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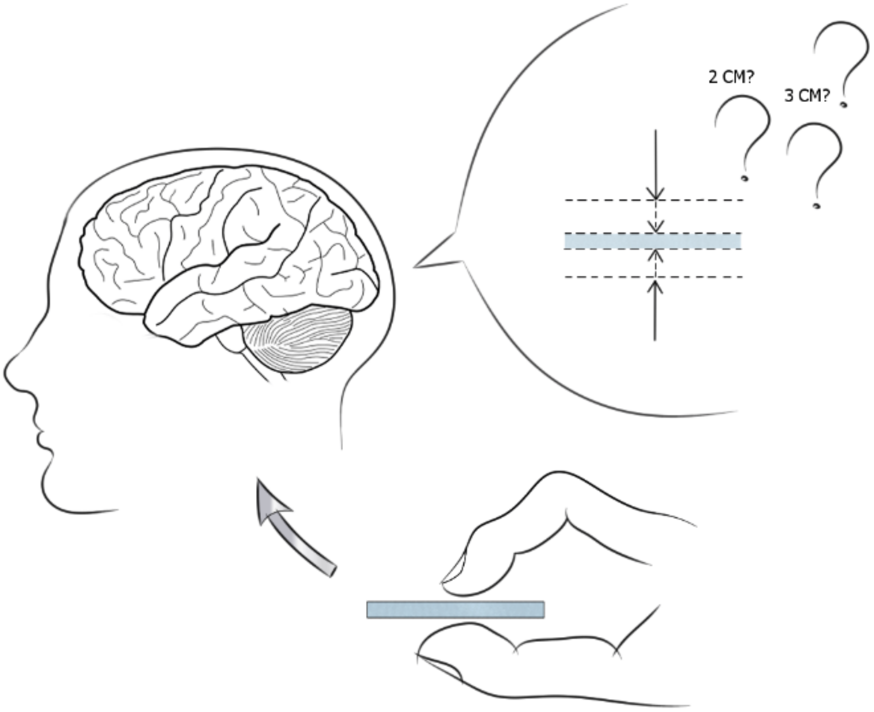

Study of Perceived Thickness of light Incontinence Products

Master of Science Thesis in the master degree program, Industrial Design Engineering

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Cover:
Illustration of a man perceiving the thickness of a plate by hand

Printed by:
Reproservice, Chalmers university of technology
Gothenburg, Sweden 2012

Abstract

For most global companies, leading technology is one of those characteristics which make them distinctive among competitors. SCA is such an international company which has cutting-edge technology in incontinence product development. But the competition today no longer remains in technical areas. Some problems need to be solved with interdisciplinary knowledge and user-centred respect. Thickness of incontinence products is one of those problems. This study explored the concept "perceived thickness" by three experiments regarding thickness perception threshold, user experience, and material properties respectively. The methods adapted were: blindfold haptic test, finger-span method, experience rating, and some descriptive statistics.

The results of the first Experiment A described the relationship of "perceived thickness" and "objective thickness". The variation of discrimination ability with reference of different objective thickness was also found. A method of estimating users' threshold of thickness perception was introduced. In Experiment B, the effects of thickness on three dimensions of user experience were revealed. In Experiment C, the traditional positive correlation between thickness and stiffness was challenged for soft materials. A workshop was then proposed to figure out how to thinner the product without losing its actual thickness. Application of results, limitation of methods, and future research focus were discussed in this thesis.

The outcome of this study will give the company: 1. more comprehensive and deeper understanding of "perceived thickness"; 2. some guidelines and implication of product development.

Key words: perceived thickness, thickness discrimination, haptic, incontinence, discretion, user experience, stiffness

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1 INTRODUCTION

1.1 Background

With the trend of increasing aging population all around the world, especially for developed economies, healthcare for aging people or grown-ups are now given more attention than ever before. Incontinence, or involuntary leakage of urine, is a common health or medical problem suffered by millions of people all around the world (see chapter 3.1 "*Incontinence*"). According to Information Resources, Inc. (Supermarket Business, 2000), incontinence category showed an 11% sales increase to 700 million dollars in 1999. Strong increase of adult incontinence products sales can also economically prove the importance of continuously improvement for these products.

However, since the technical aspects of such products are already of high quality for a company like SCA, with the largest market share in Europe (SCA, 2012), the concerns of experience-level aspect are increasing. Key factors such as "secure", "modern", and "familiar" appear as user experiences could be treated more tangible by mapping with different product properties. These factors are being studied in the launch of some projects in SCA. Different variants of products are also determining the interaction and thus affecting user experience. Experiences includes several aspects of a person's total product experience, which could be the emotional, aesthetic and cognitive aspects (Desmet & Hekkert, 2007).

Among all the properties of these products, **"perceived thickness"** has been recently studied and supposed to be a crucial variant of incontinence product (e.g. adult diaper) experience. Thickness, as one parameter of incontinence products, has been paid great attention to technological respect due to the increasing demands of discretion (see section below). But everyone has to face the truth that losing thickness might be accompanied with the losing of security (absorbency capacity). So there is an urgent need to figure out how to make the product perceived thinner without making it "physically thinner". Even if the actual thickness is changed, how can we make it sufficient so that users will experience the difference, instead of regarding it the same as before? There is a hint from SCA that users' impression or feeling of a product can be affected by 'shape', 'colour', 'smell', 'texture', etc. Designers in company are aware of three prominent user experiences (security, comfort and discretion) of incontinence products (see chapter 3.2).

1.2 About SCA

SCA (Svenska Cellulosa Aktiebolaget) is a leading hygiene products supplier in the world, with 45,000 employees all over the world and a turnover about 107 billion SEK. The product range covers personal care products, tissue, paper products and solid-wood products. The products of SCA are now available in more than 100 countries. TENA, as a brand of SCA, is one of the best-known incontinence brands and includes 11 products in production (SCA, 2012).

1.3 Brief of incontinence

This short introduction of incontinence is based on my college's presentation (*Nurse Advisor Hygiene* in SCA). More medical and detailed description is in chapter 3.1

Urine incontinence is now a common problem, especially for women after childbirth and old people. It happens to women usually because of weaken pelvic floor muscles after childbirth. For old people, the risk of having incontinence is higher. It can be caused by various diseases, such as immobility, dementia, stroke or diabetes, which can either cause the problem or deteriorate it. Incontinence was categorized into disease by WHO (world health organization) in 1998. Patients usually will have problem with their involuntary urine leakage, which happens in daily life and may hazard their life styles. There are 4 types of incontinence, which refers to "*Stress incontinence*, "*Overflow incontinence*"," *Urge incontinence*" and" *Mixed incontinence*".

1.4 Discretion (discreetness)

When talking about assessing the patients' condition considering nature of continence problem, Cottenden et al. (2009) argues:" Generally smaller, more discreet products should be tried before larger bulkier products"

Discreetness or discretion, which means "concealment of problem", is regarded very crucial for light-incontinence products. Because users of these products do not have very serious problem, they like to have a more active and positive attitude towards their lives. For young people, the problem of "body image" is very important because they don't want others detect their problem. They are afraid of being isolated from social & interpersonal lives (EsHocking, 1999; Low, 1996).

It is not difficult to imagine that reducing the thickness can bring positive effects on discretion. Wearing a very thin product will mean lower possibility of exposing patients' problem to others. The detailed relation between discretion and thickness will be studied later in chapter 5.2.

1.5 Purpose

This project is a part of larger project in SCA. The purpose is to perform a study exploring the concept and effects of “perceived thickness”. Users’ behaviour (i.e. how do users feel or check the thickness) should also be investigated. Another intention is to provide good suggestions in future product development.

1.6 Research questions:

Based on the basic information I have collected and the interests of company, the following 5 research questions are proposed to guide my work:

1. **What is “perceived thickness”?**

   This will be answered in chapter 3.4 based on literature review.

2. **How do users perceive thickness?**

   This will be based on an investigation conducted in France (see chapter 5).

3. **Relationship between “perceived thickness” and “objective thickness”?**

   This is about human thickness discrimination ability regarding soft product. It will be answered based on the results of Experiment A (see chapter 4.1).

4. **What effects does “perceived thickness” have**?

   This question regards 3 prominent dimensions of user experiences for incontinence products (i.e. security, discretion, and comfort). It will be answered based on Experiment B (see chapter 4.2).

5. **What determines “perceived thickness”?**

   This is about how to improve the products by means of changing “perceived thickness” instead of changing the physical thickness. A mapping relationship between “product features” and “thickness” were created. This question will be answered by Experiment C and a workshop (see chapter 4.3 & chapter 6).

1.7 Limitations

1. This thesis was focusing on light incontinence product, specifically TENA normal series.
2. Experiments within this project were trial tests. The purpose was to give the company more fresh ways of thinking and some suggestions for product

development.

3. The stimuli for experiments were made by hands. Due to the limited materials available in this short period, the stimuli could not be said perfectly made. If more materials were given, they can be made better.
4. All experiments were made in laboratory with staff in SCA, not with the real end users.
5. Other limitations with details are listed in “notes” sections of each chapter.

2 METHODS

2.1 Overall description

Different methods were used in order to find out the answers to the research questions. The mapping relationship representing the contribution of each method to each question is shown below (Table 2-1). For this project, both qualitative and quantitative methods were used. Three small experiments were made and statistical data were driven from that. The number of subjects (sample size) was smaller for some studies in which answers are converging, and was larger when answers seem to be dispersive. The detailed process and procedure of each method are elaborated in corresponding chapter.

Table 2-1: Contribution of each method

Methods / Research Question	Literature Review	Interview	Exp-A	Exp-B	Exp-C	Workshop
1.What is perceived thickness?						
2. How do users perceive thickness?						
3.“Perceived thickness” &“objective thickness”?						
4.What effects does ”perceived thickness” have?						
5.What determines “perceived thickness”?						

2.2 Literature review

Literature review is a necessary part for almost all thesis work. The advantage of letting students do the research work is that they are sometimes more familiar or feel more comfortable with doing large volumes of literature review. In this project, conference papers, relevant books, previous theses (especially done in SCA) and lecture slides for unfamiliar concepts were read and extracted. Especially within the area of “thickness” study, it was important that breakthroughs in certain areas were not missed. Keywords used for searching literature included:

"thickness", "perceived thinness", "thickness discrimination", "weber's law", "product experience", "perceived coarseness", "perceived compressibility", "somatosensory", "design of meaning", "incontinence", "haptic", "somatosensory", "sample size", "descriptive statistics", "compressibility", "softness "and "stiffness", etc.

2.3 Interview

Why do we need interviews? It is an extremely wide used tool for researchers in user experience. Inteviews can give you large amount of information and it is useful for a lot of user experience studies (Arhippainen & Tähti, 2003). Interviews can be held in a free form (face to face) or in a closed form with limited alternative choices (Hancock, 1998). In this project, it was at first planned to do some face to face interviews with around 15 questions. But after several rounds of revision, form of telephone interview with fewer questions (only five were remained) was thought to be a better idea. This way of solving critical problems at first priority is admirable in real commercial project.

2.4 Blindfold haptic apparatus

In studies about haptic product experience, blindfold apparatus (see in Figure 2-1) is sometimes used so as to get haptic feedback without interference of vision sense (Ho & Srinivasan, 1991; Dagman, et al., 2010; Gao, 2011). This device usually consists of a screen which is opaque and a tunnel (hole) which allowed subjects to touch the samples. In this project, this devise was used for figuring out the relationship between "perceived thickness" and "objective thickness" (Experiment A). Why users were not allowed to see the samples? The answer was simple; because it was a bit too easy to discriminate the thickness by vision (subjects can compare two samples by side view). In Experiment A, the devise was improved to meet our specific requirements (see chapter 4).

Figure 2-1: A simple blindfold haptic apparatus(Gao, 2011)

2.5 Finger-span method

This term is straightforward, which means let the subjects use two fingers to measure the stimuli. The subject can hold the plate vertically or horizontally (Figure 2-2). This method is widely used in "thickness discrimination" experiments in psychophysics or experimental psychology. Two other methods that can be used for measuring length are *temporal-sweep* method (relative movement between hands and stimuli) and *cutaneous-extent* method (stimulus pressed onto the skin), according to Durlach et al. (1989).

Figure 2-2: finger-span method used in this project

2.6 Experience rating

Nowadays more and more companies introduce experience rating system. There exist different types of experience rating (or ranking). Most of them record the subjective feedback of users in number or scores, which represent different magnitudes of user experience (Utamura et al., 2009). One advantage is that it can save time of long interview or qualitative analysis for free answers. Results of experience rating can easily be processed statistically or quantitatively. In this study, rating methods were often used to differentiate the "perceived thickness". The problems of this method are discussed in chapter 7.3.

2.7 Data analysis

In this study, due to quantitative data were driven from three experiments, some simple data analysis was performed. In most cases, mean value and standard deviation were calculated for different purposes. Considering the application of thickness threshold results, Chebyshev's theorem and distribution theory were introduced (Everitt, 2002). Regards quantitative interviews, the statistical way of determining sample size was illustrated. Raw data of experiments are attached to the appendix. In some cases, ratings from experiments were converted into scores so as to be processed.

2.8 Workshop

To understand the behaviour and feedback of real users, workshops and product trials should be performed before new products or improved models are to be sold. The workshop proposal in this project demands real users (incontinence patients) and well-made prototypes. The process will simulate the real scenario of using the products in order to explore the possibility of thinning products effectively and smartly.

3 LITERATURE REVIEW

3.1 Incontinence

This section will describe the basic information of incontinence. The content is mainly based on literature and presentation of my colleague (*Nurse Advisor Hygiene* in SCA).

Urine incontinence is medically defined as" the involuntary leaking of urine, to the extent that it becomes inconvenient." The most near-term definition given by International Continence Society (ICS) is: "Urinary incontinence is the complaint of any involuntary leakage of Urine" (Snad & Dmouchowski, 2002). It was defined as a disease by WHO (World Health Organization) in 1998. In Sweden, there are estimated more than 800 000 people suffered from this to some extent. But barely 200 000 of them have tried to seek help (Westström, 2010). In UK, according to 'The Continence Foundation', 2.5-4 million adults have continence problems (Busutill-Leaver, 2010). One reason adding the variation of sufferers is due to different understanding of incontinence. Some people may have the disease; someone may have urine leakage very occasionally; someone may have not noticed it yet. All possible situations can lead different statistics.

The syndrome is more serious for older people. For people with age of 50, the percentage of incontinence is 15% till 20%, while for people in elderly care homes, the rate can be 80%. Common diseases for old people such as immobility, dementia, stroke or diabetes will also cause or deteriorate the problem. Problem among women is more common than men. "Urinary incontinence is commonly thought to be an almost exclusively female problem" said by Busutill-Leaver (2009). Most common cause for incontinence of young or middle aged women is pregnancies and childbirth. Because childbirth can weaken pelvic floor muscles which will result in leakage of urine and meanwhile, women have a shorter urethra than men (Westström, 2010). But as a syndrome, risk of incontinence can exist in both men and women. With men, the most common cause is a grown prostate.

For a normal human body, our bladder can hold around 300-600ml urine, and excrete like 150ml once. There are muscarinic receptors involved in bladder contraction function, called M2 and M3 receptors. When the bladder is full, signals will be transmitted to "micturition centre" through our spine till brain, which gives the feeling of eager to pee. The overactive receptors can cause very frequent peeing. However, medication for overactive receptors will also affect other receptors all around the body. That is why some people feel dry in mouth or feel discomfort in stomach after medication. This makes them attempt to drink more water, which leads to more urine. Medical reasons such as diabetes, Parkinson's disease, sclerosis, stroke, prolapse and dementia can also cause urine incontinence.

There are two "clogs" preventing the leakage of urine. One is "urine tract sphincter", and another is "pelvic floor muscles". Any problems or infections impair these two parts will cause incontinence. For example, factors such as pregnancy, overweight of body, aging or after prostatectomy can possibly weaken the pelvic floor muscles. Small good news is the pelvic floor muscles can be trained by a program which requires exercising 3 times a day and lasting for 6 month. There is a practice by Professor Kari Bo in Norwegian School of Sport Sciences shows a 60%-70% improvement rate for this exercise.

Among four main kinds of incontinence, '*Stress incontinence*' which happens when people carrying heavy load, laugh, cough, etc. is typical for women who have given birth to children. '*Overflow incontinence*' troubles more men than women. It happens because the bladder has been stretched and weakened and thus never empties completely, which results in a constant leakage. '*Urge incontinence* 'can result from overactive receptors in bladder. Another type of *'Mixed incontinence*' consists of features of above. Around 29% cases of incontinence are categorized into *'Mixed incontinence*'

Although the product this project concerning is "light incontinence" (or light-inco), elderly people can still be the main users as young women regarding this product. Because it is possible that old people have light-inco problem just like young women have heavy-inco problem. With aging problems, the capacity of bladder will drop, pelvic muscle will be weakened, and tissues in vagina and urinary tube will be less elastic, thinner and dryer, which will always cause incontinence.

3.2 Incontinence products

3.2.1 Products family

For lots of sufferers who cannot have their problem been treated by surgery or with slight problem who do not need surgeries, there exist various products attempting to minimize the impact on their lives. The following section will show collages of examples from different product families (see Figure 3-1 and Figure 3-2). Description about incontinence products is mainly based on book of "Incontinence" by Abrams et al. (2009). In this project, the focus will be put on light incontinence (sometimes called light-inco in this report), and especially on pads.

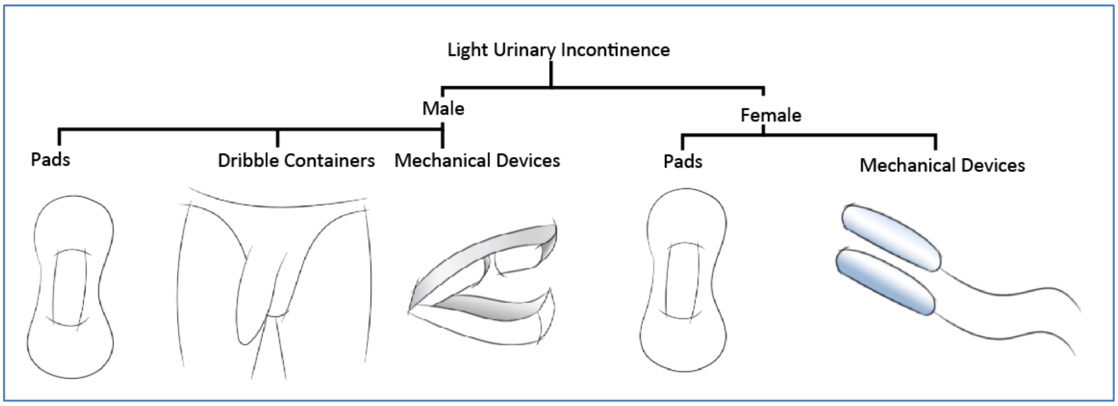

Figure 3-1:Examples of Light inco Products

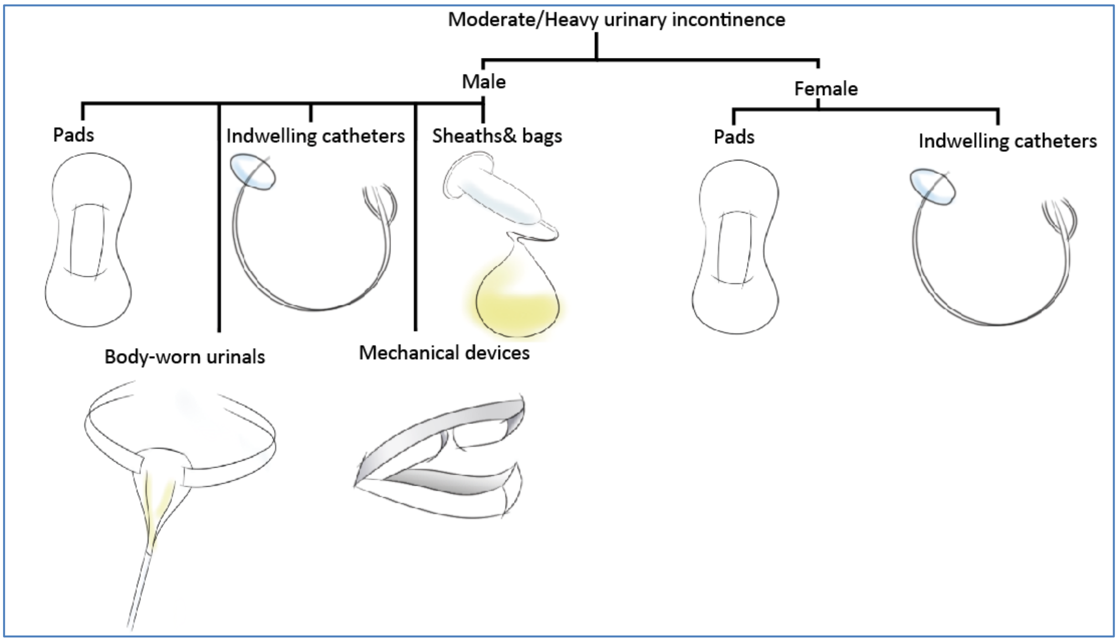

Figure 3-2:Examples of moderate/heavy inco Products

Even just considering light incontinence (urinary), products have their history of evolution. The following information is mainly based on the presentation of a colleague in SCA (Associate Scientist).

In 1960, the most widely used prevention for incontinence was bed sheet, something like the medical bed sheet nowadays. Nurses or healthcarers usually needed to change them every day. It looked clean but actually not with so good bacteria-free technologies. In 1975, net pants equipped with leakage prevention were invented, which remarked the emergence of concept of “pants”. Later in 1978, T-shape pants came to the market and were sold in different sizes. 1982 was the year witnessed the occurrence of light-inco products for men, which looked like a package with the function of holding penis inside it. In 1998, the thinner and smaller pant was invented and in 2002, series of TENA-Flex(by SCA) with improved design which allows users to put on by themselves came to be available. In the same year, triangle design pocket (pad) especially for male users was invented. In 2009, the latest new TENA flex appeared with the philosophies of being more "discreet".

There is another type of incontinence products-"washable/reusable diapers". But interestingly, recent report about baby diapers found that there is no significant difference in environment impact among 3 diaper systems, which are: disposables, home &commercial, laundered (Cottenden et al., 2009). On the other hand, lots of evidences show that men do not prefer washable diapers (Cottenden et al., 2009). So the focus of this project remained disposable pad.

3.2.2 Pads (absorbent products)

Comparing with other Light-inco products, pads have the following merits or advantages (Cottenden et al., 2009):

- Manual Dexterity
- Sound cognition
- More acceptable
- Preventing leakage rather than containing

There are also three types of situations in which people will choose pads (Cottenden et al., 2009):

- Users with frequent but low flow rate of urine.
- Someone maybe doesn't have leakage for some days but then with a large quantity.
- Women prefer to change small pads frequently, which means more mobile.

For female light incontinence products, lots of them (especially pads) look very similar with menstrual pads, but there are some functional differences (Burvall & Sellgren, 2004). For sanitary pad, blood is relatively thicker and the flow is slower compare with incontinence pad which requires the ability to quick absorb fluid due to the large volume in once. Furthermore, Inco pads need to keep the skin dry and without leakage or wet feeling.

A real pad structure can be generalized to four parts;
1) Surface layer
2) Acquisitions layer
3) Storage layer
4) Back side layer

The core of pad is built up by different layers. From the top, there is a non-woven "top sheet" which gives the product feelings like comfort or softness, and more important thing is that its hydrophilic property will allow it to absorb liquid very fast to prevent the leakage before it going into the core. Below that, "acquisition &

distribution layer" will help to spread the liquid very quickly in order not to let liquids stay in a small area which will increase the risk of leakage. Then a pulp mixed with SAP (super absorbent polymers) will help to store and absorb the liquid. There is a plastic film below the core of pad which prevents any leakage after absorption. In the end there is a non-woven layer again called "back sheet" (back side layer). The product series of TENA family is shown below (Figure 3-3):

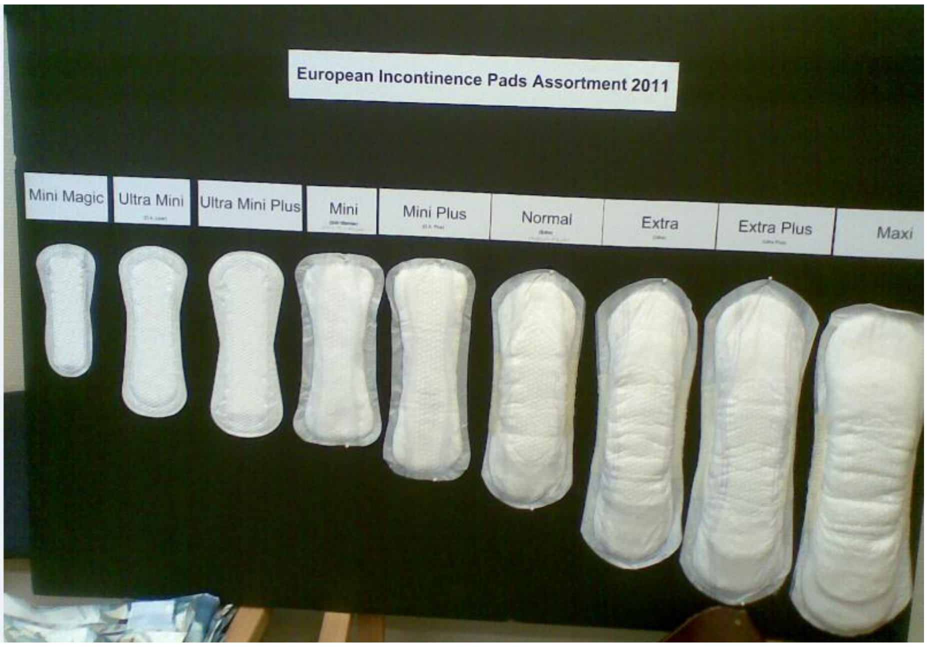

Figure 3-3: TENA pads assortment

It is widely regarded in incontinence area that products should meet the 3 priority of customer needs. They are respectively: **"Leakage security"** (ability to absorb urine and preventing leaking)**, "Comfort"**(comfortable while wearing it), **and "Discreetness**"(hard to be detected, good concealing of problem). Sometimes there can be a priority of "Skin-interaction". Cottenden et al. (2009) also pointed out the consistent opinion among different user groups (both heavy incontinence and light incontinence; both men and women) about the priority of product characteristics:

1. "Hold urine"
2. "Discreetness"
3. "Containment of smell"
4. "Stay in place"
5. "Comfort when wet"
6. "keep skin dry"

This list of priority shows a high need of " **Discreetness**" for absorbent products, which means discreetness is not only a big concern of light-inco users, but also for other user groups. That is why "perceived thickness", which contributes a lot to the dimension of discreetness, will be my research focus.

3.3 Sense of touch

> "Whereas vision and audition are recognized for providing highly precise spatial and temporal information, respectively, the haptic system is especially effective at processing the material characteristics of surfaces and objects" said by Lederman & Klatzky (2009B).

The above saying still reminds us the importance of touch sense in this project even through the concept "thickness", is not just material characteristics. Visual and haptic modalities are both crucial for subjective evaluation of textiles' properties (Grunwald, 2008). The pad product is used by wearing, which means "touching the product every moment". Vision is widely regarded as a dominant modality in lots of studies; one reason is its large proportion in our brain cortex. Haptic research has been given more attention in recent years. Schifferstein (2006) found the relative importance of different senses is dependent on the choice of product and found that smell can be important for detergent while touch is important for watering a plant (sensing weight and balance).

For this product, different senses are used in different product stages, but sense of touch is the main means of interacting with the product. Nevertheless, the hitherto studies in design theory or practices about haptic product experience are mainly concerning active exploration of products by hands (haptic). However, for some industrial products, (menstrual pads, diapers, seats, etc.), the "touch" experience is not just mediated by hands. Different body parts are involved and complex factors like humidity, temperature, body movements and sense of pain will start to affect product experience. This whole "touch" system is called **"somatosensory system**". Meanwhile the other term "**haptics**", is always used in design engineering or psychology with the focus on perception and HMI (human machine interaction). This chapter will talk about definitions and differences of involved terms.

3.3.1 Somatosensory system

Somatosensory system or **somatic sense (colloquially)** is a very complex system among human sensory modalities. It is composed of 3 major components:

1. Tactile perception system (touch, vibration, pressure, etc.)
2. Proprioceptive system (muscle lengths, body positions, joints, etc.)
3. Nociception (Pain system)

However, in colloquial language, terms like **touch** or **tactition**(formal) is traditionally used in five senses (Sight, hearing, taste, smell, and touch). While the formal names of these five senses are: vision, audition, gustation, olfaction, and **somatosensory.** Actually, the sense of somatosensory system has wider meaning than the word "touch". Except for pressure, vibration, or temperature, somatic sense includes the feeling of pain, and the dynamic state or body positions. The receptors spreading through our whole body, among them, skin solely is already the biggest organ of human (George, 2008).

The important issue regarding somatic sense is self-correlating. Romo et al. (2004) found out that somatosensory perception includes an iteratively comparison between 2 cortical areas in our brain, which represent the current activity and the new activity. Study of Weiss and Flanders (1991) proved this mechanism of somatosensory, and found out the somatosensory has a self-adjusting ability by the process of constantly accumulating haptic information and knowledge.

Brain anatomy in Figure 3-4 shows that different lobes are responsible for different senses. The auditory cortex is located in the temporal lobe. Above that there are two parietal lobes responsible for somatosensory system (blue) and somatomotor system (sometimes called motor system, shown yellow in figure). You can also call them somatosensory cortex. The olfactory cortex locates in the inferior surface behind the frontal lobe. Locations in cortex are illustrated by colours in this picture.

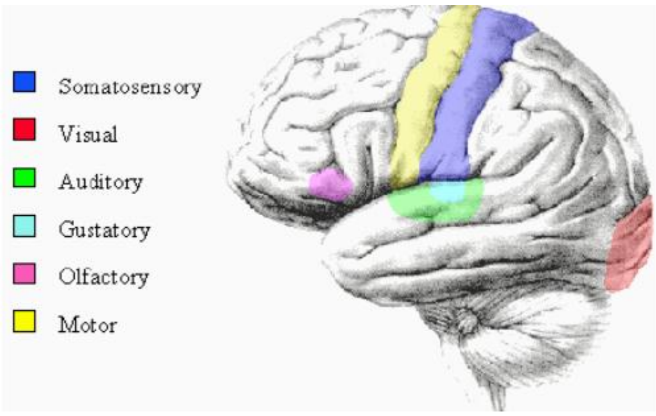

Figure 3-4: Location of each sense in cortex (Jakubowski, 2002)

3.3.2 Haptics

Haptics, which means **haptic sense,** some people also interpret it as **sense of touch** (Paterson, 2007)**.** The word originated from Greek ἅπτω(haptesthai), which means "to touch" and contains meaning of tactile feedback. Revesz(1950) firstly made "haptic" well known and composed it of kinematic and tactile senses.

Now the most accepted definitions of haptic sense consists of two parts: Kinaesthetic and cutaneous, most typically refers to active manual exploration (Lederman & Klatzky, 2009A). The cutaneous system receives signals and inputs from outside by skin. The kinaesthetic system is rather more about body positions, movements, tendons and joints (Lederman, 1986).

”Haptics” can refer to either passive touch or active touch. Both include the process of receiving haptic impulses and transmission of nerve impulses to the brain. Haptic perception is regarded as a two-way communication with the objects (Dagman, 2010).

The scope of haptics is actually overlapped with some parts of somatosensory system. They both include aspects like “tactition”, “touch”, “body position”, and “active/passive”. But there are some differences between these two terms. Haptic perception is studied a lot mainly in areas of design and cognitive science, whilst somatic sense is more studied in medical science or psychology. Somatic sense consists of more comprehensive physiological meaning than haptics.

3.3.3 Indications for this project

Regarding the research topic “perceived thickness”, very few studies can be found in this area. However, there is highlighted importance of haptic system regarding “perceived intensity”, *“The consensus seems to be that the visual and haptic systems are equally good at perceiving roughness”* (Lergmann Tiest & Kappers, 2006).

Traditionally, lab trials for these products are easily performed in ‘breathable’ environment (e.g. exposed in air). However, pad product is not used in such environment because the real condition is warmer and wetter.

On the other hand, haptic product experience is now more about ’hands’. The majority of studies care about mechanoreceptors and thermo receptors for “hairless skin” (“glabrous skin”) (Jones & Lederman, 2006). Few studies exist for “hairy skin” (such as the lower body, which is less sensitive).

Thirdly, this product is touched mainly passively, or strictly speaking, touched passively when being used. When users choose it or open the package of it, they touch it actively. When they wear it, it becomes a passive touch experience. Before they use it, vision and olfactory are also channels of inputs. Not like the case when they wear it, touch almost works as the only input perception modality. The effects and interrelation of these modalities can be interesting for this project, just as said by Lederman & Klatzky (2009B), “Intersensory interaction has become an interest to perception researchers”. There might be variations of product experience in different use stages, which will be discussed later.

3.4 Perceived thickness

This chapter is trying to answer the research question 1: **What is “perceived thickness”?**

3.4.1 Related concepts

The word "perceived thickness" by its meaning of "thickness perceived by users" is more or less regarded inside the incontinence products industry. In area of haptic research, thickness belongs to geometric properties (one of the 6 surface or object properties. The others are: surface texture, compliance, thermal quality, weight, and orientation.), according to Lederman & Klatzky (2009B). But normally the term "perceived thickness" is always used in food science or food technology (Guinard & Mazzucchelli, 1996,). For example, Heinzerling et al.(2008) studied the impact of salivary composition on "perceived thickness".

Interestingly, texture perception is always considered the most important factor of haptic perception. *"Texture is predominantly thought of as a property that falls within the domain of touch."* said by Klatzky and Lederman (2010). That is also why "Perceived roughness" instead of "perceived thickness" is the most commonly studied aspect (Klatzky and Lederman, 1999, 2009B).

Skedung, et al.(2010) conducted an experiment investigating how "perceived coarseness" is linked to physical roughness or friction, in which each participants are allowed to use their own natural numeric scale for "perceived coarseness". The results show that "perceived coarseness" has a positive high correlation with physical roughness, which indicates users have ability to discriminate the surface roughness.

There is also some study in psychology about "perceived compressibility". Bergmann Tiest & Kappers (2006) found out that there is an exponential function relation between "objective compressibility" and "perceived compressibility". They also found out the exponent value and number of dimensions for this function.

In respect to surface properties and user experience, although lots of studies has been done in both areas, studies about the relations between haptic perception and the physical properties of materials are not so ample (Bergmann Tiest & Kappers,2006). However, this project is not solely focusing on material and their perceptions; it is talking about perceptions and product experience regarding "perceived thickness".

3.4.2 Thickness discrimination

There is a related term called "thickness discrimination", which is studied in psychology and psychophysics: Summers et al. (2008) suggested that Thickness can be discriminated via either perception of thickness (e.g. joint angle between two fingers when holding a plate-"finger span method" (Durlach et al., 1989), or via perception of stiffness. Thickness discrimination for very thin stimulus was studied by John et al. (1989), which found the resolution of users judgment can be 0.075 mm when the reference thickness of plate is 0.2mm. Whilst Durlach et al.(1989) found that human can discriminate a difference of 1 mm with the reference length of 10mm and 2.5mm with the reference length of 80mm. From this comparison, Ho and Srinivasan (1991) devised an experiment to investigate human thickness discrimination ability in a larger range: from 0.05 mm to 10 mm. Plates of steel and plastic, bendable and unbendable were used in this experiment. They also found that there is a "critical thickness", below that, human thickness discrimination ability will increase (0.5mm- 1.0mm for plastic plates and between 0. 1mm-0.25 mm for steel). An important conclusion of his study is that for bendable plates, people will tend to use the deformation and curvature to tell how thick it is. Someone calls these "**discrimination threshold experiments".**

3.4.3 JND and Weber's law

An important concept in psychophysics concerning many sensory modalities is **"Just noticeable difference (JND)**", which always refers to a fixed proportion of reference sensory level. For example, people can distinguish 1 mm from the 10mm-11mm thickness comparison and then 2 mm from the 20mm-22mm comparison. This rule was firstly found by Ernst Heinrich Weber (1795–1878). The simple and straightforward expression of Weber's law is:

$$\frac{\Delta I}{I} = K_w$$

(Weber's law)

Here ΔI is the JND (noticed increment of intensity), and I is the intensity of stimulus. K is called "Weber's fraction"(see Figure 3-5). This law is useful to predict the JND with a given reference.

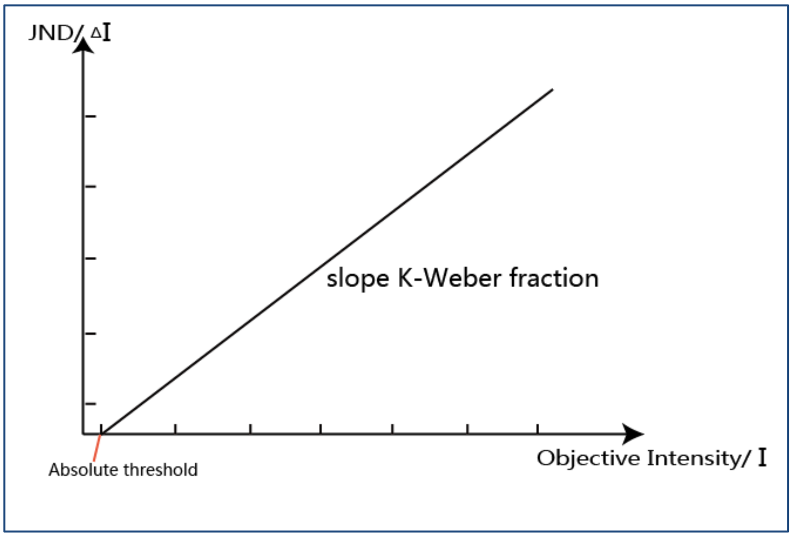

Figure 3-5: Weber's law (relation of ΔI & I)

Gustav Theodor Fechner (1801–1887) then gave a rationale for Weber's law, by bridging the physical magnitude of stimuli and the perceived intensity. Thus this law is also called **Weber-Fechner law** (Figure 3-6). The formula is shown below:

$$dp = k\frac{dS}{S}$$

dp expresses the differential of perception, dS states the differential of stimulus and S is the reference at this moment. After deduction, it becomes:

$$p = k \ln \frac{S}{S_0}.$$

(Fechner's law)

S_0 is the threshold of perception. ***P*** is the intensity of perception and S is the instant stimulus.

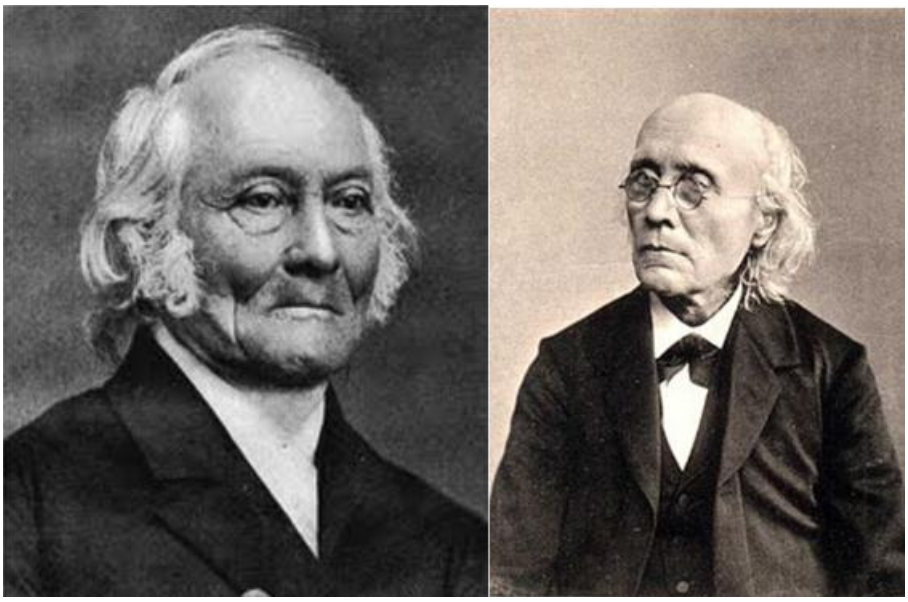

Figure 3-6: Ernst Heinrich Weber (left)(1795–1878) and Gustav Theodor Fechner (right) (1801–1887)

This law reveals a logarithmic relationship between the stimulus and perception. E.g. when the stimuli tripled twice (i.e., 3x3x 1), the corresponding perception will follow an arithmetic progression (i.e., 1 + 1 + 1) (Brown et al., 2008). Fechner's law and Weber's law are mathematically consistent. Readers can easily find the deduction from Fechner's equation to Weber's one. It will not be presented here.

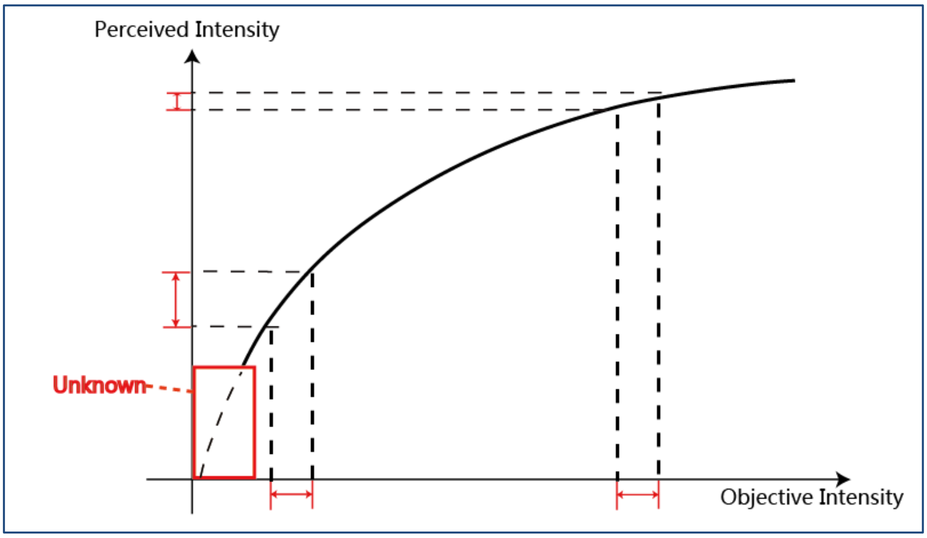

Figure 3-7: Elaboration of Weber-Fechner's law

In Figure 3-7, it is not difficult to understand the principle of this law if by using simple real life example. For instance, one may feel very happy if his salary increases from 200 bucks to 500 bucks. But the increment of happiness will not be the same if the salary goes from 5000 to 5300. For a higher reference, you will have a bigger threshold. The red box in the left bottom in Figure 3-7 tells us that Weber's law always breaks in a small range. This will be treated later in chapter 4

4 EXPERIMENTS

This chapter includes three experiments with focus on different aspects relating to thickness. The mapping relation (contribution) to this project of each experiment is shown in Table 2-1.

4.1 Experiment A

4.1.1 Introduction

This experiment was trying to answer the research question 3**: Relationship between “perceived thickness” &”objective thickness”?**

As mentioned in chapter 3.4”*perceived thickness*”, the reason of finding JND in “discrimination threshold experiments” is that it is hard for subjects to answer the question “how many millimeters do you think it is?” That is why psychologists always let them compare the different stimuli with a reference plate, and record the difference (JND) they can tell. In order to see whether the ability of thickness discrimination for soft plate fits Weber-Fechner law (instead of steel or plastics studied previously), and to see whether the “critical thickness” exist (under which human discrimination ability will increase), this experiment was carried out.

10 people participated in the experiment (staff in SCA, 9 women and 1 man). In previous studies, John et al. (1989) selected 4 adults for subjects, and Ho & Srinivasan (1991) used 5 subjects. The reason they used small sample sizes was that both studies consisted of more repetition for each trial. The test duration was quite long. Limited by available resources and volunteers, fewer repetition but larger sample size was adopted in this study

As hypothesized by John et al. (1989), the crucial mediations of sensing thickness (finger-span method) include: 1. Joint angle. 2. The amount of compression of finger pads.

4.1.2 Fabrication of stimuli

For real products, different layers inside are composed of different materials, such as nonwoven, cellulose fibres, superabsorbent particles (SAP, which can hold 25 times liquid of its own weight) and plastic film. In this experiment, such a concept was simulated by using nonwoven material (widely used in hygiene products, made by bonding long fibres together via chemical or physical process).

For this research question, only one variable-"objective thickness" was allowed. So it was important to control other variables invariant. The first thing should be done is using the same materials. The materials using here were also used in real product (top sheet and acquisition& distribution layer). The second thing was to use the same outer surface to eliminate the disturbance of texture, because surface texture can largely affect the touch perception (see chapter 3.4.1). The third factor was the weight of stimuli, which was eliminated by clamping the samples and hanging them up (see Figure 4-1).

Figure 4-1: Samples of stimuli

Tests samples were built up with nonwoven material made of polyester and polypropylene (PP). Each sample had the same surface material, a PP nonwoven fabric. Further, samples were constituted of nonwoven with different thicknesses (0, 11 mm, 0, 64 mm, 1, 25 mm and 2, 4 mm. see Figure 4-2). These layers were combined together to achieve the desired thickness. The step of increment was tried to be made small so subjects would not omit the JND (see Table 4-1). Thin layers were glued together by a spray gun.

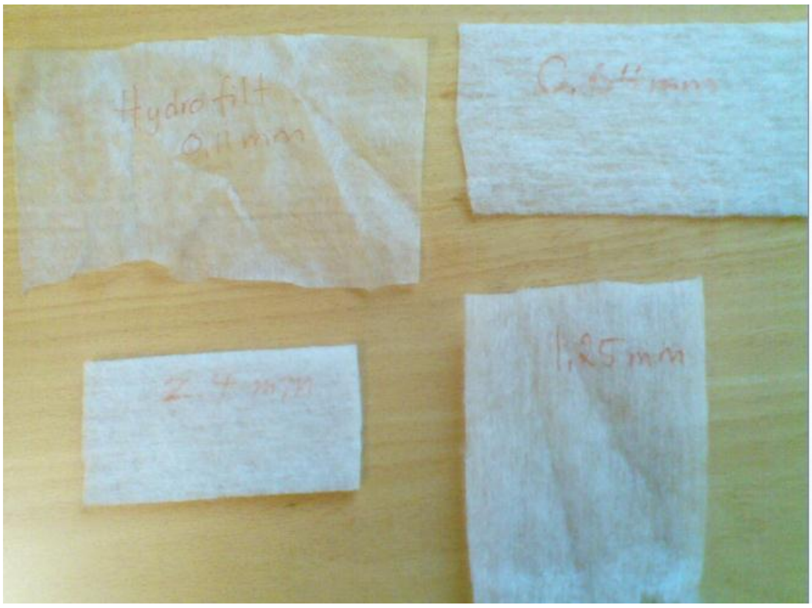

Figure 4-2: Layers of stimuli

Table 4-1: Comparison plates for each reference

Session	Reference thickness	Comparison Plate Thickness/mm				
1	2 mm	2.2	2.4	2.6	2.8	3.0
2	4 mm	4.2	4.4	4.6	4.8	5.0
3	6 mm	6.25	6.5	6.75	7.0	
4	8 mm	8.25	8.5	9.0	9.25	
5	10 mm	10.25	10.5	10.75	11.0	11.5
6	12.0	12.5	13.0	13.5	14.0	
7	14.0	14.5	15.0	16.0	17.0	
8	16mm	16.5	17.0	17.5	18.0	
9	18mm	19.0	19.5	20.0		

4.1.3 Procedure

As proved by previous studies, training session for this kind of "discrimination threshold experiment" is very important. One reason was to make subjects learn how to position their hands. They should not rub or press the samples too hard otherwise would be destroyed. Usually people use their index finger and thumb to press it. But there was still something that needed to be taught. For example:

- Example reference of 10mm was used for teaching because this was not too difficult either too easy. This pair of tutoring had been used by previous studies (John et al., 1989; Ho & Srinivasan, 1991).
- How to touch the stimulus and trying best not to destroy it.
- Do not keep the finger-span fixed because that can mechanically help them

measure.

- Learn to tell the difference when feel it apparently exists;
- Touch the middle; and rubbing is allowed;
- Do not try too hard or think too much, tell the host your first impression.

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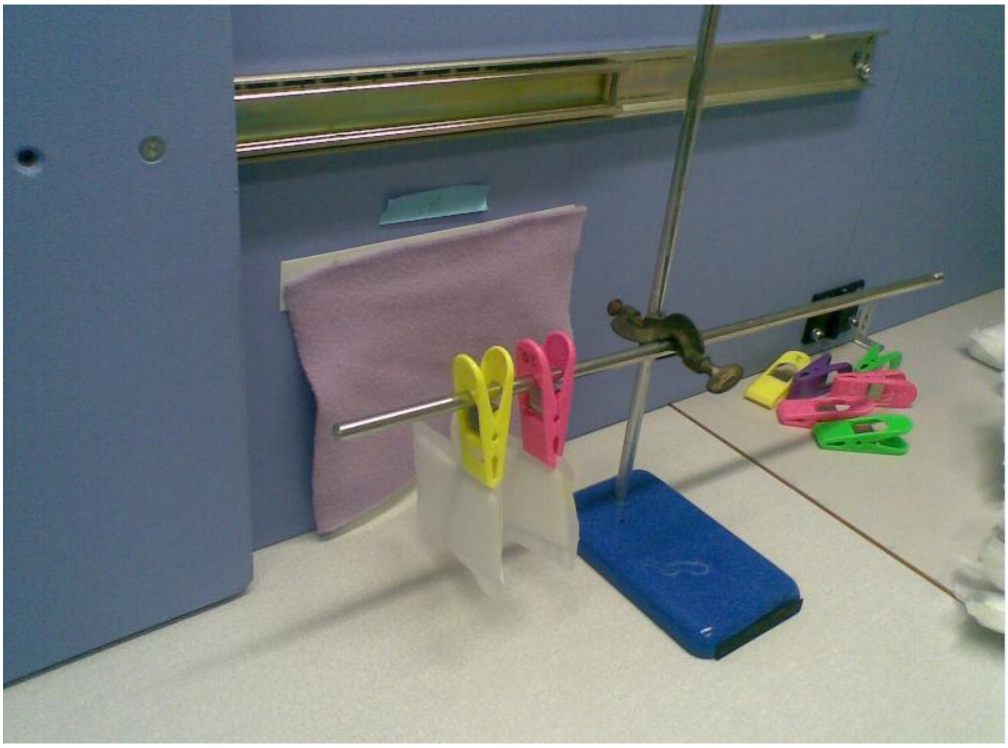


Figure 4-3: Apparatus of experiment

The process of conducting of the test was as following:

1. Subject sat behind the opaque screen and could only use their hands to touch the stimuli.
2. Training session: subject was faced of reference sample with 10 mm and the comparing samples.
3. Subject was told that they are facing two stimuli, one is the reference and the other is either the same thickness or a comparison thickness.
4. Subject should use their dominant hand and touch the stimuli one by one instead of touching them by both hands at the same time (avoid measuring).
5. Subject was required to tell "yes" or "no" to show if they could sense the difference.
6. After each trial, host changed the comparing sample but kept the reference the same.
7. When the subject noticed the difference, host let subjects touch the thicker sample after they tell the difference to avoid guessing.
8. Let the subject touch the "distinguishable" samples again and swap the left-right samples behind the screen to verify the results.
9. If the subject failed once on which he was able to tell difference, that result

should not be counted as JND since the real user in daily life will have less caution with thickness

10. Host recorded the answer (JND) of each run.
11. After training session, test started from reference plate of 2 mm and end with 18 mm. In all there were 9 sessions.

Each person needed to go through 9 sessions (Table 4-1), and each session consisted of several trials until they were able to tell the JND. The apparatus (blind-folded haptic apparatus, see chapter 2.4) were available at SCA and is shown in Figure 4-3. The experimental time for each subject should not be too long to prevent the decrease of tactual discrimination ability (Ho & Srinivasan, 1991). It turned out that one test for each person took 20 minutes.

4.1.4 Results

The recorded JNDs and calculated values of mean and standard deviation are shown in the Table 4-2. The original data is shown in Appendix I

Table 4-2: JNDs of all tests

Reference thickness	2 mm	4mm	6mm	8mm	10mm	12mm	14mm	16mm	18mm
Subject1	0.6	0.6	0.25	0.5	0.25	0.5	0.5	0.5	1.5
Subject2	0.8	0.2	0.25	0.25	0.25	0.5	0.5	1	1
Subject3	0.8	0.2	0.25	0.5	0.75	1	0.5	1	1.5
Subject4	1	0.6	0.75	2	1	2.5	1	1	1.5
Subject5	0.6	0.4	0.25	1.25	0.75	0.5	0.5	1	1
Subject6	0.6	0.8	0.75	1.25	1	2.5	0.5	0.5	2
Subject7	0.8	0.6	0.5	0.5	0.75	1.5	1	1	1
Subject8	0.4	0.4	0.25	0.25	0.25	0.5	0.5	1	1
Subject9	0.6	1	0.75	0.5	0.75	2	1	2	2
Subject10	0.6	0.8	0.75	1	0.75	1.5	1	2	2
Mean	0.68	0.56	0.475	0.8	0.65	1.3	0.7	1.1	1.45
STD	0.168655	0.263312	0.248607	0.562731	0.293447	0.823273	0.258199	0.516398	0.437798
coefficient of variation(CV)	24.8%	47.0%	52.3%	70.3%	45.1%	63.3%	36.8%	46.9%	30. 2%

The blue curve represents the mean value of JNDs in Figure 4-4 is in the middle between the maximum threshold and minimum thresholds. The straight dash line in slight blue indicates the possible theoretical JND if Weber’s law holds. Here the slope is 0.8125, which is called weber’s fraction.(in Weber’s law, here d=0.8125*R, d is JND, and R is reference)

However, like previous studies, Weber’s law always breaks when the intensity of stimuli is very small. For example, Durlach et al. (1989) pointed out that in some occasions, the dependence of ΔL on L does not satisfy the Weber's law is not a surprise (also see chapter 3.4.3). Ho and Srinivasan (1991)'s finding of critical thickness also conflicted with the curve of Weber's law. But for a relatively large range (35-100 mm), Gaydos (1958) proved it obeys the Weber's law by finger-span method. Whether Weber's law works after 20 mm for soft materials can be a possible interest after this study.

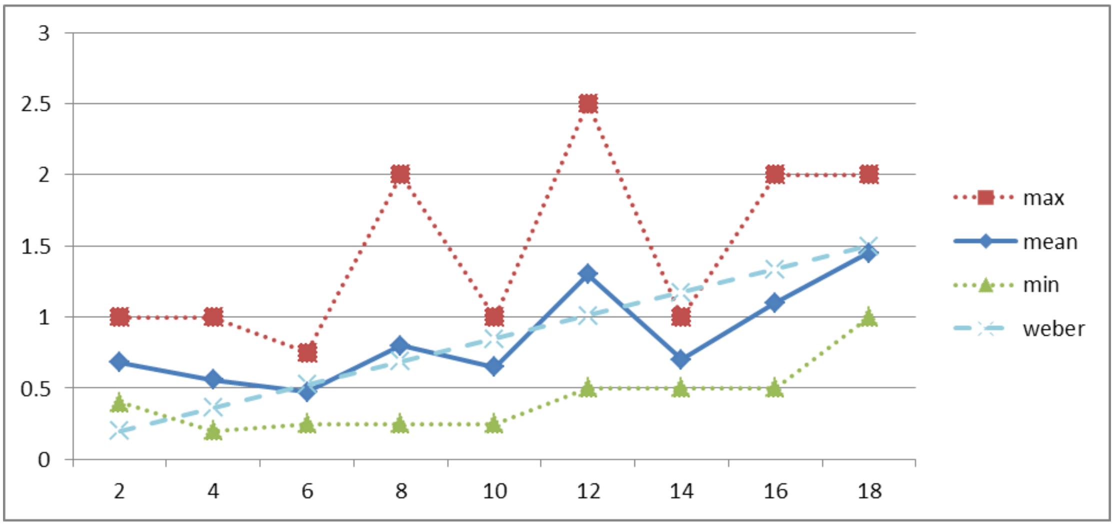


Figure 4-4: Comparison of thresholds

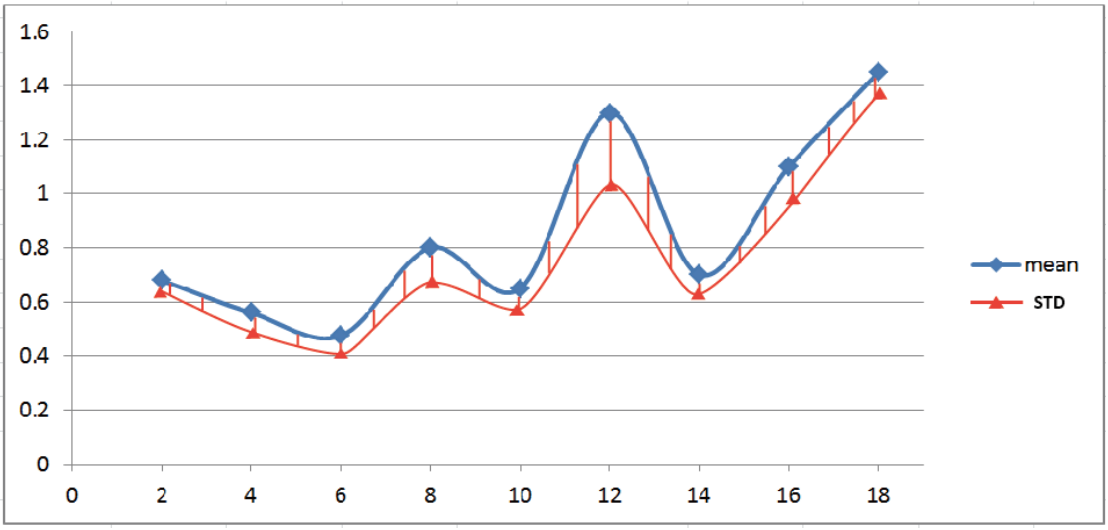


Figure 4-5: Mean with STD comb

The mean curve fluctuates a lot from 6mm to 16 mm. Figure 4-5 with STD comb also shows the JND with 8mm, 12mm, and 16mm are of high deviation, which means subjects' perceptions of thickness vary a lot within this range. But only by this chart it was not possible to estimate how many people would notice the difference if the product, for example, is made 0.5 mm thinner. So it was necessary to look at the distribution. Two most possible and convenient models of distribution were chosen:

normal distribution and **dispersive distribution**. Assume our dispersive distribution was symmetry. Another premise is the **fact that people can also tell the difference beyond JND**. For example, when a reference is 2 mm and JND is 0.68 mm, half of the population can also tell the difference beyond 0.68mm in these two distributions (see Figure 4-6).

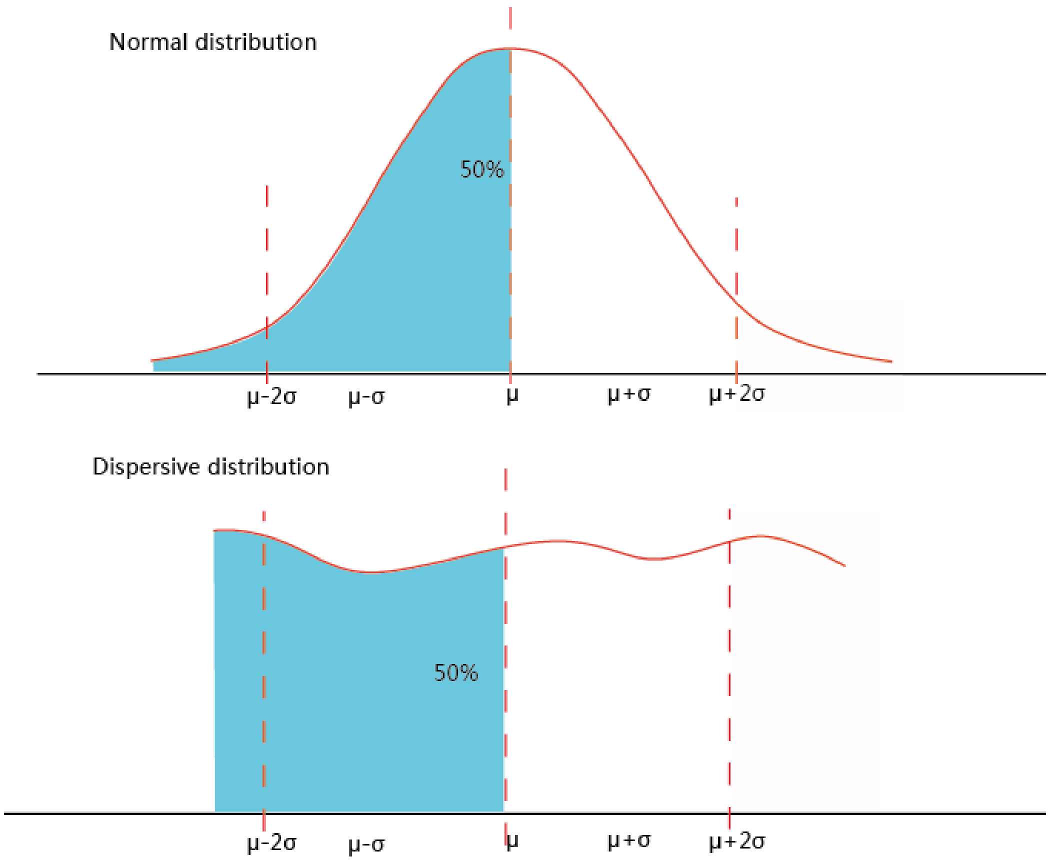


Figure 4-6: Distribution(mean of μ, σ is one standard deviation)

In normal distribution, there is a law of 68(1σ)-95 (2σ)-99.7 (3σ) rule, which mean, the interval within $\mu \pm 1\sigma$ will cover 68% population, and an interval between (μ -2 σ) and (μ +2 σ) will cover 95% , and so forth.

But what is the case for arbitrary distribution? To estimate the proportion of population above 50% for dispersive distribution, "Chebyshev's theorem"as a traditional tool for descriptive statistics was introduced (Everitt, 2002). The advantage of "Chebyshev's theorem" is that it can be used for arbitrary distribution and easy to be conducted. The expression is shown below:

$$1 - \frac{1}{k^2} = x \qquad \text{(Chebyshev's theoem)}$$

This means for a mean of μ, a fraction of x of whole population will lie in the area of $\mu \pm k\sigma$. In which σ is one standard deviation. For example, if k=2, x will become 75%. Which means at least 75% of people will fall in area of $\mu \pm 2\sigma$. But remember another proportion of 12.5% should be included, so 2σ will result in around 90%

people (75%+12.5%≅ 90%) (see Figure 4-7).

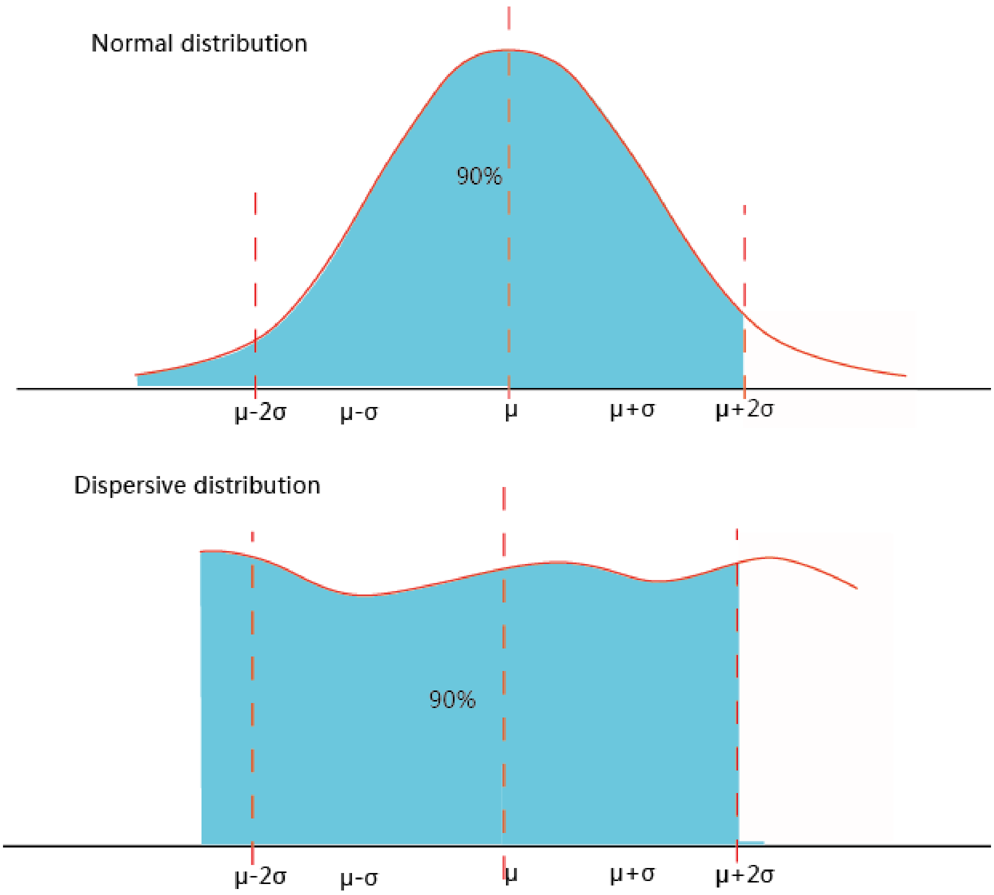


Figure 4-7: Estimated proportion of population

The results were organized in the following table:

Table 4-3: Estimation of JND with proportion of population

Reference / Proportion	2 mm	4mm	6mm	8mm	10mm	12mm	14mm	16mm	18mm
≈50% (mean)	0.68	0.56	0.475	0.8	0.65	1.3	0.7	1.1	1.45
≈90%	1.02	1.09	0.91	1.5	1.24	2.6	1.22	2.13	2.33

The dispersive results of subjects' thickness perception also revealed subjects' various thickness discrimination ability (see Figure 4-8). Thickness discrimination ability or "thickness sensitivity" A was calculated as following:

$$A = \frac{1}{d/R} \qquad \text{(Discrimination Ability)}$$

In which d is the JND at the instant and R is the reference thickness at that moment. This formulation means that the higher a fraction (d/R) is the poorer discrimination ability one has. Figure 4-8 shows the ability variation comparing with Weber's fraction. Areas around 8, 12, and 16 were marked red because high standard deviation, which means subjects' performance varied a lot in this "critical range".

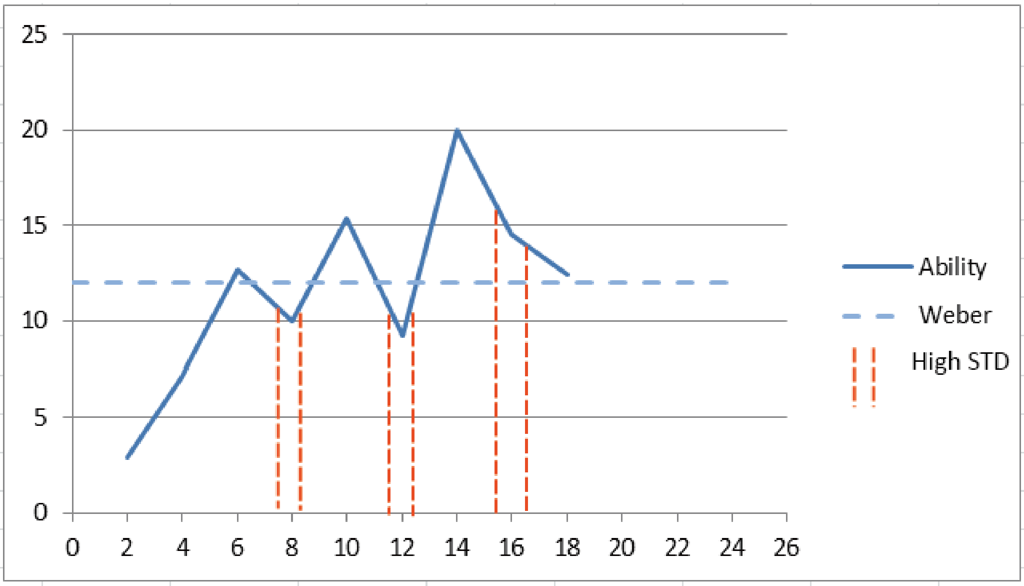


Figure 4-8: Curve of thickness discrimination ability

4.1.5 Conclusions of experiment A:

1. Below thickness of 6mm, the thinner the stimulus is, the poorer the discrimination ability is.
2. Discrimination ability and JND within 8-18mm is averagely higher than 2-6mm.
3. As proved by previous studies, perception of thickness will not obey Weber's law in a small range. But from 14mm, the JND did increase when the reference increase. What will happen beyond 20 mm is unsure.
4. Being able to thinner the product according to Table 4-3 so as to make people feel obvious difference. For instance, if the product is made 1 mm thinner when it was 2 mm, most people will feel it's obviously thinner. However, if making the product 1.5 mm thinner when it was 18 mm, only around 50% people will feel it thinner. But making it 2.33 mm thinner will satisfy most people (see Table 4-3). Notice the results is based on touch experiment, human thickness discrimination ability is actually quite high when they can see it (they are able to check the side view).
5. Exact JNDs ranging from 8mm to 16 mm are hard to predict, in which the responses from subjects are dispersive. Some explanations are:
   - Stimuli within this thickness range (8-16 mm) became quite fluffy, which created different thickness in different part of one sample. Even though subjects were told to touch the middle, this uncertainty still remained.
   - Stimuli within this thickness range (8-16 mm) were not easy to be fabricated (e.g. to make 0.25 mm difference for an 8 mm sample is difficult), which

might cause the imprecision.

- This experiment used even numbers as reference (8, 10, 12, etc.). If odd numbers (9, 11 13, etc.) are used, the results might vary in another way in this range.
- An assumption is that people may feel relatively familiar with this thickness range (e.g. thickness of a pen, a cellphone, a document folder can be within this thickness range). Higher frequency of interacting with this certain thickness range in daily life could make this a "sensitive area" for thickness perception.

4.1.6 Notes:

1. This experiment worked as a trial test. The statistics presented here is a guide for how to drill and utilize current data or resources.
2. To get more accurate results, sample sizes need to be larger, significance; validity and reliability of data need to be verified. But it is not recommended to reproduce this experiment in a large scale. The reasons are:
   A) In reality, users are able to see the products sometimes, not always blindfolded, which means their thickness perception ability is will be different.
   B) When users wear the product, while tactile sensory plays a single role, they do rely heavily on somatosensory, instead of relying on haptic feelings of hands. So the best way to reproduce this experiment is to do it for real users, focusing on lower-body perception. But first of all, it is necessary to know if the use stage of wearing the product plays a major role for thickness perception (user might have decided how thick it is before they wear it) before the costly experiment.

4.2 Experiment B

4.2.1 Introduction:

This experiment was focusing on research question 4: **What effects does "perceived thickness" have?**

Just understanding the concept and composition of "perceived thickness" is not enough. As talked in chapter 3.1 "incontinence", Discretion, Security and Comfort are the three most significant aspects for incontinence products. This experiment used relatively simple tools to figure out the relationship between "thickness" and each of these dimensions.

There were 5 subjects (all female, staff in SCA) who attended this experiment and each test took around 15 minutes. During the experiment they only needed to do the ranking of stimuli according to each dimension. The ranking results were converted to scores in order to be calculated and analysed.

4.2.2 Stimuli

The same stimuli fabricated for **Experiment A** (thickness discrimination experiment) were used. Thickness ranged from 2mm to 20mm with an increment of 1 mm (see Figure 4-9). In all there were 19 pieces. Subjects were allowed to see and touch the stimuli because the responses collected by blindfolded would not be valuable regarding user experience. In reality, users always see the product before or after using it. Subjects were asked to sit beside a table, where stimuli were exhibited randomly (see Figure 4-10).

Figure 4-9: Stimuli

Figure 4-10: Subjects are selecting samples

4.2.3 Procedure

1. Host put a pile of stimuli (19 pieces) in front of subject.
2. Subject was able to see the stimulus but without seeing the number on the label.
3. Host explained the 3 dimension: discretion, comfort & safety (see Chapter 3.1) to the subject
4. Subject was asked to choose the one felt most discreet.
5. Host picked the selected sample and put it aside.
6. Host recorded the score of this sample, the first one picked was 20 (recorded in Table 4-4)
7. Subject then again needed to choose the sample which felt most discreet among the stimuli left (18 pieces).
8. The score of this sample was 19, etc.
9. The process was iterated until the last one was left.
10. Dimensions of comfort and safety followed the same procedure.

*Note of procedure:

- To avoid subject seeing the number on the label, label was overwritten by random alphabet. The mapping relationship is shown in Table 4-3.
- Host must remind the subjects to disregard other dimensions when ranking for one specific dimension.

- Host needed to remind the subjects to go through all pieces instead of looking at some pieces of all stimuli.
- Host needed to remind them that thickness was the only difference among pieces. Subjects needed to assume softness and texture were the same (even though they had slight difference in reality).
- The concepts of 3 dimensions (discretion, comfort & safety) must be explained thoroughly to make sure the subjects truly understand.

Table 4-4: Mapping relations of thickness and label

	label	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5
2mm	O					
3mm	H					
4mm	K					
5mm	C					
6mm	Q					
7mm	L					
8mm	E					
9mm	S					
10mm	A					
11mm	N					
12mm	J					
13mm	F					
14mm	M					
15mm	D					
16mm	I					
17mm	R					
18mm	G					
19mm	B					
20mm	P					

4.2.4 Results

The mean scores with each reference thickness were calculated (for raw data, see Appendix II). Then a scatter chart was plotted in Figure 4-11. Since the score were quite correlated with thickness (negative), linear regression method was used to draw a straight line (green) in chart. R squared (coefficient of determination), which ranges from 0-1. 1 represents a perfect matching and 0 means not fitting at all. Here the R squared equals to 0.9964, which means the straight line could represent this trend well. One thing interesting in the scatterplot is that some dots are almost parallel (e.g. scores of 8mm and 9 mm were similar, and the same for 12 mm and 13 mm). This feature was not just coincidence, when subjects chose the one they felt most discreet, they tended to choose the thinnest one, these samples which get similar scores could actually be difficult to discriminate, as proved in the experiment A. But remember in this experiment subjects were allowed to see the stimuli, that's why it was generally easier for them to tell the difference.

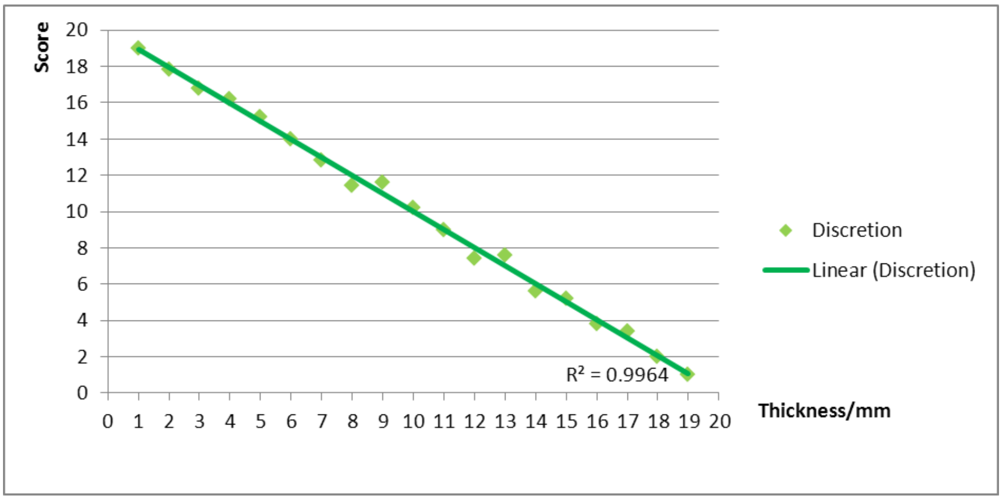


Figure 4-11: Discretion vs thickness

Regarding the dimension of security(see Figure 4-12), the answers could also be described by a linear relationship. But the scatter actually fluctuated a bit more than the dimension of discretion, which means some subjects did not think thicker products means safer. Another cause could be that they felt hard to recognise thickness difference sometimes.

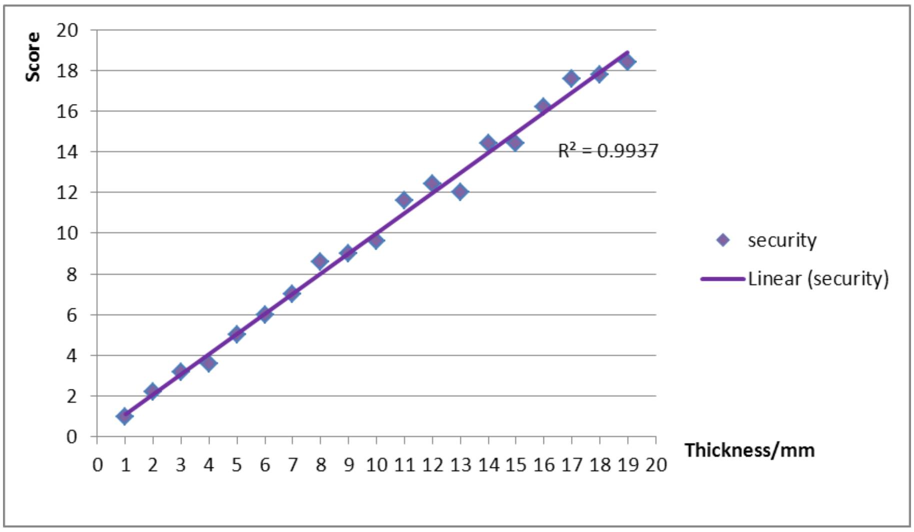


Figure 4-12: Security vs thickness

The same method was used to plot the chart of comfort dimension(see Figure 4-13). This time since the relation between comfort and thickness was not linear, polynomial regression was introduced because its good fitting to this type of scatters . The mathematical representation of this relationship is shown below:

$$y = -0.0003x^4 + 0.0211x^3 - 0.4796x^2 + 3.2776x + 8.7703$$

(Y is score getting in comfort, x is thickness.)

This was a curve with order of 4(highest power is 4). R square in this case was 0.9772, which was also high enough.

But the important thing is not the math, is the trend itself. It could be seen clearly that the relation between comfort and thickness was not as simple as the other 2 dimensions. Actually, the responses were also more diverse. This implies that different people will tend to have different understanding and preference of comfort. Someone thought thinner products were more comfort, someone felt the opposite. But averagely, thickness ranges from 3 mm to 8 mm were perceived most comfortable. And generally thinner products were considered more comfortable than thicker one.

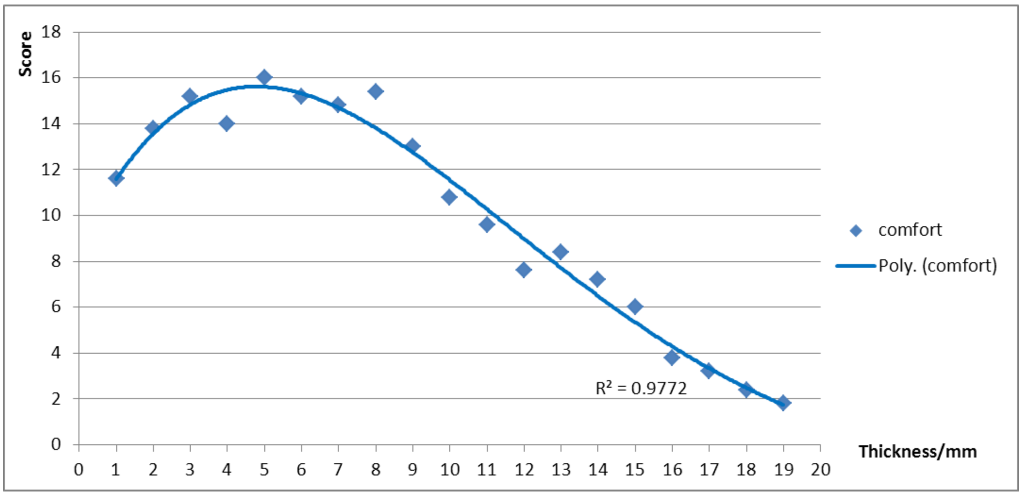


Figure 4-13: Comfort vs thickness

Product experience is a complex concept. These 3 dimensions can not represent everything in product experience. A simplified method by assuming each of the 3 dimensions has the same weighting in product experience was used to draw a trade-off curve regarding the confilict demands (see Figure 4-14).

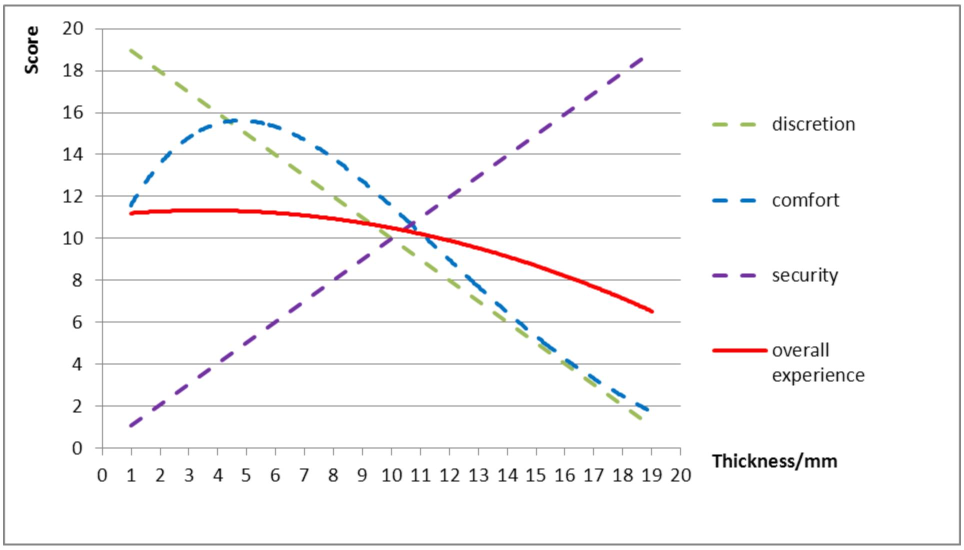


Figure 4-14: Trade off of 3 dimensions

4.2.5 Conclusions of experiment B:

1. Consistent with the traditional thoughts, dimension of discretion negatively correlated with thickness, while dimension of security positively correlated with thickness.
2. Comfort is a dedicate dimension. It turned out that thickness did not simply correlate with comfort experience. Subjects were actually seeking their "best" product with a pre-set thickness range in their mind. Someone preferred 8 mm while someone preferred 2mm. But generally thinner products were regarded more comfortable than thicker products. Averagely thickness within 3 mm- 8mm was perceived as most comfortable.
3. In the trade-off chart, the overall product experience did not vary too much (scores: 7-11) in span of 2mm-20mm amid the big variance in each dimension. And thinner products seemed to be perceived better than thick ones, which was consistent with the feedback from costumers (according to the company). And extremely thin product (2mm) was not perceived best, which also fit the real user needs.

4.2.6 Notes:

- In dimensions of discretion and security (Figure 4-12 and Figure 4-13), user experience extensity was displayed as a linear relationship with the thickness. The reality might not be so. The linear relationship was partly due to the "ranking mechanism" of tests (see chapter 7.3 Experience rating). Users did feel thicker products more secure, but how much more? This delicate relationship could not be answered by this experiment.
- In the trade-off chart of 3 dimensions (red curve in Figure4-14), each dimension

was multiplied by 33.33%, but in reality, security is more important than the other two. There is no consensus of how much proportion it should be. So the trade-off curve has its limited application when users refer to that.

4.3 Experiment C

4.3.1 Introduction

Experiment C was trying to partly answer research question 5: **What determines "perceived thickness"?**

Besides the major impact of objective thickness, it is not difficult to imagine that stiffness can affect the perception of thickness. With the change of thickness, stimuli sometimes starts to become bendable (John et al., 1989). Ho and Srinivasan (1991) proved that people will tend to bend the plates (made of wood and steel) so as to get information of thickness. These 2 studies also mentioned factors like texture (affecting discrimination ability) and heat flux (influencing the perception time). A sum up from literature review told us the possible effectors of perceived thickness:

1. **Objective thickness**
2. **Stiffness**(for elastic body)
3. **Texture**(affecting discrimination ability))
4. **Heat flux / Thermal conductivity** (people can calculate time of heat conduction between 2 fingers)
5. **Weight /density**
6. **Visual clues**(shape, pattern, colour)

Notes of selecting factors:

- Notice the objective thickness and material properties will change after it gets wet.
- Stiffness calculation will also be affected by the structure of sample. If the structure of sample is controlled, Young's modulus can be used to represent the "rigidity" of samples.
- When the shape and objective thickness are controlled, changing the stiffness by replacing the material (foam) will also change the thermal quality.
- Weight will always change with the change of objective thickness and density will change with the materials (the same for stiffness and heat flux).

So the most convenient factors to be proceeded were objective thickness (has been done in Experiment A) and Stiffness (in Experiment C). There were 8 participants (6 female, 2 male) within age range of 20-50 years old. They were staff in SCA.

4.3.2 Stimuli:

Three groups of stimuli (thin-2mm, middle-10mm, and thick-16mm) were fabricated and each group consisted of 4 stimuli (see Figure 4-15). They were made by gluing the layers of the same foams together and were labelled 1, 2, 3, and 4 randomly. The layers were all made by different types of PU (polyurethane, which is always used to make foams. e.g. foam in a car seat) with the same thickness but with different stiffness (if one feels them by hands).

Figure 4-15: Stimuli of Experiment C

4.3.3 Measurement of elastic modulus (stiffness)

First of all, it needs some clarification for some concepts. All of four materials were treated as elastic body because of the linear relationship of the load and deformation (see Appendix III). For elastic body, **pliability** is the reciprocal of bending stiffness. The stiffness will change with the change of the structure. But **elastic modulus** or **Young's modulus** is a material quality that will not change with structures. Another concept sounds related is **compressibility,** a reverse of **bulk modulus**, the perceived compressibility is studied by Bergmann Tiest & Kappers(2006). Compressibility reflects the change of volume under infinitesimal pressure **from all direction**, which is a different case comparing to this project. But compressibility can be applied and often applied in thermal dynamics for fluid and gases. Young's modulus and Bulk modulus are convertible in some cases. So the approach is to utilize Young's modulus to differentiate the materials' softness. Elastic modulus was measured referring to **Hooke's law:**

$$F = k\Delta L \qquad \text{(Hooke's law)}$$

In which, ***F*** is the load applied to an elastic body (N), **Δ*L*** is the deformation (m), and ***K*** is called "spring constant" (N/m). For tensile objects, K equals to the **stiffness**. For example, within range from 0mm-20mm, the elastic linear relation between the load and the extension for material no.1 is shown below (Figure 4-16).

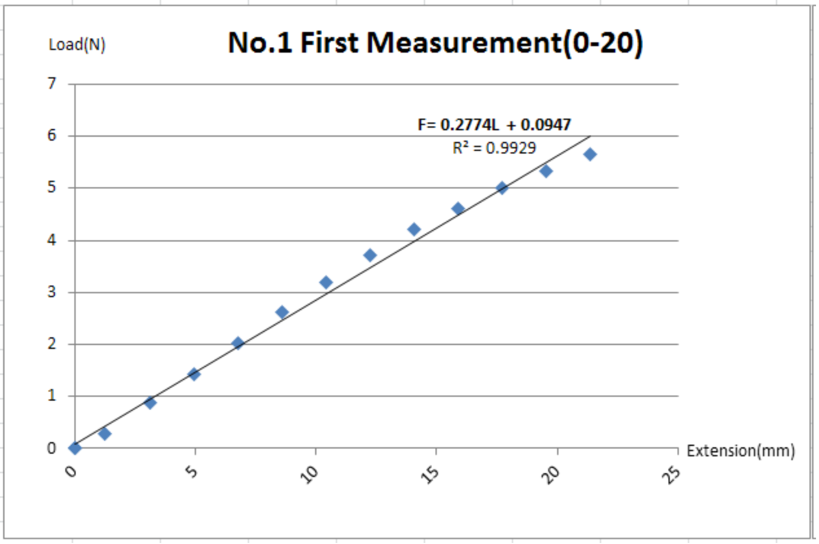


Figure 4-16: Linear fitting of material no.1

Meanwhile, for a tensile object, Young's modulus can be calculated by the following formula:

$$E = \frac{\sigma(stress)}{\varepsilon(strain)} = \frac{F/A_0}{\Delta L/L}$$

Where A_0 is the cross-section area perpendicular to the force applied; **Δ*L*** is the deformation same as in Hooke's law and ***L*** is the original length of the sample. Therefore, the relation between Young's modulus E and string constant **k** is given:

$$E = (\frac{A_0}{L})K$$

In our measurement, the sample had a size shown below (Figure 4-17):

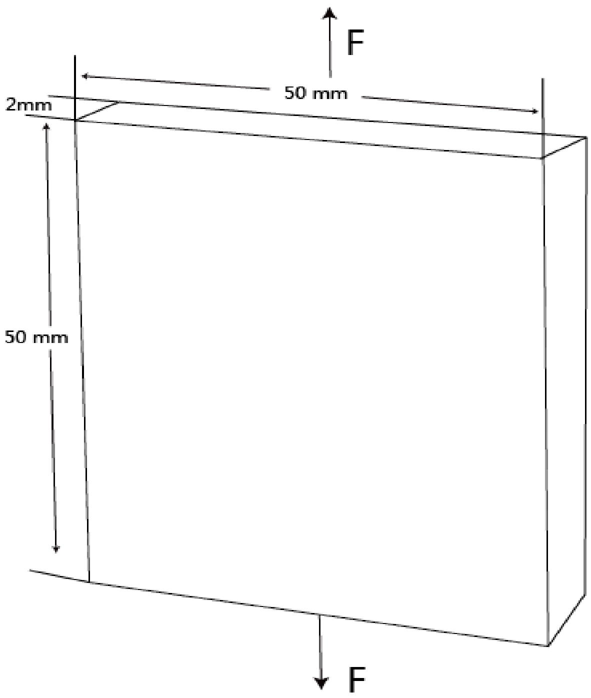


Figure 4-17: Dimensions of sample

It is not difficult to see that the cross-section area equals (2mm* 50mm), the original length equals 50mm. So far, it had been proved that in this study, the spring constant ***k*** was correlating with Young's modulus ***E***. To save the calculation, **the spring constant *k* was used to present the stiffness of material.**

The sample was elongated by clamp (which is represented by F in Figure 4-17) on each side until it broke (meet yield stress). The Load (N) - extension (mm) curve for material no.1 is shown below (Figure 4-18):

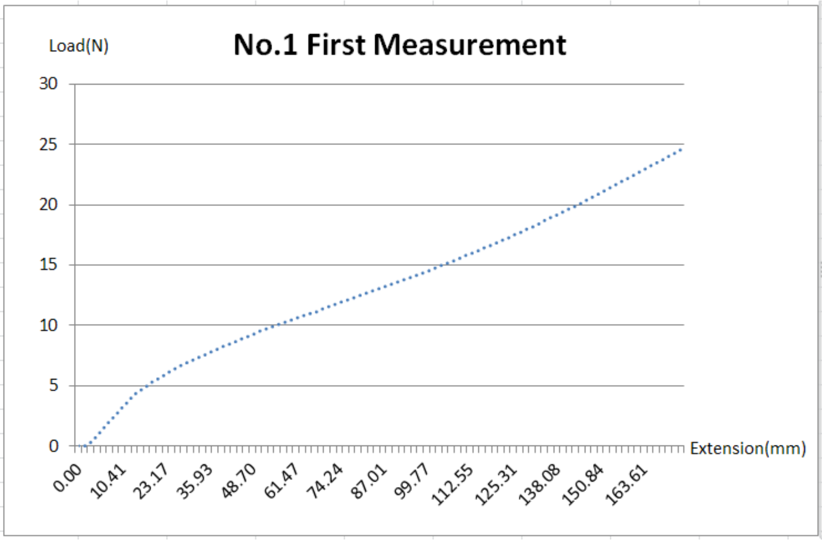


Figure 4-18: Load-extension curve of material no.1 (first measurement)

The interesting thing is: the load ***F*** is a **piecewise function** of extension ***L***, which means it contains two sections: range around 0-20 is a linear relationship; and range around 20-160 is another linear relationship. Load-extension curves for all materials are listed in Appendix III. And this rule can be found in every material and every test. This means there are two spring constants (slopes). However, thickness of samples in experiment C did not exceed 20mm (16mm maximum). So the slope in the first range (0-20) was adopted, as shown in Figure 4-18.

Another interesting thing was found in the measurement is that 4 foams have almost the same spring constant (see Appendix IV). The results of all slopes in "Load-Extension" scatters are shown below (Table 4-5):

Table 4-5: Comparison of objective stiffness and perceived stiffness (darkness of gray shows the extend of stiffness)

Foam	Slope 1	Slope 2	Mean	Objective stiffness	Perceived stiffness
no.1	0.2774	0.1916	0.2345	no.1	no.2
no.2	0.1845	0.1927	0.1886	no.2	no.1
no.3	0.1917	0.2105	0.2011	no.3	no.4
no.4	0.1956	0.2241	0.20985	no.4	no.3

As can be seen in Table 4-5, not only the mean values are quite close, the slopes of each single measurement are also very close. It shows the fact that the four foams have almost the same Young's modulus. And this result was also partly proved by previous test inside the company (no.2 and no.3 have the same **Gurley Stiff** (33 mgf), which represents bending stiffness of material, developed by Gurley Precision Instrument. In this case, Gurley stiff can be proved to be correlated with Young's modulus.

Also in Table 4-5, it could be found that the perceived stiffness is different with the actual stiffness. It was not difficult to get the ranking of perceived stiffness by hand touch. The results of perceived stiffness (ranking of hand touch stiffness) are in the far right column of this table. So far, there seemed to be necessary to compare the experimental results not only with the objective stiffness, but also with the perceived stiffness.

4.3.4 Procedure:

The process of this experiment is similar with the **Experiment B.** The essence was to let subjects perceive the stimuli and rank it.

1. Starting from group of 10mm (because it's not so difficult)； 4 samples were presented to the subject.
2. Subject was told to pick out the thickest one he/she felt. He/she was allowed to see and touch the samples.
3. Host reminded the subject to make sure he/she had examined every piece.
4. If the subject had hesitation, let him/her take it slow and be certain of the answer.
5. After recording the label of the thickest one, the procedure was repeated for the stimuli left.
6. All answers were recorded and repeated for the other 2 groups (2mm, 16mm).

4.3.5 Results

Means values of each test were calculated. To be able to show the difference among 3 groups in thickness (because of the ranking mechanism, scores were among 1-4 for 3 groups, which would be hard to read if plotted), the ranking scores were multiplied by a constant for groups of 10mm and 16mm (see Table 4-6).

Table 4-6: Data analysis (darkness of gray shows the extend of stiffness, for raw data, see Appendix V)

Group of 2 mm						
Label	Objective stiffness (spring constant K)	Perceived Stiffness	Thickness ranking-Mean	Multiplied Mean *1	STD (AVG: 0.89)	Multiplied Mean of special cases
No.1	0.2345		2	2	1.195229	--
No.2	0.1886		2	2	0.534522	--
No.3	0.2011		3.625	3.625	0.517549	--
No.4	0.20985		2.375	2.375	1.30247	--
Group of 10 mm						

Label	Objective stiffness (spring constant K)	Perceived Stiffness	Thickness ranking-Mean	Multiplied Mean *4	STD (AVG:0.86)	Multiplied Mean of special cases
No.1	0.2345		2.375	9.5	0.916125	9
No.2	0.1886		1.375	5.5	0.517549	8
No.3	0.2011		2.875	11.5	1.246423	4
No.4	0.20985		3.375	13.5	0.744024	16
Group of 16 mm						
Label	Objective stiffness (spring constant K)	Perceived Stiffness	Thickness ranking-Mean	Multiplied Mean *8	STD (AVG:0.99)	Multiplied Mean of special cases
No.1	0.2345		2.125	17	0.834523	12
No.2	0.1886		2	16	1.069045	28
No.3	0.2011		3.5	28	0.755929	20
No.4	0.20985		2.375	19	1.30247	20

The results were plotted as two figures, namely Figure 4-19 and Figure 4-20. In Figure 4-19, it can be seen that the range of spring constant (x axis) was too small, which means four foams are mostly the same hard or the same soft. So the perceived thickness could not be simply regarded not correlating with objective stiffness.

It was found that averagely, perceived thickness was correlating with perceived stiffness (Figure 4-20). What was interesting was that there existed special cases, in which the subjects thought the softest one was the thickest or vice versa.

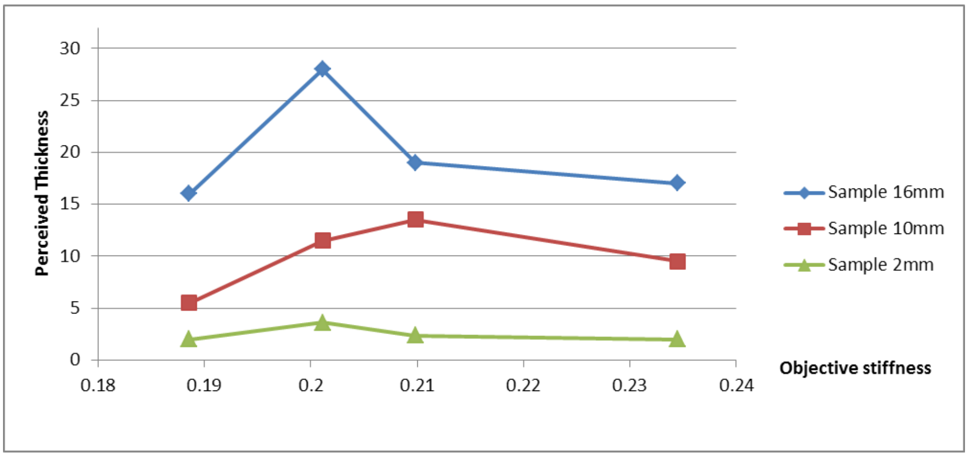


Figure 4-19: Perceived thickness VS objective stiffness

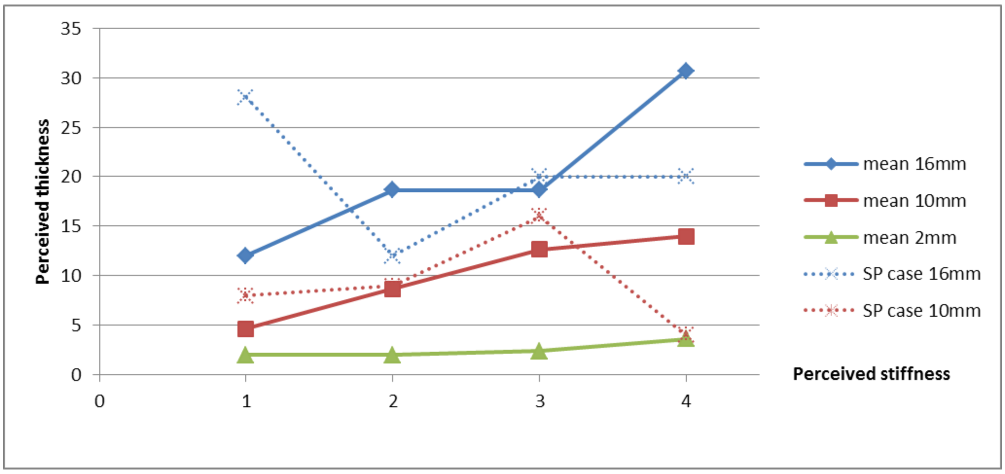


Figure 4-20: Perceived thickness VS perceived stiffness (mean excludes SP cases)

4.3.6 Conclusions of experiment C:

- The study found that perceived thickness was correlating with the "perceived stiffness". The four samples used are with the almost same Young's modulus. In previous studies, such as John et al. (1989) and Ho & Srinivasan (1991), there was a conclusion claimed "the stiffer, the thicker". These studies were mostly done for hard material, such as wood or steel. Our study described a different scenario for fluffy materials.
- Another problem interrelated occurred, which was "**stiffness perception**". Although the samples are with almost the same Young's modulus (which means differ very little in stiffness), subjects easily felt them with different stiffness. This might be due to the difference in other material parameters. For example, the speed of recovering to the original shape, the permeability, the thermal conductivity, or hydrophobicity.
- If the stiffness of samples had a larger difference, there could be a better correlation between "perceived thickness" and "perceived stiffness". In

Experiment A, in which it was found that thickness perception ability was better when the sample was thicker. In the process of experiment, there was also a fact that some users were using stiffness to differ the thickness. But they found it difficult when facing samples with only 2mm.

- Some subjects had the reverse feeling about "thickness-stiffness" relation (special cases). In most cases, if people feel the sample stiffer, they should feel it thicker. But these special cases thought the opposite. The proportion of these cases was roughly 25%. This is a special phenomenon regarding thickness perception for soft materials. Two hypotheses were proposed to explain this phenomenon.
  1. They had either special or opposite preset of "thickness-stiffness" relation.
  2. Other parameters could disturb them. Such as the speed of deformation recovery. Long time of recovery may let the users interact with the sample for longer time, which made the samples give them more impression, and more impression could result in a higher score of subjective rating.

4.3.7 Notes:

- In this experiment, only 4 types of foams were used. That was mainly due to the availability of materials in this short term. The foams used should be really thin sheets with the same thickness but with different perceived stiffness. If materials with larger stiffness range were used. Further comparison between "perceived thickness" and different "objective stiffness" could be done.
- During the measurement of elastic modulus, the whole processes were only repeated twice. The reason was that same spring constant occurred even there are only 2 pairs of data (see Table 4-5). If the whole process was repeated more, there would be high possibility that the spring constant still overlapped.
- For simple tensile spring, spring constant equals to the stiffness. With the constants given, spring constant will correlate with Young's modulus. The deduction is given in Chapter 4.3.4.

4.4 Cross analysis

The framework of all studies carried out is shown in Figure 4-21. Regarding the problem of thickness, the first idea occurs in people's minds could be "objective thickness". That was also how the series of experiments were initiated (Experiment A)". Another important factor affecting thickness is stiffness, which was studied in Experiment C. Other factors, such as "design style, visual clues, density, or heat flux", will be solved in the proposed workshop. Considering three dimensions of product experience (incontinence product), Experiment B was made based on subjective experience ranking principle. The second research question, regarding user behaviors, will be answered by a proposed interview in the future.

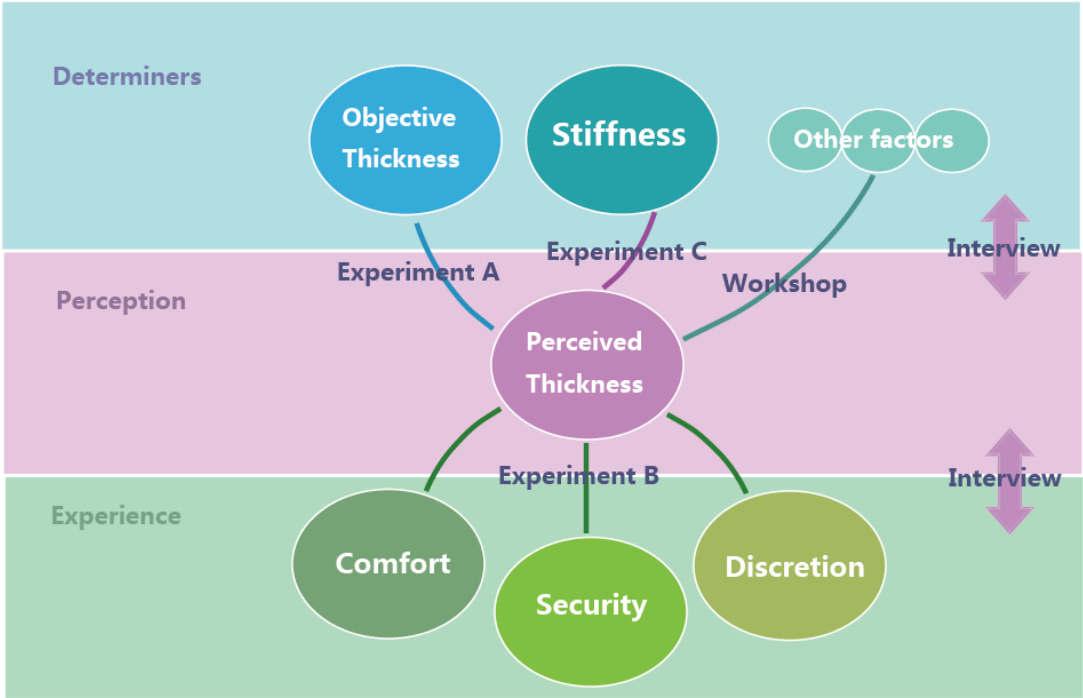


Figure 4-21: Framework of all studies surrounding "perceived thickness"

Some factors determining thickness are interrelating. For example, changing the thickness will inevitably also change the stiffness (because change of structure); changing some design styles will also affect thickness and product experience (a better shape makes the diaper more comfortable or discrete); and naturally the conflicting demands of three dimensions experience (thin product means more discrete, but less leakage security).

Another problem is the overlap when perceiving other material or product properties, such as perceived stiffness, perceived weight, and perceived roughness etc. These factors during thickness perception are quite hard to be eliminated. In this project, perceived differences of other objective intensities were reflected in form of thickness.

This thesis studied each factor in a relatively independent way, by controlling other variables. The reality can be quite complex, if all of the elements are put into together. For the answers to all research questions, see chapter 8. For discussions around the results and application of three experiments, see chapter 7.

5 INTERVIEW (PROPOSED)

5.1 Objective

The interview aims at finding out feedback and description about perceived thickness from users, trying to answer the research question 2: **How do users perceive thickness?** Due to practical reasons, interviews have not been finished in the company. But the author reckons the investigation is very valuable to the company because it is a very good way to know how users think.

5.2 The iteration of designing interview questions

The guidelines for interview was designed and firstly discussed with my supervisors. The problem of the first version was that it went to ask questions about thickness too early while users may feel difficult to adapt to this concept. On the other hand, general questions and open questions should be prepared in the beginning of interview.

Later on, after the discussion with my colleague in SCA (international market manager), some questions were decided to be changed or combined to avoid redundancy and ineffectiveness. And one important factor of the success interview is to make sure the subjects are "TENA Lady -Normal" users. The interview was suggested to be better if let users hold, touch and see the products all the time of interview. Because of the complexity of some questions, it was supposed to be a face to face interview. However, users are sometimes quite old women and will not able to tell the impression of the products they used some years ago. So the question was changed to investigate users' frequency of checking thickness in different use stages. The comparison was then about the "importance of thickness" not the "value of thickness".

Other important points based on the discussion with my supervisors and colleagues were:

1. Users always think they use thinner products than reality. So it is very important to make sure they are "TENA-lady- normal" users in recruitment.
2. Some questions which require users' recall can be helped with letting them holding the products all the time.
3. Some users need thick products while some need thin products. There could be a study with large samples for exploring which product is more sensitive to thickness. (e.g. Mini, Normal or Extra)
4. A lot of products are quite new. Some of them were just launched 3 months ago.

Subjects can use very different products before (omit the long-term questions).

The guideline of this interview can be found in APPENDIX VI

5.3 Telephone interview:

5.3.1 Introduction:

After several rounds of modifying the interview questions, I met with a very experienced colleague (International market manager, SCA) in this area. She gave me some precious and useful advices: First of all, asking most crucial questions in a most concise way. Secondly, face to face interview may gather more information but can cost more than telephone interview with larger sample size. Thirdly, for an interview carried out internationally, multi choice format will be cheaper and easier to conduct. So it ends up with a questionnaire consists 5 questions, see APPENDIX VII.

This investigation was planned to be done in France, because most complains about thickness and discretion come from this country.

5.3.2 Sample size

This part is mainly based on Watson (2001) and Israel (1992).

There is no absolute answer for sample size choosing. It depends on to which level of precision or reliability you desire to achieve. The way to calculate sample size is complex, since you need to consider various variables (Type I error, Type II error, power, variance under the null, mean under the null and sample sizes under two groups, etc.), according to Van Belle (2008). But there is another way to go, by using the available Published Table (Table 5-1) to find out which sample size you should use. For this simpler method, there are 3 matters need to be taken care of.

- **The Level of Precision**

It is also called **sampling error** or **margin of error**. For example, if you have a question with 3 choices given (A, B, and C), after investigation, your estimate point is 75%, which means 75% of the users will choose the answer B from 3 answers. And you are informed that your precision is 5%, so the actual range (interval) of your estimation should be 75% ±5%, Then you can conclude that 70% to 80% will choose answer B.

- **The Confidence Level**

It is also called **confidence** or **risk level**. A 95% risk means that if you do a 100 times sample for the population in the same way, results of 95 times will locate within the range of precision, which indicates the original sample data captures 95% of the true population. Nowadays, 95% is a standard or convention for most social statistics.

A 95% confidence level can sometimes leads to a significance level of 0.05(which means 95% chance to reject the null hypothesis), but not always. For representing statistical significance, one star (*) 0.05, two (**) 0.01, and three (***) 0.001 / 0.005 are used. Just like confidence level, level of 0.05 is used most.

- **Degree of Variability**

If the attribute is distributed more variable, it becomes more heterogeneous (higher variability, 50%-50%). Oppositely, if less variable, it is called more homogeneous (30%-70%). For example, if 30% of women use TENA products, it is less variable than if 50% women do. Because either 30% or 70% will mean most people do or do not. The variability will be 0.3 rather than 0.5. If the minority is too low, for example, only 5% users use this product, it will be a different case.

The most conservative or safe way is to assume the value is 0.5, which is a maximum variability for a population and require more measure than other cases. This value is also used for most social studies.

***Table 5-1**: Sample size with different precision levels (where confidence level is 95% and Variability is .5, "a" means the entire population should be sampled (Israel, 1992)*

Size of Population	Sample Size (n) for Precision (e) of:			
	±3%	±5%	±7%	±10%
500	a	222	145	83
600	a	240	152	86
700	a	255	158	88
800	a	267	163	89
900	a	277	166	90
1,000	a	286	169	91
2,000	714	333	185	95
3,000	811	353	191	97
4,000	870	364	194	98
5,000	909	370	196	98
6,000	938	375	197	98
7,000	959	378	198	99
8,000	976	381	199	99
9,000	989	383	200	99
10,000	1,000	385	200	99
15,000	1,034	390	201	99
20,000	1,053	392	204	100
25,000	1,064	394	204	100
50,000	1,087	397	204	100
100,000	1,099	398	204	100
>100,000	1,111	400	204	100

Without doubt the users in France will be more than 100,000. So when a sample size of 100 is chose, it will be with ±10% precision, a Confidence level of 95% and P=0.5(variability). So if the answer of questionnaire is like "60% people choose to worry about the thickness at home", it means 95% possibility that (60±10)% of users will do so, even assuming TENA lady is not a top choice for users

6 WORKSHOP (PROPOSED)

6.1 Objective:

The purpose of this workshop is to figure out the impact of possible factors affecting thickness perception. As a result of that, the company will know how to make the product perceived thinner but without losing the absorbance security (actual core thickness). Limited by time and various reasons, this workshop is just a proposal to the company.

6.2 Possible factors

Based on literature and experience, the following factors are considered important for thickness perception:

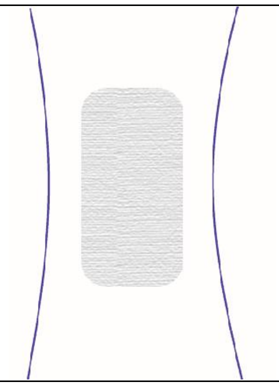
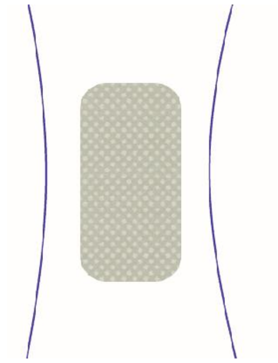
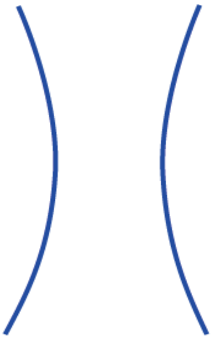
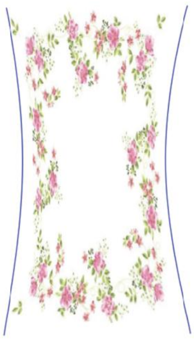
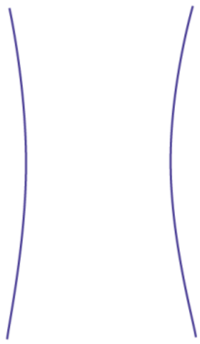
1. **Objective thickness**
2. **Stiffness**(for elastic body)
3. **Texture**(affecting discrimination ability))
4. **Heat flux / Thermal conductivity** (people can calculate time of heat conduction between 2 fingers)
5. **Weight /density**
6. **Visual clues**(shape, pattern, colour)

The impact of objective thickness and stiffness has been studied by experiments in this thesis work. Factors left are: texture, thermal conductivity, density and visual clues. Certainly, regarding product design, some small details or "**design style**" are also important.

6.3 Prototype:

To figure out the impact of each parameter, it is necessary to control other factors invariable (i.e. keeping the same thickness, using the same material, etc.). Pairwise comparison method should be used to study these factors. Each factor will be tested by one pair of products with only one variable. Suggestions of producing these prototypes are as follows:

Table 6-1: Prototypes for workshop

Factor	Design 1	Design 2
Texture		
Shape 1		
Shape 2		
Density		
Pattern		

6.4 Process:

- Host describes the mission and goal of this workshop to the subjects. It is important that they feel the same as they usually do. Thus means, they should not be panic, anxious, or nervous.

- Let the subject try one pair (wearing each for 20 min) and select the one they feel thicker. During this time they should act freely as how they use the product in real life. For example, they should sit, stand, walk, or even lie down as they do in daily life.
- The host needs to record everything noticeable (e.g. they touch their trousers after they put on the prototype, or they check the pattern or shape carefully by hands)
- The whole process needs to be conducted twice in order to make the results more reliable.

6.5 Notes:

- When the density or stiffness of the product is changed, it is worth of noticing that product function will change when the core material changes. This can mean losing weight of the product or making the core stiffer will make the product not the same security level as before. That is another trade-off situation needed to be recalibrated.
- Limited by time issues, this workshop cannot be done during the thesis work. But it is highly recommended that the company should do that.

7 DISCUSSION

7.1 How to use the results got from different studies?

The results and conclusions should be used with a holistic thinking. For example, the average threshold for a reference of 10 mm was 0.65 mm in Experiment A(see Table 4-2), but it doesn't mean thinner the product 0.65mm can make exact 50% of whole population feel it thinner. Other factors are also needed to be noticed, such as the standard deviation (around 0.3 in this case) and the coefficient of variation (CV, in this case equals 45.1% which means the results diverse a lot.) On the other hand, the result was got in lab. It is not sure how users perceive thickness (maybe by lower body?), which will make difference. Moreover, the real product does not have the same stiffness as the stimulus in lab, which will also affect the perceived thickness. If the 3 dimensions of user experience are considered, thinning the product 0.65mm will decrease its security but increase its discretion. Comfort will possibly be elevated because it is approaching the most confortable area (3-8mm). The influence of stiffness will also be a factor (see Experiment C). This way of thinking gives us an example of how to read data.

7.2 Can the experiments be improved to make the conclusions more general?

The answer seems to be yes but is also complicated. For example, in Experiment A, if more subjects were tested, the CV and STD may become smaller, which makes the mean values more useful. And if better technology and better materials are used to make the stimuli, the results will surely become more convincing. However, even ig better data from Experiment A is collected, the conclusions of this are only applicable for products with this certain material, certain stiffness, texture, and more important, in a condition of being touched by hands without regarding other senses. As a matter of fact, just TENA series alone have 9 products with different stiffness and haptic feeling. So even with so many efforts made, the better data will be useful to only 1 module of a product series, which among hundreds of products SCA are producing.

7.3 Method of experience rating

As for Experiment C, relatively better stimuli were produced because the ease of making them by foams. In this study, ranking mechanism was introduced to rate the user experience. But just as mentioned in chapter 4.2.6, the linear correlation or the linear increment was partly due to the ranking mechanism. If the user felt sample A was better than sample B, he would rank it one place higher, which resulted in an increment of one integral in the result. But the slight increment of experience was not able to be shown (i.e. if the 16mm sample feels more discreet than 17mm sample, the discretion increment might not be the same as from 2mm to 3mm, but by using this ranking mechanism, it will be the same). One way to solve this is using experience scale. The discussion of subjective scale will be extensive.

Problem that samples sometimes had similar scores was considered before the conduction of experiment. The original solution was relying on averaging mechanism. For example, for one subject, 2.1mm may perceived thicker than 2.0 mm, but since it was very close, there could be higher possibility that another subject may perceive 2.0mm thicker than 2.1mm or thought they were the same. So the average scores of 2.0mm and 2.1mm could be closer than the comparison of 2.0mm and 3.0mm, thus could different increments be displayed.

7.4 Is there any other way to perceive the product thickness besides watching and touching?

It is possible to perceive thickness with other ways or other modalities. For example, in auditory sense, user may be able to hear the chafing sound when they wear the product, which will cause the decrease of discretion, and a possibly high “perceived thickness”. From point of olfactory sense, odour control is always considered a significant factor in incontinence product development (Cottenden, et al. 2009). Unpleasant odour can also decrease the discretion and make users feel the existence of the product. Nevertheless, in order to get rid of the odour of urine, some products intentionally use a certain medical smell to cover that odour, which leads to users’ conditioned reflex of reluctance (every time they sense that clinical or chemical smell, they associate this with the image of incontinence).

7.5 Further work: A different scenario

In our experiments, subjects were given a few pieces of samples, in which case subjects naturally compared one piece with other pieces. That is not the same in real scenario. One user unusually uses the same thick product for a while, during which period he/she has the experience without any actions of comparison. For example, he may feel the newly delivered thinner product is the same as what he used before. How to solve this problem? The answer is trying best to simulate the real user scenario, let them feel or use the product for a period which is naturally long enough. Then replace it with another one (theoretically different perceived thickness), and collect the feedback. However, this will take a long time and high cost (needs personnel to follow-up and big sample size).

Another different scenario is about somatosensory system. As is talked in chapter 3.3 “Sense of touch”, the feeling of lower body can be another case comparing with the feeling of hands. However, in order to carry out a very real life study, a clinical trial or a workshop instead of lab tests will be needed for each effector (objective thickness, stiffness, etc.). This could be considered as further work after this project.

8 CONCLUSION

8.1 What is perceived thickness?

- Literature review shows that "perceived thickness" as a concept regarded in product development in incontinence industry was almost not touched. Most studies relating to thickness discrimination were made in discipline of experimental psychology. Researchers usually were keen on mapping the relationship between objective intensity (stimuli) with the perceived intensity. The term "perceived thickness" often occurred in food industry, and another word "perceived thinness" is always referred to body slimness.
- In this project, it was interpreted as "thickness perceived by users" or more formally "neural reflection of physical thickness in the brain". And the main interest was to research it regarding user experience. It was reckoned in this study that people can perceive it not only by hands, but also by eyes or any sensory channels.
- Weber's law states that a higher threshold is needed when the intensity of stimulus is higher. In our study, it was noticed that the thickness range within 0~15mm was a quite sensitive interval, in which the relationship between perceived thickness and objective thickness was not so simple.

8.2 How do users perceive thickness?

- Unfortunately, this research question cannot be answered so far. It will be based on the proposed investigation which the company is proceeding with.

8.3 Relationship between "perceived thickness" and "objective thickness"

- Experiment A was conducted to answer this question. It turned out that the relationship between these two variables was not a simple linear correlation, at least within thickness range (2mm~18mm), and with this certain material used.
- Concept of JND (just noticeable difference) was introduced to measure the threshold of thickness perception. It turned out to be a helpful tool.
- Even if the sample size was small and could not be said statistical

descriptive, the analysis process of data shows us a good method of estimating the threshold of a group of population in case of thinning the products.

- Human thickness discrimination ability will decrease when the reference gets very small. In this study, it decreases obviously below 6mm.
- For fluffy material (product), individuals have various thresholds.

8.4 What effects does "perceived thickness" have?

- Only three prominent dimensions of product experience (incontinence products) were considered. The Experiment B was conducted for this exploration and revealed the positively correlation between thickness and security. It also revealed negatively correlation between thickness and discretion. Dimension of comfort is not as simple as the other two. Normally people thought thinner products were comfortable, but their attitudes changed when the product became very thin. The most confortable range was 3mm~8mm, according to our study.
- With referring to the diagram of 3 dimensional experiences (Figure 4-14), designers can trade off among three dimensions and decide the pros and cons if the thickness is changed.

8.5 What determines "perceived thickness"?

- Experiment C was designated to partly answer this question. It focuses on a very effective variable—stiffness, or reflected as softness in some cases. The results challenged the traditional thinking "the stiffer, the thicker". It turned out that "perceived thickness" was "positively correlating with "perceived stiffness", instead of just simply with "objective stiffness"
- The occurrence of special cases proved the interesting phenomenon for soft material thickness perception, which was not much studied before. Those people either have reverse feeling of "thickness-stiffness" relation or were disturbed by other factors.
- Another important composition to this matter is workshop (proposed). It will tell us the influence of design factors (patterns, shape, and design style) besides physical parameters (density, permeability, etc.). If the company proceeds to conduct the workshop, they will truly harvest much.

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APPENDIX I: DATA OF EXPERIMENT A

Data of individual subject

date	Name	2	4	6	8	10	12	14	16	18	
14-Jun	Subject1	0.6	0.6	0.25	0.5	0.25	0.5	0.5	0.5	1.5	0.577778
14-Jun	Subject2	0.8	0.2	0.25	0.25	0.25	0.5	0.5	1	1	0.527778
14-Jun	Subject3	0.8	0.2	0.25	0.5	0.75	1	0.5	1	1.5	0.722222
13-Jun	Subject4	1	0.6	0.75	2	1	2.5	1	1	1.5	1.261111
13-Jun	Subject5	0.6	0.4	0.25	1.25	0.75	0.5	0.5	1	1	0.694444
13-Jun	Subject6	0.6	0.8	0.75	1.25	1	2.5	0.5	0.5	2	1.1
13-Jun	Subject7	0.8	0.6	0.5	0.5	0.75	1.5	1	1	1	0.85
13-Jun	Subject8	0.4	0.4	0.25	0.25	0.25	0.5	0.5	1	1	0.505556
11-Jun	Subject9	0.6	1	0.75	0.5	0.75	2	1	2	2	1.177778
11-Jun	Subject10	0.6	0.8	0.75	1	0.75	1.5	1	2	2	1.155556
	mean	0.68	0.56	0.475	0.8	0.65	1.3	0.7	1.1	1.45	
	std	0.168655	0.263312	0.248607	0.562731	0.293447	0.823273	0.258199	0.516398	0.437798	

Maximum, Minimum, R/d (discrimination ability) and Weber's assumption

R/d	2.941176	7.142857	12.63158	10	15.38462	9.230769	20	14.54545	12.41379
Max	1	1	0.75	2	1	2.5	1	2	2
Min	0.4	0.2	0.25	0.25	0.25	0.5	0.5	0.5	1
weber	0.2	0.3625	0.525	0.6875	0.85	1.0125	1.175	1.3375	1.5

APPENDIX II: DATA OF EXPERIMENT B

Discretion

Ref	Label	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Mean
2mm	O	19	19	19	19	19	19
3mm	H	18	18	18	18	17	17.8
4mm	K	17	17	15	17	18	16.8
5mm	C	16	16	17	16	16	16.2
6mm	Q	15	15	16	15	15	15.2
7mm	L	14	14	14	14	14	14
8mm	E	13	13	12	13	13	12.8
9mm	S	12	12	10	12	11	11.4
10mm	A	11	11	13	11	12	11.6
11mm	N	10	10	11	10	10	10.2
12mm	J	9	9	9	9	9	9
13mm	F	8	8	7	7	7	7.4
14mm	M	7	7	8	8	8	7.6
15mm	D	5	5	6	6	6	5.6
16mm	I	6	6	5	5	4	5.2
17mm	R	3	4	3	4	5	3.8
18mm	G	4	3	4	3	3	3.4
19mm	B	2	2	2	2	2	2
20mm	P	1	1	1	1	1	1

Confort

Ref	Label	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Mean
2mm	O	17	15	4	19	3	11.6
3mm	H	19	16	12	18	4	13.8
4mm	K	18	17	11	17	13	15.2
5mm	C	12	18	10	16	14	14
6mm	Q	14	19	16	15	16	16
7mm	L	15	14	18	14	15	15.2
8mm	E	13	12	19	13	17	14.8
9mm	S	16	13	17	12	19	15.4
10mm	A	11	11	14	11	18	13
11mm	N	9	8	15	10	12	10.8
12mm	J	10	10	13	8	7	9.6
13mm	F	5	8	8	7	10	7.6
14mm	M	8	7	7	9	11	8.4
15mm	D	7	6	9	5	9	7.2

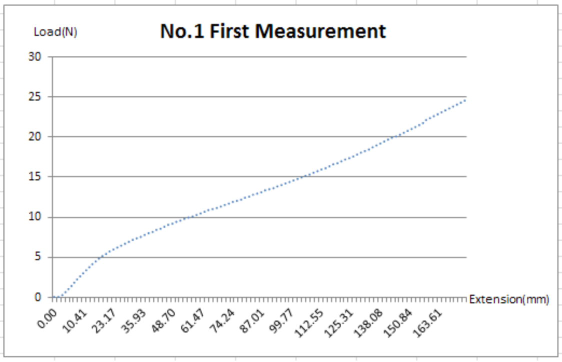
16mm	I	6	5	5	6	8	6
17mm	R	2	1	6	4	6	3.8
18mm	G	3	4	1	3	5	3.2
19mm	B	4	3	2	2	1	2.4
20mm	P	1	2	3	1	2	1.8

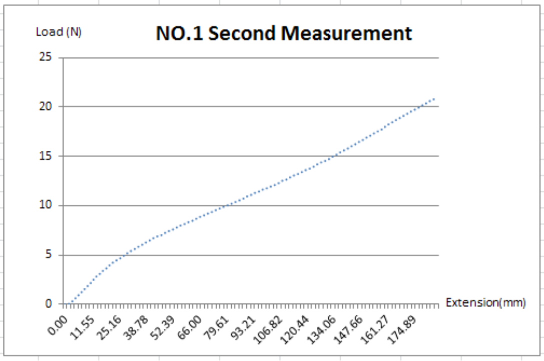
Security

Ref	Label	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	Mean
2mm	O	1	1	1	1	1	1
3mm	H	2	3	2	2	2	2.2
4mm	K	3	4	3	3	3	3.2
5mm	C	4	2	4	4	4	3.6
6mm	Q	5	5	5	5	5	5
7mm	L	6	6	6	6	6	6
8mm	E	7	7	7	7	7	7
9mm	S	8	8	8	8	11	8.6
10mm	A	9	9	9	10	8	9
11mm	N	10	10	10	9	9	9.6
12mm	J	11	11	11	13	12	11.6
13mm	F	12	12	12	12	14	12.4
14mm	M	13	13	13	11	10	12
15mm	D	15	14	15	15	13	14.4
16mm	I	14	15	14	14	15	14.4
17mm	R	16	16	17	16	16	16.2
18mm	G	17	19	16	17	19	17.6
19mm	B	18	17	18	19	17	17.8
20mm	P	19	18	19	18	18	18.4

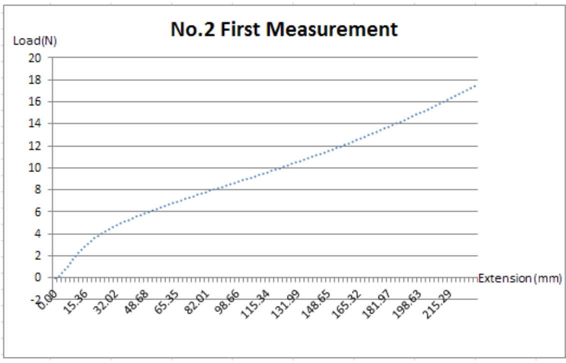
APPENDIX III: MEASUREMENT OF ELASTIC MODULUS

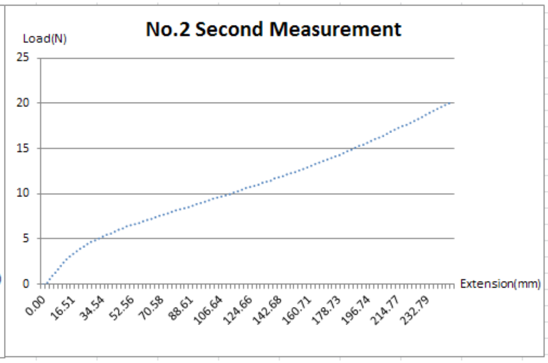
Measurement of Material no.1





Measurement of Material no.2





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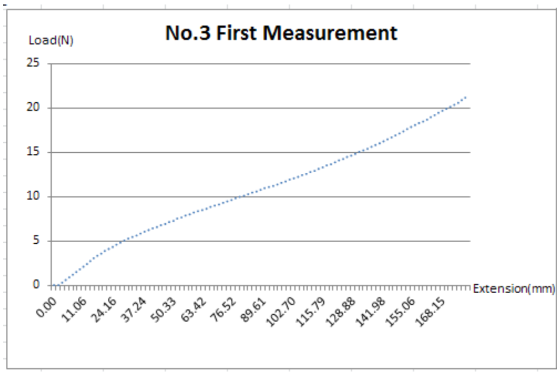
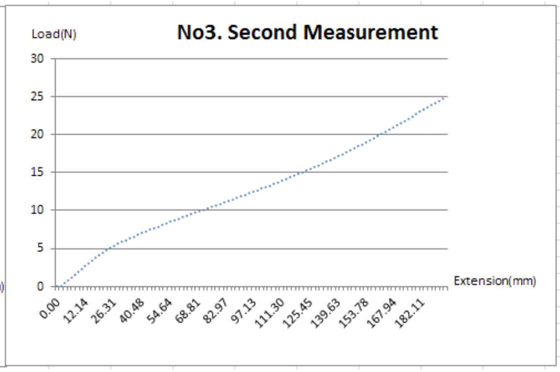
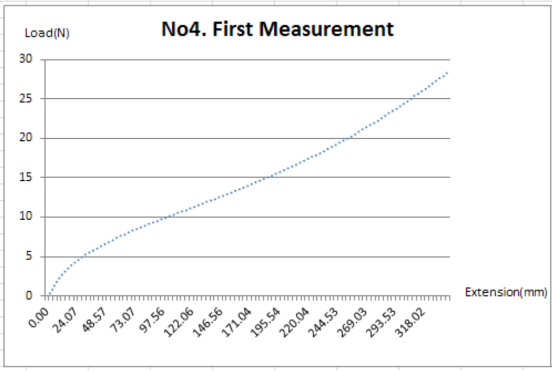
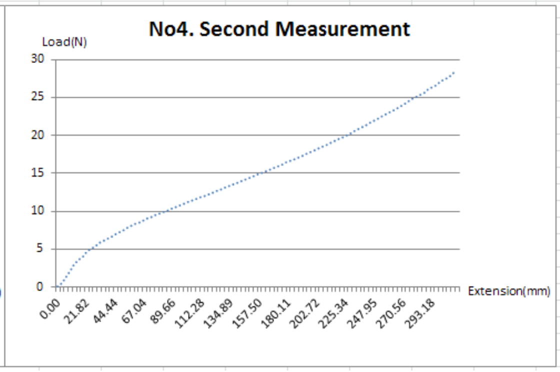




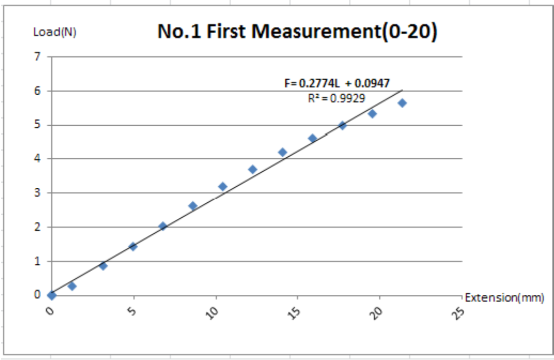
Measurement of Material no.4

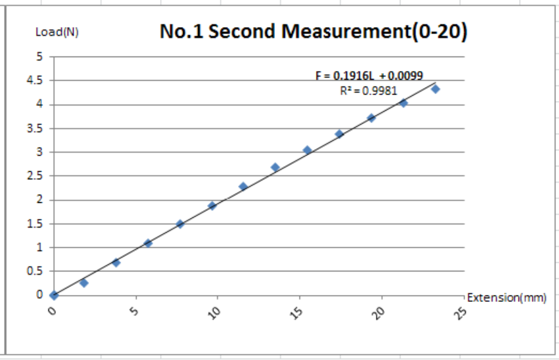




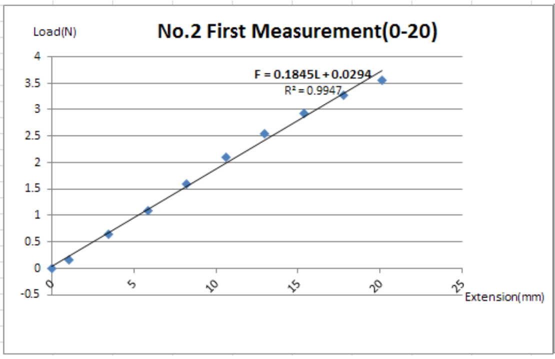
APPENDIX IV: LINEAR REGRESSION OF FORCE-EXTENSION SCATTERS

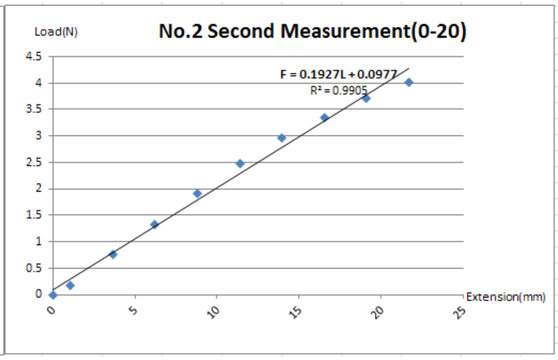
Linear fitting of Material no.1



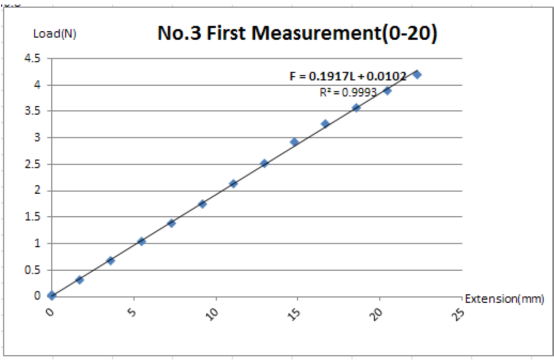


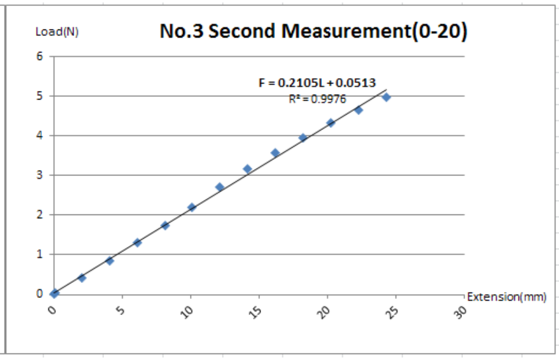
Linear fitting of Material no.2



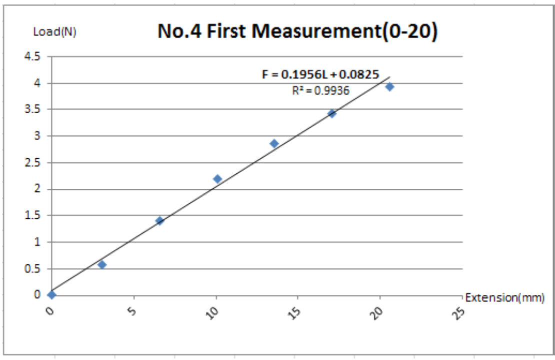


Linear fitting of Material no.3





Linear fitting of Material no.4



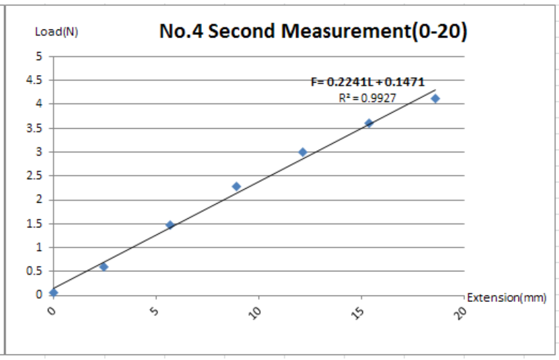


Table: Comparison of objective stiffness and perceived stiffness (darkness of gray shows the extend of stiffness)

Foam	Slope 1	Slope 2	Mean	Objective Softness	Perceived softness
no.1	0.2774	0.1916	0.2345	no.1	no.2
no.2	0.1845	0.1927	0.1886	no.2	no.1
no.3	0.1917	0.2105	0.2011	no.3	no.4
no.4	0.1956	0.2241	0.20985	no.4	no.3

APPENDIX V: DATA OF EXPERIMENT C

					16mm			
	Subject 1	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**	**Subject 6**	**Subject 7**	**Subject 8**
no.1	2	1	2	2	3	1	3	3
no.2	4	3	1	1	2	2	1	2
no.3	3	2	4	4	4	3	4	4
no.4	1	4	3	3	1	4	2	1

					10mm			
	Subject 1	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**	**Subject 6**	**Subject 7**	**Subject 8**
no.1	2	2	1	3	3	2	2	4
no.2	1	1	2	2	2	1	1	1
no.3	4	3	3	1	1	4	4	3
no.4	3	4	4	4	4	3	3	2

					2mm			
	Subject 1	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**	**Subject 6**	**Subject 7**	**Subject 8**
no.1	4	1	1	1	1	3	2	3
no.2	2	2	2	2	2	1	3	2
no.3	3	3	4	3	4	4	4	4
no.4	1	4	3	4	3	2	1	1

Area marked red indicate special cases(SP), in which 1 refers to thinnest and 4 refers to thickest.

APPENDIX VI: GUIDELINES FOR INTERVIEW

Perceived thickness is users' neural representation of physical thickness.

*The product in using is TENA Lady- Normal

1. a. Have your lifestyle changed due to incontinence? Describe before and now.
   b. Have your dress style changed due to incontinence? Describe before and now.

2. a. What kind of personality do you think you have? (if they cannot describe, give them choices like "positive", "active", "introvert", "quiet", "extrovert", "shy")
   b. Has it been like this through your lives?

3. What is the best or worst with this product?

4. Do you think the product is thick/or thin? Why?

5. Do you think thickness is an important factor for this product? How important is it?

6. Do you believe thickness affects discretion? In what way?

7. Do you have any worries when using this product? If so, in which situation will you worry about the thickness of product? (walking, party, office, sports, etc.)

8. Do you check the thickness? If so, when do you do that (Different use stages: selecting products, putting it on, wearing, taking it off)? How?(mirror, by hands, by using it, see it, feedback from others)

9. What kind of feelings do you have when you think the product is thick?/ or thin?
   a. Describe freely
   b. Give choices like(Awkward, relief, worry, pleasure, shame, anger, sad, happy, secure, comfort, familiar)(based on Geneva wheel)

10. Have you tried other products (other brands, mainly pads)? Do you like it or not?

APPENDIX VII: QUESTIONNAIRE OF TELEPHONE INTERVIEW

You may choose more than one options!

1. How old are you?
   - 25-35
   - 36-45
   - 46-55
   - 56-65
   - 65 +

2. Are you happy with the thickness of product?
   - Yes
   - No

3. In which situation, if any, will you be more concerned with the thickness of product?
   - At home
   - In a public area (bus, shop, street, etc.)
   - In working place(office, factory, school)
   - Having party
   - Doing sports
   - Other____________

4. Will you check the thickness of the product consciously or unconsciously?
   - Yes
   - No

5. How do you check the product thickness
   - Looking at it before use
   - Touch it by hands before use
   - Looking into the mirror when wearing it
   - Examine it outside the pant/underwear after putting on
   - By feeling it when wearing it
   - Other________