1.20.	One-Sample Kolmogorov-Smirnov Test	.582	Retain the null hypothesis.
5	The distribution of M5 is normal with mean 3.89 and standard deviation 1.23.	One-Sample Kolmogorov-Smirnov Test	.451	Retain the null hypothesis.
6	The distribution of M6 is normal with mean 5.17 and standard deviation 1.72.	One-Sample Kolmogorov-Smirnov Test	.537	Retain the null hypothesis.
7	The distribution of M7 is normal with mean 3.02 and standard deviation 1.33.	One-Sample Kolmogorov-Smirnov Test	.200	Retain the null hypothesis.
8	The distribution of M8 is normal with mean 4.89 and standard deviation 1.33.	One-Sample Kolmogorov-Smirnov Test	.541	Retain the null hypothesis.
9	The distribution of M9 is normal with mean 3.75 and standard deviation 1.14.	One-Sample Kolmogorov-Smirnov Test	.482	Retain the null hypothesis.
10	The distribution of M10 is normal with mean 5.42 and standard deviation 1.29.	One-Sample Kolmogorov-Smirnov Test	.596	Retain the null hypothesis.
11	The distribution of M11 is normal with mean 3.92 and standard deviation 1.19.	One-Sample Kolmogorov-Smirnov Test	.035	Reject the null hypothesis.
12	The distribution of M12 is normal with mean 5.22 and standard deviation 1.35.	One-Sample Kolmogorov-Smirnov Test	.288	Retain the null hypothesis.
13	The distribution of M13 is normal with mean 3.44 and standard deviation 0.86.	One-Sample Kolmogorov-Smirnov Test	.190	Retain the null hypothesis.
14	The distribution of M14 is normal with mean 4.64 and standard deviation 1.16.	One-Sample Kolmogorov-Smirnov Test	.099	Retain the null hypothesis.
15	The distribution of M15 is normal with mean 3.30 and standard deviation 1.14.	One-Sample Kolmogorov-Smirnov Test	.002	Retain the null hypothesis.
16	The distribution of M16 is normal with mean 5.39 and standard deviation 1.61.	One-Sample Kolmogorov-Smirnov Test	.428	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

(Small lids)

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of S1 is normal with mean 3.94 and standard deviation 0.87.	One-Sample Kolmogorov-Smirnov Test	.202	Retain the null hypothesis.
2	The distribution of S2 is normal with mean 4.94 and standard deviation 1.15.	One-Sample Kolmogorov-Smirnov Test	.180	Retain the null hypothesis.
3	The distribution of S3 is normal with mean 3.33 and standard deviation 1.03.	One-Sample Kolmogorov-Smirnov Test	.428	Retain the null hypothesis.
4	The distribution of S4 is normal with mean 4.50 and standard deviation 1.58.	One-Sample Kolmogorov-Smirnov Test	.100	Retain the null hypothesis.
5	The distribution of S5 is normal with mean 3.44 and standard deviation 1.10.	One-Sample Kolmogorov-Smirnov Test	.509	Retain the null hypothesis.
6	The distribution of S6 is normal with mean 4.11 and standard deviation 0.76.	One-Sample Kolmogorov-Smirnov Test	.322	Retain the null hypothesis.
7	The distribution of S7 is normal with mean 3.39 and standard deviation 0.80.	One-Sample Kolmogorov-Smirnov Test	.332	Retain the null hypothesis.
8	The distribution of S8 is normal with mean 4.08 and standard deviation 1.01.	One-Sample Kolmogorov-Smirnov Test	.148	Retain the null hypothesis.
9	The distribution of S9 is normal with mean 3.97 and standard deviation 1.09.	One-Sample Kolmogorov-Smirnov Test	.627	Retain the null hypothesis.
10	The distribution of S10 is normal with mean 5.39 and standard deviation 1.09.	One-Sample Kolmogorov-Smirnov Test	.069	Retain the null hypothesis.
11	The distribution of S11 is normal with mean 3.78 and standard deviation 1.11.	One-Sample Kolmogorov-Smirnov Test	.227	Retain the null hypothesis.
12	The distribution of S12 is normal with mean 5.44 and standard deviation 1.62.	One-Sample Kolmogorov-Smirnov Test	.828	Retain the null hypothesis.
13	The distribution of S13 is normal with mean 3.39 and standard deviation 1.09.	One-Sample Kolmogorov-Smirnov Test	.069	Retain the null hypothesis.
14	The distribution of S14 is normal with mean 4.94 and standard deviation 1.21.	One-Sample Kolmogorov-Smirnov Test	.249	Retain the null hypothesis.
15	The distribution of S15 is normal with mean 3.11 and standard deviation 1.02.	One-Sample Kolmogorov-Smirnov Test	.490	Retain the null hypothesis.
16	The distribution of S16 is normal with mean 5.47 and standard deviation 1.40.	One-Sample Kolmogorov-Smirnov Test	.550	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

APPENDIX N: ANALYSIS RESULTS OF LID DESIGN CHARACTERISTICS IN MEDIUM LIDS IN PHASE 2

Medium lids
All subjects
Mixed model
Fixed effects

SPSS Code:

```
MIXED M_Borg BY SubID TopShape SideShape Height Texture
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0,
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=TopShape SideShape Height Texture TopShape*SideShape TopShape*Height TopShape*Texture
    SideShape*Height SideShape*Texture Height*Texture TopShape*SideShape*Height
    TopShape*SideShape*Texture TopShape*Height*Texture SideShape*Height*Texture | SSTYPE(3)
  /METHOD=REML
  /RANDOM=SubID | COVTYPE(CS)
  /REPEATED=TopShape*SideShape*Height*Texture | SUBJECT(SubID) COVTYPE(CS)
  /EMMEANS = TABLES(TopShape*SideShape) COMPARE(TopShape)
  /EMMEANS = TABLES(TopShape*SideShape) COMPARE(Sideshape)
  /EMMEANS = TABLES(TopShape*Height) COMPARE(TopShape)
  /EMMEANS = TABLES(TopShape*Height) COMPARE(Height)
  /EMMEANS = TABLES(Sideshape*Height) COMPARE(Sideshape)
  /EMMEANS = TABLES(Sideshape*Height) COMPARE(Height).
```

Type III Tests of Fixed Effects^a

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	10.789	419.671	.000
TopShape	1	350.618	1.073	.301
SideShape	1	350.618	.001	.975
Height	1	350.618	104.066	.000
Texture	1	350.618	.167	.683
TopShape * SideShape	1	350.618	5.250	.023
TopShape * Height	1	350.618	4.691	.031
TopShape * Texture	1	350.618	.285	.594
SideShape * Height	1	350.618	14.425	.000
SideShape * Texture	1	350.618	1.073	.301
Height * Texture	1	350.618	.025	.875
TopShape * SideShape * Height	1	350.618	2.563	.110
TopShape * SideShape * Texture	1	350.618	1.073	.301
TopShape * Height * Texture	1	350.618	1.822	.178
SideShape * Height * Texture	1	350.618	1.499	.222

a. Dependent Variable: M_Borg.

Medium lids
All subjects
Top shape * Side shape

Pairwise Comparisons^b

(I) SideShape	(J) TopShape	(J) TopShape	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
C	H	R	-.368 [*]	.156	350.618	.019	-.676	-.060
	R	H	.368 [*]	.156	350.618	.019	.060	.676
F	H	R	.139	.156	350.618	.375	-.169	.447
	R	H	-.139	.156	350.618	.375	-.447	.169

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg.

Pairwise Comparisons^b

TopShape	(I) SideShape	(J) SideShape	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
H	C	F	-.257	.156	350.618	.101	-.565	.051
	F	C	.257	.156	350.618	.101	-.051	.565
R	C	F	.250	.156	350.618	.111	-.058	.558
	F	C	-.250	.156	350.618	.111	-.558	.058

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg.

Medium lids
All subjects
Top shape * Height

Pairwise Comparisons^b

	(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
h	H	R	-.354 [*]	.156	350.618	.024	-.662	-.046
	R	H	.354 [*]	.156	350.618	.024	.046	.662
s	H	R	.125	.156	350.618	.425	-.183	.433
	R	H	-.125	.156	350.618	.425	-.433	.183

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg.

Pairwise Comparisons^b

TopSha pe	(I) Height	(J) Height	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
H	h	s	-1.368 [*]	.156	350.618	.000	-1.676	-1.060
	s	h	1.368 [*]	.156	350.618	.000	1.060	1.676
R	h	s	-.889 [*]	.156	350.618	.000	-1.197	-.581
	s	h	.889 [*]	.156	350.618	.000	-.581	1.197

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg.

Medium lids
All subjects
Side shape * Height

Pairwise Comparisons^b

Height	(I) SideShape	(J) SideShape	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
h	C	F	-.424 [*]	.156	350.618	.007	-.731	-.116
	F	C	.424 [*]	.156	350.618	.007	.116	.731
s	C	F	.417 [*]	.156	350.618	.008	.109	.724
	F	C	-.417 [*]	.156	350.618	.008	-.724	-.109

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg.

Pairwise Comparisons^b

SideShape	(I) Height	(J) Height	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
C	h	s	-1.549 [*]	.156	350.618	.000	-1.856	-1.241
	s	h	1.549 [*]	.156	350.618	.000	1.241	1.856
F	h	s	-.708 [*]	.156	350.618	.000	-1.016	-.401
	s	h	.708 [*]	.156	350.618	.000	.401	1.016

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg.

Medium lids
Hand healthier subjects
Mixed model
Fixed effects

SPSS Code:

```
MIXED M_Borg_H BY SubID_H TopShape_H SideShape_H Height_H Texture_H  
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0,  
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)  
  /FIXED=TopShape_H SideShape_H Height_H Texture_H TopShape_H*SideShape_H TopShape_H*Height_H  
    TopShape_H*Texture_H SideShape_H*Height_H SideShape_H*Texture_H Height_H*Texture_H  
    TopShape_H*SideShape_H*Height_H TopShape_H*SideShape_H*Texture_H TopShape_H*Height_H*Texture_H  
    SideShape_H*Height_H*Texture_H TopShape_H*SideShape_H*Height_H*Texture_H | SSTYPE(3)  
  /METHOD=REML  
  /RANDOM=SubID_H | COVTYPE(CS)  
  /REPEATED=TopShape_H*SideShape_H*Height_H*Texture_H | SUBJECT(SubID_H) COVTYPE(CS)  
  /EMMEANS = TABLES(Sideshape_H*Height_H) COMPARE(Sideshape_H)  
  /EMMEANS = TABLES(Sideshape_H*Height_H) COMPARE(Height_H).
```

Type III Tests of Fixed Effects^a

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	19218.194	3.248	.072
TopShape_H	1	90.000	1.545	.217
SideShape_H	1	90.000	2.746	.101
Height_H	1	90.000	33.640	.000
Texture_H	1	90.000	2.478	.119
TopShape_H * SideShape_H	1	90.000	1.758	.188
TopShape_H * Height_H	1	90.000	.247	.620
TopShape_H * Texture_H	1	90.000	.336	.563
SideShape_H * Height_H	1	90.000	7.476	.008
SideShape_H * Texture_H	1	90.000	.989	.323
Height_H * Texture_H	1	90.000	.110	.741
TopShape_H * SideShape_H * Height_H	1	90.000	1.545	.217
TopShape_H * SideShape_H * Texture_H	1	90.000	.989	.323
TopShape_H * Height_H * Texture_H	1	90.000	.989	.323
SideShape_H * Height_H * Texture_H	1	90.000	1.160	.284
TopShape_H * SideShape_H * Height_H * Texture_H	1	90.000	1.984	.162

a. Dependent Variable: M_Borg_H.

Medium lids
Hand healthier subjects
Side shape * Height

Pairwise Comparisons^b

							95% Confidence Interval for Difference ^a	
	(I)	(J)	Mean Difference				Lower	Upper
	Height_ape_H	SideSh_ape_H	(I-J)	Std. Error	df	Sig. ^a	Bound	Bound
h	C	F	-.232	.305	90.000	.448	-.838	.373
	F	C	.232	.305	90.000	.448	-.373	.838
s	C	F	.946 [*]	.305	90.000	.003	.341	1.552
	F	C	-.946 [*]	.305	90.000	.003	-1.552	-.341

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

b. Dependent Variable: M_Borg_H.

Pairwise Comparisons^b

			Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
(I)	(J)	Lower Bound					Upper Bound	
SideShape_H	Height_H	Height_H						
C	h	s	-1.839 [*]	.305	90.000	.000	-2.445	-1.234
	s	h	1.839 [*]	.305	90.000	.000	1.234	2.445
F	h	s	-.661 [*]	.305	90.000	.033	-1.266	-.055
	s	h	.661 [*]	.305	90.000	.033	.055	1.266

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg_H.

Medium lids
Hand dysfunctional subjects
Mixed model
Fixed effects

SPSS Code:

```
MIXED M_Borg_D BY SubID_D TopShape_D SideShape_D Height_D Texture_D
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0,
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=TopShape_D SideShape_D Height_D Texture_D TopShape_D*SideShape_D TopShape_D*Height_D
TopShape_D*Texture_D SideShape_D*Height_D SideShape_D*Texture_D Height_D*Texture_D
TopShape_D*SideShape_D*Height_D TopShape_D*SideShape_D*Texture_D TopShape_D*Height_D*Texture_D
SideShape_D*Height_D*Texture_D | SSTYPE(3)
  /METHOD=REML
  /RANDOM=SubID_D | COVTYPE(CS)
  /REPEATED=TopShape_D*SideShape_D*Height_D*Texture_D | SUBJECT(SubID_D) COVTYPE(CS)
  /EMMEANS = TABLES(TopShape_D*Height_D) COMPARE(TopShape_D)
  /EMMEANS = TABLES(TopShape_D*Height_D) COMPARE(Height_D)
  /EMMEANS = TABLES(Sideshape_D*Height_D) COMPARE(Sideshape_D)
  /EMMEANS = TABLES(Sideshape_D*Height_D) COMPARE(Height_D).
```

Type III Tests of Fixed Effects^a

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	7.446	280.051	.000
TopShape_D	1	196.419	.017	.897
SideShape_D	1	196.419	3.154	.077
Height_D	1	196.419	64.209	.000
Texture_D	1	196.419	1.173	.280
TopShape_D * SideShape_D	1	196.419	3.154	.077
TopShape_D * Height_D	1	196.419	6.095	.014
TopShape_D * Texture_D	1	196.419	.017	.897
SideShape_D * Height_D	1	196.419	5.675	.018
SideShape_D * Texture_D	1	196.419	.152	.697
Height_D * Texture_D	1	196.419	.017	.897
TopShape_D * SideShape_D * Height_D	1	196.419	.827	.364
TopShape_D * SideShape_D * Texture_D	1	196.419	.152	.697
TopShape_D * Height_D * Texture_D	1	196.419	.677	.412
SideShape_D * Height_D * Texture_D	1	196.419	.317	.574

a. Dependent Variable: M_Borg_D.

Medium lids
Hand dysfunctional subjects
Top shape * Height

Pairwise Comparisons^b

(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
h	H	-.341	.186	196.419	.068	-.707	.025
	R	.341	.186	196.419	.068	-.025	.707
s	H	.307	.186	196.419	.100	-.059	.673
	R	-.307	.186	196.419	.100	-.673	.059

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg_D.

Pairwise Comparisons^b

(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
H	h	-1.375 [*]	.186	196.419	.000	-1.741	-1.009
	s	1.375 [*]	.186	196.419	.000	1.009	1.741
R	h	-.727 [*]	.186	196.419	.000	-1.093	-.361
	s	.727 [*]	.186	196.419	.000	.361	1.093

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg_D.

Medium lids
Hand dysfunctional subjects
Side shape * Height

Pairwise Comparisons^b

(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
h	C F	-.545 [*]	.186	196.419	.004	-.911	-.180
	F C	.545 [*]	.186	196.419	.004	.180	.911
s	C F	.080	.186	196.419	.669	-.286	.445
	F C	-.080	.186	196.419	.669	-.445	.286

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg_D.

Pairwise Comparisons^b

(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
C	h s	-1.364 [*]	.186	196.419	.000	-1.729	-.998
	s h	1.364 [*]	.186	196.419	.000	.998	1.729
F	h s	-.739 [*]	.186	196.419	.000	-1.104	-.373
	s h	.739 [*]	.186	196.419	.000	.373	1.104

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: M_Borg_D.

APPENDIX O: ANALYSIS RESULTS OF LID DESIGN CHARACTERISTICS IN SMALL LIDS IN PHASE 2

Small lids
All subjects
Mixed model
Fixed effects

SPSS Code:

```
MIXED S_Borg BY SubID TopShape SideShape Height Texture  
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0,  
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)  
  /FIXED=TopShape SideShape Height Texture TopShape*SideShape TopShape*Height TopShape*Texture  
    SideShape*Height SideShape*Texture Height*Texture TopShape*SideShape*Height  
    TopShape*SideShape*Texture TopShape*Height*Texture SideShape*Height*Texture | SSTYPE(3)  
  /METHOD=REML  
  /RANDOM=SubID | COVTYPE(CS)  
  /REPEATED=TopShape*SideShape*Height*Texture | SUBJECT(SubID) COVTYPE(CS)  
  /EMMEANS = TABLES(Sideshape*Height) COMPARE(Sideshape)  
  /EMMEANS = TABLES(Sideshape*Height) COMPARE(Height).
```

Type III Tests of Fixed Effects^a

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	17.020	813.826	.000
TopShape	1	256.000	13.173	.000
SideShape	1	256.000	16.369	.000
Height	1	256.000	126.455	.000
Texture	1	256.000	1.278	.259
TopShape * SideShape	1	256.000	.004	.953
TopShape * Height	1	256.000	.000	1.000
TopShape * Texture	1	256.000	2.039	.155
SideShape * Height	1	256.000	14.051	.000
SideShape * Texture	1	256.000	1.873	.172
Height * Texture	1	256.000	1.713	.192
TopShape * SideShape * Height	1	256.000	3.186	.075
TopShape * SideShape * Texture	1	256.000	.354	.552
TopShape * Height * Texture	1	256.000	.173	.677
SideShape * Height * Texture	1	256.000	.906	.342

a. Dependent Variable: S_Borg.

Small lids
All subjects
Side shape * Height

Pairwise Comparisons^b

	(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
h	C	F	.035	.165	256.000	.834	-.290	.360
	F	C	-.035	.165	256.000	.834	-.360	.290
s	C	F	.910 [*]	.165	256.000	.000	.585	1.235
	F	C	-.910 [*]	.165	256.000	.000	-1.235	-.585

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

b. Dependent Variable: S_Borg.

Pairwise Comparisons^b

SideSha pe	(I) Height	(J) Height	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
C	h	s	-1.750 [*]	.165	256.000	.000	-2.075	-1.425
	s	h	1.750 [*]	.165	256.000	.000	1.425	2.075
F	h	s	-.875 [*]	.165	256.000	.000	-1.200	-.550
	s	h	.875 [*]	.165	256.000	.000	.550	1.200

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: S_Borg.

Small lids
Hand healthier subjects
Mixed model
Fixed effects

SPSS Code:

```
MIXED S_Borg_H BY SubID_H TopShape_H SideShape_H Height_H Texture_H
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    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=TopShape_H SideShape_H Height_H Texture_H TopShape_H*SideShape_H TopShape_H*Height_H
    TopShape_H*Texture_H SideShape_H*Height_H SideShape_H*Texture_H Height_H*Texture_H
    TopShape_H*SideShape_H*Height_H SideShape_H*Height_H*Texture_H | SSTYPE(3)
  /METHOD=REML
  /RANDOM=SubID_H | COVTYPE(CS)
  /REPEATED=TopShape_H*SideShape_H*Height_H*Texture_H | SUBJECT(SubID_H) COVTYPE(CS)
  /EMMEANS = TABLES(Sideshape_H*Height_H) COMPARE(Sideshape_H)
  /EMMEANS = TABLES(Sideshape_H*Height_H) COMPARE(Height_H)
  /EMMEANS = TABLES(TopShape_H*Sideshape_H*Height_H) COMPARE(TopShape_H)
  /EMMEANS = TABLES(TopShape_H*Sideshape_H*Height_H) COMPARE(Sideshape_H)
  /EMMEANS = TABLES(TopShape_H*Sideshape_H*Height_H) COMPARE(Height_H).
```

Type III Tests of Fixed Effects^a

Source	Numerator df	Denominator df	F	Sig.
Intercept	1	3.263	175.248	.001
TopShape_H	1	135.802	1.920	.168
SideShape_H	1	135.802	9.721	.002
Height_H	1	135.802	63.488	.000
Texture_H	1	135.802	.053	.818
TopShape_H * SideShape_H	1	135.802	.213	.645
TopShape_H * Height_H	1	135.802	1.920	.168
TopShape_H * Texture_H	1	135.802	.120	.730
SideShape_H * Height_H	1	135.802	7.054	.009
SideShape_H * Texture_H	1	135.802	.053	.818
Height_H * Texture_H	1	135.802	.053	.818
TopShape_H * SideShape_H * Height_H	1	135.802	7.681	.006
TopShape_H * SideShape_H * Texture_H	1	135.802	.013	.908
TopShape_H * Height_H * Texture_H	1	135.802	.013	.908
SideShape_H * Height_H * Texture_H	1	135.802	.053	.818
TopShape_H * SideShape_H * Height_H * Texture_H	1	135.802	1.080	.301

a. Dependent Variable: S_Borg_H.

Small lids
Hand healthier subjects
Side shape * Height

Pairwise Comparisons^b

(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
Height_ H	SideSh ape_H	SideSh ape_H					
	C	F	.071	.229	114.832	.756	-.382 .525
	F	C	-.071	.229	114.832	.756	-.525 .382
s	C	F	.893 [*]	.229	114.832	.000	.439 1.347
	F	C	-.893 [*]	.229	114.832	.000	-1.347 -.439

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

b. Dependent Variable: S_Borg_H.

Pairwise Comparisons^b

(I)	(J)	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
						Lower Bound	Upper Bound
SideSh ape_H	Height_ H	Height_ H					
	C	s	-1.643 [*]	.229	114.832	.000	-2.097 -1.189
	s	h	1.643 [*]	.229	114.832	.000	1.189 2.097
F	h	s	-.821 [*]	.229	114.832	.000	-1.275 -.368
	s	h	.821 [*]	.229	114.832	.000	.368 1.275

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: S_Borg_H.

Small lids
Hand healthier subjects
Top shape * Side shape * Height

Pairwise Comparisons^b

				Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
SideSh ape_H	Height_ H	(I) TopSha pe_H	(J) TopSha pe_H					Lower Bound	Upper Bound
C	h	H	R	-.786 [*]	.324	114.832	.017	-1.427	-.144
		R	H	.786 [*]	.324	114.832	.017	.144	1.427
	s	H	R	.500	.324	114.832	.125	-.142	1.142
		R	H	-.500	.324	114.832	.125	-1.142	.142
F	h	H	R	-.071	.324	114.832	.826	-.713	.570
		R	H	.071	.324	114.832	.826	-.570	.713
	s	H	R	-.500	.324	114.832	.125	-1.142	.142
		R	H	.500	.324	114.832	.125	-.142	1.142

Pairwise Comparisons^b

				Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
TopSha pe_H	Height_ H	(I) SideSh ape_H	(J) SideSh ape_H					Lower Bound	Upper Bound
H	h	C	F	-.286	.324	114.832	.380	-.927	.356
		F	C	.286	.324	114.832	.380	-.356	.927
	s	C	F	1.393 [*]	.324	114.832	.000	.751	2.035
		F	C	-1.393 [*]	.324	114.832	.000	-2.035	-.751
R	h	C	F	.429	.324	114.832	.188	-.213	1.070
		F	C	-.429	.324	114.832	.188	-1.070	.213
	s	C	F	.393	.324	114.832	.228	-.249	1.035
		F	C	-.393	.324	114.832	.228	-1.035	.249

Pairwise Comparisons^b

TopShap e_H	SideSha pe_H	(I) Height_ H	(J) Height_ H	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
								Lower Bound	Upper Bound
H	C	h	s	-2.286 [*]	.324	114.832	.000	-2.927	-1.644
		s	h	2.286 [*]	.324	114.832	.000	1.644	2.927
	F	h	s	-.607	.324	114.832	.063	-1.249	.035
		s	h	.607	.324	114.832	.063	-.035	1.249
R	C	h	s	-1.000 [*]	.324	114.832	.003	-1.642	-.358
		s	h	1.000 [*]	.324	114.832	.003	.358	1.642
	F	h	s	-1.036 [*]	.324	114.832	.002	-1.677	-.394
		s	h	1.036 [*]	.324	114.832	.002	.394	1.677

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: S_Borg_H.

Small lids
Hand dysfunctional subjects
Mixed model
Fixed effects

SPSS Code:

```
MIXED S_Borg_D BY SubID_D TopShape_D SideShape_D Height_D Texture_D
  /CRITERIA=CIN(95) MXITER(100) MXSTEP(10) SCORING(1) SINGULAR(0.000000000001) HCONVERGE(0,
    ABSOLUTE) LCONVERGE(0, ABSOLUTE) PCONVERGE(0.000001, ABSOLUTE)
  /FIXED=TopShape_D SideShape_D Height_D Texture_D TopShape_D*SideShape_D TopShape_D*Height_D
    TopShape_D*Texture_D SideShape_D*Height_D SideShape_D*Texture_D Height_D*Texture_D | SSTYPE(3)
  /METHOD=REML
  /RANDOM=SubID_D | COVTYPE(CS)
  /REPEATED=TopShape_D*SideShape_D*Height_D*Texture_D | SUBJECT(SubID_D) COVTYPE(CS)
  /EMMEANS = TABLES(Sideshape_D*Height_D) COMPARE(Sideshape_D)
  /EMMEANS = TABLES(Sideshape_D*Height_D) COMPARE(Height_D)
  /EMMEANS = TABLES(Sideshape_D*Texture_D) COMPARE(Sideshape_D)
  /EMMEANS = TABLES(Sideshape_D*Texture_D) COMPARE(Texture_D).
```

Type III Tests of Fixed Effects^a

Source	dimension1			
	Numerator df	Denominator df	F	Sig.
Intercept	1	95439.590	270.510	.000
TopShape_D	1	330.241	20.109	.000
SideShape_D	1	330.241	14.079	.000
Height_D	1	330.241	120.603	.000
Texture_D	1	330.241	2.420	.121
TopShape_D * SideShape_D	1	330.241	.075	.784
TopShape_D * Height_D	1	330.241	1.206	.273
TopShape_D * Texture_D	1	330.241	3.693	.055
SideShape_D * Height_D	1	330.241	13.400	.000
SideShape_D * Texture_D	1	330.241	5.235	.023
Height_D * Texture_D	1	330.241	3.350	.068
TopShape_D * SideShape_D * Height_D	1	330.241	.302	.583
TopShape_D * SideShape_D * Texture_D	1	330.241	1.013	.315
TopShape_D * Height_D * Texture_D	1	330.241	.536	.465
SideShape_D * Height_D * Texture_D	1	330.241	2.714	.100
TopShape_D * SideShape_D * Height_D * Texture_D	1	330.241	.134	.715

a. Dependent Variable: S_Borg_D.

Small lids
Hand dysfunctional subjects
Side shape * Height

Pairwise Comparisons^b

(I) Height_ D	(J) SideSh ape_D	SideSh ape_D	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
h	C	F	.011	.177	324.495	.949	-.338	.360
	F	C	-.011	.177	324.495	.949	-.360	.338
s	C	F	.920*	.177	324.495	.000	.571	1.270
	F	C	-.920*	.177	324.495	.000	-1.270	-.571

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

b. Dependent Variable: S_Borg_D.

Pairwise Comparisons^b

(I) SideSha pe_D	(J) Height_ D	Height_ D	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
C	h	s	-1.818*	.177	324.495	.000	-2.167	-1.469
	s	h	1.818*	.177	324.495	.000	1.469	2.167
F	h	s	-.909*	.177	324.495	.000	-1.258	-.560
	s	h	.909*	.177	324.495	.000	.560	1.258

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

b. Dependent Variable: S_Borg_D.

Small lids
Hand dysfunctional subjects
Side shape * Texture

Pairwise Comparisons^b

Texture_ D	(I) SideSha pe_D	(J) SideSha pe_D	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
0	C	F	.182	.177	324.495	.306	-.167	.531
	F	C	-.182	.177	324.495	.306	-.531	.167
1	C	F	.750*	.177	324.495	.000	.401	1.099
	F	C	-.750*	.177	324.495	.000	-1.099	-.401

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

b. Dependent Variable: S_Borg_D.

Pairwise Comparisons^b

SideSha pe_D	(I) Texture_ D	(J) Texture_ D	Mean Difference (I-J)	Std. Error	df	Sig. ^a	95% Confidence Interval for Difference ^a	
							Lower Bound	Upper Bound
C	0	1	-.091	.177	324.495	.609	-.440	.258
	1	0	.091	.177	324.495	.609	-.258	.440
F	0	1	.477*	.177	324.495	.008	.128	.826
	1	0	-.477*	.177	324.495	.008	-.826	-.128

Based on estimated marginal means

a. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

*. The mean difference is significant at the .05 level.

b. Dependent Variable: S_Borg_D.

**APPENDIX P: CORRELATIONS BETWEEN PERCEIVED
EFFORT AND DISCOMFORT RATINGS BASED ON
PEARSON CORRELATION COEFFICIENT TEST**

Medium lids

CORRELATIONS

/VARIABLES=M_Borg M_Comfort

/PRINT=TWOTAIL NOSIG

/MISSING=PAIRWISE.

Correlations

Correlations		M_Borg	M_Comfort
M_Borg	Pearson Correlation	1	.593**
	Sig. (2-tailed)		.000
	N	288	288
M_Comfort	Pearson Correlation	.593**	1
	Sig. (2-tailed)	.000	
	N	288	288

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

Small lids

CORRELATIONS

/VARIABLES=S_Borg S_Comfort

/PRINT=TWOTAIL NOSIG

/MISSING=PAIRWISE.

Correlations

Correlations		S_Borg	S_Comfort
S_Borg	Pearson Correlation	1	.479**
	Sig. (2-tailed)		.000
	N	288	288
S_Comfort	Pearson Correlation	.479**	1
	Sig. (2-tailed)	.000	
	N	288	288

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

APPENDIX Q: QUESTIONNAIRE USED IN PHASE 3

Study Title: Development of Electronic Human Factors Information
Repository for Designers

Researcher: Wei-Ting Yen and Dr. Carolyn Sommerich (PI)

Your Name: _____

Background Information

1. **What is your gender?**

☐ Male ☐ Female

2. **How many years of work experience have you been in industrial design area?**

_____ year(s)

3. **What is your current employment status as an industrial designer?**

☐ Full-time employment ☐ Part-time employment ☐ Freelance

4. **What are your specialties in industrial design?** *(Check all applied)*

☐ Consumer electronics ☐ Furniture ☐ Housewares ☐ Software interfaces

☐ Medical devices ☐ Transportations ☐ Packages

☐ Others. Please specify: _____

- THE END OF SURVEY -

APPENDIX R: PHASE 3 PARTICIPANTS' BACKGROUND INFORMATION

S#	Gender	Yrs of work	Employ	Specialties in Industrial Design								Others
				Consumer electronics	Furniture	Housewares	Software interface	Medical devices	Transportations	Packages	Hand tools	
1	M		1 Full-time									concept visualization
2	M		1 Part-time	x		x						industrial equipment
13	M		1.5 Full-time	x		x						prototyping
7	M		4 Full-time	x		x		x				
11	M		5 Full-time	x		x		x		x		
9	M		6 Full-time			x				x		
14	M		7 Full-time	x	x	x		x	x			
3	M		12 Full-time			x					x	construction equipment, office supply
6	M		16 Full-time									plumbing fixtures
4	M		20 Full-time								x	strategy, management, plumbing products
5	M		20 Full-time	x		x				x		sporting goods, lawn and ground hardware
15	M		20 Full-time	x		x	x				x	commercial electronics
16	M		20 Full-time			x			x			consumer products: cleaning items, feminine products
8	M		22 Full-time			x						materials handling, business tactics
12	F		25 Full-time	x		x						
10	M		35 Full-time	x		x		x				
	mean	13.47	count	9	1	13	1	5	2	3	4	
	SD	10.20										

APPENDIX S: PARTICIPANTS' DESIGN TIMELINE SHEETS IN PHASE 3

S2

$\bar{X} = \frac{\text{relative \# of obsiders / team}}{\text{members involved}}$

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

Design Timeline Sheet

**APPENDIX T: PARTICIPANTS' HUMAN FACTORS
STICKERS ON DESIGN TIMELINE SHEETS IN PHASE 3**

ID	Yr	Info	Idea	Model	Eval	HF#	Goal	Activity	Content	Media	Resource	Description
1	1	x				1	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	what's known and written	written report with pictures, links, video, citation	focus on previous studies (academic or otherwise), or website	Secondary research/info Parallel with HF2. What scientific research is out there? Is there any media on + or of lid design -- > what is public opinion? Look to nature
1	1	x				2.1	Explore what solutions are already made	Review the current similar products in the market	what's known and made/done	video recording, audio, pictures, observations, actual products - want to interact with them	go to target/Amazon, people watch	Primary research/action and stuff Parallel with HF1. Gather all available lids, handles, jar openers, twisting levers etc. focus also on lids which the elderly use: pill bottles for example. Watch people use.
1	1	x				2.2	Clarify the design problem	Observe (see method) how target users interact with current product(s)	what's known and made/done	video recording, audio, pictures, observations, actual products - want to interact with them	go to target/Amazon, people watch	Primary research/action and stuff Parallel with HF1. Gather all available lids, handles, jar openers, twisting levers etc. focus also on lids which the elderly use: pill bottles for example. Watch people use.
1	1		x			5	Evaluate the design concept	Examine how the target users react to the new design concepts	users inspired design	picture, video, model drawing	users	User test each, gather feedback
1	1				x	6	Evaluate the design concept	Examine how the target users react to the new design concepts	validation	very formal written report	users	Validate final concept
2	1	x				1	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	statistics, existing problems of products, competition, new technology, more "ergonomic" data, actual interaction with specific products, opinion	reports, charts/graphs	internet, books, experts articles	Secondary: (1) online forums, complaints, (2) examples of ergonomic bottles/caps, (3) ergonomics books/reading, (4) materials research
2	1	x				2	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	"ergonomic" data, actual interaction with specific products, opinion	videos, photos, audio, testimonials	focus groups, surveys, observation	Primary: (1) Focus -- 20 older people, 20 younger people, discuss current bottles + 2 or 3 other ideal bottles, (2) Survey -- wide range of participants in online survey; focus on past experience opening containers
2	1		x			4	Evaluate the design concept	Examine the new design concepts by testing designers themselves	how does it feel? function? look? how obvious is it?	got down notes, photos, video	self, other teammates, observation + first hand experience	First hand testing of models
2	1		x			5	Evaluate the design concept	Examine how the target users react to the new design concepts	same as #4, but not necessarily asking direct or "leading" question	notes, photos, videos, recordings	focus group users, observation	More focus testing of models
3	12	x				1	Explore what solutions are already made	Review the current similar products in the market	-	pictures of individual items, might chart 10 or so together with applied ranking	-	Look at similar products on the market that solve the same problem in terms of ergonomics, i.e. OXO product etc. (Ref. good shapes & forms)
3	12	x				2	Clarify the design problem	Observe (see method) how target users interact with current product(s)	-	video clips capturing key interaction moments, detail pictures of problem areas	-	Observation study
3	12	x				3	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	Survey study create to help HF2 video observations	-	-	Questions & Answer study (might not be necessary & could be covered in HF2)
3	12	x				4	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	-	Book/data form similar to Henry Dryfus books or looking at "ergonomic hand books"	-	Review ergonomic handbooks or hire ergonomic specialist to help evaluate problems
3	12		x			5	Evaluate the design concept	Examine how the target users react to the new design concepts	-	video	-	Evaluate physical 3D printed closures review with elderly or intended user

(Appendix T continued on the next page)

(Appendix T continued from the previous page)

ID	Yr	Info	Idea	Model	Eval	HIF#	Goal	Activity	Content	Media	Resource	Description
3	12			x		6	Evaluate the design concept	Examine how the target users react to the new design concepts	-	no solid deliverable	-	Conduct final review of physical form and functions
4	20	x				1	Gather bg info of target users	Collect general info from previous research about the target users	age, gender, race, abilities (dexterity)	report - words & pictures	from client or ergonomic expert	Demographic dynamics of problem, age, gender, racial
4	20	x				2	Clarify the design problem	(no specific method mentioned) Examine how target users use/feel about the current product(s) and their preferences	actual user problems, likes/dislikes, unmet needs, how they solve the problem, attitudes about problem	video, picture	ethnographic research	Research with consumers to discuss problem
4	20	x				3	Gather bg info of target users	Collect anthropometric data from previous research about the target users	statistical data	graphic, words, pictures	HumanScale, websites, ergonomic experts	Gather ergonomic data
4	20		x			4	Evaluate the design concept	Examine how the target users react to the new design concepts	user reaction to concepts	video, pictures	consumer research	Refine and concepts
4	20			x	x	5	Evaluate the design concept	Examine how the target users react to the new design concepts	user reaction to prototypes	video, pictures	consumer research	Refine CAD & prototype concepts
5	20	x				1	Probe the "solutions" of target users	(no specific method mentioned) Interact with target users and let them tell you what they preferred	dimension of preferred diameter of cap, tactile form preferred	record measurement: (1) photograph session, (2) record video	user experience - they tell us what works	Brief consumer research hands on use by older/aged participants (65+ M/F)
5	20	x				2	Explore what solutions are already made	Review the current similar products in the market	diversity in shape, size, materials, and comfort	actual products, document in photographs	existing products: containers, lids, caps, etc.	Audit of cap/containers: (1) review ease of opens, (2) materials, (3) features, (4) reseal/close, (5) tamper proof
5	20		x			3	Gather bg info of target users	Experience the physical difficulties that target users have	designers experience with limited grip	verbal, visual	designers, participants	Adjust designs to limit hand grip/coordination: gloves, tape fingers, slippery, test current grip
5	20			x		4	Evaluate the design concept	Examine how the target users react to the new design concepts	validation of design: comfort, function, solves issue	photograph, video, verbal	verbal, tactile	Review study models with audience 65+, and then refine study models
5	20				x	5	Evaluate the design concept	Examine how the target users react to the new design concepts	final validation	documentation, visual	consumers, client review	Review/Research -- Test with several consumers, age 8-12, 13-18, 18-50, 50-65, 65+
6	16	x				2	Explore what solutions are already made	Review the current similar products in the market	lists of products that solve same problem	site visits, web	client, design team	Voice of market -- what else is available in the market that solves this problem
6	16					3	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	understand the problem we are solving	reports/text, transcript of consumer complaints	consumer, focus groups	Voice of consumer -- what are the main complaints
6	16	x				4	Gather bg info of target users	Collect general info from previous research about the target users	what are the use limitations	print, web, expert interviews	ergonomic research publications	Voice of consumer -- assess limitations of target consumer
6	16	x				5	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	what are known solutions to this problem	print, web, face to face meetings	experts, publications	Voice of consumer -- identify correct use patterns
6	16			x		7	Evaluate the design concept	Examine the new design concepts by testing designers themselves	how does it feels to me	personal experience	self	Use 3D CAD data to generate test mock-ups to understand each idea potential and limitations
6	16				x	6	Evaluate the design concept	Examine how the target users react to the new design concepts	level of success of proposed solution	reports - graphs, charts, anecdotal evidence	consumer testings	Test with consumers to make final revisions/selections

(Appendix T continued on the next page)

(Appendix T continued from the previous page)

ID	Yr	Inf	Idea	Model	Eval	HIF#	Goal	Activity	Content	Media	Resource	Description
7	4	x				1	Gather bg info of target users	Collect anthropometric data from previous research about the target users	size(s) of users hands	interactive book / anatomical book	human factors book	Who's using/drinking?
7	4			x		2	Evaluate the design concept	Compare with other similar products	what works w/ certain individuals - what doesn't work	prefer to use live test subjects	live test subjects	Gather similar products off the shelf --> Test
7	4				x	3	Evaluate the design concept	Examine how the target users react to the new design concepts	any flaws in the design	photos of model	live	Test --> audience(s) yes? No? easier or more difficult?
7	4	x				4	Clarify the design problem	Observe (see method) how target users interact with current product(s)	task analysis - use to find/prove if why product does not work	-	live test subject	Task analysis
7	4			x		5	Evaluate the design concept	Use computer anatomical models	Engineering: using human factors within 50%-75%	interactive anatomical model	web based easy to access	Engineering mock-ups
7	4		x			6	Support ideation sketches	Use anatomical drawings	anatomical drawings for underlays	print-offs	-	Underlays
8	22	x				1	Explore what solutions are already made	Review the current similar products in the market	any reviews of comfortable lids available?	I would look at photos, magazines etc. for reference	I would buy products in stores for use in testing	Assemble a variety of existing lids for reference
8	22	x				2	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	I would talk to people to better understand their specific challenges one-on-one because everyone's different	-	I would talk to people one-on-one	Conduct research with people one-on-one comparing existing lid w/ reference lids - video and still photography documentation
8	22		x			3	Gather bg info of target users	Measure anthropometric data from target users directly	I would measure and trace each person's hand for comparison later - (1) open-hand, (2) gripped hand	-	-	Measure participant open hand sizes (perhaps tracing on paper) & grip sizes
8	22	x				4	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	I would photograph the interviews for review later on	video and still	I would talk to people one-on-one	Compare and analyze responses to determine similarities and responses
8	22		x			5	Determine the benchmark product	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	I would have the participants rank the designs in terms of function and comfort (ease-of-use) to establish (hopefully) a favorite benchmark lid	-	-	Have participants rank lid samples in terms of comfort/ease of use in removing from bottle, and ask "why"?
8	22			x		6	Evaluate the design concept	Examine the new design concepts by testing designers themselves	quick mock-up lids, tested informally with people on hand, would quickly tell me if I am on the right track, or not	-	-	Informally test w/ people in office for top-level feedback

(Appendix T continued on the next page)

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ID	Yr	Info	Idea	Model	Eval	HIF#	Goal	Activity	Content	Media	Resource	Description
8	22				x	7	Evaluate the design concept	Examine how the target users react to the new design concepts	I would want to know if the prototypes work, and if people find them easy to use, and if not, "why?"	-	-	Have each person test all the lid prototypes - have them rank their preferences and ask "why?"
9	6	x				1	Gather bg info of target users	Experience in person the physical difficulties that target users have	how hard is it to open a given design	physical interaction (cannot replace experience)(walk a mile in someone's shoes)	personal experience	Sit on my hand until it feel asleep and try to open containers to get a feel for what it's like to try and open things
9	6	x				2	Explore what solutions are already made	Review the current similar products in the market	qualitative examples of products that work	articles	internet	Internet audit at easy to open containers
9	6	x				3	Gather bg info of target users	Collect anthropometric data from previous research about the target users	(1) quantitative information on force requirements to open, (2) information on users strength, dexterity, etc.	hard information, ex: tables, charts, anything quantifiable	client, expert	Get info from client
9	6				x	4	Evaluate the design concept	Examine how the target users react to the new design concepts	info on recruits	bio and stats of participants to assure they fit within target	-	Recruit elderly participants to evaluate functional prototypes
10	35	x				1	Clarify the design problem	Observe (see method) how target users interact with current product(s)	range of users interview	video, photo pictures	field reference, research observation	Observe users how they use hand open the bottles
10	35	x				2	Explore what solutions are already made	Review the current similar products in the market	-	-	store checks, online research	Look for other products that have lids/caps that can be opened more easily
10	35	x				3	Gather bg info of target users	Collect anthropometric data from previous research about the target users	anthropometric data	dimensions, force requirement	computer	Find out about the range of strength/force requirements
10	35		x			4	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	-	charts	computer/online	Develop range of dimensions guidelines for grip areas
10	35				x	5	Evaluate the design concept	Examine how the target users react to the new design concepts	-	video, photo pictures	-	Take prototype models test with users
11	5	x				1	Gather bg info of products	Determine the manufacturing standards about the target product(s)	measure using force gauge/consumers compare to internet	-	internet	How much force is required?
11	5	x				2	Gather bg info of target users	Collect general info from previous research about the target users	get background from consumers of Starbucks	-	consult internet	Who - who is using this product currently?
11	5				x	3	Evaluate the design concept	Examine how the target users react to the new design concepts	feedback from consumers	-	focus group people	Get consumer feedback from prototypes
12	25	x				1	Gather bg info of target users	Collect anthropometric data from previous research about the target users	human factors chart/grip strength, force needed to open, sizes for "older" demographic	would prefer online resource	can not certain where I would look to find demographic on "older" people - if it is in Henry Dreyfuss charts or not	Gather human factors data on "older people" hand grip info: sizes, strength, etc.
12	25	x				2	Gather bg info of target users	Collect anthropometric data from previous research about the target users	would like to check online for current data (newer than Henry Dreyfuss)	-	not certain which resource, Google it	Visit website/web research for ergonomic grips/materials etc.

(Appendix T continued on the next page)

(Appendix T continued from the previous page)

ID	Yr	Info	Idea	Model	Eval	HF#	Goal	Activity	Content	Media	Resource	Description
12	25	x				3.1	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	group session/ informal with friends - (1) measure hands, (2) measure strength? How?, (3) overall height/weight	charts available?	-	Informal review with friends/network of DC to review Starbucks bottle + others based on in store samples purchased
12	25	x				3.2	Gather bg info of target users	Collect anthropometric data by target users directly	group session/ informal with friends - (1) measure hands, (2) measure strength? How?, (3) overall height/weight	charts available?	-	Informal review with friends/network of DC to review Starbucks bottle + others based on in store samples purchased
12	25			x		4	Evaluate the design concept	Examine how the target users react to the new design concepts	review session with informal friends group	test, video, record what they respond to like/dislike	group session	Review with friends/network of DC Starbucks phase 1.0 test group
12	25				x	5	Evaluate the design concept	Examine how the target users react to the new design concepts	review session with informal friends group	test, video, record what they respond to like/dislike	group session	Review samples with informal test group, ask them about texture/grips they prefer
12	25				x	6	Evaluate the design concept	Examine how the target users react to the new design concepts	find info about age demographic	prefer online	don't know where to go	Select one final overall shape + delineate textural grips / details that will help ergonomics
13	15	x				1	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	what is the problem - (1) their "solutions", (2) their human factors	interviews, blogs	internet, people (1st hand)	Interview "clients" (people who currently struggle with design + want an easier solution) - have them show and tell you what's wrong + what they want
13	15	x				2	Gather bg info of target users	Collect anthropometric data from previous research about the target users	sizes, dimensions, etc	a program? something intuitive	internet, books	Consider different hands (sizes, fragility, etc.)
13	15	x				3	Gather bg info of target users	Collect general info from previous research about the target users	what ages struggle with product	seems very specific but if a data base could provide then that would be cool	internet, blogs, interviews	Think about age range
13	15				x	4	Evaluate the design concept	Examine how the target users react to the new design concepts	reaction, fit, comfort	-	interview (has to be first hand, face to face)	Good time to test solutions with the consumer and assess what they say then go back (if changes are necessary)
14	7	x				1	Clarify the design problem	Survey/interview/focus group (say method) how target users use/feel about the current product(s) and their preferences	user feedback on existing product	video record interview, use existing products that provide a range of means to open objects, ask which is easier, quantify why it's easier	active users	Define force requirements for opening the lid by: Qualitative research: (1) visit to end users, (2) provide multiple diameters/force feedback
14	7	x				2.1	Gather bg info of products	Determine the manufacturing standards about the target product(s)	quantitative data: force, diameter, etc.	documentation	internet, library, experts	Define force requirements for opening the lid by: Quantitative research: identify previously created documents on ergonomic data for the elderly
14	7	x				2.2	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	quantitative data: force, diameter, etc.	documentation	internet, library, experts	Define force requirements for opening the lid by: Quantitative research: identify previously created documents on ergonomic data for the elderly
14	7				x	3	Evaluate the design concept	Examine how the target users react to the new design concepts	feedback of users, easy/hot easy to open?	-	-	Return to end users + evaluate models

(Appendix T continued on the next page)

(Appendix T continued from the previous page)

ID	Yr	Info	Idea	Model	Eval	HF#	Goal	Activity	Content	Media	Resource	Description
15	20	x				1	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	"hand ergonomics" "easy grip" "age-in-place"	visual with examples, text, whatever is available	internet or phone calls to experts found through searches	Search for ergonomic info (i.e. HumanScale) and existing research documents
15	20			x		2	Evaluate the design concept	Examine how the target users react to the new design concepts	how does solution feel/work from limited point of view	verbal and tactics	models	When making new models...
15	20				x	3	Evaluate the design concept	Examine how the target users react to the new design concepts	"consumer" feedback through focus group	survey and interview	models	Focus group test final solutions
16	20	x				1	Look for design reference guide	Collect general info or design guidelines from previous research about the target product(s)	human scale guide, look for basic dimensions, best practices, advice on how to design for situations	pictures, video, charts comparisons	online, Google	Consult human factors guides either printed/online to see what standards already exist
16	20			x		2	Evaluate the design concept	Examine the new design concepts by asking human factors experts	expert consultation to evaluate concepts	face to face meeting to have expert evaluate concepts	online/contact profession network like LinkedIn or other social media/ call other designers for referral	Have valued by experts in human factors

APPENDIX U: PARTICIPANTS' DESIGN WORKS IN PHASE 3

Designer #1

WIREFRAME

1 of 3

SUMMARY

Tablet with touch screen (1:1)

Tablet with touch screen (1:1)

2 of 3

FINDINGS

Tablet with touch screen (1:1)

3 of 3

You can play on this, it's interactive. And then you also have over here, a column **A** of what the actual things your tests were that come up with these results. So if you click on one of those it gives you a preselected set of data once. And it shows you, right here **B** is a little chart where each one of these has a different graph like if it's a bell curve or linear progression. It highlights where on that graph your little slider is. And then it calculates the average over here **C**. In addition to that, I think it's very important that each one of these models you did your test on, that's where you got your data from. I think that there should be a little link under that that takes you to the actual, like where that came from, where that research came from **D**. And I made, this shouldn't be just a single page you get to, this should be a page within a greater system. So essentially, you have a homepage **E**, you have somewhere to find this, which I think is visual. You have users, the same, I like this I don't like this. And you can link to the finding which will be more detailed, maybe something like this.

Researcher: Depends on how much time you have, how much budget you have?

Very true. But well whose guy here is self (??). And then I also want to see very detail information on what each one of this study was. What's the sample size over the controlled they use, like this is the new people, and this is former. I also want to see cite to sources, like you say something, or some scientist said this, I want link at that. So if you click on that it takes you directly to the original source.

Designer #2

Tablet with touch screen (1:1)

I ADJUST THIS

Tablet with touch screen (1:1)

THIS MOVES

THIS CHANGES

So, in this idea, I mean, we were interested in how easy this lid is to open. So there is a column **A** that says how easy the lid is to open. On this side, there are all the factors you might want to consider. So there is shape of the lid, there is texture on the lid, it's height of the lid, the concavity of the lid, and any other number or factors **B**. And all of these are interactive by this slide, if I want to make it higher, I want to make it more concave or convex, I want to see and use some texture. As I am switching these elements, the rating will dynamically change, will go up and down. This is what I am trying to affect here.

Researcher: You just want to see the ratings?

Yes, I want to see the ratings, but in addition to that, and this is something I saw on your sheet and I totally changed that too. You can have the shape, so base on what I am doing over here **C**, they can show oh, that actually gets taller or gets smaller, or it becomes more convex or more concave, or the textures sort of change. So it's sort of a live visual representation of what I am doing over here that's affecting this **D**. So it continuously changes into an interactive game and I think after couple minutes, you know everyone will be able to find the correct combination here and gets this to be the most or green, I mean color can come into play in this.

Researcher: So basically you want to play around to see different combinations?

Sure, and I mean that graph, after you can explain what each of these elements mean. I mean if we were going for something that is below on the scale, then you know, what are the characteristics navigate the most. So we are interested in what navigates the most.

Designer #3

I really have a hard time for this exercise, because I saw the two pieces of information I actually don't know. And it just jarred in my brain and I couldn't get pass that. Because I think whoever put on the difference sketches division says (??), that's controlled. And it looks right the standard is going to be right. And function with user end is going to be right. So data at this point is no help then, and anyone deal with it. And so you know I

have this real problem of I getting over that and try to fit these pieces of information because if it's information on the screen they are all done, why do we bother, why do we waste the time going through the exercise. So it's really hard for me to get over that. But we are always kind trained like to offer solutions even though we don't really believe in them. So, or it's you know to be productive or show solutions.

So, there will be a front page with, because I think it's hard to do diameters with textures, it just doesn't look right, for me. So I just did diameters and heights. On the front of any new page **A** you will be able to select, which one you are interested in, and see the menu probably you get a menu of hard or easy, which is a scale **B**. And then you might have a little description **C** of what information are there. So in that way you definitely have a picture **D**, you know, that gives you detailed information associated to this graph.

Something that is tangible. Because it's just the graph, or the line, it doesn't register.

And maybe there is, if you want to compare the diameter heights with texture. There will be a line cross them **E**, clearly lining the two. And you have an evaluate texture bottom **F**.

Tablet with touch screen (1:1)

Tablet with touch screen (1:1)

Mine is actually pretty similar. So this is an app, you select the gender **A**, then you pinch up or scroll up which age you want to investigate **B**. And then what you do is then take and you pinch to take heights, you pinch to get diameter **C**, and then you see the results here **D**, that it gets updated real time. And then what you do is you drag, okay then you understand that, and you say well I want to think about what texture it might have **E**. And then it gives you a difficulty rating automatically here **F**. So you can just go that far, or where you say well I want to think about what texture I might have to do. So you take and you drag this texture on, and you say, oh, okay, that texture increased the difficulty of that height, then maybe if I pinch this down, what does that do. It gives you a difference.

Researcher: So you want to play around?

Yeah, exactly. And then, you say okay what about the actual shape? And you can bring it up there, and you can basically play around all these dynamics. Then you do the same thing with the profile **G**. You always see the actual design update up here, and you always see the actual difficulty rating update there.

Researcher: So where would you use it during your design process?

So just like <Another subject's name> said, I sit down after I have spoken to consumers and gotten a sense of their problems. There would be an ideation. And then you could then use this in some form when you present to the client to say here is the rationale of what I am doing. So, like I said, I don't like those charts, I want completely easy and sort of let me play with the dynamics, but don't make me digest data.

Designer #5

Desktop/Laptop screen

I kind of did similar, and I took the height of the cap and just pick short or tall so it's very simple **A**. There is no multiple, although on the other one, I have multiples. But then you select the deviation of the side **B**, so you have minus one if you want to go pinch and or plus up whatever. Then you have some scrolls so you can you know go further **C**.

Researcher: We can use mouse to adjust?

Yeah, you could do that, and it really gonna deviate whatever that shape.

So, before I guess on the first one I had, I guess similar to <The other subject's name> where you had different shapes you can scroll. Maybe you get different shapes of lids and then you pick one you want. You get different lids and you scroll again.

Researcher: So what is the chart on the right corner?

Okay so back to that. So that could have a better access of the feel. Then you select a texture **D**. I think I want visual, so there is gloss, wood, wherever it progresses to heavy, maybe it's like a real knurl and you select that again. Maybe there is two ways of scenes where you can look at this way or side view.

But those give you a menu up here where you can select a short or high, side deviation of three, texture satin, and that gives you a chart **E**. I think the chart would kind of show the progression of comfortable to difficult, and maybe somewhere it's stated that when you get difficult it's red, then it's green. So over that overlay, this is kind of a little difficult, you see where your selection is. So over that you see you have gone to difficult because

you are short height, big deviation which you said is “hinderous”, and the smooth satin of texture which is kind of slippery. So that might give you some more. So again it's a menu, and you see the results.

Designer #6

Smartphone with touch screen (1:1)

Smartphone with touch screen (1:1)

My design is very linear. So it's kind of old school HTML: select the shape **A**, hit the next page, then texture **B**. And then it shows you what you selected, the results **C**. And then you can add other variable and shows you numbers in two columns **D**, but it's not interactive. I think the three solutions I seem so far presented are much better solutions.

Designer #7

Smartphone with touch screen (1:1)

Tablet with touch screen (1:1)

For the first one, I kind of downing(?) it down. I mean there is no grasp really, you just basically sew up the shape of your lid, top view, round, square, hexagonal. And then you select the profile with the round or straight sides, texture or no texture **A**. And then you just enter in what type of dimensions, any type of dimensions **B**, and that will move the

graph. This is like an interactive, click and everything changes. So you would change the dimensions and that will move the scale C, whatever the difficulty was. Whether it was really easy. And you can play with any dimensions, so you can interactively see how things get more difficult or easier based on the relative changes. And that was the same for this as well D. But instead of doing a hexagonal, I did a round lid. You have your age, age range, and then textures, shape, and then difficulty level instead of going in and out on the graph, we will just have the number displayed E.

Researcher: So where would you use it during your design process?

I guess I would use it side-by-side, like I would use it handheld whenever I was using ProE or SolidWorks that's on engineering something. If I change the dimension, like let's see how difficult this would be to use. Like if I have designed a handle, this opening, type in the dimension, and based on findings from the test, you have this information, you can see how difficult it was from using it.

Designer #8

Tablet with touch screen (1:1)

Tablet with touch screen (1:1)

Tablet with touch screen (1:1)

Tablet with touch screen (1:1)

Smartphone with touch screen (1:1)

I started with the smaller screen and I thought you got it so small, use the emoticon like smiley. Like <Another subject's name>, I would go blind looking at those graphs and try to figure make heads and tails of it because it's so confusing. So I just want to see graphics, just simple, and how they, when you change a variable, how it relates visually to that change. Whether it could be good, better, and different.

So here I just think the emoticon screen A is small but forget that because we want to get a bigger thing. So I started by saying you know if you had something like one thing at a time on the screen. So in this case you have to set diameters for example, you would type that in, and it would spit out right here what your ideal height would be B. But then you would have an up and down arrow elsewhere so if you change the diameter, how it dynamically affects. And you would see a little graphical of that lid going up and down, so you can see the dynamic relativity. And then you could go from that to...

Researcher: So where would you put your emoticon?

I wouldn't on this, because this is fairly literal. Just saying, this is assuming I trust all of the data. It's parametric, and it's always giving me the easiest jar opening solution.

But you can't really design a hard to open cap.

It's just predicated on the assumption that I trust your graphs, okay. And I will put a caveat tell this when I am done, you know. So I will start right there. And then if you get more information, and you still have that stuff. But in this case, you can pick either smooth to rough C, and maybe, there's a little, that's what I really like about <Another subject's name> and <Another subject's name> did, and <Another subject's name>, where you have a little graph image of what does smooth mean, what does rough mean, what does something in between mean. You can just slide your finger along there, and see as you have these numbers in here. It's changing dynamically this little scale that goes up and down, I got better on top, worse on the bottom D. So as you are adjusting this, that little scale is going to go up and down. But then you have a hard number to refer to. And maybe the tall lid versus the short lid you know is probably redundant because you are just changing it. You really don't care what's shorter or tall. You only

care about is what the height is relative to the diameter. And then it's changing and you would just slide your finger to adjust whether it's an upright wall or if it's a convex wall E. You are zipping in and that little scale is going up and down. So it's just all relative. It's keeping everything relative.

But I would use this to get me to the very first step at the very beginning of the info gathering to say, okay, what lids do I need to buy. When I go to Target, I am going to buy a bunch of these lids that exists because I think <Another subject's name> made a good point. We are not designing something that doesn't exist already. There's stuff out there that's already solved this problem. I think he's exactly right. What this is helping me do is find the right sample things at Target or Walmart or whatever to take with me to my consumer research. Because I want people to validate that. And then after I can gather that information, I can show the client and say, well based upon this trusted ergonomics data from OSU and this problem that I use, it got me to this point, and then I confirm that in this informal research with people to better understand why these variables change the way they do.

Designer #9

Desktop/Laptop screen

Desktop/Laptop screen

So, I am a mechanic (mathematician?). So I look at graphs to see what exactly am I looking at here. So it is a bit like the nod thing that was made earlier where if it was just a video, you don't have the context. So I am like okay, so what is the important thing I

am supposed to be looking at here. So what I have is this interface, where typically your results aren't all of a straight line. There is a spectrum of your results and it averages out A. And so here you have kind of a short cut bottom B. And so from this serving, what was the easiest, so I would put the easiest bottom. I will click the easy bottom, and then along that spectrum, the result that came back as being the easiest. So, if I click a bottom and say, for example, easiest, I don't know what all these bottoms would be. It would call out a result that was identified as being the easiest. And then, I will see some background information on that result C. So for instance, what was the info or the bio of the participant, so how old are they, male female, what's their occupation, they have any health concerns. And then maybe some of the things you could normally just click from these, like the specifics. So what exactly was the lid height, what exactly was the lid shape, texture, and any other variables that may exist D. So in that way not only can I see the big picture here, but I can dive in on the results. And you know kind of a clean graphical interface and see some more details.

Researcher: So what are the bottoms at left composed of?

So I don't know. I am still trying to think it through. But my thought was as I was looking at the graphs I am like wait a minute, so which one is the easiest? The one is on that scale right there or ...? And so it's like okay, for all the participants, what result was easiest, which was most difficult. And it's kind like the short cuts, I could just click on these results themselves. But you know since I am not a very graph savvy guy, I can just say okay, let me just click on this and it will take me to the result I am looking for, what was the average. And then I am sure there is other, you know if you spend more time thinking about it, there is other statistics that could be looking for that maybe relevant to what I am doing. Because you know I probably will not be looking for like the entrance (??) spectrum, the easiest then most difficult. I probably will look for what is the average. So basically it's all about getting some more details. What is the story behind this. And then if I add two different sets of information I am trying to evaluate. What I really want to be able to do is in a kind of very clean simple arrow phases, select different results E. And you know, in this case I am selecting kind of the extremes of the sample. But then once if I select this one and I select that one, then some sort of interface will come up showing me what is the difference between these two results. So you know, it could be difference in height. So this was, you know, the most difficult result was, you know, a quarter of an inch shorter than the easiest result. So that I can say what's the relationship between...

Researcher: So the red one will be the most difficult part and the green one is the easiest one? You want to see why they are different?

Yes, so rather than me having to, you know, put a thing of cap on, and just remember what these results were, you know. And then also I can say, okay, what ages between those two participants.

Researcher: So where would you use that for your design?

I would use that at the early phase of the project as I am starting to identify what my buckets or concepts are going to be. At the information gathering phase, absolutely. But then I am sure along the way, this would come back into play as I am going back and checking my results. But it makes its first appearance and I think the most important appearance in the information gathering.

Designer #10

I am a designer. I am concerned about what to get out of it. Meaning that I have to design some not so much interested in graphs, I need to use it to make shapes, to create shapes. **So ideally I would like to have an interaction.** But I need to understand if I

applied these different factors. If I apply this, so I need to deal with a shape **A**. And I have the variables, so here is from the difficulties. So this is the scale **B**, and here I can apply different heights to the lid **C**. And so **I introduce value change** here **D**, from where whatever the variables from half inch high to a few more whatever. **And then I should be able to see this indicator, gives me an idea of where I am on the scale.** So the indicator moves up and down. According to here, and then I need to be able to save it **E**. So if I see, I mean **I am interested how far I can get up on this scale, without getting too tall or too wide. I mean I am looking for a range, the best range of things. But I am only interested to look for maybe two or three different where I can go back to the guy and say if I made this lid that tall, we get that high on this scale.** You know if we get too tall like you said on the second one, it's a diminishing return on the things.

Researcher: So are you looking for optimal solution or just acceptable solutions?

Well, I am looking for the optimum, and then we can have a discussion of what's acceptable. But that has to go back to what am I looking for. And what we usually have to deal with, what I have to deal with, you know, I can say human factors wise it's optimum to closer it get to the 10. However, somebody may say this lid gets too big. So where can it fall that we can still have a claim of better opening lid. And I want to be able to show the improvement over where we were.

Researcher: So how about your other idea?

So my other idea this was texture. This is where I was asking initially. I have the same thing. **I mean I can contribute to put in what the height is on both of this **F** with what the diameter is. And then I have a range of textures down here **G**. So I have the scale again here for easy to difficult and it should be applied texture here.** And then show me whether it can be end up as an optimum or acceptable solution.

Researcher: So where will you use it during the design process?

Especially when we do ideation it's where I start to look at how it will affect the overall shape and design. And then I mean I have to confirm with between the modeling and the ideation of what this is. And ideally we will be able to change the shape. Because in my opinion, so here is the thing, and this has been my self part, I am glad you ask me that. There is a real delicate balance between human factors and visual, okay. It's very important that shapes are looked that they are easy to grip, that they are approachable, and how you approach it. So if you just say scallops, you know just even relationship, this scallop with how sharp it is. I should be able to influence that because it has everything to do with the brand, with the image, with what I create. It's not about just optimum grips strength, it's about unique shapes, okay. So this is what I always say, when I go to the books, I see generic shapes, and everybody says, if you have this shape, it should be the optimum. It's not like that! It's not at all like that. I should be able to, you know, even if I vary, I can vary two of these shapes and get the different result, and they are visually unique. So those things I think are really important as part of this tool, I should be able, you know, how big this scallop is, what the shape is, on this, between, in between, and what the differences does it in total. But this app will be cool for me to, because otherwise I will have to draw it up, I have to make it, I have to test it. If I can get an initially validation of this when I could look up and say, I have to be here, what this is also important I need to be able to understand where we started. So we should be able to put this lid in and say this is at point 5 or whatever it is. And with this shape we get to here.

Researcher: So will you play around after having some ideas or before that?

Before that. I mean that gives me a start to say, if I want an improvement, this is where I need to start.

Designer #11

Desktop/Laptop screen

Desktop/Laptop screen

- sex women
- Age 21-45
- location Hand

C

List of Info

Search

- grip strength
- finger dexterity
- etc ...

Desktop/Laptop screen

So this is what I want to get to this information. So you go to the website, there is a bunch of icons, people from a little overall all the way up to an old lady A. And there is going to be the same with guys. You click on, this is the age from our research, okay, I click on that. And then I have the body part generically B. I click on, okay, it's stealing ice cream (??). Seal it with the lid so I click on the hand. And then it takes me to like a

search **C**, and then it will do the top searches down here, but if I want to do some of the specifics, can do that. I go to grip, whatever. And then, it gets me, I don't know, like that doesn't do me any good because it's, one it doesn't tell me what the height is, it just is short and tall, that doesn't mean anything to me.

Researcher: So you want to know the dimensions, is that right?

Right. So I want to be able to say, usually I have a starting point, right? Especially within this case we are dealing with this bottle, we know what's circumference so what if I were able to put in a diameter. And then I haven't, you know, I have started ideation and I have a height that I want to kind of, I have a hypothesis I want to prove out. So then I can put in the height and then it's going to give me a difficulty level. And then I can keep tweaking those until I, and see what the different things. I think something is on something where it shows you the last few comparisons of contrasts. You know, maybe it has a list of the last five things you have tried with. I don't know, I think it becomes more interactive.

And then the next one, I will have to ask a little bit. But if you went through all the stuff you got to this, say you have a lid, the you can drag the height **D**, you can drag like the shape. But you first you select a generic shape **E**.

Researcher: Some dynamic changes?

Right. So you, I know it's going to be a rounded because it's threaded and it's manufactured in a certain way. Just for instance you click on the round, you can drag the height, you can drag maybe a contour or something. And then it will show you instantly what, how it measures that **F**.

Researcher: So again, when would you use that? And how would you use this information?

I think I would use it probably initially to get sort of generic feedback before the ideation. And then I will use it to help validate things. Probably somewhere because I probably go back and forth between ideation and modeling a few times. And it would probably be in there to help validate those things.

Designer #13

Desktop/Laptop screen

Desktop/Laptop screen

Well, simply put, there is a lot of variables when you think of all the information that is being displayed. For example, like the age of the people, the age range, the diameter, the height, the texture, all that stuff. Kind of a lot of stuff that show things down there. You want to be able to change these parameters that is necessary to you. You know the likely

hood is not going to be just this chart sitting out there that you just happen to come across that this exact data that you need. You are going to have to manipulate data into what you to find the parameters outdate thing, especially looking at database sort of situation. I have this so I guess so you can change the x and y **A**. You know axis define what this actually is, this chart. Basically it's manipulating your graph. And it could be displayed just like a graph I mean something like that or maybe it is really a graph that is pretty easy to read as long as it is easy to read.

But **there should be maybe some kind of summary** to talk about it **B**. For example, like when you were talking about some people don't want to watch movies, some people do. **Maybe I want pictures**, maybe **I need some immediate support** you know to pull it out to show it to the point sort of thing. Or maybe there should be options that I have **C**. **Say this is the data that's here. Here is why it's here. This is the research that's done to prove it. Here is the picture of this person struggling right here.** Because it's true, this isn't just made up, something being validated.

As for you know something like this, maybe there is a cool way to show it. I don't know, **I just have this thought where you can have different axis.** There is three things here **D** essentially and maybe you can make it come next to the z that sort of thing. **See where these things start to overlapping you can actually manipulate this and kind of see where things actually start to cross over.** I mean maybe that's too complex. There is the default anyways.

Researcher: Are they complex for you?

Well you know if it's actually executed in the right manner and you can use it, then maybe it wouldn't be that complex. **Maybe it would simplify thing, but when you, it's pretty weird, you know, I guess to get your head wrapped around it first. But you just start to think about it when you start to sketch things out. And really all the numbers go away, it's just there is relative.** This I think is base on that. This is easier and this is harder so I am going to lean this way and you have all this other thing. And you kind of mash those together as you start to draw things.

Researcher: Where do you use that in your process?

This would definitely be in the beginning. This is when you are trying to figure out what's going on, what's you are trying to design for, who you are trying to design for, where the problems are, what needs to be solved. And then given in to like the texture and the diameter that sort of thing, that can be a little bit more a little bit further down the line once you start to detecting some of your earlier issues. Narrowing down on your age range where the problems are then you can use these sort of things so you can probably figure out what you want do if you design and then figure out how to solve the problem.

Designer #15

Desktop/Laptop screen

Desktop/Laptop screen

Well, initially, I was assuming I would look at this for inspiration or initial research going for projects so the bar graph didn't bother me, I mean I have seen worse. So, just if the information was presented a little more clearly and maybe there is color coding so you

know the better range is always located at certain spots or you know where to look or whatever. Just, you know, bringing a simple read.

Researcher: What does it mean by the color coding here?

The preferred rating is up here, whatever the color is. You know, blue, red, or whatever.

Researcher: Then is it the okay zone?

Sure, yes. And maybe that's consistent across all the data so as soon as you see it once, you start going in as you know where to look for that color whenever you want the data you are looking for.

Researcher: So in your case, are you looking for the optimum solution or just the acceptable solution?

I guess I am looking for whatever I am looking for, I don't know. I just want to know how you play with that. You know I don't know necessarily if there are different colors. It may just be like dark blue to light blue, dark red to light red. So the answer of aren't optimal are sort of you know more discreet words that answers more optimal or jump out at you a little more. Having said that, that's looking at pretty general information, you know like height versus ease of use. Your next parameters are included flat versus convex. What I am starting off a project, I don't know what I don't know. So I am looking at stuff like that and saying okay, it is good to start with. But as I start designing and I start looking at, I wonder how convex shapes feels. I mean I don't know that really at the beginning so much, I start looking at and I start designing. So if I want to go test a convex shape, you know that level of information is interesting, if you know that it is available. But I don't know what to do with it maybe at the beginning, as something I might have use later on, but at similar format I guess.

Researcher: If more different shapes are available for you, not just convex shape, are they more helpful for you?

Yeah, that's probably for me, less inspirational and more supportive. You know if I come up with a design I like with a convex shape, I can use that information and say this is why this is a good design.

Desktop/Laptop screen

Well, what I would do is, first of all I present the findings and the shapes of the lid in a three dimensional sort of format **A**, so it will be an x amount of shape and have active parameters to it so there will be sliding sliders on here I can either change the height, I can change the shape or profile, I could add or minimize texture from the outside **B**, and that associates with what we talked about.

And while I am sliding that, I also want to have some scale references from what is it that I changed. So there would be a series of boxes here that would tell me how high this thing is or how wide **C**. What's the shape of the curve and where the profile is and some sort of the measurement for the depth of the texture.

And then it would, I need a scale that would help me tell me what is better or worse or what is easier or harder to grab. So within its sort of Borg Scale format you have shown **D**, depending on how I have changed the parameters, there would be something that is this sort of zone or range or what all these people have told me up here is acceptable.

So up here probably it relates to existing data, so I want something that explains what this task was **E**. So a hundred users indicated blah blah blah. And then the finding **F** was the taller the lid is, the easier it is to open. And then by playing with these different parameters, I can actually see how I am either making it better or worse by changing it. You know as a designer, I think visually, so I think about objects and shapes and then that would, all that reference would make it easier for me to understand how I would change the design, how effective the performance of it, based on existing statistics.

Researcher: Where would you use this in the process?

I would use it right away. I mean if it existed, it would be awesome. It might be the first thing I get to. It would give me some guidance and then you know I don't want to add a certain profile to a sketch because it would make it worse.

APPENDIX V: USER NEEDS EXPRESSED IN DESIGN WORKS IN PHASE 3

Yr	Category	What users said (from transcriptions)	Interpretations (by researchers)
S1	Output display; Visibility of input status - design characteristics	You can play on this, It's interactive	Dynamically show the result when making adjustment
S1	Visibility of input status - design characteristics	What the actual things your tests were that come up with these restuls	Want to see what factors affect the result
S1	Output display	Little chart where each one of these has a different graph	Want charts to show main effects of each design characteristic
S1	Output display	It highlights where on that graph your little slide is	Highlight the curve of each design characteristic on a chart
S1	Output display	(immediately) calculate the average	Calculate difficulty ratings after considering all the inputs
S1	Support and documentation	There should be a little link under that that takes you to the actual, like where that came from, where that research came from	A link that can connect to the resource and details of referred research articles
S1	User control	So essentially, you have a homepage	A menu page lists info of design characteristics, target users, referred research articles, and usability evaluations
S1	Support and documentation	I also want to see very detailed information on what each one of this study was	Want to know sample size, control factors, etc. indicated in research articles
S2	Output display	There is a column that says how easy the lid is to open	A rating, score, or number to indicate the perceived effort levels of your selection
S2	User control; Output display	All of these are interactive by this slide....the rating will dynamically change	For each design characteristic, be able to use a slider to change difficulty ratings
S2	Visibility of input status - design characteristics	So it's sort of a live visual representation of what I am doing	Use graphs or charts to indicate the differences between the changes of design characteristics
S2	Output display; Visibility of input status - design characteristics	So it continuously changes into an interactive game...everyone will be able to find the correct combination here and gets this to be the most or green	Dynamically show the result when making adjustment
S2	Output display	So it continuously changes into an interactive game...everyone will be able to find the correct combination here and gets this to be the most or green	Compare different search results
S2	Output display	Color can come into play in this	Use different colors to indicate perceived effect levels, e.g. green -> better
S3	User control	You will be able to select which one you are interested in	Select lid sizes listed by diameter and height
S3	Output display	and see the menu probably you get a menu of hard or easy, which is a scale	A rating, score, or number to indicate the perceived effort levels of your selection
S3	Output display; Visibility of input status - design characteristics	Might have a little description of what information are there. So in that way you definitely have a picture, that gives you detailed information associated to this graph. Something that is tangible.	Need picture and detailed information about the lid characteristics you selected and result summary
S4	Visibility of input status; User control	So this is an app, you select the gender, then you pinch up or scroll up which age you want to investigate. And then what you do is then take and you pinch to take heights, you pinch to get diameter.	The selections and adjustments of target user infos and lid design characteristics can be made via finger control features of tablets

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Yr	Category	What users said (from transcriptions)	Interpretations (by researchers)
S4	20	Output display; Visibility of input status - design characteristics	Dynamically show the result when making adjustment
S4	20	Output display	Compare different search results
S4	20	Output display	Compare different search results
S4	20	Output display; Visibility of input status - design characteristics	Dynamically show the result when making adjustment
S5	20	User control	No multiple choices for settings of design characteristics
S5	20	User control	Have multiple choices for settings of design characteristics
S5	20	User control	Use scrolls to deal with the layouts of multiple choices
S5	20	Visibility of input status - design characteristics	Visualized lid texture - using different views
S5	20	Output display	A rating, score, or number to indicate the perceived effort levels of your selection
S5	20	Output display	Use different colors to indicate perceived effect levels, e.g. green → better
S5	20	Output display	Dynamically show the result when making adjustment
S6	16	User control	Step-by-step linear information search process
S7	4	Output display; Visibility of input status - design characteristics	Dynamically show the result when making adjustment
S7	4	Output display	Prefer absolute numbers instead of an analogic scale for difficulty ratings. But the numbers are listed next to each other so that you can still see the difference between different settings of lid design characteristics
S8	22	Output display	Use graphs or charts to indicate the differences between the changes of design characteristics
S8	22	Output display	Look for a range of good solutions
S8	22	Output display; User control;	Compare different search results
S8	22	Visibility of input status - design characteristics	Need picture and detailed information about the lid characteristics you selected

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Yr	Category	What users said (from transcriptions)	Interpretations (by researchers)
S8	22	User control	The selections and adjustments of target user infos and lid design characteristics can be made via finger control features of tablets
S8	22	Output display	Dynamically show the result when making adjustment
S8	22	Output display	Upside down the order of the Borg Scale
S8	22	Output display	Care about the relationship between the selected design characteristic and others
S9	5	Output display; Visibility of input status	Can see not only the big picture but also dive in on the results
S9	5	Output display	Care about the relationship between the results associated with different search settings (including design characteristics and users)
S9	5	Visibility of input status	Details or context of the where the results come from - design characteristics and users
S9	5	Assist work efficiency	Short-cut button for quick search
S9	5	Output display	Know optimal and worst solutions
S9	5	Visibility of input status	Details or context of the where the results come from - design characteristics and users
S9	5	Output display	Compare different search results
S10	35	Output display	Want to know whether there are interactions between the design characteristics
S10	35	User control	Can do adjustments for the selected design characteristics on a scale
S10	35	Output display	Dynamically show the result when making adjustment
S10	35	Cognitive load	Be able to save search results

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Yr	Category	What users said (from transcriptions)	Interpretations (by researchers)
S10 35	Output display	I am interested how far I can get up on this scale, without getting too tall or too wide. I mean I am looking for a range, the best range of things. But I am only interested to look for maybe two or three different where I can go back to the guy and say if I made this lid that tall, we get that high on this scale.	Look for a range of good solutions
S10 35	User control	I mean I can contribute to put in what the height is on both of this with what the diameter is. And then I have a range of textures down here	Can do adjustments for the selected design characteristics on a scale
S10 35	User control	So I have the scale again here for easy to difficult and it should be applied texture here.	Compare different search results
S11 5	Visibility of input status - target user	So you go to the website, there is a bunch of icons, people from a little overall all the way up to an old lady...have the body part fenetically... then it takes me to like a search...I go to grip	Can set up the characteristics of user
S11 5	Visibility of input status - target user	I want to know the dimentions, not just short or tall, that does not mean anything to me	It is searching background information about the particular user, for example grip strength and finger dexterity
S11 5	Visibility of input status - design characteristics	I can put in the height and then it's going to give me a difficulty level. And then I can keep tweaking those until I, and see what the different I think something is on something where it shows you the last few comparisons of contrasts.	Details about the selected design characteristics, not just "short" or "tall"
S11 5	Output display	maybe it has a list of the last five things you have tried with	Dynamically show the result when making adjustment
S11 5	Output display	I think it becomes more interactive	Compare different search results
S11 5	Cognitive load	you can drag the height, you can drag like the shape. But you first you select a generic shape.	Need a history shows what has been searched (can be used again later)
S11 5	Output display	you can drag maybe a contour or something. And then it will show you instantly what, how it measures that	Dynamically show the result when making adjustment the HF info
S13 1.5	Output display	You are going to have to manipulate data into what you to find the parameters outdate thing, especially looking at database sort of situation. I have this so I guess so you can change the x and y. You know axis define what this actually is, this chart. Basically it's manipulating your graph	Dynamically show the result when making adjustment
S13 1.5	Visibility of input status - target user	There should be maybe some kind of summary...movies...pictures... the research that's done...Here is the picture of this person struggling right here...	Be able to define the axis of a chart
S13 1.5	Output display	I just have this thought where you can have different axis. There is three things here essentially and maybe you can make it come next to the z that sort of thing. See where these things start to overlapping you can actually manipulate this and kind of see where things actually	Can show some background info about the users, e.g. movies, pictures, how users interact with products, etc.
S13 1.5	Output display		Dynamically show the result when making adjustment

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Yr	Category	What users said (from transcriptions)	Interpretations (by researchers)
S13	Output display	I just have this thought where you can have different axis. There is three things here essentially and maybe you can make it come next to the z that sort of thing. See where these things start to overlapping you can actually manipulate this and kind of see where things actually	Want to know how the selected design characteristics work together to affect the usability of lids
S13	Output display	Maybe it would simplify thing, but when you, it's pretty weird, you know, I guess to get your head wrapped around it first. But you just start to think about it when you start to sketch things out. And really all the numbers go away, it's just there is relative.	No numbers. Only care about the relationship.
S15	Output display	If the information was presented a little more clearly and maybe there is color coding so you know the better range is always located at certain spots or you know where to look	Use different colors to indicate perceived effect levels, e.g. green -> better
S16	Visibility of input status - design characteristics	I present the findings and the shapes of the lid in a three dimensional sort of format A, so it will be an x amount of shape and have active parameters to it so there will be sliding sliders on here I can either change the height, I can change the shape or profile, I could add or minimize texture from the outside	Dynamically show the result when making adjustment
S16	Visibility of input status - design characteristics	And while I am sliding that, I also want to have some scale references from what is it that I changed. So there would be a series of boxes here that would tell me how high this thing is or how wide. What's the shape of the curve and where the profile is and some sort of the measurement for the depth of the texture.	Show the current levels (settings) of the design characteristics
S16	Output display	I need a scale that would help me tell me what is better or worse or what is easier or harder to grab	A rating, score, or number to indicate the perceived effort levels of your selection
S16	Output display	There should be something that is this sort of zone or range or what all these people have told me up here is acceptable	Use different colors to indicate perceived effect levels, e.g. green -> better
S16	Output display	I want something that explains what this task was. So a hundred users indicated bla bla bla. And then the finding was the taller the lid is, the easier it is to open	Summary of the charts and search results
S16	Output display	And then by playing with these different parameters, I can actually see how I am either making it better or worse by changing it.	Compare different search results