Design Guidelines of Applying Tactile Perception of the Hand to Product Design

by

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Abstract

With the development of a diverse product market, consumers' perceptual demand of products is increasing; product perceptual design is correlated with users' perceptions of sensations. The user would usually expect a product that makes his or her perception of sensations pleasant. Tactile perceptions are one type of sensation that is often neglected in product design. Thus, this thesis is to study how to apply user's hand perception of tactile sensation to product design.

In order to determine design principles that employ tactile perceptions, research is conducted to analyze the tactile perception of different material properties and geometry properties to identify and apply those principles to product design. These principles are developed into guidelines to aid designers in designing products according to the principles of the tactile perception of hand. Finally, a design example with design sketches and physical models is given to show the feasibility of the design guidelines.

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Chapter 1

Introduction

1.1 Problem Statement

Currently, most products focus on meeting the basic needs of their users. However, those products ignore the emotional aspect and experience of the user. In this era, the product functionality or durability is not the only aspect that users care about. The packaging, the user experience, and the feeling when the user interacts with or touches the product for the first time, have become priorities for the consumer.

When the user interacts with a product for the first time, different sensations instantaneously play a role in the product evaluation. The visual sensation, tactile sensation, auditory sensation, and olfactory sensation are some examples of those sensations. Traditionally, designers always focus on the visual sensation more than anything else. However, Kurokawa Masano (2014) said “In the twenty-first century, the design industry will be changed from the visual era to the era of touch.” This statement shows that the emphasis will be on the tactile application in product design, not only to meet users’ physical needs, but also to satisfy the psychological needs of users. It allows the users to fully experience the product. Of course, by highlighting the importance of the tactile design does not mean the other sensations are not critical as well. Only when the users get to experience the harmony and beauty of all the sensations can the product then be truly human-centered design.

In many respects, the tactile experience is an integral aspect of our interactions wit the world around us. From the moment we are born, we use our hands to feel and touch the world even before opening our eyes; then, we integrate the two experiences. This basically sums up the two basic ways of human cognition: tactile experience and visual experience. Thus, the tactile sensation and visual sensation are always inseparable when a user evaluates a product. The problem is when the designer tries to isolate the effects of tactile sensation from visual sensation and then tries to make an object touch friendly. The designers must decide on what materials and geometric properties that would be applied to the product based on the effects of tactile sensation, but the designer should do so simultaneously rather than separately.

1.2 Need for Study

Kurokawa Masano (2014) claimed that the importance of visual sensation has been greatly strengthened in the promotion of mass media. The twentieth century was called 'the century of image'. Tactile sensation gradually was forgotten and therefore not studied or developed. To address this gap of knowledge, the study of the importance of tactile perception is needed. There are several subareas to consider. When touching a product, people would have different feelings regarding materials' properties, such as roughness, hardness, weight and temperature. Therefore, studying people's different tactile perceptions to materials' properties is needed.

In addition, different geometric properties of products also affect people's tactile perceptions. For example, people do not feel safe when it comes to a sharp corner especially in the case of hard materials, such as metal, glass and ceramic. On the contrary, they feel safe and pleasant when touching a rounded corner even if it is made of hard materials. So studying how geometric properties such as orientation, curvature, size and shape affect people's tactile perception is important as well.

1.3 Objectives of Study

The objectives of this research are to provide the designer with principles of consumers' tactile perceptions regarding different materials and geometric properties and to guide them on how to apply these principles to product design. The following is a summary of what this research will focus on:

– Identifying people's tactile perceptions of different materials and objects with different geometric properties.

– Developing a set of design guidelines to help guide designers on how to apply tactile perception of hand manipulation in product design.

– Executing the design implementation to illustrate the findings of design principles.

1.4 Definition of Terms

Curvature – the rate of variation of the angle that the tangent line makes with a given direction (Montiel & Ros, 1998).

Geometry – this field concerned with the properties of configurations of geometric objects, points, lines, and circles (Hobbes, 1982).

Hardness – the relative capacity of a substance for scratching another or for being scratched or indented by another (Dossett & Boyer, 2006).

Orientation – the spatial attitude or position of a plane, a line or a rigid body (Twiss & Moores, 1973).

Size – the physical dimensions, proportions, magnitude, or extent of an object (Kappers & Tiest, 2015).

Shape – it refers to all its spatially global symmetries (its self-similarities) as measured by the group of rigid motions, reflections and size-scaling of the 'parts' within the object itself (Dickinson & Pizlo, 2013).

Tactile Perception – it describes the perception based on sensory receptors located in the human skin (Hatzfeld & Kern, 2014).

Tactile Sensation – a system that can measure a given property of an object or contact event, through physical contact between the system and the object (Dargahi & Najarian, 2003).

Temperature – it is related to the average energy of a system of particles (Tritt, 2004).

Texture– repetitive or random deviations from nominal surface which form the pattern of the surface. It includes roughness, waviness, lay and flaws (Murty, 1996).

Weight – the measurement of the force of gravity between the object and the earth (Barbara, 2010).

Material – a substance or a mixture of substance that constitute a thing ("material", n.d).

1.5 Assumptions

This study involves a number of assumptions, detailed as follows. First of all, it is assumed that people are able to isolate the effects of tactile perception from visual perception when they evaluate a product. Thus, the scope of research is narrowed down to people's tactile perception.

Secondly, tactile sensitivity tends to be related to the age, gender and different parts of body. This study assumes that people have consensus to regarding the perceptions of tactile sensation. Human's hands are the major tool for people to communicate with their surroundings, so the research purely focuses on the tactile perception of the hand.

Finally, the target users of the guidelines include all the designers who regard tactile sensation as a primary consideration when choosing materials and designing the appearance of the product.

1.6 Scope and Limits

This research focuses on designing products based on hand tactile perception. However, the guidelines developed in the thesis is not limited to the hand tactile perception, so that designers could use the same method to do the research about the tactile perception of other parts of human body, such as the face, arm, hip, leg, foot and etc. However, the primary research conducted for this study is limited to the hand because of its importance as stated previously.

The material properties covered in the research are texture, hardness, temperature and weight, because people commonly emphasize those properties. Regarding the geometric properties, the curvature, size, and orientation and 3D shape are studied. This research does not cover all material and geometric properties, because the main goal is to demonstrate to designers how to design products based on the principles of human's hand tactile perception of the human hand.

1.7 Procedure of Study and Method

The following procedures are used to conduct the study:

Step 1. Literature Review

- Research what other scholars have done in this area.
- Summarize the research findings related to the current study.

Step 2. Build connections

- Build connections between the research findings with the design guidelines.

Step 3. Develop a set of guidelines for product design

- Apply the findings of tactile perception research to the material selection and the geometric design.

Step 4. Apply the design guidelines to a sample of design work

Step 5. Discuss conclusions

1.8 Summary

The research suggests that there are many issues when it comes to applying the tactile perception of hand manipulation into product design, such as isolating the effects of visual sensation from tactile sensation, understanding the relationship between consumers' perceptions of tactile perception and the actual product design. In order to successfully employ tactile perception as a design principle, the literature review emphasizes the importance of building connections between the tactile perception of the hand and product design.

Chapter 2

Literature Review

2.1 Tactile Sensation and Perception

Understanding tactile sensation and tactile perception is the basic study for the current research. This review will discuss the working principles, the importance and the relationship between tactile sensation and tactile perception as follows.

2.1.1 Definition of Tactile Sensation and Perception

The action of mechanical stimuli on human's skin (pressure receptors) causes the tactile sensation. The tactile perception is the perception of qualities and properties of material surfaces. Tactile perception consists of psychophysical and affective layers. The psychological layer determines the perception of physical properties, such as texture or temperature. A mental process translates the affective layer and it includes perceptions such as richness, cleanliness, pleasantness and kindness. Briefly speaking, tactile perception is the psychological translations or analysis of tactile sensation (Okamoto, Nagano & Yamada, 2012). Tactile sensation and perception are the most primitive ways for humans to experience the outside world and they help eyes with gathering information (Chuang, Chang & Chen 2004). So, how do the tactile sensation and perception work together? Generally, once a physical contact occurs between the human's skin and an object, tactile receptors start to work. An electrical nerve signal is generated. Then, these nerve signals flash to the brain. An overall picture of the sensation is created. Finally, people describe those pictures with words such as hot or cold, dry or moist, smooth or tough and so forth (Dargahi & Najarian, 2004).

Engineering Scientist, Ruzena Bajcsy, (1987) stated we do not just touch, we feel (Lepora, 1987). In order to feel, we must process sensations; tactile sensation is the first step in the perception formation process. Therefore, our tactile sensation and perception not only are inseparable, but they also complete each other. This combination allows users to recognize the tactile characteristics of an object, such as texture, shape, curvature, weight and etc. Additionally, it helps to define the human's psychological perceptions, which are crucial for designers. As Spence and Gallace (2011) stated that the feel of a product determines people's overall product evaluation. Since the designers are supposed to select the most suitable materials and geometry properties for the product, all the choices they make should be based on people's positive tactile perception.

2.1.2 Tactile Sensation vs. Visual Sensation

Schultz and Petersik (1994) claimed that people get all kinds of information from their surroundings through their five sensations, with pieces of information interacting and influencing each other. Hence, the tactile and visual sensations could function independently but also could complement each other. Liu (2000) and Ke (1997) conducted a study on the judgment of surface textures, and found that the tactile sensation is more accurate than visual sensation. However, for identifying shapes, using the visual sensation first and then tactile sensation is more accurate than if reversed. Combining tactile sensation with visual sensation provides a better image than using tactile sensation alone (Chuang, 2004). Both visual sensation and tactile sensation are important for people to interact with a product. However, there is an illusion among people that visual sensation is more important than tactile sensation, partly because people usually see a product first, then decide whether to touch it or not. Because sight happens before touch, the sense of touch seems to receive less attention compared to visual and auditory senses (Dargahi & Najarian, 2004). However, this does not mean tactile sensation is less important than other sensations.

2.1.3 The Importance of Tactile Perception

Touch serves a number of important purposes. Klatzky, Lederman, and Metzger (1985) claimed that tactile sensation is considered the closest sensory modality for humans, because it is the only sensation that can obtain information directly through skin contact. Using the tactile sensation to judge an object is direct and precise (Luh, 2012). Touch can also help consumers judge the quality of products. Grohman, Spangenberg, and Sprott (2006) found that the input of tactile perception had positive effects on the evaluation of products with characteristics that were best explored by touch (e.g., the softness and texture for the evaluation of a pillowcase). It is also true that if consumers do not have a chance to touch the product, they would be not confident enough to buy it (Luh, 2012). People perceive familiar products as foreign because of the lack of touch (more than the lack of vision) (Gallace & Charles, 2014).

It is common knowledge that if people see something visually unpleasant, they are not willing to touch it any more even if it feels comfortable in hand. However, Patrick (1999) found that initial perception of quality could change significantly after handling the product. For example, the tactile and auditory qualities associated with opening and closing a tape player and loading a cassette work together to create a feedback in the case of the best and worst products in the range. Those feedbacks were very emotional, including, for example, ‘that’s really nice’ or ‘that’s awful’.

There is evidence that touch is crucial for consumers not only to evaluate products but also for more indirect effects. Consumers can be influenced merely by touch. For example, people touched a Swatch that was either congruent or not congruent with the message in a brochure. This touch element was extrinsic to the actual brochure but was still found to influence the message’s persuasiveness (Klatzky & Peck, 2012). Therefore, Gallace and Charles (2014) suggested that “tactile quality” should even come before “visual quality” in the mind of the product designer. Attitudes towards the product can change greatly after handling it. The tactile perceptions can actually influence the prior visual perceptions.

2.2 Tactile Perception of The Hand

> “After the eye, the hand is the first censor to pass on acceptance, and if the hand’s judgment is unfavorable; the most attractive object will not gain the popularity it deserves” (Sheldon & Arens, 1932, p.100).

The various parts of human body have different sensitivities to touch. However, the quote above suggests that the hand works as the major tool for people to communicate with a product. The hand becomes more important when understanding that, furthermore, the skin of the hand, in particular, is one of the most important sources of detailed tactile feedback (Dargahi &Najarian, 2004).

2.2.1 Hand Movements for Recognizing Objects

As we all know, the hand is the major tool to communicate with an object. However, how does the hand perceive the information of an object? Schifferstein and Hekkert (2008) observed that tactile perception of an object and its properties is dependent on hand movement. Lederman and Klatzky (2006) found that people normally choose to execute different stereotypical hand-movement patterns when manually exploring an object. Lederman and Klatzky (1987) have documented a number of such movement patterns, or exploratory procedures (EPs) to explain how people explore object's properties (see figure 2.1).

The first exploratory procedure (EP) is "Lateral Motion". Fingers quickly rub back and forth across a small homogeneous area of the surface. People could judge an object's texture through movements between skin and object surface. The second EP procedure is "Pressure" to test the hardness of the object, using fingers to poke, press or squeeze the surface of the object, so people could feel the reaction of the object. Then people could tell the hardness. The third one is called "Static Contact" EP. People rest their hands on the object to judge the temperature. The fourth EP is "Unsupported Holding". The object is lifted and maintained in the hand without any effort to feel the object. People usually do this to judge the weight of the object. "Enclosure" is the fifth EP. It is used to judge the global shape and volume. The hand maintains simultaneous contact with as much of the envelope of the object as possible. Often one can see an effort to mold the hand more precisely to object contours. Periods of static enclosure may alternate with shifts of the object in the hand(s). The last EP is "Contour Following" and it is a dynamic EP in which the hand maintains contact with a contour of the object. Typically, the movement is smooth and not repetitive within a segment of the object; the user stops or shifts the direction when a contour segment ends, or when the user meets a non-homogeneous surface. Through the "Contour Following" EP, people could tell the exact shape and volume of the object (Lederman & Klatzky, 1987).

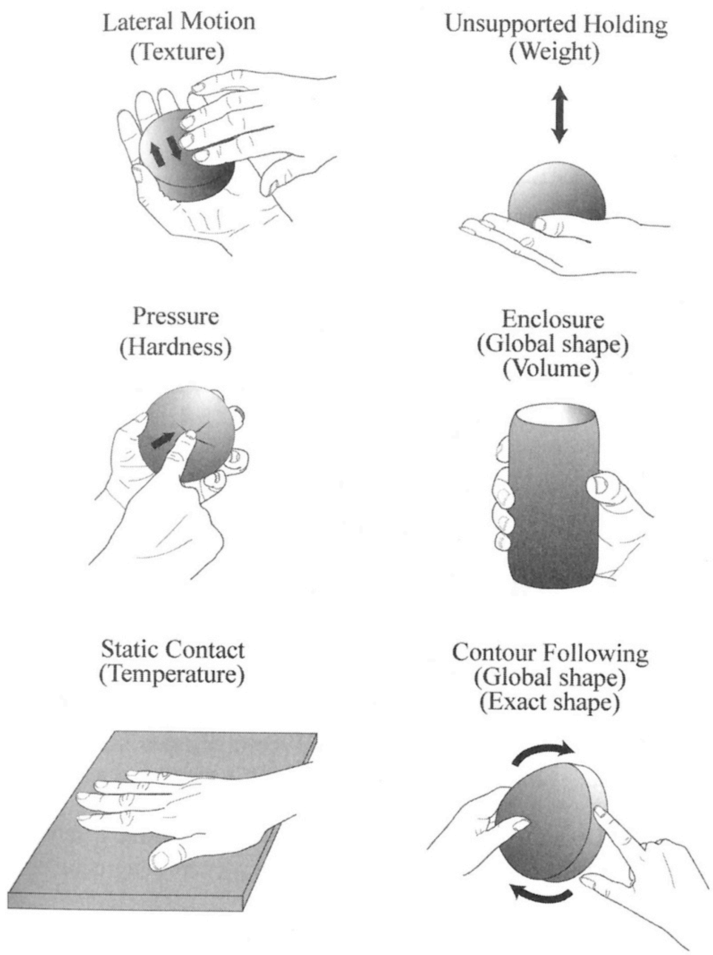


Figure 2.1: Hands exploratory procedures (EPS)

2.2.2 Tactile Perception of Objects

Generally, people perceive an object as a whole, rather than the sum of its different properties. Schifferstein and Hekkert (2008) classified tactile properties into four categories.

First, the substance category, involves the materials an object is made of, such as its hardness, elasticity, plasticity, temperature and weight. The second category is the surface of the object, such as its texture and patterns. Thirdly is the geometrical aspect of the object, such as its global shape, exact shape, volume, and weight distribution. The final category is the moving parts of the object (Figure 2.2).

Following Schifferstein and Hekkert's categorization, the tactile properties are classified into two categories in this research. One is material properties, such as texture, hardness, temperature and weight. The other one is geometric properties, such as curvature, orientation, angle, size and shape of two-dimensional and three-dimensional forms. The following sections will provide more details about these two categories.

Figure 2.2: Classification of tactile properties

2.2.2.1 Tactile Perception of Material Properties

The first category discussed in the following chapters is material properties. They include texture, hardness, temperature and weight.

2.2.2.1.1 Texture

Texture consists of a series of peaks and valleys that have characteristic shapes and spacing. Normally, the texture is made of features defined as roughness, waviness and form (Blunt & Jiang, 2003). The tactile perception of texture closely relates with the surface structure, and it is either the structure of the natural material or artificial material itself. In the study of the human tactile sense of microtexturing on plastic molding surfaces, Kawasegi, Fujii, Shimizu, Sekiguchi, Sumioka and Doi (2013) found that if the texture pitch was significantly smaller than that of a fingerprint, the convex-concave pattern was not felt. Therefore, the surface felt slick due to the increased contact area between fingers and the surface, while for the high texture pitches, the texture intrudes into the fingerprint, causing it to adhere to the texture. The surface was felt sticky and uneven (Figure 2.3).

For different textures, people have different psychological feelings. Some textures are rough, solid and bold, while others are delicate, soft, and smooth. Generally, a coarse texture triggers feelings of plainness, naturality and kindness. A delicate texture brings noble, gorgeous and cool feelings. Usually, people prefer to touch the smooth surfaces instead of rough. Etzi, Spence and Gallace (2014) conducted experiments to investigate the nature of aesthetic preferences for tactile textures in humans. The results clearly highlight the presence of significance differences in participants' aesthetic and roughness judgments. Pleasantness and roughness appear to follow a similar trend. Specifically, smoother textures were rated as more pleasant, while the rougher textures were considered more unpleasant (Etzi, Spence & Gallace, 2014). Dumitrescu (2014) confirmed that there was a strong inverse correlation between roughness and perceived characteristics, such as quality, performance, price and liking. The lower roughness materials were better perceived. In other words, the smoother surface is perceived as higher quality, better performance and more expensive. In addition, McDonagh, Hekkert, Erp and Gyi (2004) concluded that for tactile perception, positive emotional feelings, such as lively/cheerful, modern, elegant, and comfortable, are produced through touching the smooth metallic surface; while rough metallic surfaces follows with negative emotional responses such as dull/ depressing, traditional, ugly, and uncomfortable. In conclusion, research indicates that in terms of tactile perception, people attach great value to smooth surfaces.

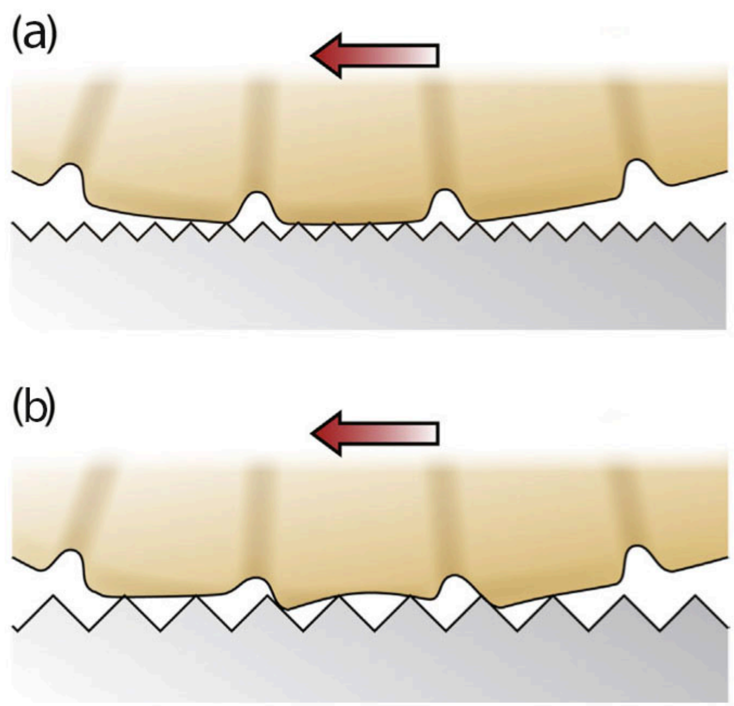


Figure 2.3: Diagrams show the contact between the finger and textured surface: (a) small texture pitch, (b) large texture pitch

However, designers can not only consider people’s emotional reactions to surface texture, but also need to decide different surface finishes based on the performance of the product. For example, to ensure a good grip on a handle, its surface should provide hands with sufficient friction to prevent slipping. The coefficient of friction and resistance to wear are affected by surface roughness. The handle grip for bicycle is a good example to illustrate this point. Holding the grips of bicycle for a long time makes palms sweaty and slippery. Therefore, the grips are covered with rough texture to prevent hands from slipping (Figure 2.4). Designers also could make use of the coarse texture to hint that the product is not for short or long time touching. As stated previously, for tactile perception, people prefer smooth surfaces rather than rough ones. However, when applying this finding to product design, designers need to balance the pleasantness of tactile perception with product performance.

Figure 2.4: An example of the bicycle grip

2.2.2.1.2 Hardness

Hardness is the ability of a material to resist indentation, scratching or abrasion. Harper and Stevens (1964) showed that hardness and softness judgments were relatively related. Softness is not the opposite property of hardness. In engineering terms, there is no property called "softness". A soft material deflects when being handled. However, once released, it restores to its original form or shape (Ashby & Johanson, 2014). Srinivasan and LaMotte (1995) claimed that for discrimination of hardness, cutaneous information is both necessary and sufficient.

Chen, Barns, Childs, Henson and Shao (2009) explored the relationship between the affective and sensory judgments and the physical measurements. They found that with an increase of hardness perception, the appreciation of the delicateness decreases (Figure 2.5), and the delicateness also correlates with the feeling of being relaxed (Figure 2.6). According to an interesting study by Horen and Mussweiler (2014), they found that when people attempt to deal with uncertainty and unpredictability, they would resort to the experience of softness for security, comfort, and reassurance. The defect of their study is that it does not isolate the contribution of visual and auditory perception from tactile perception.

However, these findings are still meaningful for the current research. When touching a soft surface without seeing it, people feel safe, comfortable, relaxed. On the contrary, they would touch a hard surface very carefully, because it may hurt them. In addition, soft materials are usually perceived as being alive and warm while hard materials are considered dead and cold.

Furthermore, Chen et al (2009) also confirmed that the tactile perception of softness is proportionate to the surface's thermal property, and this is the reason that compared with the hard surface, we feel warmer when touching the soft surface.

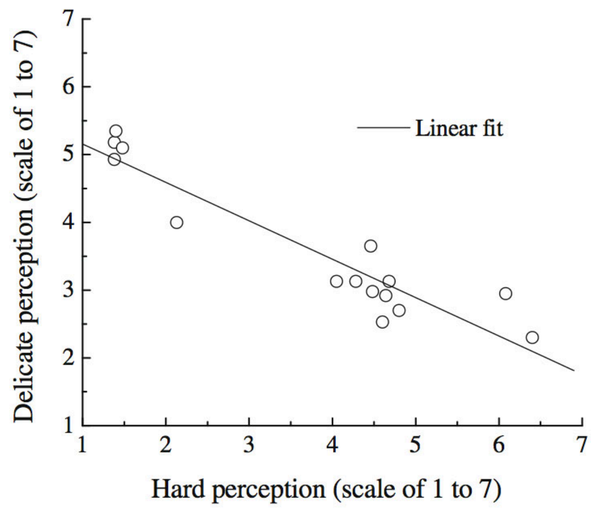


Figure 2.5: The correlation between hardness and delicate perception

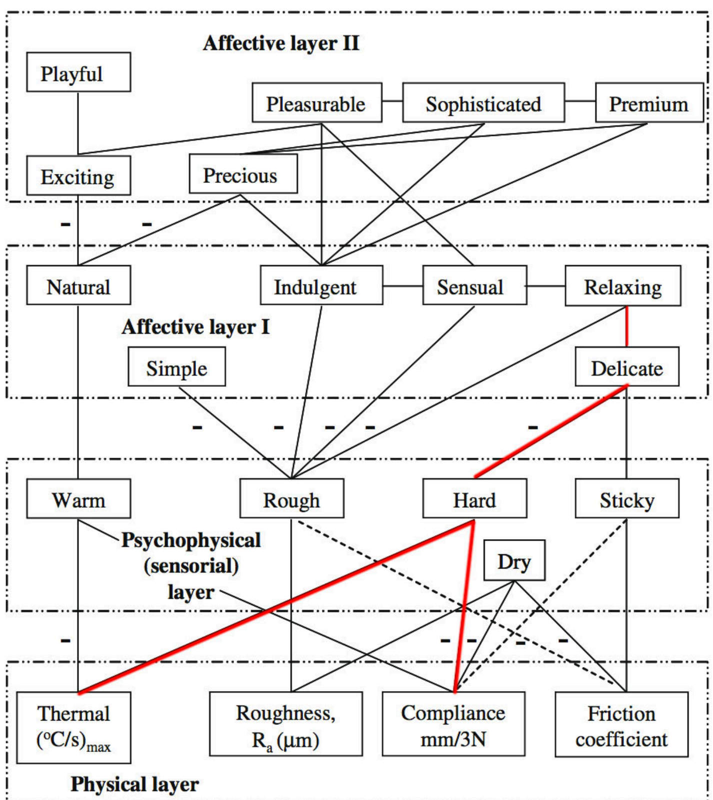


Figure 2.6: Dependency diagram analysis of the correlation between psycho-physical words and hardness

In conclusion, from the studies reviewed in this section we know that people attach great value to the soft materials. When applying this finding to product design, designers should notice that it is not the softer the better is not an applicable rule. If the material is too soft to be sticky, people would feel uncomfortable even disgusted. For example, when people use the soft sticky glue gum silica gel to clean the dust of the PC keyboard (Figure 2.7), because it is sticky in people's hand, they feel that it is so dirty and disgusting. Therefore, choosing a proper degree of hardness is important for designers. Although people prefer soft material tactually, not all the products could be made of soft materials because of the restrictions of materials and the requirements of product performance. However, it is advisable for designers to apply multiple materials to the products to determine the best choice. OXO products are famous for their large rubberized handles (Figure 2.8). The rubberized material not only provides hands with enough friction to prevent slipping, but also makes it soft and comfortable to hold it.

Figure 2.7: Glue gum silica gel

Figure 2.8: OXO product examples

2.2.2.1.3 Temperature

Many researchers have confirmed that temperature is one of the most important features for people to distinguish between different materials. The material's tactile warmth describes how cold or warm a material feels to touch. Generally, the material temperature corresponds to the ambient temperature. For example, a piece of metal at freezing temperature feels cooler than the metal at room temperature. As a matter of fact, the thermal behavior of material determines how it interacts with the surroundings. For example, metal feels colder than wood, even if both of them are at room temperature. A material is cold to the touch if it conducts heat away from the finger quickly but it feels warm if it does not. Materials with low temperature resistance are considered 'cold' (e.g., metal, glass) and those with high temperature resistance are considered 'warm' (e.g., wood, plastic). In conclusion, higher thermal effusivity and conductivity lead to a colder temperature of tactile perception (Wastiels, Schifferstein, Wouters & Heylighen, 2013). Chen and Chuang (2014) found that smooth plastic gave the "cold" feelings, while a matted surface elicited the "less cool" or even "warm" feelings. They also stated that all the materials felt cold in tactile sense, no matter what they are, whether metal, glass, plastic, stone, or fabric (silk), always eliciting a "delicate" image simultaneously. However, the result of Chen, Barns, Childs, Henson and Shao's experiment shows that the delicate perception of delicacy increases with a decrease of hardness perception. Therefore, their statements contradict each other. In contrast, Stevens and Choo (1988) observed an illusion that warm and cold objects placed on the hand feel heavier than the thermally neutral objects.

Generally, if the material (e.g. wood, silk) is literally warm to touch, it is perceived as inviting, cozy and comfortable, while, if the material (e.g. steel, stone) is cold to touch, it tends to be perceived as more distant and cool (Karana, Pedgley & Rognoli, 2013). In a study of warm pleasant feelings in the brain, the results provide the evidence that people rated warmth more pleasant than the neutral and the cold temperature when people were at room temperature (Figure2.9) (Rolls, Grabenhorst & Parris, 2008). The deficiency of their study is that it does not provide a set of continuous temperature data to validate this point. As we know, if the ambient temperature changes, the pleasantness of touch changes accordingly. For example, we would like to touch something cool when feeling hot, while we prefer to touch something warm when we feel cold. Just as Cabanac's (1971, cited in Stellar & Stellar, 1985) confirmed that when people are hyperthermic, they judge cold temperatures on their hands as most pleasant and warm temperature as unpleasant, while, with hypothermia, cool temperatures are unpleasant and warm ones are very pleasant (Figure 2.10).

For product design, designers need to choose the proper material based on the working context. For example, if the product works at the average room temperature, we could choose a material with low thermal conductivity. Therefore, when touching it, people will feel it is warm in the hand.

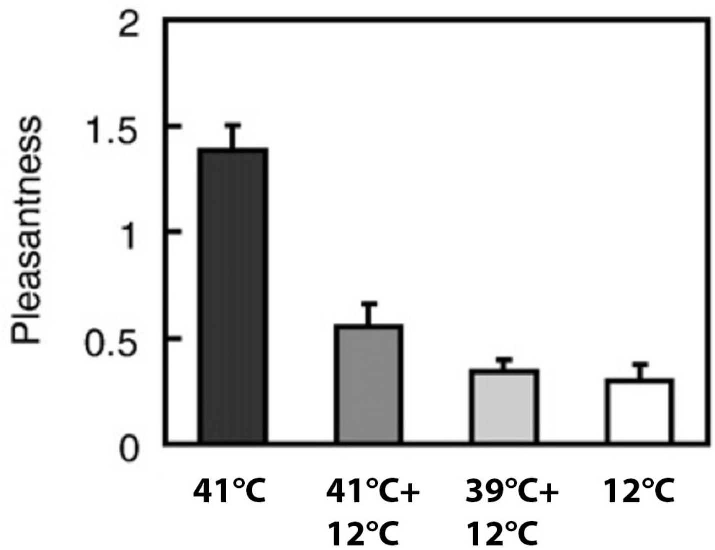


Figure 2.9: The correlations between temperature and pleasantness.

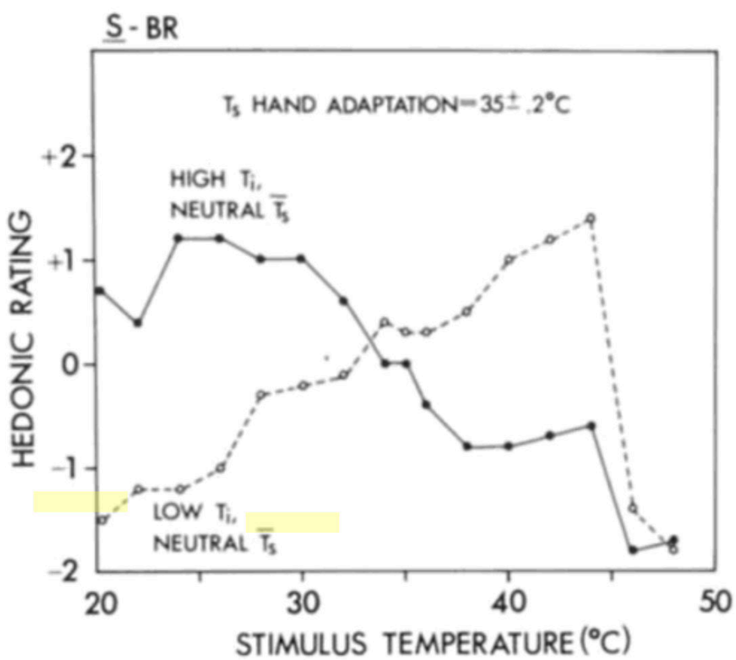


Figure 2.10: Ratings of pleasantness of hand bath

2.2.2.1.4 Weight

Jones and Lederman (2006) claimed that unsupported holding is the best way for judging weight. This helps to provide information by haptic sensing which consist of tactile and kinesthetic sensing. Weight is perceived to be less effective when the object rests on a stationary hand that is supported by a rigid surface. Bordie and Ross (1985, cited in Jones & Lederman, 2006) stated that the value was 1.46 times larger than the actual weight through the tactile sensing. But as Karana, Pedgley and Rognoli (2013) stated although the perception of weight comes from haptic sensing, whether a material feels heavy or light still correlates to tactile feelings.

Stevens and Marks (1979) noted an illusion involving weight perception for tactile sensing: cold and warm weights felt substantially heavier than the neutral weights in people's hands. Ellis and Lederman (1993, cited in Jones & Lederman, 2006) also found the illusion that weight perception is strongly influenced by object's size and the density of surface material. A large and a small object with the same mass are not perceived as equal weights. Perceived weight decreases with the increase of volume and surface material. Generally, we could conclude that temperature, size and materials affect peoples' weight perception.

For tactile perception, people feel good with the object's lightness rather than heaviness. In fact, feeling a sensation of heaviness took the positive sense away and evoked negative emotions, such as unpleasant, annoyed and angry (Jeon, 2011). However, people usually associate heavy weight with high quality. Wansik and Ittersum (2003) mentioned Swain's (2003, cited in Wansik & Ittersum, 2003) study in which he presented three headphones with different weight to participants. Participants preferred heavier headphones during holding and lighter headphones during viewing, because people usually associate lightweight materials with plastic, glass and etc., and they think these materials are cheap and brittle. However, as the material science develops, lightweight materials are not necessarily cheap and weak, and they could be very strong and smart (ex. lightweight composites, high-strength fibers, and bio-plastics). People's current perception of the materials is being updated. For example, compared with iPhone4 and iPhone5, iPhone6 is much bigger and lighter (Figure 2.11). Customers are surprised and excited to hold it, because it is lighter than expected, and then positive emotions such as curiosity, amusement, relief and happiness follow. People prefer a product that is too heavy since too light products are experienced as not serious. The weight is limited by the human's ergonomics (Isaksson, 2004). Therefore, ergonomics is the most important factor for designers to decide the weight. For example, according to Eastman Kodak (1983), tools held in one hand should not weight more than 2.3kg, Furthermore, for more precise operations, tool weights should be less than 0.4kg (Karwowski & Marras, 1998). So we can conclude that weight is closely related with ergonomics dimensions. If it satisfies the ergonomics, people will experience pleasant tactile feelings.

Figure 2.11: iPhone series comparison between different size and weight

2.2.2.2 Tactile Perception of Geometry Properties

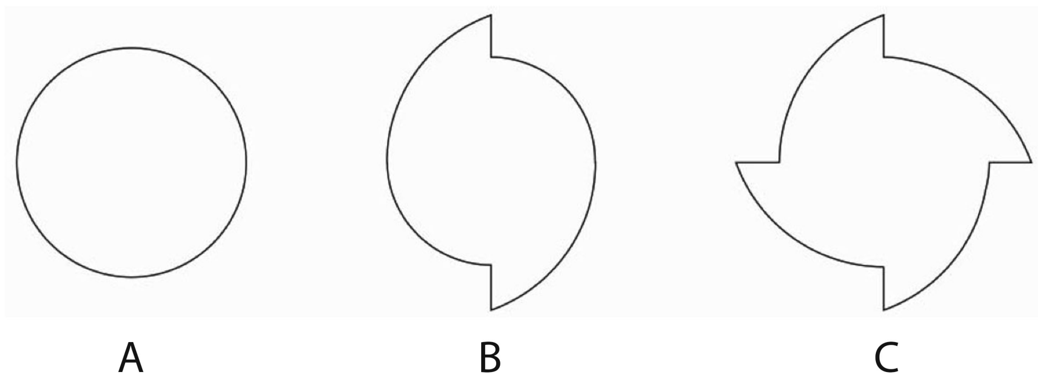
The second category will discuss how the geometric properties affect tactile perception. The properties include orientation, curvature, size and shape.

2.2.2.2.1 Orientation

Orientation of an object such as a line, plane or rigid body is part of the description of how it is placed in the space and also plays an important role in processing forms. For example, people could recognize the form through tracing the orientation of the edges. Orientation provides critical information about how an object is positioned on the hand, which helps people with grasping and lifting objects (Hsiao, Lane & Fitzgerald, 2002).

It is known that a point moves into a line, a line moves into a surface, a surface moves into a solid. A point does not have an orientation. Therefore, the orientation of a line is a very basic discussion. For lines, orientations are presented to the distal portion of the fingertip, and observers can reliably discriminate changes in orientation better than when the standard stimulus is oriented horizontally or vertically as opposed to obliquely. So observers could use the more accurately perceived horizontal and vertical axes as perceptual anchors to judge the orientation (Jones & Lederman, 2006). Bensmaia, Hsiao, Denchev, Killebrew and Craig (2007) found that if contours differ in orientation from 10° to 15°, people will regularly perceive them as being parallel. Therefore, for detecting changes in orientation, the contours should differ at least about 20° from each other.

In a study of relationship between tactile perception of geometry features and cognition of operation direction, three different geometric shapes were selected as a bottle's cap to test people's operational behavior (Table 2.1). The results show that the edges of sample C gave participants more orientation information to rotate the cap (Wang & Lin, 2008). We can conclude that the orientation could guide people to respond to its purpose.



samples	ratio of clockwise rotation	ratio of anti-clockwise rotation
A	98 %	2 %
B	58 %	42 %
C	28 %	72 %

Table 2.1: Test different shapes to decide the orientation

2.2.2.2.2 Curvature

Curvature is the rate of changes in the angle of line tangential to a curve as the tangent point moves along the curve. Curvature decreases as scale increases; for example, a circle with a larger radius has a smaller curvature (Jones & Lederman, 2006). Silvia and Barona (2009) suggested that curves are generally felt to be more beautiful than straight lines. Curves are graceful, serene, tender-sentimental and pliable, and avoid the harshness of straight lines. In Lundholm's (1921) experiment, he found that people associate angular lines with feelings such as agitating, hard, and furious; curved lines were associated with feelings such as gentle, merry, sad, quiet and lazy. Bar and Neta (2006) suggested that people prefer curved objects because angularity conveys a sense of threat. Sharp and jagged objects are often dangerous, while, curves are seen as harmless by comparison, so people are more attracted to the curved objects than to angular ones (Silvia & Barona, 2008). Carbon and Jakesch (2012) showed that these evaluations from Bar and Neta's study are quite dependent on cultural and Zeitgeist aspects. So they proposed that cultural and Zeitgeist aspects should affect the haptic sense less. They found that curved stimuli were still judged as more preferable (Figure2.12).

There are several illusions involved in the perception of curvature. Firstly, Vogels (1996) demonstrated that the statically judged curvature of a spherical surface was strongly influenced by a previously touched surface. In a later study, subjects more often judged a flat surface to be convex had previously touched a concave surface than after touching a convex surface (Vogels, Kappers & Koenderink, 1998). Secondly, Sanders and Kappers (2008) found that convex and concave surfaces had qualitatively different effects: convex lengths were overestimated, whereas concave lengths were underestimated. Finally, another study showed that the length of a stimulus influences the perception of the curvature. If the curvature is the same, the longer of two stimuli will be perceived as more curved. This led to an intriguing prediction that as the hands are usually longer than wide, a spherical object is perceived as an ellipsoid (Kappers & Tiest, 2014).

From the above studies we can conclude that people attach great value to curved objects in tactile perception. From the design perspective, whether the surface should be curved or angular depends on the designer's intentions. If designers want to express the feelings of strength, stability, hardness and masculinity in tactile perception, a more angular surface and straighter line will be adopted. At the same time, designers also could make use of the discomfort of touching angularity to promote avoidance of touching. On the contrary, the tactile feelings of softness, gentleness, femininity and complex are expressed though curved forms. In Figure 2.13, the hand blender designed by Braun applies flat surfaces and straight lines. It gives people very straightforward and solid feelings. Compared with the Braun's design, the form of Alessi's hand blender is very organic. People's hands flow with its contour very smoothly, and they feel more relaxed, gentle and dynamic.

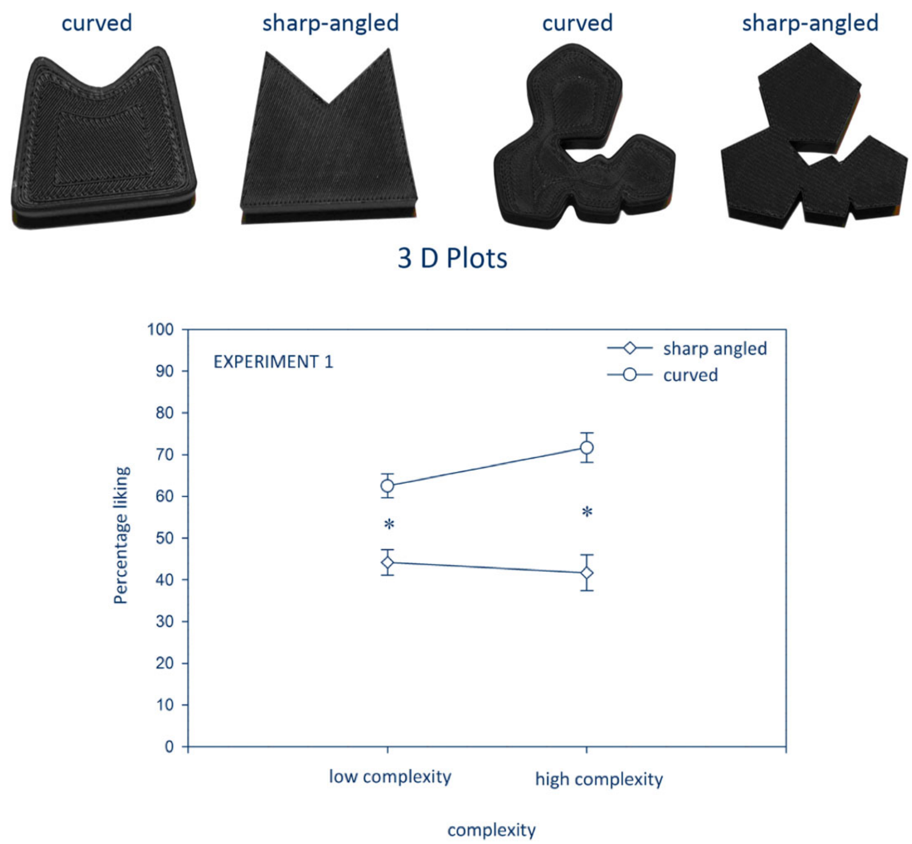


Figure 2.12: Samples and liking percentage (curved vs. sharp-angled)

Figure 2.13: The left hand blender was designed by Braun, and the right one was designed by Alessi.

2.2.2.2.3 Size

Objects are extended and thus have a certain size. Size can be measured in one, two or three dimensions, which corresponds to length, area and volume (Kappers & Tiest, 2015). Size is an important factor for tactile sensation in order to distinguish among objects, because the size of a certain kind of product usually changes within a small range such as cell phones, water bottles, laptop and etc., and some of the products even have a standard size. So people could distinguish the objects just by touching (Craddock & Lawson, 2009). There are several illusions involved in tactile perception. For example, people perceive small sized objects as being lighter and large sized ones as being heavier (Jones & Lederman, 2006). In addition, the size of a vertical line is shorter than a horizontal line's, but actually they are the same size (Hirsiger, Pickett & Konczak, 2012). Bartley (1953, cited in Liddle & Foss, 1963) reported that the further away the object is, the more its size tends to be underestimated.

What is a perfect size of a product that would make people touch it with pleasant feeling? The answer is the size should be based on the ergonomic factors. Designers apply the measurements of the human body to designs or products, which makes products more comfortable to use (Ryan, 2011). There are hot discussions currently about the size of cell phones. Is bigger better? Fowler (2014) claimed that as phones get bigger, the thing that won't change is the capability and limits of human hands (Table 2.2). If the phone does not fit in your hand, you would feel insecure and uncomfortable especially for a long time holding. Because the capability of human won't change, designers always need to go back to check whether the size of the product goes too far away from ergonomic principles and users' understanding of size. When people talk about size, they typically associate it with the proportion. Proportion concerns the relationship of one size to another; it can be used to balance, contrast or highlight different areas of a design. Proportion is important for aesthetics. As Dieter (2012) said a good design creates powerful long-lasting relationships with products as good design creates objects with balanced proportions.

Average Hand Size (Length)	
Male	**Female**
189 mm (7.44 inches)	172 mm (6.77 inches)
Average Hand Size (Width)	
Male	**Female**
84 mm (3.30 inches)	74 mm (2.91 inches)

Table 2.2: Average male and female hand's size

2.2.2.2.4 Shape

Shapes are classified into 2D and 3D shapes. The research is limited to 3D shape, because product design focuses more on 3D shape. Shape is an important cue for recognizing an object. Several features, such as edges, curvature, surface area, and aspect ratio, are associated with 3D shape recognition. Edges and vertices are most salient features of 3D shape for people to perceive a product (Plaisier, Tiest & Kappers, 2009).

For different shapes tactile discrimination, Ng and Chan (2014) found that circle, square, and triangle were discriminated significantly faster than other polygons and star shape patterns. They also found that tactile symbols with a few number of edges were recognized significantly faster than those with many edges. These findings are useful for designers to develop better tactual shape coding so as to improve users' performance. In terms of complex and simple shapes, liking ratings increased in relation to familiarization. From Figure 2.14, it can be concluded that when touching an object which people never or seldom encounter, people would prefer the simple shapes rather than complex ones at the beginning. However, after being more familiar with the complex shapes, the pleasantness increases (Jakesch & Carbon, 2012). Complex shapes are perceived as constituted of simpler shapes (geometric primitives) such as straight edges or elliptical arcs (Ehrich, Flanders & Soechting, 2008). Thus, it takes some time and effort for people to decompose the shapes into simple ones for perception. The process actually stimulates people's tactual interest. On the contrary, people gradually lose interest in simple shapes, while it is not necessarily the case the more complicated the better. No matter if the shape is complex or simple designers should keep Sullivan's (1896) statement in mind that the shape of a building or an object should be primarily based on its intended function and purpose.

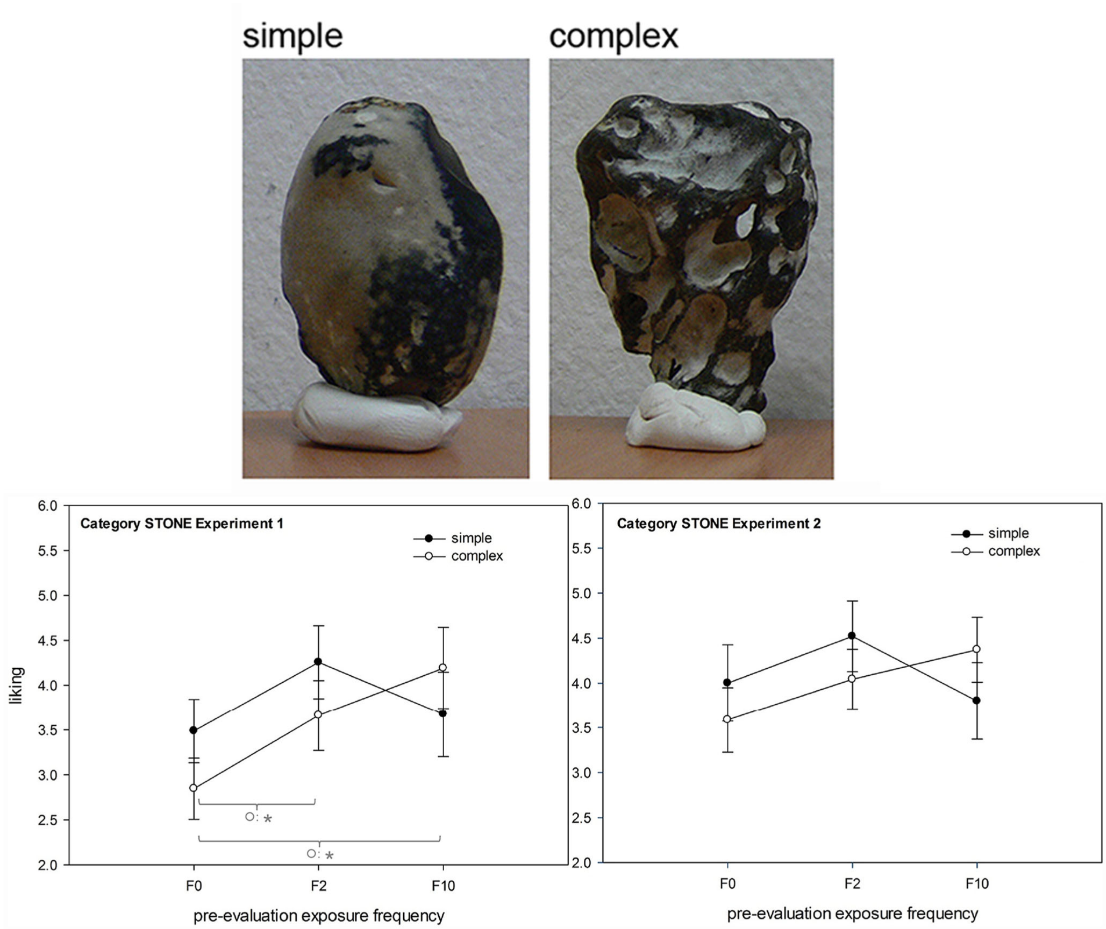


Figure 2.14: Stimulus and liking ratings and exposure frequency

Symmetry is a very salient property of shape. A lot of findings support the idea that shape symmetry can facilitate tactile perception without any specific demands or training (Ballesteros, Millar & Reales, 1998). And in the study of aesthetic appreciation of tactile unity-in-variety in product designs, Post, Blijevens and Hekkert (2014) found that unity and variety positively influence tactile aesthetic appreciation and there exists an optimum balance preferred by tactile aesthetics between tactile levels of unity and variety. In Figure 2.15, the left key was perceived as being more ordered and unified than the right one. People are trying to find unity in variety, so designers need to control the balance between unity and variety to achieve the best tactile perception.

Figure 2.15: Example of two keys used in the study of unity in variety. The left key was regarded as more unified than the right.

2.2.3 Conclusion

In summary, tactile perception is important in product design. However, despite the considerable research on how hand perception of material and geometric properties work, there is little or no research about applying the principles of hand tactile perception of material properties and geometry properties to product design. Thus, it is necessary to develop design guidelines for designers who set hand tactile perception as one of the primary considerations. The research conducted for this thesis will demonstrate design guidelines to show designers how to apply the hand tactile perception of material properties and geometric properties to the product design through the design process.

Chapter 3

The Development of Design Guidelines of Applying Tactile Perception of the Hand to Product Design

The development of design guidelines will be based on summarizing the findings from research in Chapter 2. The design guidelines will explore the application of the hand's tactile perception from three different perspectives: Customer Expectation Identification, Material Selection and Geometry Design.

3.1 Users' Expectations

The design process usually starts with marketing research. It includes identifying target customers, identifying competitive products and defining market segments. We need to integrate the research of customers' expectations of tactile perception into identifying the targeted customer section. Only by understanding people's needs can designers have accurate design direction.

As stated in Chapter 2 people have different feelings when touching objects with different materials. Table 3.1 summarizes Chapter 2's findings of hand tactile perception in terms of texture, hardness, temperature and weight. Additionally, in Chapter 2 we learned that when it comes to texture and weight, people also attach price value to the object. For example, people think a smooth textured object is more expensive than a rough textured one. Specifically, for the same kind of headphone, they think the lightweight headphone is cheaper than the heavy one. However, this kind of situation cannot be applied to all products, such as bicycles, cellphones, laptops and etc. For these products, the one with lighter weight is more expensive. Sometimes these situations are too complicated to fully understand all the nuances. Generally, we need to specify the information of the product before asking customers' tactile expectations.

PROPERTIES	FEATURES	HAND TACTILE PERCEPTION
Texture	Smooth	delicate, elegant, cool, lively, modern, comfortable
	Rough	natural, plain, traditional, bold, uncomfortable
Hardness	Soft	alive, secure, comfortable, relaxed, warm
	Hard	dead, cool, cold, insecure
Temperature	Warm	inviting, cozy, comfortable, pleasant
	Cold	cool, distant, unpleasant
Weight	Light	comfortable, curious, relief, pleasant
	Heavy	uncomfortable, unpleasant, annoyed

Table 3.1 Summary of all material properties

We conclude that for each material property, people have corresponding feelings of tactile perception. For geometric properties, people also have different tactile perceptions. However, unlike the material properties, for geometric properties except curvature, people have their preference instead of correspondingly physical and psychological feelings. For orientation and shape, they prefer the ones that could help them with accurate perception. Size is closely related to human ergonomics. For the case of this study, the design guidelines focus on the tactile perception of hand. Therefore, as long as the size of a product fits in people's hands, people usually will experience pleasant feelings of size perception (Table 3.3).

PROPERTIES	HAND TACTILE PERCEPTION	
Orientation	● horizontal and vertical orientations are preferred for accurate perception. ● the angle should be at least 20° for accurate perception.	
Curvature	Curved	softness, gentleness, femininity, complex, safe.
	Straight, angular or flat	threatening, strength, stability, hardness, masculine.
Size	relate with human ergonomics, refer to Table 2.2.2.2.3 in chapter 2.	
Shape	● circle, square and triangle are preferred for accurate perception. ● with the increase of familarity, complex shapes are preferred. ● Being unified in variety is preferred.	

Table 3.2: Summary of all geometry properties

Based on these summarized findings, we can see that people usually use adjectives to express their feelings of tactile perception, because it is hard for people to define a certain property. For example, if they are asked how much roughness and hardness they want, they might not know how to answer the question. The only thing they know or care is whether it is comfortable or not when in their hand. Therefore, it is advisable for designers to ask people to use adjectives to tell their feelings. Then designers could use these descriptions to find the corresponding properties of material and geometry. Table 3.5 is developed based on Table 3.1 and Table 3.3. Users should choose all the adjectives they want from each column in Table 3.5 to show designers the feelings of tactile perception they expect.

HAND TACTILE PERCEPTION
delicate, elegant, cool, lively, modern, comfortable
natural, plain, traditional, bold, uncomfortable
alive, secure, comfortable, relaxed, warm
dead, cool, cold, insecure
inviting, cozy, comfortable, pleasant
cool, distant, unpleasant
comfortable, curious, relief, pleasant
uncomfortable, unpleasant, annoyed
soft, gentle, feminine, complex, safe
threatening, strong, hard, stable, masculine

Table 3.3: List of adjectives

3.2 Corresponding Adjectives to Features

After studying the expectations of people's tactile perception through the selected adjectives, designers need to use Table 3.4, which summarizes all the adjectives from Table 3.1 and Table 3.2 to check the corresponding properties. For example, if the adjectives such as 'elegant', 'traditional', 'expensive', 'inviting', 'curious', 'stability', 'masculine' are selected, then we see 'smooth', 'rough', 'light', 'warm' and 'straight, angular and flat' features are involved. If the adjectives of modern and natural are selected, both smooth and rough are preferred by users. In terms of this situation, designers could choose the middle value of the roughness to satisfy people's need.

HAND TACTILE PERCEPTION	FEATURES	PROPERTIES	CATEGORY
delicate, elegant, cool, lively, modern, comfortable	Smooth	Texture	Material
natural, plain, traditional, bold, uncomfortable	Rough		
alive, secure, comfortable, relaxed, warm	Soft	Hardness	
dead, cool, cold, insecure	Hard		
inviting, cozy, comfortable, pleasant	Warm	Temperature	
cool, distant, unpleasant	Cold		
comfortable, curious, relief, pleasant	Light	Weight	
uncomfortable, unpleasant, annoyed	Heavy		
softness, gentleness, femininity, complex, safe	Curved	Curvature	Geometry
threatening, strong, stable, hard, masculine	Straight, angular, flat		

Table 3.4: Material and geometry features

3.3 Ratings of Features

After checking the corresponding features, designers need to rate these features according to people's need and product's function to obtain more specific information (Figure 3.1). If the chosen value of the feature affects the realization of the product function, the value of the feature should be readjusted. For example, for designing a water bottle, if 'soft' was chosen, the softness of the material should be not only pleasant for people to touch but also be hard enough to support the body of the bottle.

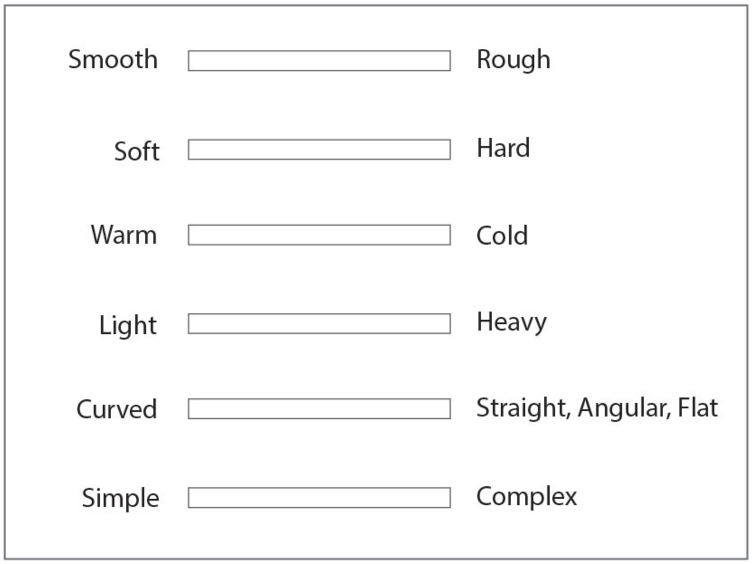


Figure 3.1: Ratings of features

3.4 Material Selection and Geometry Design

Based on the ratings of material properties, designers need to find the right materials. Firstly, for texture or roughness, the material is determined by the processing technology. Figure 3.2 shows designers an example of aluminum’s different surface roughness visually, so designers can get an idea about how to differentiate roughness visually. Secondly, the materials commonly used in design are metal, plastic, rubber, fabric, glass, wood, leather and ceramic. For these common materials, a general ranking of the hardness from high to low is ceramic, glass, metal, plastic, wood, rubber, leather and fabric. Designers should remember that the hardness of the same material would be different because of different components. So once a general material is selected, designers need to go deep into the material to know which one more closely satisfies the tactile requirements of hardness.

Thirdly, the property of temperature is determined by thermal conductivity, and a general ranking of the hardness from high to low is metal, glass, ceramics, plastic, rubber, wood, leather and fabric. The higher thermal conductivity lets the heat from the hand leave faster. Designers should choose the proper temperature based on the working context of their products. For example, for designing outdoor playground equipment, designers need to take the strong exposure of sun, especially in the afternoon, into consideration. If metal is selected as the main material, it will be very hot and dangerous for children to play on the equipment, so materials with low thermal conductivity are preferred. Last, as stated in Chapter 2, since too heavy or too light products are experienced as not serious by people. As mentioned previously, for the property of weight, people have different tactile perception because of different types of products. From the ergonomics perspective, if the product is to be held in one hand, it should not weigh more than 2.3kg and for more precise operations, its weight should be less than 0.4kg. Another situation is that if the product is not for holding, the weight does not play a critical role in tactile perception.

Figure 3.2: Different roughness of aluminum

Besides making use of the positive function of the material, the negative function also could be used. For example, if some parts of the product or the whole product are not for touching, designers could increase the value of the texture or softness to make it uncomfortable and unpleasant for people to touch, based on the premise of the guarantee of user's safety.

According to the ratings, designers decide the general appearance of the product. The orientation and size are not involved in the ratings even if the shape just involves the terms of simplicity and complexity. This does not mean they have nothing to do with the pleasantness of tactile perception. However, as stated previously, these properties are closely related to the accuracy of tactile perception and ergonomics dimensions. As long as the perception is accurate and the dimensions fit in people's hands, people will experience pleasant feelings of tactile perception.

Following is a detailed discussion of each property. Firstly, the main function of orientation is to guide people's hands to flow with a certain direction either for aesthetics purpose or for functional purposes. As Table 2.1 in Chapter 2 shows, the oriented profile lines tell people how to rotate the button. At the same time, the profile lines make the shape of bottle can more complicated than the first one. Therefore, designers need to balance these two points. Secondly, curvature largely determines the overall styling of the product's appearance. Applying more curved lines and curved surfaces to the product makes the overall appearance soft, gentle, feminine and so forth. On the contrary, straight lines, angular surfaces and flat surfaces make the product stable, masculine, strong and so forth. Designers usually mix the use of these two properties to avoid the product being too masculine or too feminine. Thirdly, the property of size is closely related to human ergonomics. If the product is for holding, the size should be based on the size of people's hands. Designers can refer to Table 2.2 for dimensions. Last, except for the function, shape also plays an important role in aesthetics. If people choose the adjective word of 'simple', designers need to reduce the application of surfaces and curvature. On the contrary, more surfaces and curvature could make the product more complicated. Lastly, simple shapes such as circle, square and triangle are much easier to perceive correctly. Additionally, symmetric shapes facilitate tactile perception. As the findings showed in Chapter 2, for shapes, people are looking for the unity in the variety. So designers should find the optimum balance between unity and variety.

In addition, designers also could use the negative function of the geometry properties for the purpose of not touching. For example, designers could use comparable sharp angles or bigger sizes to encourage avoidance of touching. Choices of angles and sizes still should guarantee people's safety.

3.5 Selective Use of Illusions

It is important to remember that sometimes, our hands can cheat ourselves, just as the illusions found in Chapter 2 that for the objects with same mass, different sizes, surface densities and temperatures could lead to different weight perceptions (Table 3.2). Designers actually could make use of these illusions to achieve their desired effects. For example, after setting the weight of the product, if designers want people to feel lighter weight in their hands, they could increase the size appropriately to achieve their design goals. Table 3.4 summarizes the illusions regarding the tactile perception of curvature and size. However, this section is optional not required. Designers use it according to their needs.

PROPERTIES	WEIGHT (same mass)	
Size	Large	light
	Small	heavy
Surface Density (Texture)	High	light
	Low	heavy
Temperature	Warm	heavier than the one with neutral temperature
	Cold	heavier than the one with neutral temperature

Table 3.5: Illusion of weight

PROPERTIES	ILLUSIONS
Curvature	• Subjects judged a flat surface to be more convex after touching a concave surface than after touching a convex surface. • convex lengths are overestimated, whereas concave lengths are underestimated. • for same curvature, the longer of two stimuli will be perceived as more curved.
Size	• small sized objects are lighter than large sized ones. • the size of a vertical line is shorter than a horizontal line. • the further away the object is, the more its size tends to be underestimated.

Table 3.6: Illusions of curvature and size

3.6 Summery of Design Guidelines

To make the design guidelines easy for users to use, a booklet (see Figure 3.3, Figure 3.4, Figure 3.5, Figure3.6, Figure 3.7) is developed. Therefore, designers just need to follow each step to finish the whole process.

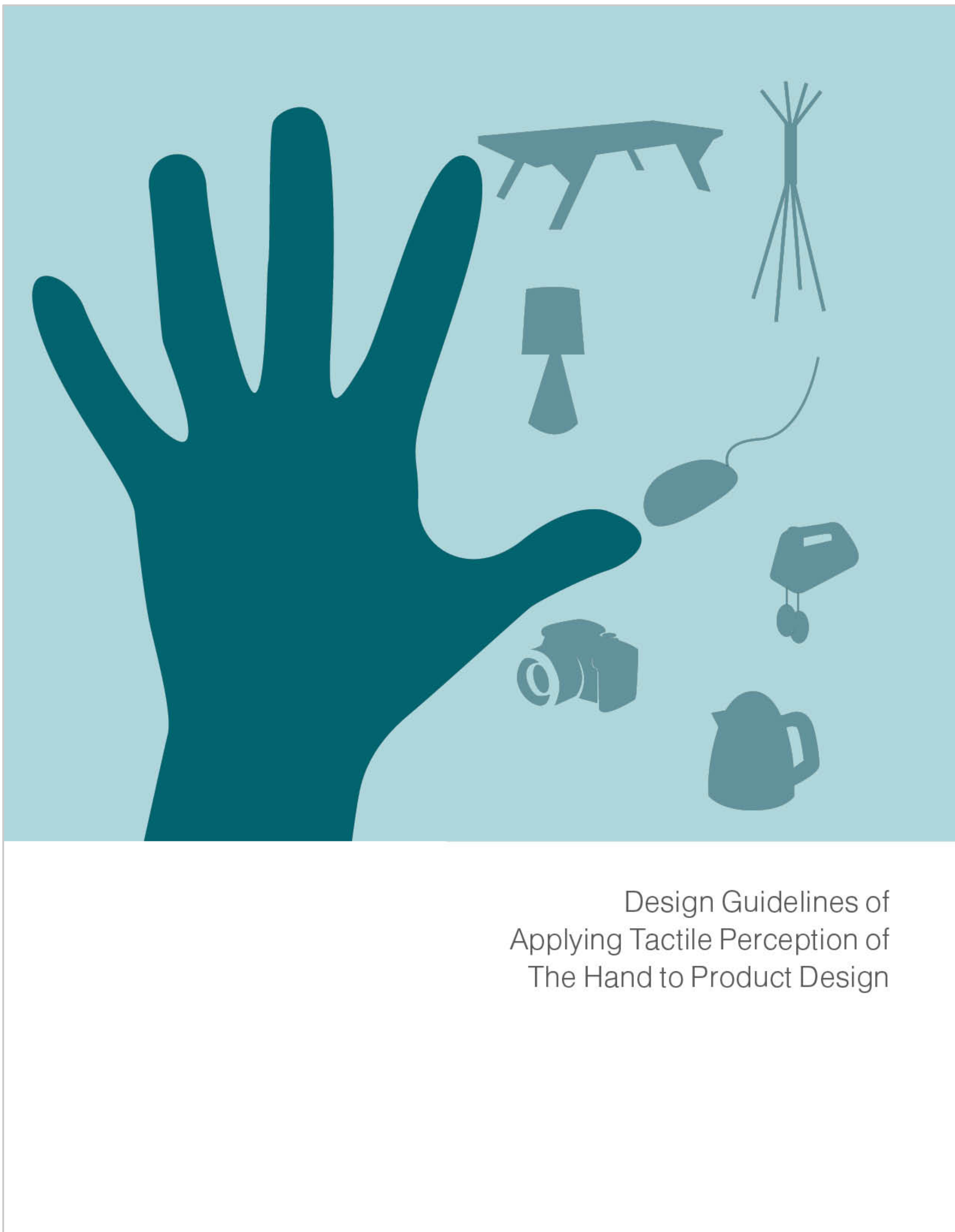
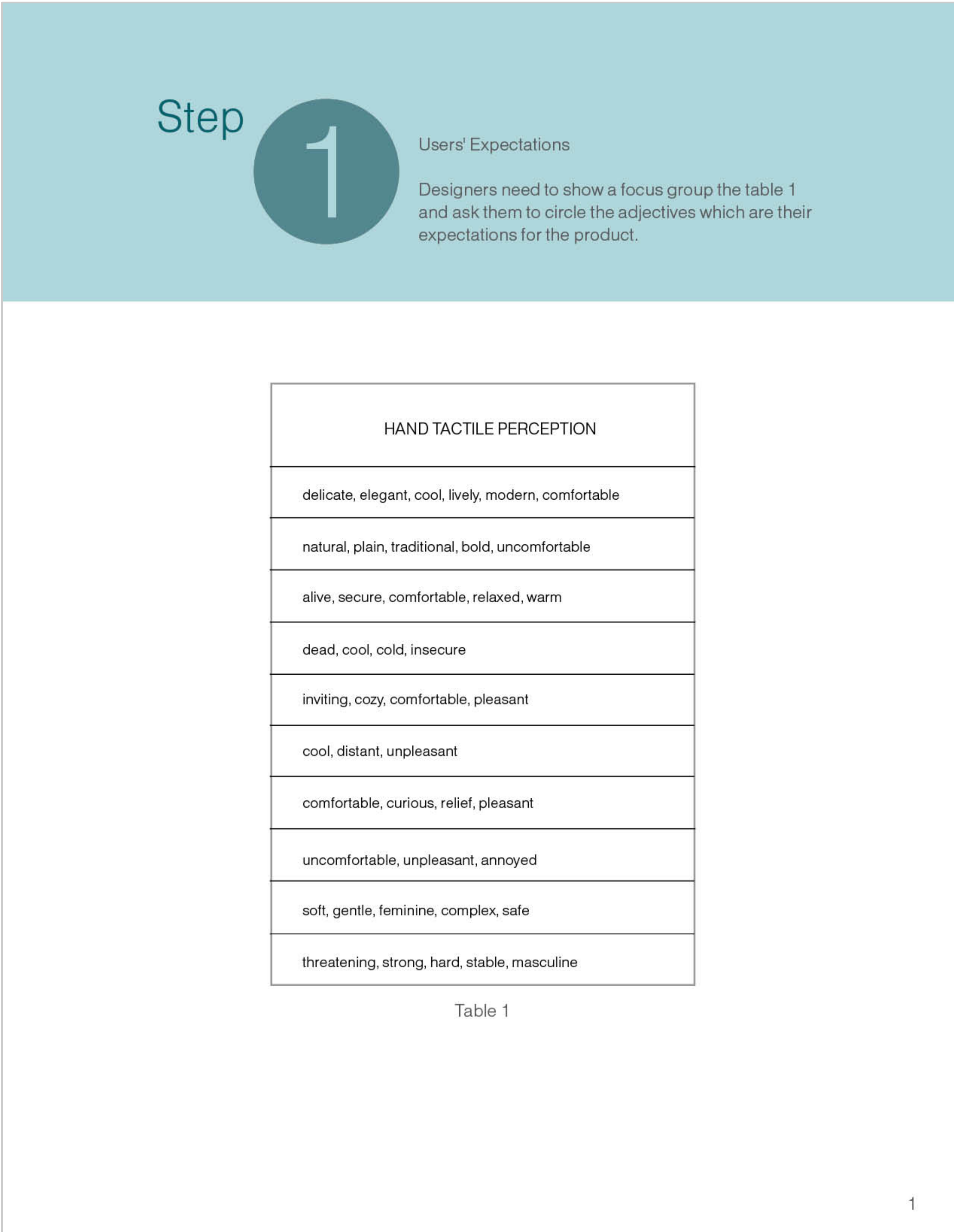


Figure 3.3: Booklet cover page

Contents

Figure 3.4: Booklet content page



Step 1

Users' Expectations

Designers need to show a focus group the table 1 and ask them to circle the adjectives which are their expectations for the product.

HAND TACTILE PERCEPTION
delicate, elegant, cool, lively, modern, comfortable
natural, plain, traditional, bold, uncomfortable
alive, secure, comfortable, relaxed, warm
dead, cool, cold, insecure
inviting, cozy, comfortable, pleasant
cool, distant, unpleasant
comfortable, curious, relief, pleasant
uncomfortable, unpleasant, annoyed
soft, gentle, feminine, complex, safe
threatening, strong, hard, stable, masculine

Table 1

1

Figure 3.5: Booklet first page

Step 2

Corresponding Adjectives to Properties

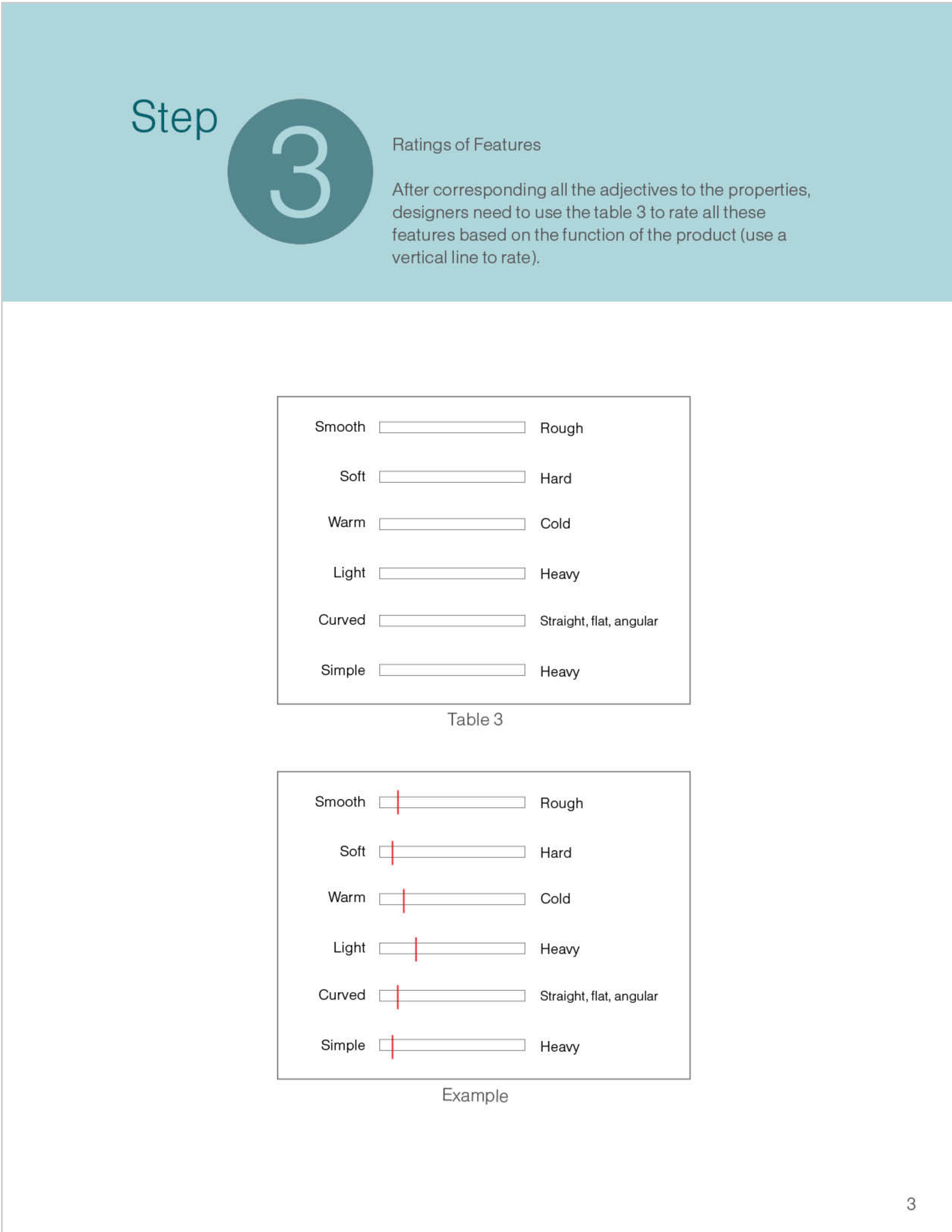
According to the adjectives circled by the focus group, designers need to use the table 2 to correspond the adjectives to all the properties.

HAND TACTILE PERCEPTION	FEATURES	PROPERTIES	CATEGORY
delicate, elegant, cool, lively, modern, comfortable	Smooth	Texture	Material
natural, plain, traditional, bold, uncomfortable	Rough		
alive, secure, comfortable, relaxed, warm	Soft	Hardness	
dead, cool, cold, insecure	Hard		
inviting, cozy, comfortable, pleasant	Warm	Temperature	
cool, distant, unpleasant	Cold		
comfortable, curious, relief, pleasant	Light	Weight	
uncomfortable, unpleasant, annoyed	Heavy		
soft, gentle, feminine, complex, safe	Curved	Curvature	Geometry
threatening, strong, hard, stable, simplemasculine	Straight, flat, angular		

Table 2

2

Figure 3.6: Booklet second page



Step 3

Ratings of Features

After corresponding all the adjectives to the properties, designers need to use the table 3 to rate all these features based on the function of the product (use a vertical line to rate).

Smooth		Rough
Soft		Hard
Warm		Cold
Light		Heavy
Curved		Straight, flat, angular
Simple		Heavy

Table 3

Smooth		Rough
Soft		Hard
Warm		Cold
Light		Heavy
Curved		Straight, flat, angular
Simple		Heavy

Example

3

Figure 3.7: Booklet third page

Step 4

Material Selection and Geometry Design

Based on all the previous information, designers could start to choose the material and also refer to Table 4 which shows geometric design principles to design the geometry.

CATEGORY	PROPERTIES	HAND TACTILE PERCEPTION
GEOMETRY	ORIENTATION	• Horizontal and vertical orientation are preferred for accurate perception. • The angle should be around 20 degrees for accurate perception.
	SIZE	• If the product is a handheld tool, its size closely relates to human's hand size: length 6.5"-7.5", width 2.5"-3.5".
	SHAPE	• Circle, square and triangle are preferred for perception. • With the increase of familarity, complex shape is preferred. • Unity and variety positively affect tactile aesthetics.

Table 4

4

Figure 3.8: Booklet forth page

Step 5

Selective Use of Illusions

There are some illusions invloved in the tactile perception of weight, curvature and size. According to Table 5 and Table 6, designers could make use of the illusions to achieve their design goals. This section is optional for designers.

PROPERTIES	WEIGHT ILLUSIONS (same mass)	
SIZE	Large	Light
	Small	Heavy
SURFACE DENSITY (TEXTURE)	High	Light
	Low	Heavy
TEMPERATURE	Warm	Heavier than the one with neutral temperature.
	Cold	Heavier than the one with neutral temperature.

Table 5

PROPERTIES	GEOMETEIC ILLUSIONS
CURVATURE	• Subjects are judged a flat surface to be more convex after touching a concave surface than after touching a convex surface. • Convex lengths are overestimated, whereas concave lengths are underestimated. • For same curvature, the longer of two stimuli will be perceived as more curved.
SIZE	• Small sized objects are lighter than large sized ones. • The size of a vertical line is shorter than a horizontal line. • The further away the object is, the more its size tends to be underestimated.

Table 6

5

Figure 3.9: Booklet fifth page

3.7 Conclusion

As we all know, when touching a product, people will not separate all the properties discussed here to perceive the product. They perceive the product and its associated properties as a whole. They may just tell you it is comfortable in the hand rather than explain each material and geometric property that promotes comfort. The properties of material and geometry are interrelated and interactional, such as size and weight, and shape and texture. For example, 3D shapes can work as a texture that avoids hand slipping. For example, the Nike bottle uses texture to avoid slipping, while the curved shape of the Bobble bottle makes it firm for hands to hold the body of the bottle (see Figure 3.3). Therefore, designers need to balance material and geometric properties to work together for satisfying people's expectations.

Figure 3.10: The left is Nike bottle, the right is Bobble Bottle

Chapter 4

An Application of the Design Guidelines

This chapter will show designers how to use the design guideline developed in Chapter 3 through a mouse design application.

4.1 Design Opportunity

A computer mouse interacts with people's hand very frequently every day. People just move it, click it and scroll it without seeing the mouse. Therefore, it should provide user's hand with enough tactile information and pleasant tactile features to use and touch it. Generally, putting the tactile perception as a primary consideration is necessary for designing a mouse.

4.2 Design Process

Different combination of adjectives will contribute to different design results. Two sets of adjectives will be selected as examples to show designers how to use the design guidelines generated from Chapter 3. One set will be delicate, elegant, lively, modern, comfortable, expensive, alive, secure, relaxed, warm, inviting, cozy, pleasant, curious and relief. The other set will be cool, uncomfortable, natural, plain, traditional, bold, cheap, dead, insecure, cold, distant, annoyed and unpleasant.

4.2.1 First Set of Selected Adjectives

One set of adjectives is selected such as delicate, elegant, lively, modern, comfortable, expensive, alive, secure, relaxed, warm, inviting, cozy, pleasant, curious, relief, soft, gentle, feminine, simple and safe as shown in Table 4.1.

HAND TACTILE PERCEPTION
delicate, elegant, cool, lively, modern, comfortable
natural, plain, traditional, bold, uncomfortable
alive, secure, comfortable, relaxed, warm
dead, cool, cold, insecure
inviting, cozy, comfortable, pleasant
cool, distant, unpleasant
comfortable, curious, relief, pleasant
uncomfortable, unpleasant, annoyed
soft, gentle, feminine, complex, safe
threatening, strong, hard, stable, masculine

Table 4.1: One set of adjectives

4.2.1.1 Corresponding Adjectives to Properties

According to Table 3.4, corresponding these adjectives to the properties of material and geometry is needed as Table 4.2 shows. It is concluded that the properties of smooth, soft, warm, light and curved are preferred.

HAND TACTILE PERCEPTION	FEATURES	PROPERTIES	CATEGORY
delicate, elegant, cool, lively, modern, comfortable	Smooth	Texture	Material
natural, plain, traditional, bold, uncomfortable	Rough		
alive, secure, comfortable, relaxed, warm	Soft	Hardness	
dead, cool, cold, insecure	Hard		
inviting, cozy, comfortable, pleasant	Warm	Temperature	
cool, distant, unpleasant	Cold		
comfortable, curious, relief, pleasant	Light	Weight	
uncomfortable, unpleasant, annoyed	Heavy		
softness, gentleness, femininity, complex, safe	Curved	Curvature	Geometry
threatening, strong, stable, hard, masculine	Straight, angular, flat		

Table 4.2: Selected material and geometry properties

4.2.1.2 Rating Each Feature

Then using Table 3.1 to rate these properties according to a mouse's function of overall body or individual parts is needed as Table 4.3 shows.

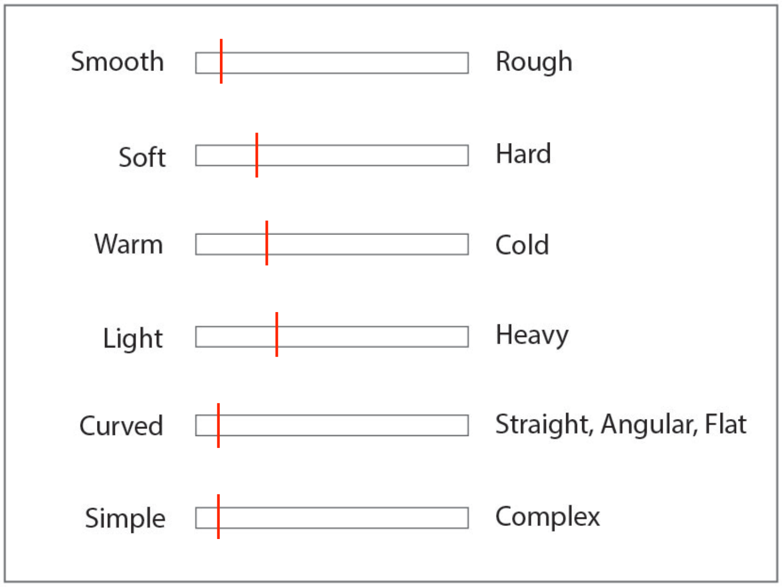


Figure 4.1: Ratings of features

4.2.1.3 Material Selection and Geometry Design

For the properties of the material, plastic, such as ABS, PP and PE, is selected as the main material. Differently textured plastic will be applied to prevent the hand from slipping. Because plastic has lower thermal conductivity, at room temperature, plastic will not get very hot in the hand after a long time of interaction. Geometric properties of curved and simple are chosen, so curved lines and surfaces should be applied, and reducing the use of too many surfaces can make the overall appearance simple. The overall length of the mouse is from 6.5" to 7.5", and overall width is from 2.5" to 3.5". The orientation of curves and shapes should guide people's hand to hold and use the mouse.

4.2.1.4 Selective Use of Illusions

The adjective word 'expensive' is selected. As it is mentioned in Chapter 3, proper heavy weight leads to the tactile perception of expensive. Based on weight illusions (see Table 4.4), the size could be relatively smaller to achieve this goal.

PROPERTIES	WEIGHT (same mass)	
Size	Large	light
	Small	heavy
Surface Density (Texture)	High	light
	Low	heavy
Temperature	Warm	heavier than the one with neutral temperature
	Cold	heavier than the one with neutral temperature

Table 4.3: Selected illusion property related to weight

PROPERTIES	ILLUSIONS
Curvature	● Subjects judged a flat surface to be more convex after touching a concave surface than after touching a convex surface. ● convex lengths are overestimated, whereas concave lengths are underestimated. ● for same curvature, the longer of two stimuli will be perceived as more curved.
Size	● small sized objects are lighter than large sized ones. ● the size of a vertical line is shorter than a horizontal line. ● the further away the object is, the more its size tends to be underestimated.

Table 4.4: Selected illusion property related to curvature and size

4.2.1.5 Concept Generation and Prototype Model

According to all the information, designers could start to sketch design ideas (Figure 4.1). Different prototypes are made (Figure 4.2) and painted in different textures for testing tactile perception (Figure 4.3).

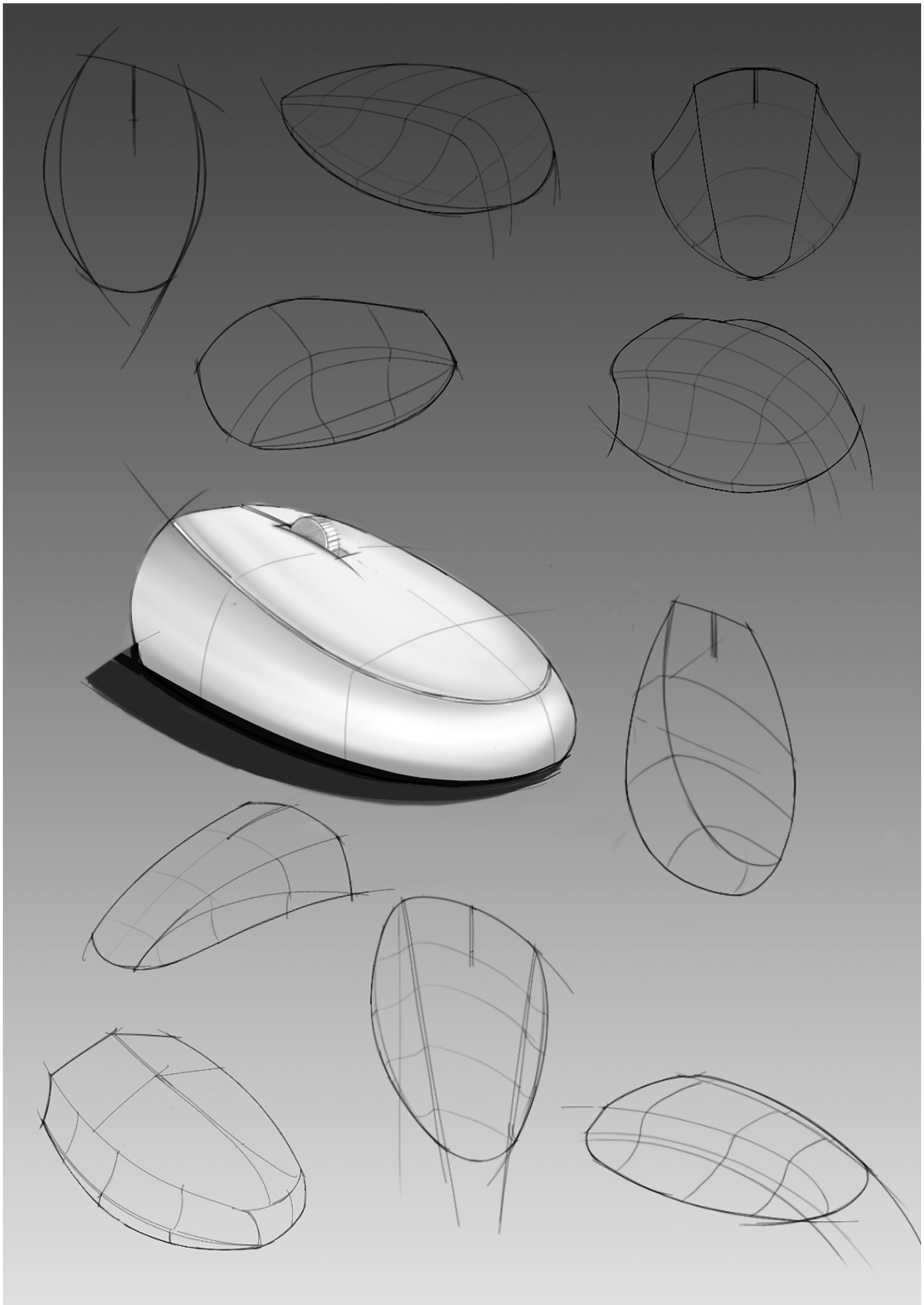


Figure 4.2: Concept generation

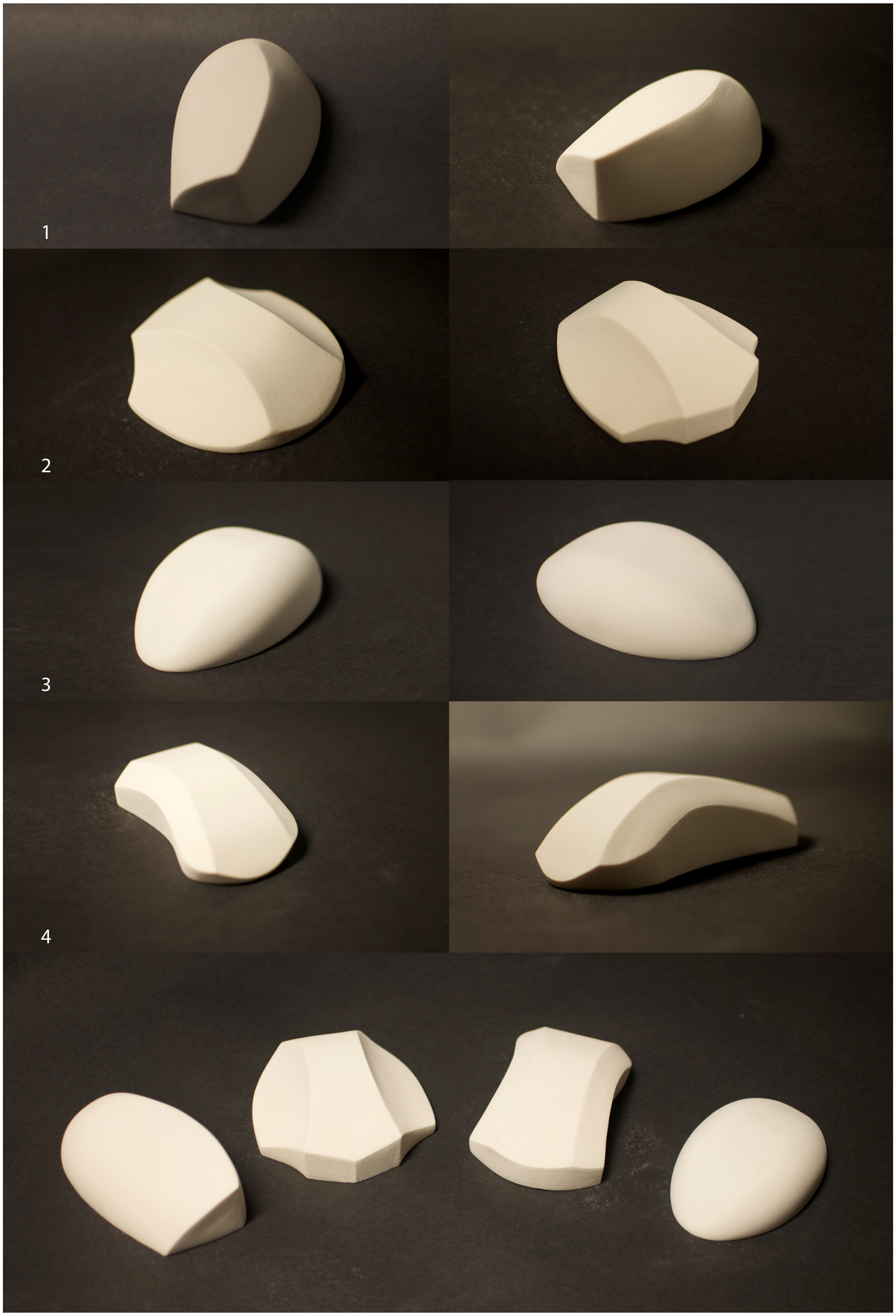


Figure 4.3: Prototype models

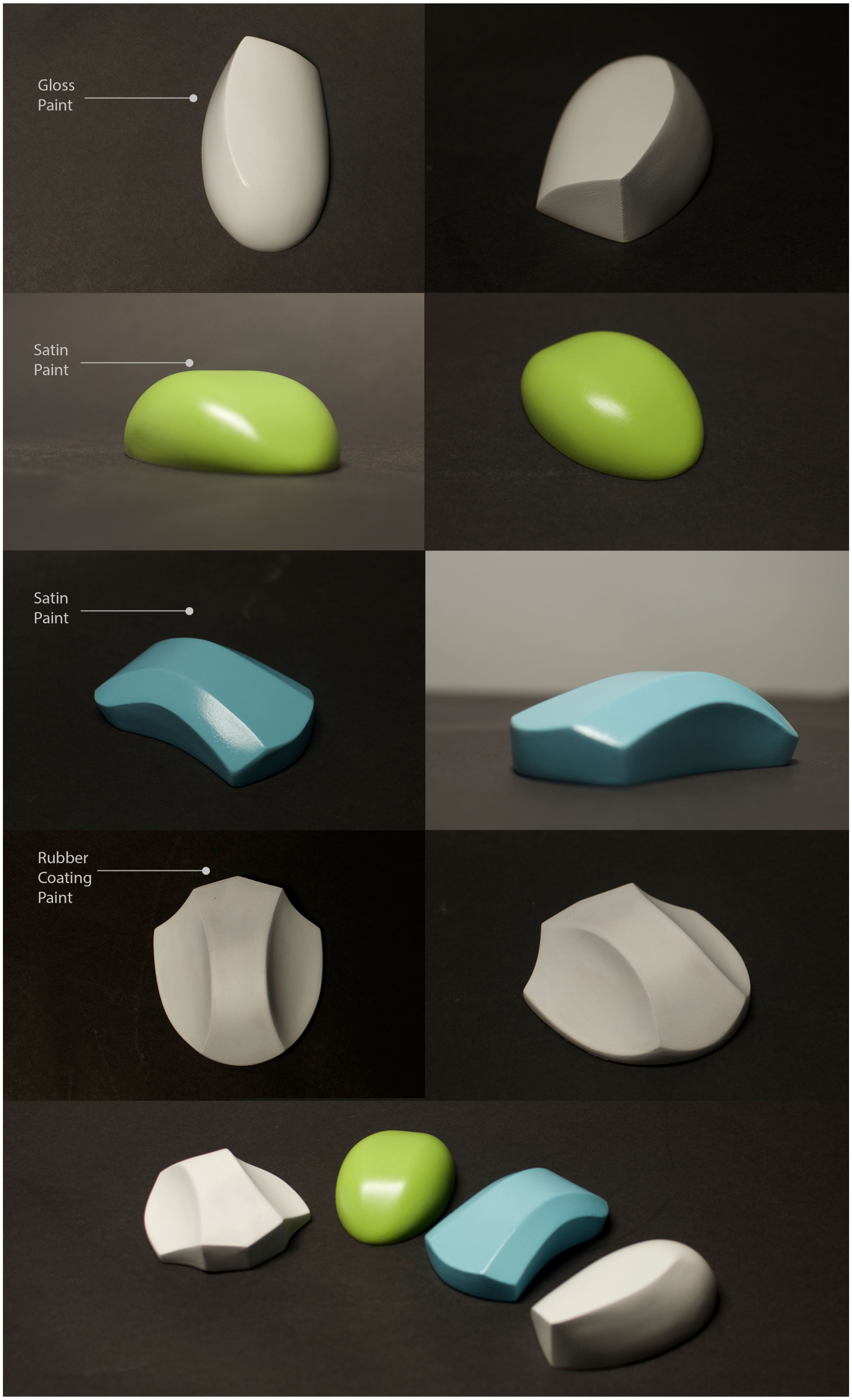


Figure 4.4: Prototypes with different paint

4.2.2 Second Selected Adjectives

The other set of adjectives is selected such as cool, uncomfortable, natural, plain, traditional, bold, cheap, dead, insecure, cold, distant, annoyed, unpleasant, complex, strong, stable, hard, masculine and threatening, is selected as it shows in Table 4.6.

HAND TACTILE PERCEPTION
delicate, elegant, cool, lively, modern, comfortable
natural, plain, traditional, bold, uncomfortable
alive, secure, comfortable, relaxed, warm
dead, cool, cold, insecure
inviting, cozy, comfortable, pleasant
cool, distant, unpleasant
comfortable, curious, relief, pleasant
uncomfortable, unpleasant, annoyed
soft, gentle, feminine, complex, safe
threatening, strong, hard, stable, masculine

Table 4.5: The other set of adjectives

4.2.2.1 Corresponding Adjectives to Properties

It is concluded that properties of rough, hard, cold, heavy, light, straight, angular and flat are selected as Table 4.6 shows.

HAND TACTILE PERCEPTION	FEATURES	PROPERTIES	CATEGORY
delicate, elegant, cool, lively, modern, comfortable	Smooth	Texture	Material
natural, plain, traditional, bold, uncomfortable	Rough		
alive, secure, comfortable, relaxed, warm	Soft	Hardness	
dead, cool, cold, insecure	Hard		
inviting, cozy, comfortable, pleasant	Warm	Temperature	
cool, distant, unpleasant	Cold		
comfortable, curious, relief, pleasant	Light	Weight	
uncomfortable, unpleasant, annoyed	Heavy		
softness, gentleness, femininity, complex, safe	Curved	Curvature	Geometry
threatening, strong, stable, hard, masculine	Straight, angular, flat		

Table 4.6: Selected material and geometry properties

4.2.2.2 Rating Each Feature

Then designers need to use Table 3.1 to rate these properties as Table 4.7 shows according to a mouse's function of overall body or individual parts.

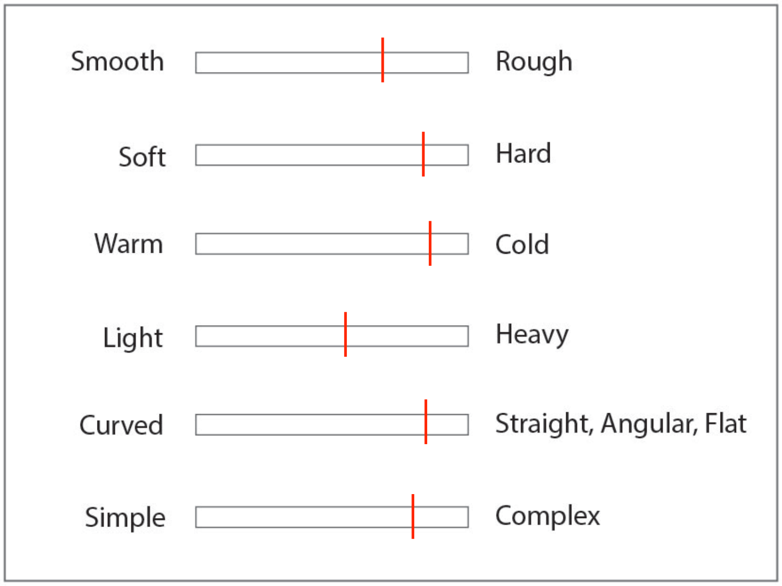


Figure 4.5: Ratings of features

4.2.2.3 Material Selection and Geometry Design

Metal such as aluminum alloy and plastic such as ABS are selected as the main material. Aluminum alloy will be applied to the top part of the mouse, so when touching the mouse at room temperature, the product would feel cold in the hand. Rough rubber coated ABS will be applied to two sides of the mouse to prevent fingers from slipping. Rough textures could lead to uncomfortable and unpleasant feelings. Because the cheap tactile perception is selected, as we mentioned in Chapter 3, rough texture also could cause the cheap tactile feeling. In terms of geometric properties of straight, angular, flat and complex, straight lines and angular and flat surfaces will be applied to use more surfaces to make the overall appearance tactually complex. The overall length of the mouse is from 6.5" to 7.5", and width is from 2.5" to 3.5".

4.2.1.4 Selective Use of Illusions

The adjective word ‘cheap’ is selected. According to the weight illusions (Table 4.8), the larger size could be perceived as being lighter.

PROPERTIES	WEIGHT (same mass)	
Size	Large	light
	Small	heavy
Surface Density (Texture)	High	light
	Low	heavy
Temperature	Warm	heavier than the one with neutral temperature
	Cold	heavier than the one with neutral temperature

Table 4.7: Selected illusion property related to weight

4.2.2.4 Concept Generation and Prototype Model

Based on all the information, designers start to sketch design ideas (Figure 4.4). For testing tactile perceptions, different prototypes (Figure 4.5) are made and painted with different textures (Figure 4.6).

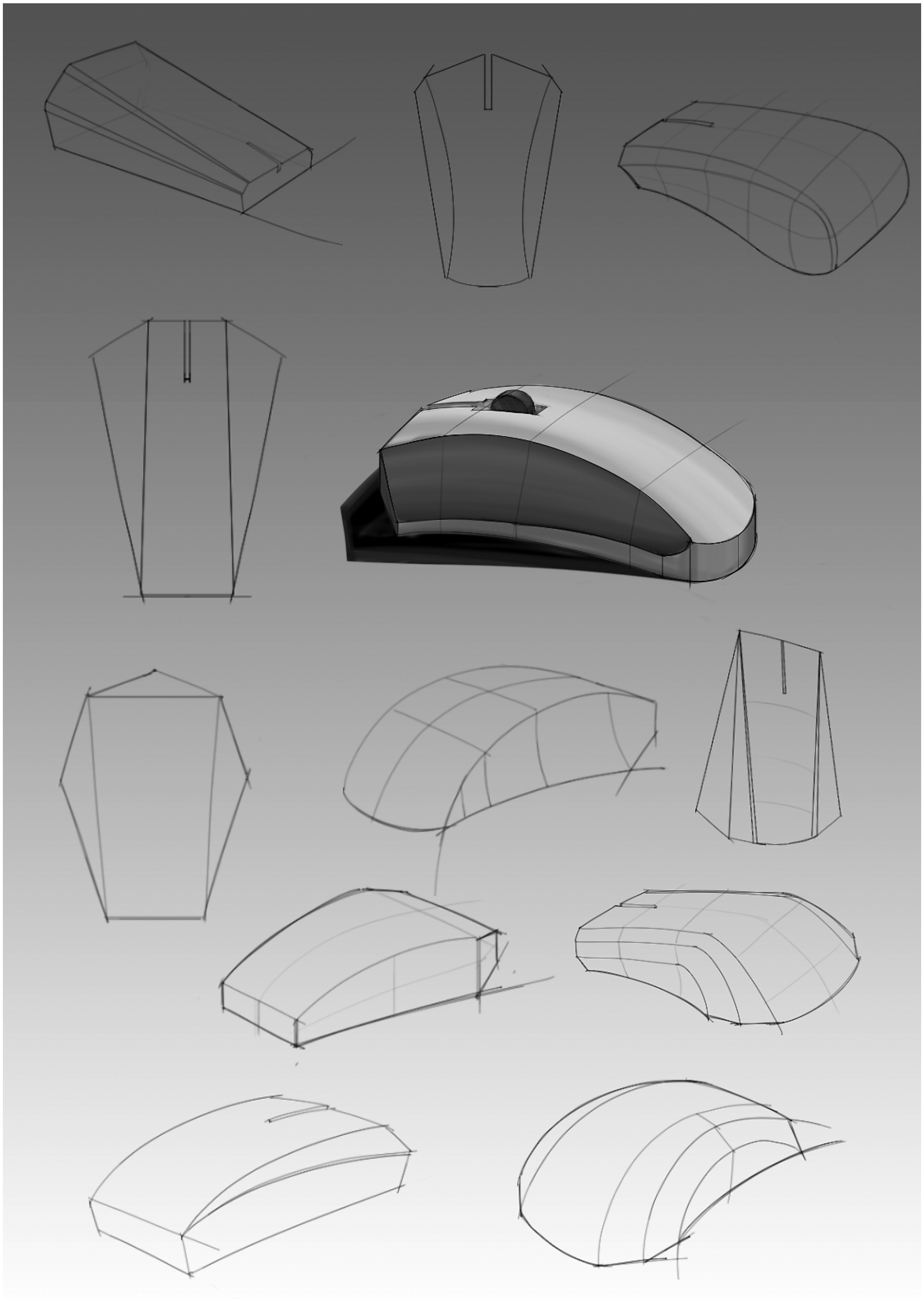


Figure 4.6: Concept generation

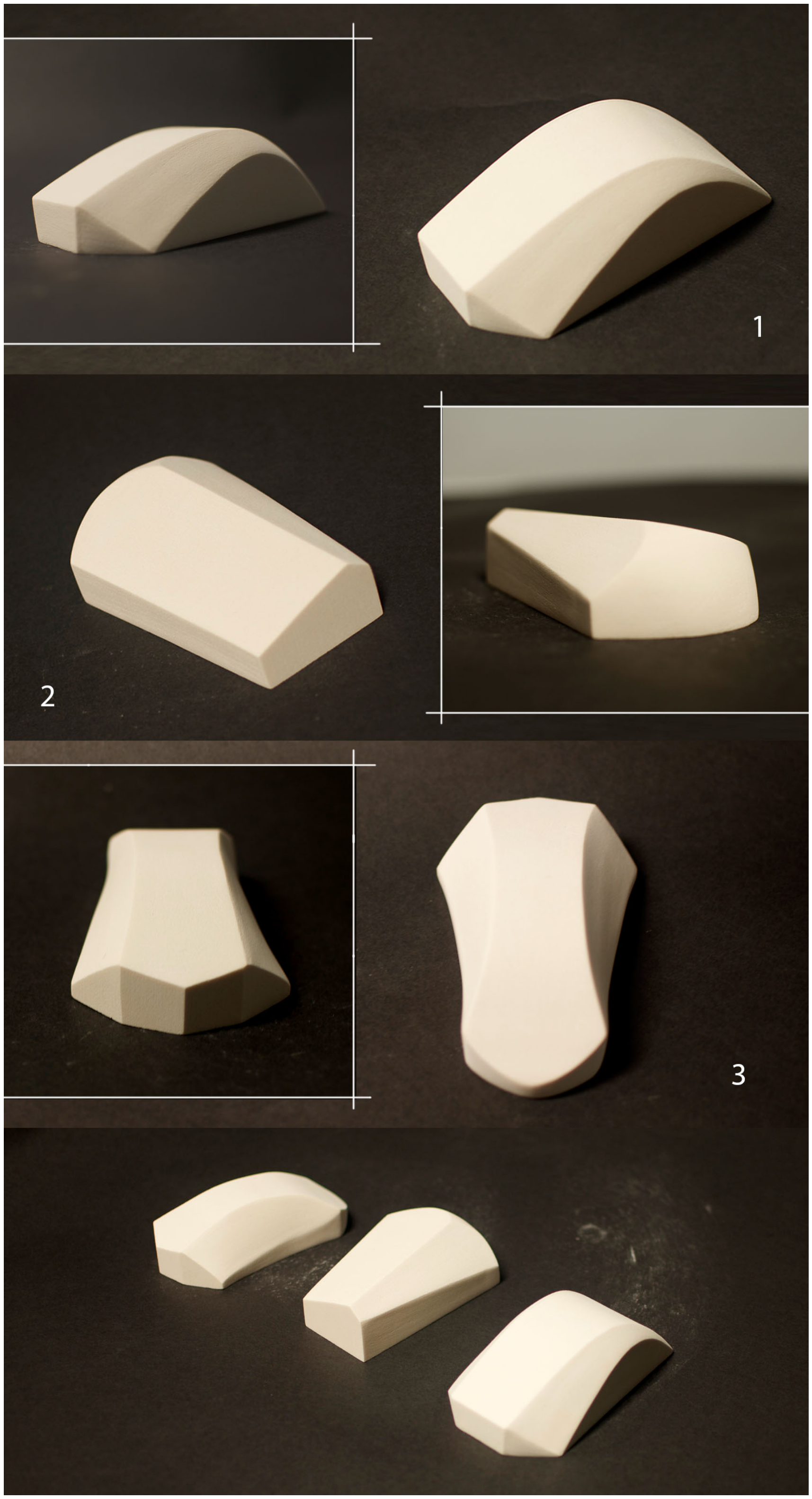


Figure 4.7: Prototype models

Figure 4.8: Prototypes with different paint

4.2.3 Summary

These given two examples successfully follow the design guidelines and show explorations of the design guidelines. Every product involves people's tactile perception. Designers could use the guidelines to explore some other product designs.

Chapter 5

Conclusions and Suggestions for Future Study

The objective of this thesis is to propose design guidelines to apply the tactile perception of the hand into product design. The purpose of the guidelines is to help designers with designing geometric properties of the product and selecting materials from the perspective of tactile perception.

The research starts with in-depth studies of the relationship between tactile perceptions of people's hand and products material and geometric properties. For the properties of material and geometry, the research discusses the tactile perception of texture, hardness, temperature, weight, orientation, curvature, size and shape in details. Based on analysis, the opportunity of applying hand tactile perception of properties of material and geometry into product design was found. Thus, the design guidelines were created. The sample of work is designed to demonstrate the application of the design guidelines.

There are still more aspects that can be further investigated in the next phase. Suggestions for the further research as follows:

1. Hands are just one part of the human body. Designers can use the same methodology proposed in this thesis to analyze the other parts of human body, because the tactile sensitivity of different parts of the human body are different.

2. Among all these features, research could be done to figure out what are the most salient features for people to perceive a product.

3. More specific hand tactile perception of material and geometry experiments need to be carried out. For example, what are certain degrees of roughness causing the negative feelings of hand tactile perception? Or what is the exact range of curvature causing the positive feelings of hand tactile perception? The information is helpful for designers to make more straightforward decisions.

4. Both tactile perception and visual perception are essential for people to perceive a product. Designers could research how the visual sensation affects people's overall perception. Then they need to combine visual perception with tactile perception to study how they could work cooperatively to get best design results.

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