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Analysis of Affective Response to Kinesthetic Stimulation

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송 주 봉

Abstract

Analysis of Affective Response to Kinesthetic Stimulation

Joobong Song

Department of Industrial Engineering

The Graduate School

Seoul National University

Although the degree of freedom is increasing in technological perspective related to haptic, more research on the technology itself and the method of technology application is still needed to actualize the haptic interaction. The necessity of researches using systematic approach to explore application method considering haptic perception characteristics of user to implement affective experience and social message is becoming a rising topic. This study consists of two: (1) study on affective response related to kinesthetic feedback and (2) analysis of the perception characteristics according to mode of haptic. In this study, thirdty three force profiles represented by specific sine wave having width, magnitude, detent type, and detent width were used as stimuli. Six affective variables such as perspicuity, smoothness, heaviness, elasticity, liltingness, and satisfaction of each stimulus were evaluated on 7-point likert scale and 100-point magnitude estimation scale by 25 subjects. The experiments with jog dial were divided into active haptic where the participants were directly involved with controlling devices and into passive haptic where the participants remained uninvolved. A statistical model has been developed to describe the relationship between satisfaction and affective variable using regression analysis. Also, the relationship between affective variables and elements of force profile as design variables has been found by quantification I analysis. Based on factor analysis, affective variables could be classified into force-related variables and movement-related variables. Affective elements and satisfaction had high relationship level (R^2=0.6). Also, each affective variables could be explained by design variables (R^2=0.2~0.5). In order to analyze the perception characteristics according to haptic mode, averages of affective elements in each mode were compared and change pattern according to force profiles parameter was investigated through statistical analysis. As a result, perspicuity, heaviness and elasticity were perceived larger when the mode was set to active haptic, while smoothness was perceived larger in passive haptic, and perspicuity and heaviness have shown significant difference according to haptic mode ($\alpha<0.05$). When it comes to change pattern of affective elements caused by force profiles parameter, it has linear relationship in active mode, but it doesn't in passive mode. Experiment result shows that the affective elements related with force are largely evaluated in active haptic than in passive haptic and assessment according to magnitude of stimuli was not consistent in passive haptic. This study investigates research issues that need to provide affective response utilizing haptic technology in human–robot interaction and virtual reality. By performing the fundamental research on the affective dimensions related to kinesthetic perception of the users and on the characteristics of feedback elements, the affective perception of complex kinesthetic perception was able to be analyzed, which in turn will allow us to build the foundation to provide the best haptic feedback to the users. Moreover, the perception of the feedback that the users receive passively has been analyzed, which also suggests further comparative analysis with the feedbacks provided from actively interacting with devices.

Keywords: Haptic perception, Kinesthetic feedback, Force profile, Affective engineering, Mode of haptic
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Chapter 1. Introduction

1.1 Research background

As the importance of multimodal interaction in the field of HCI has been acknowledged, haptic technology has gained greater attention and its various studies have been introduced (Bolt, 1980; Hayward, 2008; Shimoga, 1993; Tähkäpää and Raisamo, 2002). The existing studies have applied haptic technology in a form of multimodal interaction to improve the presence and performance, while proving its benefits for the cases limited major modality such as vision and auditory (Chellali et al., 2011; Chouvardas et al., 2008; Qian et al., 2011). However, the practical usage of the technology still stays limited with the mobile device applications (Raisamo et al., 2009). The technical aspect of the major limitations of the haptic technology is being improved as the recent actuators, which provide haptic stimulation, offer better performance with smaller size and lower price (Hayward et al., 2004; Wall and Brewster, 2006). While such limitation has been improved for greater degree of freedom in technical aspects, the current literature still lacks the research on the practical application of the technologies developed from the implementation of such multimodal interaction.

Haptic perception has significant differences from the other major modality such as vision and auditory in two aspects. First, the mechanism of perceiving stimulation is different from the other modality. While vision and auditory occur at specific sensory organs, which are the eyes and ears, haptic perception occurs through various somatic receptors that are spread throughout the body. The perception is not one-to-one interaction between a receptor and the stimulation but is occurred through combining various information received from more than one receptor

(Bleyenheuft and Thonnard, 2009; Kim, 2008). It is also important to decide which part of the body should be studied since the characteristics, distribution and density of receptors vary throughout the body (Shimoga, 1993).

The second difference is the characteristic of the delivered messages. The messages are delivered in the aspects of cognition and emotion through all of the senses, but delivering elements show differences between them. This can be seen as the difference between verbal communication and nonverbal communication. Vision and auditory are mainly occupied with delivering specific information, whereas haptic perception is often involved with simple information and other emotions such as affection, warmth and friendliness (Andersen and Guerrero, 2008). The examples of delivering affective messages through haptic sensation can be seen from a baby inside the bosom of the mother or from the physical touch between two lovers (Gallace and Spence, 2010). Moreover, the messages delivered through haptic perception are not explicit and thus may convey different meanings in the context of different cultures and situations (Knapp and Hall, 2009). Because of these unique characteristics of haptic perception, there are many researches on developing haptic feedback to provide the users with various social interaction and affective involvements (Tsetserukou, 2010; Yohanan and MacLean, 2011).

As technology has advanced, haptic technology has been adapted into various fields such as human-robot, human-device and telecommunication interactions (Bolt, 1980; Lederman and Klatzky, 2009b; Raisamo et al., 2009). Due to its technical limitations, the previous haptic technology had primarily been utilized to provide simple haptic feedback information. However, as the recent technologies have advanced and as various research on user perception characteristics have been conducted, the range of haptic technology has been extended to providing haptic experiences such as emotion and feelings, as well as to the fields of Human-Robot

Interaction and virtual reality. The recent focus of the technology is being geared toward applying haptic perception for better delivery of affective and social interactions through the tactile senses (Raisamo et al., 2009; Smith, 1997; Tan et al., 1994).

1.2 Haptic sensational dimension & research keyword

This study categorizes the important topics found in the existing research of haptic technology and its applications as the following: types of stimulation as cutaneous sensations and kinesthetic sensations, haptic modes as active haptic and passive haptic, dimensions of information characteristics as cognition and emotion (Gibson, 1962; Loomis and Lederman, 1984).

The perception of haptic stimulation can be divided into two categories. First, cutaneous (tactile) sensations are spread throughout the body at skin level that perceives information related to roughness, pressure and temperature. Second, kinesthetic (deep, proprioceptive or force) sensations are located around the muscles, bones and joints and perceive information related to force and movement. The details are discussed in Chapter 2.1.1.

The modes of touch in terms of haptic stimulation are also divided into two categories: active and passive touch. Active touch refers to the haptic perception that occurs during physical and direct manipulation/exploration of target objects, whereas passive touch refers to the perception that occurs through physical contacts of the objects without the user’s intention. The details are discussed in Chapter 2.1.2.

The characteristics of information delivered through haptic perception are divided into two categories. Cognition is the information related to the method and effect of feedback provided for discriminating stimulation. Emotion is the information related to affective communication through affective responses and physical contacts of haptic feedback. The details are discussed in Chapter 2.1.3.

This study focuses on kinesthetic aspect of stimulation, two modes of active and passive haptic, and emotions from the characteristic of information. In other words, this study examines the differences of the emotions between two modes of haptic (active and passive) perceived through the kinesthetic sensations in interaction with objects.

Type of sensation		**Mode of haptic**		Information characteristic	
Cutaneous	**Kinesthetic**	Active haptic	Passive haptic	Cognition	**Emotion**

Figure 1 Research keyword

1.3 Motivation

As the fields of Human-Robot Interaction and Virtual Reality become more notably importance and their related technologies have advanced, the performance of presence has been improved while the interest on haptic modality for providing stimulation has recently increased (Gallace & Spence, 2010; Raisamo et al., 2009). The technologies on providing haptic stimulation can be used in various applications such as haptic feedback during device control and tactile stimulation during interaction with virtual object through virtual reality. The process of constructing haptic interface must consider and allow the users to recognize properly on the primary purpose of feedback design, and in order to accomplish this, various elements such as technical properties, user perception properties and environment of providing stimulation must be all considered together (Robles-De-

La-Torre, 2008; Song, Lim, & Yun, 2012).

In this respect, many studies on the perception of haptic stimulation have been conducted, but there had been few studies considering affective aspects in haptic. To perform haptic research in respect to emotion, combinations of perceptual properties and their effects on users' affective responses should be analyzed (Chen et al., 2009). But existing studies are limited in investigating single perceptual properties such as roughness and hardness rather than considering combination of perceptual properties due to difficulties in design of experiment.

Haptic perception includes sensation activated via tactile stimulation and kinesthetic stimulation. In terms of tactile stimulation, the existing research has been focused on surface and material properties which would influence tactile sensation. There are studies demonstrated the relationship between physical properties and various properties of tactile perception such as roughness, stiffness, texture and vibration and effects of physical properties on users' perception (Hollins, Bensmaļa, & Roy, 2002; Lederman & Taylor, 1972). The studies that considered affective responses of tactile stimulation includes investigation of single perceptual properties (Hwang & Hwang, 2010; Salminen et al., 2008) and perceptual properties related to materials of touched object (Chen et al., 2009).

The studies on the perception of kinesthetic stimulation have been investigating the force, movement and position. The related studies attempted to identify elements that influence the perception of stimulation such as force, movement and position, as well as the psychophysical aspects of both absolute and relative sensitivity in the kinesthetic sensation (Kern, 2009; Tan et al., 1994). The studies on affective responses in relation to kinesthetic stimulation include a design research on switch (Wellings, Williams, & Tennant, 2010) and an experimental study on affective responses toward physical controls such as knobs (Swindells et al., 2007). In addition, there are other studies on the design attributes that could affect perception of kinesthetic stimulation (Weir et al., 2004).

However, there are few studies that investigate the relationship between kinesthetic perception and physical properties which influences on emotion on the specific experience. Similar to the studies related to tactile stimulation, the studies related to kinesthetic stimulation need to be conducted to deduct the dimensions of haptic perception and to consider combination of perceptual properties to investigate the affective response on real-life product. In order to analyze affective response related to kinesthetic sensation, a structure of recognizing emotions must be suggested while deriving meaningful dimensions of haptic perception. Then analysis of relationships between subjective response to a haptic stimulus (satisfaction or likeness), dimensions of perception, and design variables are necessary.

The research related to affective engineering have concerned various aspects of vision, auditory and tactile modalities. However, the existing studies still lack the understanding of the connection between the user's affective responses to the physiological process and have not been able to answer the entire process of affective perception. In order to overcome this limitation, a systematic modeling scheme that builds from the basic process of physiological phenomenon must be considered.

Also, the context of providing haptic feedback needs to be studied in respect for its effect on haptic experience. Acknowledging the increase of various applications using Virtual Reality and Human-Robot Interaction, we must consider the passive interaction as well as the active one which user actively explore the haptic stimulus. As we have seen the existing studies that observed the effect of the mode of haptic in shape and texture perception (Heller, 1984; Lederman, 1981; Smith et al., 2009), further research on the effects of the mode of haptic is necessary in the context of affective perception through kinesthetic feedback (Song et al., 2012).

1.4 Objective of this study

The aims of this study are 1) to confirm dimension of affective perception related to kinesthetic feedback and relation between affective element and design variable and 2) to analyze difference of perception according to mode of haptic.

This study has hypothesized that the affective elements based on the characteristics of proprioceptor that recognizes kinesthetic perception were affected by the types of stimulation, and the experiment was performed by utilizing a simulator that can create specific haptic feedbacks to verify the hypothesis. In order to verify that the affective responses of the users can be divided into the elements of force and movement, the design variables from the existing psychophysical research have been categorized to analyze the relationship with the affective elements.

We have also investigated the differences seen in the evaluation of the mode of haptic in terms of affective responses, and the existing studies that compare the superiority of time and preciseness have been used to analyze the related causes of the differences.

The main elements discussed in this study are shown in Fig. 2, and this study has attempted to find the relationship among the elements. In this study, elements of force profile are utilized as design variable to analyze characteristics of user perceived emotion based on literature review.

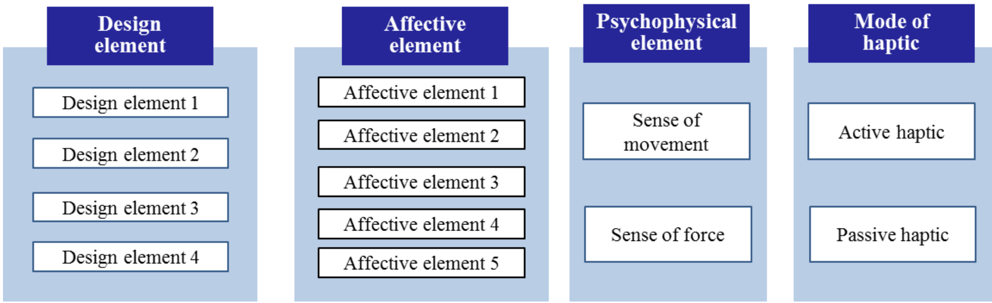


Figure 2 Elements related to this study

Research questions are as follows.

- Determining the major affective dimensions: Which elements affect the emotions related to kinesthetic sensations, and what is the relationship with the elements categorized in the aspect of physiological and psychophysical studies?
- Analyzing the relationship between affective elements and design variables: What is the relationship between the affective elements and the variables that can describe the pattern changes of haptic feedback?
- Comparing difference of perceptions characteristic between active and passive haptic: How are the perceptions different with the haptic feedback received from manipulating the devices directly with hands and the feedback received without any active movement?

Affective evaluation of real product feedback and simulated feedback is conducted to modeling of affective element related kinesthesis and to analyze difference between haptic modes.

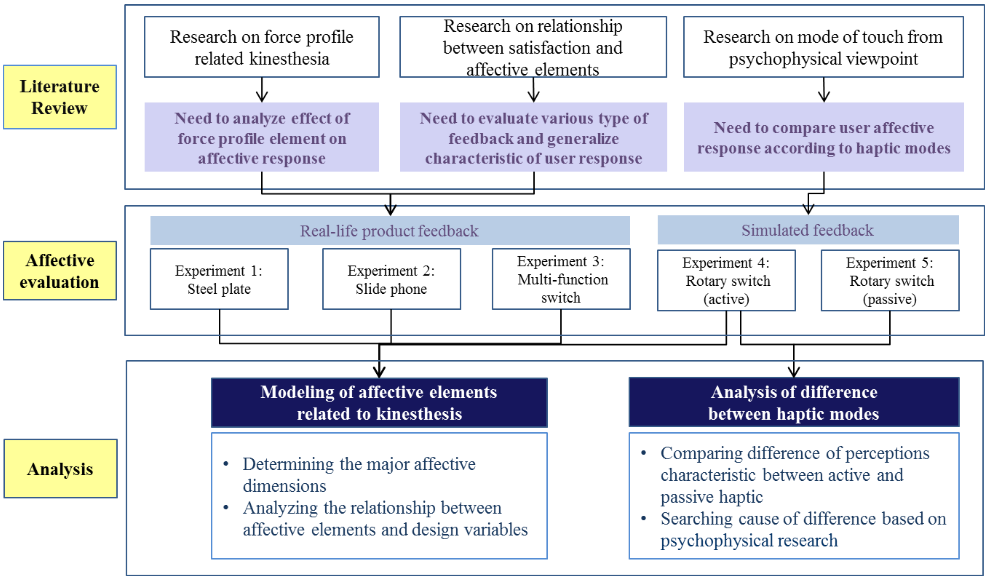


Figure 3 Overview of this study

1.5 Organization of the thesis

This study consists of three sections: 1) affective evaluation of kinesthetic sensations from the existing products, 2) user affective assessment experiment with a haptic feedback simulator, and 3) the analysis of user perception characteristics with respect to the conditions of providing feedback. The details of each section are as the following.

In Chapter 2, the research on the types of haptic stimulation and the related receptors have been examined to analyze the characteristics of affective perception on kinesthetic sensations. Then, the characteristics and effects of mode of haptic were studied while investigating the existing studies of emotions related to haptic. And characteristics and limitation of affective engineering research on kinesthetic sensations is summarized.

In Chapter 3, various designs of exploratory procedures of hands in manipulating products and the types of stimulation have been constructed for the evaluation of the users in order to analyze the characteristics of stimulation with respect to each design attribute and to analyze the affective elements that affect the satisfaction of the users through kinesthetic sensations.

In Chapter 4, a hypothesis has been proposed based on the result of Chapter 4 and the characteristics of proprioceptors, and the characteristics of the affective perception on kinesthetic sensations have been analyzed by utilizing a simulator. In turn, the main dimensions that affect the emotions related to kinesthetic sensations were determined, and the relationship between the affective elements and design variables was analyzed. And the effect of mode of haptic on kinesthetic feedback perception has been analyzed. The same haptic feedback was provided through active mode and passive mode to analyze the changes of the affective elements between the two modes.

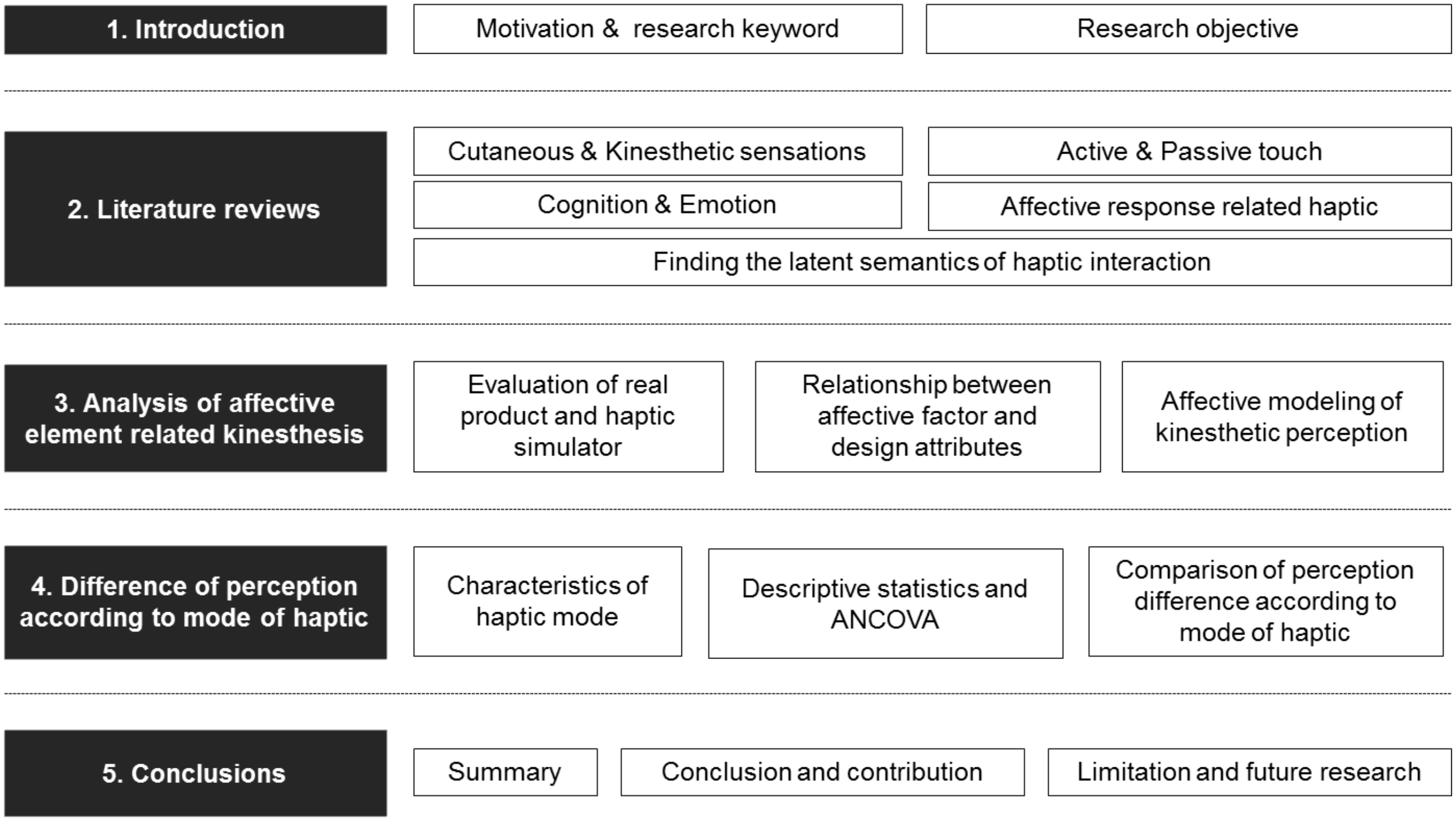


Figure 4 Structure of thesis

Chapter 2. Literature review

2.1 Haptic sensational dimension

2.1.1 Cutaneous and kinesthetic sensations

The perceptions of somatosensory system can be divided into cutaneous sensations and kinesthetic sensations (Bear et al., 2007; Goldstein, 2009; Smith, 1997). The roughness and the vibration of an object touching human skin are recognized through cutaneous sensations, while kinesthetic sensations recognize the force, movement and position of an object in manipulation. The cutaneous sensations perceive the senses related to the contact of an object on the human skin such as pressure, vibration, and heat through the mechanoreceptors. The receptors are categorized according to the characteristics of reactions to the stimulation, the scope of reception, and adaptation speed, and there are four categories of the mechanoreceptors: meissner corpuscles, merkel receptor, pacinian corpuscles and ruffini endings. The kinesthetic sensations relate to the senses of recognizing the movements around the body and the limbs, which are perceived through the muscle spindle, golgi tendon organ and joint capsule. The feedback of the kinesthetic sensations consists of the information of the tension and the length of the muscles (Powers and Howley, 2011).

The studies on the cutaneous sensations related to psychophysics mainly focus on the two-point discrimination threshold and point localization of tactile acuity (Kaczmarek 1995; Tan et al., 1994; Taylor-Clarke et al., 2004), while those of the kinesthetic sensations on force, sensations and joint angle (Burdea and Brooks, 1996; Tan et al., 1994). The existing studies on stimulation and sensations have often focused on the hand but still lack the research on the other parts of the body (Kern, 2009). Previously, the hands had been the main part of the body for manipulating an object; thus, the previous studies on the sensations have been mainly around the hands. However, as the research interests of HRI and tele-communication have been recently increased for the interactions between the users and other devices present in different locations, and the research on the characteristics of the haptic perception for the other parts of the body have obtained a greater attention (Lemmens et al., 2009; Tsetserukou, 2010; Yohanan and MacLean, 2011). Moreover, there have been a number of studies on the quantitative analysis of thresholds in the fields of psychophysics, and their research scope is slowly expanding to analyze the characteristics of stimulation and the perception system that determines the relationship among the users.

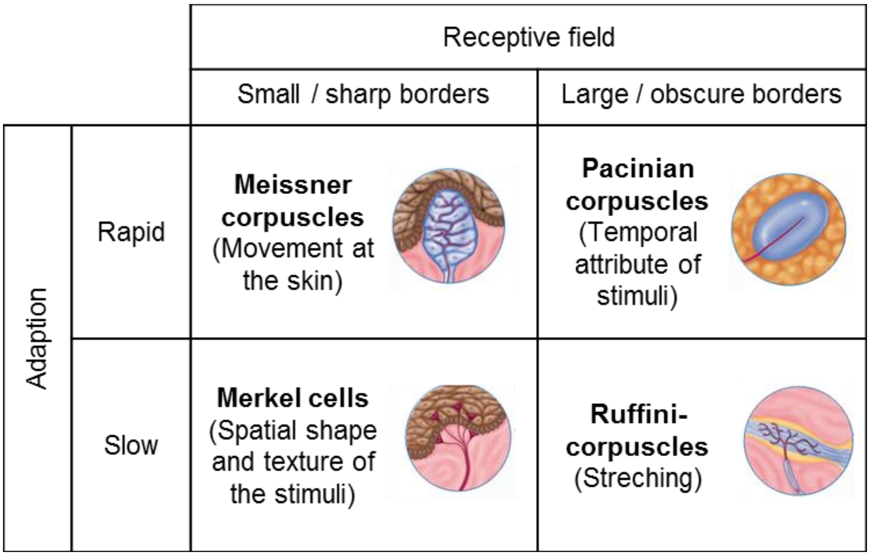


Figure 5 Characteristics of somatic sensory receptor

Table 1 Psychophysical research related to haptic sensations (Adapted from Kern (2009))

Characteristic value	Body part	Value
Skin-deformation, absolute value	Fingertip	10 μm
Two-point threshold (Spatial resolution)	Fingertip	2-3mm
	Palm	10-11mm
Force, absolute threshold	Fingertip	0.8mN
	Palm	1.5mN
Pressure, Absolute threshold	Fingertip	$0.2N/cm^2$
Force, Difference-Limen (DL)	Total body	5-10%
Pressure, Difference-limen (DL)	Wrist	4-19%
Maximum force	Index finger	40-50N
	Wrist	35-65N
Position-resolution, Difference-limen (DL)	Finger joint	2.5 °
	Wrist	2.0 °

Kinesthetic perceptions include perceptions of a sense of joint movement, a sense of joint position, a sense of muscle force and a sense of a sense of muscle tension, and they can be divided into the senses of joint movements and muscle forces (Proske, 2005; Proske & Gandevia, 2009). A sense of movement recognizes direction, velocity, distance and timing through relative position of body parts and perceives its movement. A sense of force recognizes and distinguishes the weight and its applied force by perceiving the force exerted from muscle contraction and relaxation.

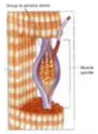
	Information	
Muscle spindle	Muscle length and velocity information	
Golgi tendon organ	Tension information	
Joint capsule	Joint angle and angular velocity information	

Figure 6 Characteristics of proprioceptor

Kinesthetic sensations occur with the combination of stimulation received from various receptors, and the characteristic of each receptor is described as the following (Bear, Connors, & Paradiso, 2007; Jones & Lederman, 2006). Muscle spindle consists of 14 bundles having the lengths of 4~10 mm, and they have two types of sensory nerve endings. Muscle spindle reacts to the extension of the muscle and provides the information of muscle length. Golgi tendon organ is an encapsulated receptor having the lengths of 0.2~1 mm and the radius of 0.1 mm, and it is directly connected with muscle spindle at the meeting point of muscle tendon and extrafusal muscle fibers. Muscle spindle reacts to the passive stretch throughout the muscle but is more sensitive to the force exerted at the muscle fibers connected with Golgi tendon organ. Joint capsule provides the information of joint movement, but it often reacts around the ends of the joint and is limited to recognize the direction of the movement as it lacks the sensitivity in the middle part. Skin receptor reacts to the stretch of skin from angular motion of joints and to the pressure exerted by holding an object with a hand, and it provides the information of location and movement of the joint, as well as the object's weight.

Kinesthetic perception can recognize stimulation through the receptors such as muscle spindle, golgi tendon organ, joint capsule and skin receptor (Bear et al., 2007; Jones & Lederman, 2006). Since kinesthetic perception usually combines various stimulations such as muscle length, joint angle and stretch of skin through each receptor, it may be difficult to distinguish movement, position, force and tension, but we can categorize them as the following based on the existing research. The studies on movement often focus on measuring the smallest imposed movement that can be recognized by the subjects, and it was discovered that the size of threshold is affected by speed (Proske, 2006). The studies on the sensation of position and movement mainly deal with the recognition of each joint's angular velocity and angle differences. Based on these studies, among the affective elements of kinesthetic perception that are recognized from touching switch or moving parts, the elements related to movement among those may be described by the movement beyond the threshold of a joint angle. Meanwhile, the sensations of force and tension are perceived by the force of muscle contraction and relaxation, and the affective elements related to force can be described by the force that are recognized from beyond the threshold of force.

Although there are some studies related to the resolution and differential threshold of movement and force (Jones, 2000), there still lacks the appropriate standard of the minimum threshold for recognizing the user's emotion. This study has determined the minimum thresholds as 2 cm of movement for the stimulation related to movement and 20% of force change for the stimulation related to force.

2.1.2 Active and passive touch

The tactile interaction with an object in contact can be categorized into active touch and passive touch (Gibson, 1962; Heller, 1984; Hughes and Jansson, 1994; Loomis and Lederman, 1984). The active touch refers to the senses aroused during active movements of manipulating or searching for an object, while the passive touch to the senses from a contact with an object without the person's intention. The two types of touch can be distinguished by the objectivity and the context. The active touch often has a purpose of obtaining information and involves the movements of the hands (Prescott et al., 2011). In the past, the related studies have focused on the movement of manipulating or searching an object (Lederman, 1981; Lederman and Klatzky, 1987; Smith et al., 2009), but the recent studies are also taking account of the emotions aroused from the manipulation of the object (Weir et al., 2004). On the other hand, the passive touch does not involve a purpose and is not only limited to the hands but also the rest of the bodies. Since it is a group of sensations aroused from passive movements, it mainly uses cutaneous sensations as opposed to the active touch that uses both the cutaneous sensations and kinesthetic sensations (Loomis and Lederman, 1984).

The research related tactile senses are mainly divided into active touch and passive touch for interacting targets (Gibson, 1962; Loomis & Lederman, 1984). The research related to perception characteristics with respect of mode of touch can be also divided into tactile and kinesthetic studies. The studies of tactile perception attempt to understand the superiority between the two modes in terms of efficiency, and their main concern is focused on the perception characteristics of textual roughness (Heller, 1984; Lederman, 1981; Lederman, Klatzky, Hamilton, & Ramsay, 1999). The studies of the differences between the modes of touch related to superiority have shown different trend for different methods and types of tasks to provide stimulation (Loomis & Lederman, 1984).

Table 2 Attribute of active & passive touch

	Active touch	Passive touch
The experience of touch	The object being touched	The sensation experienced in the skin
The type of information	Cutaneous and proprioceptive information	Cutaneous information
The degree of control	Control	No control
Major recognition parts	Fingertip & palm	Upper and forearms
Purpose	To acquire information and to manipulate their environments	To acquire feeling

The explanations of having different trends for different experimental conditions are as the following. The active touch mode often involves voluntary movement and thus is able to improve the performance by utilizing motor strategy (Chapman, 1994); the users are able to take as much time as desired when needed to obtain the kinesthetic information at any point of the task. Therefore, in order to determine the effects of the mode of touch more systematically, the exploratory conditions such as stimulation, position of stimulation and exploration time should be equally set and be analyzed. Under the same exploratory conditions, the experiment has shown lower performance in the case of active touch due to the movement-related suppression of the sensory inputs (Smith et al., 2009). When effect of motor strategy brought different results, the mode of active touch turned out to be more superior. In the case of the decrease of movement-related suppression, either they remained the same or the passive touch mode became more superior.

The studies on the effects of the mode of touch related to kinesthetic perception have shown that the active touch mode had higher sensitivity than the passive touch mode. In the study of Gandevia, McCloskey, and Bruke (1992), the threshold for detection of passive movement was shown to be 10 times larger than in the case of active movement, and the study of Taylor and McCloskey (1992) has shown smaller detection thresholds to maintain active flexion movement than in the case of passive limb.

2.1.3 Cognition and emotion

Among the research related to haptic, Raisamo et al. (2009) has suggested two categories: cognitive sensation for obtaining information through the tactile senses and affective sensation aroused from actions involving the tactile senses, such as comfort from a hug. Meanwhile, Essick et al. (2010) has proposed the affective responses of tactile stimulation as affective touch and quantitative judgment of tactile stimulation as discriminative touch. Likewise, the majority of the research studies related to haptic can be categorized into the fields of cognition and emotion.

(1) Research on cognition

The research studies that focus on cognition can be categorized into the studies on the discrimination of stimulation and on providing information through different feedbacks and effects, and they are mainly focusing on the tactile information obtained from active movements of hands for searching for objects. This can be related to the terms cutaneous sensations, active touch and hands from the previous section.

The research studies related to the discrimination of stimulation often focus on the stimulation that are recognized through cutaneous sensations such as vibration and roughness, and their main topics are the elements of stimulation, absolute and relative acuities and the characteristics of receptors (Hollins et al., 2002; Lederman and Taylor, 1972; Verrillo, 1963). The recent trend also realizes the influences of materialistic characteristics, such as texture, weight and compliance, and of geometric characteristics, such as curvature, orientation and size, on searching and recognizing objects (Ballesteros and Heller, 2008); therefore, the related studies take account of not only cutaneous sensations but also of kinesthetic sensations (Drewing and Ernst, 2006; Frisoli et al., 2011; Overvliet et al., 2008; Sanders and Kappers, 2009).

The research studies related to feedback information mainly focus on the characteristics of tactile modality for improving the effectiveness of haptic feedback. The characteristics of tactile modality offer more direct delivery of the information than the other senses such as visual and auditory, and they can also provide haptic feedbacks to help certain situations where other senses are limited. In other words, the tactile modality can be characterized by the fact that the delivery of information occurs directly through tactile senses without other senses. Due to such characteristics that require physical contact with the devices, there seems to appear active research on the touch screens of mobile devices. Brewster et al., (2007) has suggested a way of reducing errors while typing texts in mobile devices by providing haptic feedbacks. Moreover, in the research of Tähkäpää and Raisamo (2002), a tactile mouse was proposed to offer more effective task operation and work satisfaction by providing haptic feedbacks during target selection tasks.

(2) Research on emotion

The research studies on emotion can be categorized into the affective responses from haptic feedback and sentimental interaction through tactile contacts. The affective responses may be aroused from the force feedback of clicking a switch or from touching different clothing materials such as velvet and cotton, and they are related to the terms cutaneous sensations, kinesthetic sensations, active touch and hands that were mentioned in the previous section. The sentimental interactions can be described through the examples of pet robots and telecommunication, which offer remote contacts between the users, and they are related to the terms cutaneous sensations, passive touch, forearm and chest.

The research studies on haptic feedback that are related to affective responses can be divided into those of the affective changes in relation with the elements of haptic feedback and the others concerning the elements that affect the haptic perception. Such studies of haptic perception often focus on the affective responses of the vibration and texture related to the tactile feedback. The scope of the existing research covers from the psychophysical aspects of discriminating vibration and texture to studying the trend of the affective responses of the frequency and amplitude of the vibration(Hwang and Hwang, 2010; Salminen et al., 2008). Essick et al. (2010) has shown the tendency of the users having more pleasant feelings with soft and comforting materials such as velvet, cotton and plastic mesh than with hard and rough materials. In order to investigate such elements of haptic perception, Weir et al. (2004) has shown a graph of affective changes in his study to analyze the possible elements related to the changes in force. However, the major concern of the research studies related to emotions is about the user’s responses through cutaneous sensations, and the kinesthetic sensations related to switches and alike are still lacking in the current literature. Other studies that conduct research on object recognition and detection consider both of the sensations, but affective aspects are still neglected in such studies (Drewing and Ernst, 2006; Frisoli et al., 2011; Overvliet et al., 2008).

The research studies that concern the sentimental interactions mainly focus on the emotions occur during the communication among the users or between the users and devices, as well as the similar interactions in the fields of virtual reality and robotics. Hertenstein et al., (2006) has shown the possibility of affective interactions through tactile contacts without visual information in his experiments. Also, he has also shown in his experiment that a person is able to recognize the other person's affective intention through tactile contacts around the arms, and there were 6 basic emotions that could be also recognized through facial expressions and voices. In Bailenson et al., (2007), force-feedback haptic devices for virtual interpersonal touch was used to recognize the affective intention of the other person, and the patterns of expressive motions were categorized. In Tsetserukou (2010) for developing devices that offer affective interactions, haptic displays were proposed to provide emotions that are aroused from hugging the other person in online communication. Moreover, Yohanan and MacLean (2011) has conducted an experiment among the robot pet owners to analyze the affective interactions with the touch-centric social robot. Those studies have shown us the possibility of affective communication through tactile contacts and have proposed the implementation of certain devices, but there still lacks the research on the detailed analysis of the touch patterns that stimulates emotions (Field, 2011). Therefore, the related research fields also need to conduct research on the fundamental methodologies of implementing devices for specific purposes of affective delivery.

2.2 Finding the latent semantics of haptic interaction research

This chapter focuses on the review of various research studies on haptic while investigating different issues on the implementation of haptic technology for virtual reality and human-robot interaction. Therefore, the overall review of the fields related to haptic has been conducted to investigate the relationship between each field. Through the contents analysis, the common terminologies were extracted to categorize each field, and the network analysis was used to study the relationship between the terminologies as the reference for the categorization. Lastly, the frequency of each term and the centrality index were used to quantify the importance of each field.

2.2.1 Contents analysis results

Major area related to haptic research is medicine, neuroscience before 2000, but change to engineering, computer science after 2001 (Table 3). As a result, it is confirmed that research topic has been changed from basic perceptual mechanisms and characteristics associated with haptic perception to the implementation of multi-modal equipment by utilizing haptic feedback and sensing technology. And the number of published papers has been steadily growing from 2001. Major areas of study are to be roughly classified into research related technology to provide haptic stimuli and research related user characteristic to percept haptic stimuli.

Table 3 shows the terms with the highest frequencies that are categorized into different characteristics. The research areas related to haptic are field of application, relationship between the visual modality, cognitive trait of objects, body site, physiology of haptic sensation, mode of touch and more. The detailed characteristics are as the following:

- **Field of application :** the terms that are related to the research areas that focus on developing devices and systems with the haptic technologies such as virtual reality, human-robot interaction and haptic displays (e.g., virtual, robot, interface, display)
- **Haptic stimulation :** the terms that are related to stimulation via tactile senses (e.g., feedback, touch, and force)
- **Performance :** the terms that are related to the performance of haptic stimulation (e.g., control, time, and performance)
- **Relationship between the visual modality:** the terms that are related to the reactions of haptic stimulation in the cases of limited sight or visual stimulation (e.g., blind and visual)
- **Cognitive trait of objects :** the terms that are related to the characteristics of a target object such as vibration, texture and shape, which can be recognized through haptic stimulation (e.g., shape, texture, surface, and vibration)
- **Body site:** the terms that are related to the body site of haptic stimulation (e.g., hand, finger, and fingertip)
- **Physiology of haptic sensation :** the terms that are related to the neural senses and receptors that receive stimulation (e.g., cortex, neural, and brain)
- **Haptic search :** the terms that are related to the movement of a hand for recognizing the properties of a target (e.g., exploration and movement)
- **Mode of touch :** the terms that are related to the ways of contacting

the target (e.g., active and passive)

- **Haptic perception characteristics :** the terms that are related to the information and characteristics of perception via haptic stimulation (e.g., cognition and emotion)

The frequency of each term appearing in a paper was counted separately for the title, keywords and abstract. The keyword frequency was then computed for the years before 2000 and after 2001. Taking account of the ratio difference of the overall frequencies between the two time periods being 1.6, the relative ratio was computed as (frequency after 2001) / (frequency before 2000 x 1.6). The relative ratio greater than 1.0 represents the increase of the frequency of a term appearing in the texts over time between years before 2000 and after 2001. As the result, the frequencies of the keywords appearing in the context of the field of application and users have shown to be increased, while those of the body site and physiology have decreased. The detailed discussion of the research texts and the characteristics of changes in each category are shown in the following sections.

Table 3 appearance frequency and relative ratio of keyword

Category	Word	After 2001				Before 2000				Relative ratio			
		total	title	key word	abs tract	total	title	key word	abs tract	total	title	key word	abs tract
Field of application	virtual	2260	268	382	1610	716	114	37	565	2.0	1.9	2.7	1.9
	system	3195	299	188	2708	1724	215	48	1461	1.2	1.1	1.0	1.2
	device	2188	167	153	1868	728	65	10	653	1.9	2.1	4.1	1.9
	interface	1684	209	400	1075	641	134	26	481	1.7	1.3	4.1	1.5
	display	1688	223	238	1227	795	139	29	627	1.3	1.3	2.2	1.3
	interaction	1670	216	207	1247	464	59	28	377	2.3	3.0	2.0	2.2
	sensor	1482	221	230	1031	1592	364	26	1202	0.6	0.5	2.4	0.6
	robot	1212	197	181	834	740	161	33	546	1.0	1.0	1.5	1.0
	surgery	1014	152	126	736	429	59	25	345	1.5	2.1	1.3	1.4
	actuator	482	98	38	346	77	42		35	3.9	1.9	0.0	6.4
	tele	451	57	91	303	182	8	5	169	1.6	5.9	4.8	1.2
	subtotal	17326	2107	2234	12985	8088	1360	267	6461	1.4	1.3	2.2	1.3
Haptic stimulation	feedback	2559	288	291	1980	710	103	36	571	2.3	2.3	2.2	2.3
	touch	1431	119	202	1110	730	72	43	615	1.2	1.4	1.3	1.2
	cutaneous	115		18	97	232	25	17	190	0.3	0.0	0.3	0.3
	force	2501	140	197	2164	1182	95	49	1038	1.3	1.2	1.1	1.4
	kinesthetic	320	19	11	290	145	21	8	116	1.4	0.7	0.4	1.6
	perception	1791	277	337	1177	754	198	48	508	1.5	1.2	1.9	1.5
	spatial	770	74	79	617	573	71	21	481	0.8	0.9	1.0	0.8

	stimulation	2073	183	55	1835	2432	328	119	1985	0.5	0.5	0.1	0.6
	subtotal	11560	1100	1190	9270	6758	913	341	5504	1.1	1.0	0.9	1.1
Cognitive trait of objects	surface	1157	95	47	1015	915	69	10	836	0.8	1.1	1.3	0.8
	shape	831	65	59	707	593	61	8	524	0.9	0.9	2.0	0.9
	texture	767	77	82	608	387	23	12	352	1.2	2.8	1.8	1.1
	vibration	833	75	96	662	372	16	12	344	1.4	3.9	2.1	1.3
	pressure	345	29	32	284	330	23	23	284	0.7	1.0	0.4	0.7
	roughness	293	28	37	228	134	17	12	105	1.4	1.4	0.8	1.4
	stiffness	303	21	23	259	146	16		130	1.3	1.1	0.0	1.3
	hardness	87		13	74	104			104	0.5	0.0	0.0	0.5
	pain	439	85	67	287	281	57	54	170	1.0	1.2	0.3	1.1
	subtotal	5055	475	456	4124	3262	282	131	2849	1.0	1.4	0.9	0.9
Performance	control	1482	157	186	1139	1229	98	20	1111	0.8	1.3	2.5	0.7
	time	1030	73	48	909	604	33	13	558	1.1	1.8	1.0	1.1
	performance	1325	60	35	1230	738	72		666	1.1	0.7	0.0	1.2
	discriminate	637	54	50	533	906	142	58	706	0.4	0.3	0.2	0.5
	subtotal	4474	344	319	3811	3477	345	91	3041	0.8	0.8	0.9	0.8
Relationship between visual modality	visual	3441	405	268	2768	1808	249	65	1494	1.2	1.3	1.1	1.2
	blind	526	61	67	398	472	67	21	384	0.7	0.8	0.8	0.7
	subtotal	3967	466	335	3166	2280	316	86	1878	1.1	1.2	1.0	1.1
Related body site	hand	1208	79	58	1071	1333	176	25	1132	0.6	0.4	0.6	0.6
	finger	786	72	22	692	722	60	15	647	0.7	1.0	0.4	0.7
	fingertip	306	21	11	274	186	12		174	1.0	1.4	0.0	1.0

	body	465	38	33	394	328	27	8	293	0.9	1.2	1.1	0.9
	arm	252	18	12	222	157	15		142	1.0	1.0	0.0	1.0
	forearm	32			32	50			50	0.4	0.0	0.0	0.4
	skin	531	51	50	430	614	55	22	537	0.5	0.8	0.6	0.5
	subtotal	3580	279	186	3115	3390	345	70	2975	0.7	0.7	0.7	0.7
Physiology of haptic sensation	brain	380	123	29	228	365	155	34	176	0.7	0.7	0.2	0.8
	cortex	439	48	74	317	538	95	85	358	0.5	0.4	0.2	0.6
	neural	645	99	47	499	777	89	33	655	0.5	0.9	0.4	0.5
	sensory	869	65	98	706	869	119	69	681	0.6	0.5	0.4	0.7
	sensitivity	379	22	13	344	641	75	29	537	0.4	0.2	0.1	0.4
	threshold	166	13	19	134	601	31	15	555	0.2	0.3	0.3	0.2
	acuity	140	15	13	112	108	15	8	85	0.8	0.8	0.4	0.9
	somatosensory	434	45	95	294	532	103	100	329	0.5	0.4	0.3	0.6
	subtotal	3452	430	388	2634	4431	682	373	3376	0.5	0.5	0.3	0.5
User	human	1617	183	229	1205	877	181	51	645	1.2	0.8	1.2	1.2
	user	1568	22	154	1392	419	20	6	393	2.4	0.9	6.8	2.3
	subtotal	3185	205	383	2597	1296	201	57	1038	1.5	0.8	1.8	1.6
Haptic search	exploratory	820	73	39	708	382	51	8	323	1.4	1.2	1.3	1.4
	movement	755	50	29	676	589	55	25	509	0.8	0.8	0.3	0.9
	subtotal	1575	123	68	1384	971	106	33	832	1.0	1.0	0.5	1.1
Haptic perception characteris	affect	254	11		243	233	9		224	0.7	1.0	0.0	0.7
	feel	471	30		441	131			131	2.3	0.0	0.0	2.2
	cognition	205	57	16	132	160	39		121	0.8	1.2	0.0	0.7

tics	emotion	158	11	11	136	6			6	16.6	0.0	0.0	14.8
	subtotal	1088	109	27	952	530	48	0	482	1.3	1.9	0.0	1.3
Mode of touch	active	406	40	45	321	292	36	11	245	0.9	0.9	1.1	0.9
	passive	244	31	16	197	151	18		133	1.0	1.4	0.0	1.0
	subtotal	650	71	61	518	443	54	11	378	0.9	1.1	1.5	0.9
Total		56781	5774	5745	45262	35795	4771	1529	29495	1.0	1.0	1.0	

(1) Field of application

In the context of the field of application, the overall frequency of the appearance of the terms was the largest, while showing the increase of the frequency from the years before 2000 and after 2001 by the relative ratio of 1.4. Among them, the relative ratios of the terms ‘virtual’ and ‘interaction’ were 2.0 and 2.3, showing large changes. Such findings could be explained by the current research studies’ tendency of focusing on the application of haptic device in virtual reality and robotics using haptic stimulation. The relative ratio of the terms ‘device’ and ‘interface’ appeared in the keywords came out to be 4.1, which was two times larger than their overall frequency ratios (1.9 and 1.7, respectively). Such trend of seeing the terms ‘device’ and ‘interface’ more frequently explains the increasing number of the research studies on the development of the devices that implement virtual reality and related user interactions. Moreover, although the overall frequency of the terms with the suffix ‘tele-’ such as telemanipulation, teleoperation and telerobotics was rather lower, the relative ratio of the terms found in titles was 5.9, which tells us that there is a large increase in such research studies that focus on haptic stimulation or other related haptic feedbacks for operating devices from the distance. In cases of remote operation between users or the users and virtual objects, haptic modality has become quite important in providing feedbacks for precise manipulation as if done in physical contact. In cases of the terms ‘display’ and ‘sensor’, which play roles as the components of haptic devices, the term ‘display’ showed an increase in the appearance by the relative ratio of 1.3 while sensor decreased by the ratio of 0.6. Especially for the ‘actuator’, a type of displays, the relative ratio was shown to be 3.9. This finding is relevant to the increase of the interest in providing stimulation and emotions to the users.

(2) Haptic stimulation

The overall relative ratio of the terms related to haptic stimulation was 1.0, which shows the consistency between the years before 2000 and after 2001. However, the relative ratio of the term ‘feedback’ showed an increase by 2.3. Haptic stimulation can be divided into cutaneous and kinesthetic, and when these two terms were compared, the terms ‘force’ and ‘kinesthetic’ showed higher frequency than the terms ‘touch’ and ‘cutaneous’, whose relative ratios were 1.3 and 1.4 respectively, during the years after 2001. Such findings tell us the trend in the research is leaning toward kinesthetic sensation from cutaneous sensation. On the other hand, the terms ‘spatial’ and ‘stimulation’, which are related to stimulation and the characteristics of stimulation, were shown to appear less after the year 2001.

(3) Performance

The terms related to performance showed the relative ratio of 0.8. More specifically, the terms ‘time’ and ‘performance’, which are related to the performance improvement of providing haptic stimulation, have increased by the ratio of 1.1 while the term ‘discriminate’ for evaluating the efficiency of stimulation has decreased by 0.4. From this, we can learn that the research studies are continuously focusing on improving the effectiveness of providing information based on modality characteristics of tactile senses as the feedback information, while the interest in the discrimination of stimulation is decreasing. The research studies related to the performance have previously focused on the usability during the interaction between a user and a device and now focuses on various characteristics related to interaction, while being expected to stay in fundamental issues.

(4) User

Although the terms related to user does not necessarily focus on a specific research area, the relative ratio of the term came out to be 1.5. Particularly, the term appearing in keywords showed the relative ratio of 6.8, which suggests the increase of attention in developing technologies that are oriented toward the users. Moreover, this finding agrees strongly with the findings in the previous section of field of application, which discussed the importance of the characteristics of a user in developing haptic devices for virtual reality and robotics.

(5) Body site & physiology of haptic sensation

The terms related to body site and physiology of haptic sensation have shown the overall relative ratio as 0.7 and 0.5, respectively. Although each body site has different characteristics of the receptors and distribution, the existing studies have mainly focused on hands and fingers for the body sites. Also, the terms related to the physiological mechanisms of the tactile senses have appeared less in the articles after the year 2001. Therefore, a wider range of body sites should be considered in the research related physiological characteristics.

(6) Haptic perception characteristics

In the case of haptic perception characteristics, the overall relative ratio of the terms ‘affect’ and ‘cognition’ came out to be 1.0, while the term ‘emotion’ have shown a significant increase by the ratio of 16.7. Although the current literature lacks the research on emotion, we have noticed a positive increase since the year 2000.

2.2.2 Network analysis results

Fig. 7 shows the visualization of the results of the network analysis on the keywords. As shown in Fig. 7, the research studies related to haptic can be divided into the technology perspective related to application of haptic technology and the user perspective related to haptic perception. In these two categories, we find ‘virtual reality’ being at the center of the technology perspective whereas ‘touch’ at the center of the user perspective, and they are connected to several other different groups around them. The groups related to virtual reality include display, sensor, haptic interface, haptic feedback and haptic rendering, and they all relate to providing haptic stimulation to the users based on haptic information collected from the virtual reality environment. The groups related to touch include cortex, visual impaired, cognitive trait of objects and haptic search, which all related to the user’s process of recognizing the target.

In the groups related to cortex, many research studies have focused on analyzing the stimulation through more than one modality such as visual senses and other activated parts of the cortex by utilizing fMRI. Various fields of study on the fundamental mechanism of recognizing haptic stimulation are expected in the near future as the neural technology is rapidly being advanced.

The research fields related to vision often focus on the reaction in the brain to recognizing objects through visual and tactile senses, and the studies related to visually impaired consider various possibilities of applying haptic technology to replace the visual information with haptic feedbacks for those who are not able to see properly. In the case of 'vision', the studies are related to 'multisensory', 'fMRI', 'perception' and 'objective cognition', while studies on 'visually impaired' relate to 'braille', 'haptic mouse' and 'tactile graphics'. Moreover, the research related to visually impaired are connected to haptic perception, which is included in the haptic search group, and often focus on analyzing the process of haptic perception without being able to see.

As shown in the network of Fig. 7, 'exploratory procedure', 'exploratory movement' and 'proprioception' are categorized under the haptic search, whose center is the 'haptic perception'. This tells us the that trend of the related research often focuses on studying different senses for haptic perception and different procedures and movements of searching for an object through tactile senses.

The groups related to cognitive trait of objects include 'texture', 'vibration', 'shape' and 'roughness'. The focuses of each haptic search group vary depending on the type of cognitive trait of objects, which is connected to the types of the senses during haptic search. Moreover, 'shape', which requires both kinesthetic sensation and cutaneous sensation, is closely related to the 'haptic perception', while 'roughness', which only requires cutaneous sensation, is related to the 'tactile perception'.

The groups related to tactile display are mainly connected with the terms related to cognitive trait of objects. The terms that connect technology perspective and user perspective are only display group and cognitive trait of objects group beside from virtual reality and touch. This is due to the fact that the characteristics of a desired stimulation must be thoroughly considered in order to implement tactile displays. The architecture of a display can be more effective and efficient if the process of a person recognizing stimulation is well known beforehand.

The groups related to haptic interface often concern the characteristics necessary for the user's tactile interaction, which include 'tactile display', 'tactile sensor', 'force feedback', 'force control' and 'tactile feedback'. The tie strength for each node of 'haptic interface' shows the ratio between 'tactile display' and 'tactile sensor' as 5:3, which reveals closer relationship with display than sensor. However, this result is not necessarily caused by the frequency difference, as seen from the frequency ratio of 1:1 between display and sensor appearing in the keywords. Meanwhile, the tie strength ratio between 'force feedback' and 'tactile feedback' is 9:4, which shows closer connection with the feedbacks related to kinesthetic sensation than with those of cutaneous sensation. Moreover, 'tacton' – a type of a haptic interface – is also related to haptic interface groups and is often used in mobile devices for providing feedbacks through a belt approach of vibration.

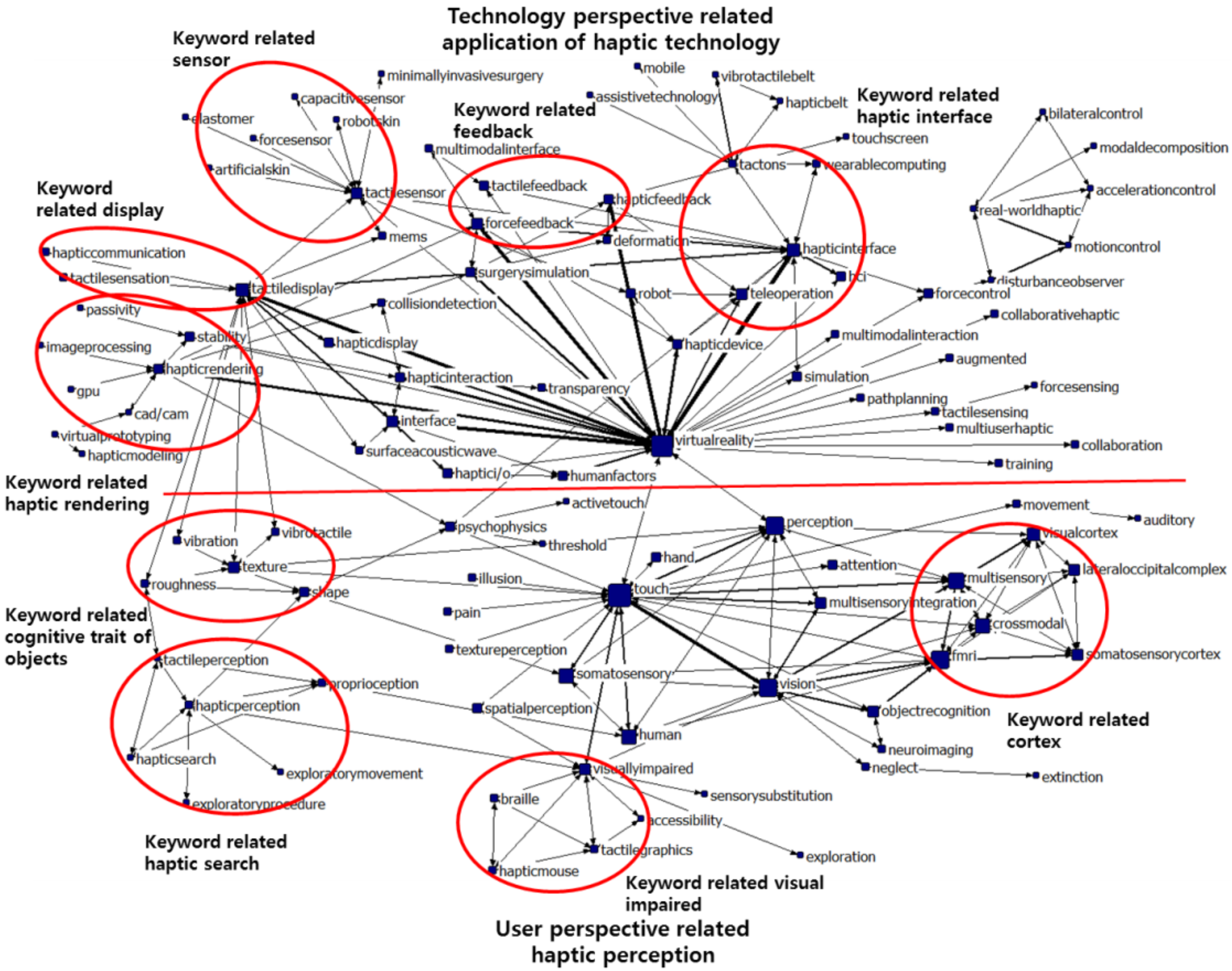


Figure 7 Visualization of network analysis results

The centrality indices are shown in Table 4. The centrality analysis was performed in terms of degree centrality, closeness centrality, betweenness centrality and eigenvector centrality. In order to compute the centrality, the ranking of each index was computed and added up to assign the scores for each term. Table 4 shows the top 25 terms with the highest scores. The result shows 14 terms related to the technology perspective and 11 terms for the user perspective; thus, the terms related to the technology perspective show higher centrality. The top two terms are ‘virtual reality’ and ‘touch’, which lie in the middle of the technology perspective and user perspective.

Although the centrality index shows a similar characteristic as the frequency ratio in the contents analysis, the terms can be analyzed in various aspects by comparing each centrality of the terms. The correlation coefficient of eigenvector centrality and betweenness centrality is 0.248, which is lower than the correlation coefficients of the other centralities, while the ranking of the terms according to eigenvector centrality and betweenness centrality showed a larger difference in the index rankings of the terms. The terms with higher betweenness centrality than eigenvector centrality are haptic device, tactile sensor, haptic display, and tactile perception, while the terms with higher rankings of eigenvector than betweenness are ‘force feedback’, ‘perception’, ‘teleoperation’, ‘interface’ and ‘vision’.

Table 4 Centrality index of keyword

No	Keyword	Degree		Eigenvec		Betweenness		Closeness	
		Value	rank	Value	rank	Value	rank	Value	rank
1	virtual reality	976	1	0.43	1	1433982.6	1	2171260	1
2	touch	543	2	0.17	3	777328.3	3	2171908	3
3	haptic interface	436	3	0.17	4	847591.4	2	2171796	2
4	tactile display	431	4	0.16	5	625137.8	5	2171984	4
5	force feedback	294	8	0.21	2	258312.2	15	2172156	5
6	perception	272	9	0.12	7	246993.2	16	2172549	11
7	haptic device	265	10	0.07	16	410433.7	9	2172484	9
8	visually impaired	247	12	0.09	11	346153.0	13	2172358	8
9	psychophysics	213	16	0.08	14	425713.5	8	2172353	7
10	tactile sensor	380	5	0.06	23	877187.9	4	2172664	14
11	haptic rendering	333	7	0.08	13	555692.8	7	2172837	21
12	teleoperation	190	18	0.11	8	146401.1	24	2172303	6
13	haptic feedback	334	6	0.07	18	557438.3	6	2173056	27
14	interface	213	15	0.14	6	150355.3	23	2172603	13
15	tactile feedback	209	17	0.09	12	245478.9	17	2172588	12
16	fmri	253	11	0.08	15	373865.3	11	2173055	26
17	human	180	22	0.06	21	145809.3	25	2172824	20
18	haptic display	179	23	0.05	30	243308.3	18	2172779	19
19	vision	228	14	0.11	9	107776.6	38	2173129	31
20	tactile perception	186	20	0.03	53	374830.4	10	2172507	10
21	texture	161	25	0.07	17	121930.8	31	2172914	23
22	hci	120	30	0.07	19	121720.3	32	2172689	15
23	haptic interaction	180	21	0.07	20	235969.4	19	2173229	37
24	haptic perception	244	13	0.03	56	362449.6	12	2172750	18
25	vibration	142	26	0.06	26	126912.9	30	2172695	17

Eigenvector centrality is an index that computes the number of ties connected to other nodes while considering the importance weight of each node. Betweenness centrality is an index that computes the number of the shortest paths between two other nodes goes through a certain node. The terms with higher eigenvector centrality than betweenness centrality are often connected with a large body of terms that have higher importance, but these terms rarely provide the connections among themselves. The terms ‘force feedback’, ‘perception’, ‘teleoperation’, ‘interface’ and ‘vision’, which have shown similar characteristics as mentioned above, have the tie strength with the terms ‘virtual reality’ and ‘touch’, which score higher importance, two times higher than the other terms. However, such terms are not located in the center of the network and thus are not connected with each of the nodes; thus, they have shown lower betweenness centrality.

The terms with higher betweenness centrality than eigenvector centrality are either connected with smaller number of the terms or with the terms having lower importance, but the terms often provide the shortest paths for the other terms. ‘Haptic device’ is one of the terms having such characteristics and was located in the center of the network, but it lacked the number of nodes connected to it and had lower tie strengths. Also, the term ‘tactile sensor’ also showed lower tie strengths among the other nodes but showed higher betweenness centrality since it was located in a position providing shortest paths between many other nodes.

There were also the terms with large differences in the rankings between closeness centrality and betweenness centrality. In such cases, the terms were considered to provide relatively lower number of shortest connections to the other nodes even though they were located closer to the most of the terms.

The terms with such characteristics are ‘haptic rendering’, ‘haptic feedback’ and ‘fMRI’, which were located in a position connecting to many other nodes but were not necessarily located in the center.

2.2.3 Comparison of analysis results

In order to view the related research areas in a broader perspective, we have taken the contents analysis and network analysis into account. The two methodologies follow an approach of analyzing unstructured data, which is advantageous in terms of providing insights about the research areas through quantitative indices. Although there exist a few differences between the two methodologies, more meaningful insights could be discovered through understanding and analyzing such differences in the process.

Since the elements that are considered in the contents analysis and network analysis cover different aspects, it may be possible to obtain more meaningful issues and insights by taking account of the both analyses together. Table 5 shows the results and the current issues obtained from the two analyses.

First, the results of the analyses on the application, both of the two analyses have shown high importance in various applications such as virtual reality and interfaces. In the contents analysis, the terms related to application fields have shown the highest percentage of the appearance frequency, among which the terms ‘virtual’ and ‘interaction’ had the highest increase ratio. In the network analysis, the terms ‘virtual reality’ and ‘interface’ have shown high centrality, which indicates an important position in the network among the terms.

Table 5 Implication by comparing of analysis results

Category	Contents analysis results	Network analysis results	Implication
Field of application	• High increase ratio for the terms virtual and interaction	• High centrality of the terms virtual reality and interface	• Increase of the interest in applying haptic technology in the fields of VR and HRI
Component of haptic system	• Increase in display while decrease in sensor • Similar overall frequency for display and sensor • Increase in actuator, as a type of display	• The groups related to tactile display often linked with the terms related to object cognitive trait – which is the only link between technology perspective and user perspective • Closer relationship between Haptic interface and sensor than with display • Closer relationship between haptic interface and force feedback than with tactile feedback	• Increase of the interest in display
Haptic stimulation	• Higher increase ratio and frequency of force and kinesthetic than those of touch and cutaneous	• The term force display not appearing in the network	• Research on force and its application of display needed
Vision	• One group for vision and blind	• Separate groups for vision and blind	• Objective analysis of relationship among research areas through network analysis
Related body site	• Lack of research on various body sites	• Hand as the only term related to perception	• More research on physiological characteristics of various body sites needed in the future
Physiology of haptic sensation	• Rapid decrease of the terms related to physiological research	• Various research on reactions of different cortex through fMRI and the characteristics of modality and stimulation	
User	• Increase of realizing the important of user-oriented research	• Appearance of the terms human and human factor	• User-oriented research on emotion related to display needed
Haptic perception characteristics	• Increase in ratio despite its lack of research before 2000	• None of direct appearance of the terms related to perception characteristics	

The issues related to display can be found in the studies on haptic stimulation and device components. Between the terms ‘display’ and ‘sensor’, ‘display’ has shown higher importance than ‘sensor’, while kinesthetic sensations than cutaneous sensations in the context of sensations. In the contents analysis, the overall frequencies for both terms came out to be similar, but the term ‘display’ has shown to appear more frequently after the year 2000 while the term ‘sensor’ has shown the opposite trend. In the network analysis, the centrality index of ‘display’ was also larger than that of ‘sensor’. Moreover, ‘display’ has shown a closer relationship with ‘haptic interface’ than ‘sensor’, as well as ‘force feedback’ than ‘tactile feedback’. In the contents analysis, there seems to have an increase in the number of studies on kinesthetic sensation. Also, while the term ‘sensor’ has appeared often with the terms ‘tactile sensor’ and ‘force sensor’, the term ‘display’ has appeared only with the term cutaneous sensation (‘tactile display’) and not with kinesthetic sensation (‘force or kinesthetic display’). This may be due to the complexity in implementation of kinesthetic sensation is higher than that of cutaneous sensation. Moreover, there are more studies related to cutaneous sensation in the context of user perspective than those related to kinesthetic sensation.

In the case of the body site and physiology of haptic sensation, the current research topics mainly focus on the fingers and the hands, while the research trend is showing a decrease in the interest of such topics on physiology of haptic sensations. However, we may expect to see more demands of the studies on the physiological characteristics of different body sites since the targets of the haptic stimulation in the fields of virtual reality and HRI can vary beside the hands. Moreover, in order to develop haptic displays for kinesthetic sensation, the current research studies must expand their interests from physiological studies on cutaneous sensation to physiological mechanisms on kinesthetic sensation.

In taking account of the increase ratio of the terms related user and haptic perception characteristics, we may also realize that the affective aspects of the users are becoming more important than before. Such trend is commonly discovered throughout the fields of HRI, including the fields of haptic (Arkin et al., 2003; Breazeal and Brooks, 2005; Kwon et al., 2007). This finding can be also regarded in relation with the display issues for the future development of haptic displays.

2.3 Research related perception of kinesthetic feedback

To analyze feeling of kinesthetic feedback, there have been various researches on force-profile such as thresholds about force and displacement of switch movement, properties of force-profile affected to switch feeling, effect of properties on feeling, and so on.

In Yang, Tan, Buttolo, Johnston, and Pizlo (2003), perceptual thresholds of feedback factor felt through manipulation of rotary-switch were measured. User perceived torque thresholds was investigated based on torque vs. travel (angular position) profiles that is being used traditionally according to switch movement.

Swindells and MacLean (2007) made the knob-model and measured information of acceleration, friction, position to capture and replay dynamics of mechanical knobs. And model's accuracy was tested through comparing real knobs with simulated test knobs made by knob-model.

Weir et al. (2004) was utilized a graphical representation technique called the "haptic profile" to define and measure haptic properties that can explain feel of switches. Feel of switches is divided into clicky, smooth, and mushy, then characteristics of haptic profile were investigated. Haptic-profile was deducted with three axles, force, position, and velocity like Fig. 8, graph projected to force-position, position-velocity, and force-velocity was used to analyze characteristics of haptic profile. Characteristics of user perceived switch-feel can be understood through Weir et al. (2004), but investigation of major factor affected on switch-feel and pattern and extent of change according to factor was lack.

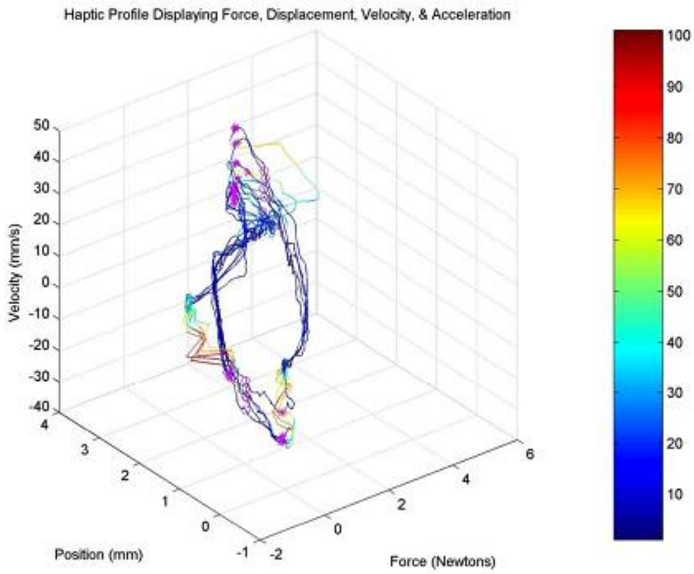


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Figure 8 Haptic profile for analyzing switch feel (adapted from Weir et al. (2004))

Research related to characteristics of force profile show that force, position, and velocity affect on user perceived switch feel and factor of force profile can explain characteristics of kinesthetic feedback.

Summary of research on affective response of kinesthetic feedback are as follows.

Swindells, MacLean, Booth, and Meitner (2007) has analyzed the change of performance of a target acquisition task and visceral emotional responses according to friction, inertia, and detent. It can be identified that position-, velocity-, and acceleration-based effects affected on user affective responses through user evaluation and bio-signal measurement on seven test knobs. But this study has limitation on systematic analysis because independent variable was just one, and level of variable was two. And there were limitation that user evaluation was conducted based on valence, not various affective elements though bio-signal such as EMG, skin conductance was measured, so this study can't analyze which affective element and how much affect on final affective satisfaction.

Wellings and his company investigated about effect of multisensory integration such as visual, auditory, and haptic, etc., on hedonic qualities on user perception of switches in automotive.

Wellings, Williams, and Pitts (2008) and Wellings, Williams, and Tennant (2010) looked at user perception of automotive switches from a holistic perspective. Perceived visual, auditory, and haptic stimulation, when users see and manipulate automotive switches, was evaluated, and then factor analysis is conducted to identify how many and what major factors are deducted. These researches conducted evaluation on stimulation perceived by various modalities as well as haptic stimulation of switch, and deducted the major factors of switch-feel perception. As a results, feeling or image integrated various modalities was deducted as major factor rather than being integrated each modality such as overall image of product, build quality related to precise or finish, and clickiness related to feeling and sound occurred when switch click.

Wellings, Pitts, and Williams (2012) has a different research scope from previous two studies, investigated effect of non-visual aesthetic qualities on experience of interaction except factor related to visual stimulation. And effect of major factors deducted from regression analysis on likeness was analyzed. As a results, four factor, unrefined loudness, positivity/precision, stiffness, and looseness/rattling, were deducted as major factors and positivity/precision and unrefined loudness is affected on likeness.

But systematic diversification of specific product properties was difficult in Wellings and his company’s studies because of evaluation of real product to increase the ecological validity. And number of sample was not enough to conduct systematic analysis. Effect of product properties on affective element couldn’t be identified because of these limitations. These study conducted analysis of effect of aesthetic qualities on the interaction experience and user perception, but relationship between aesthetic qualities and design variable needed to develop product couldn’t be analyzed.

Ha, Kim, Park, Jun, and Rho (2009) and Kim, Han, Shin, and Park (2008) aimed to develop haptic prototyping system to provide hands-on experiences, developed virtual prototype and conducted user test. Virtual prototype provided experience like using and manipulating real product to user using multimodal display utilized visual, aural and haptic modalities. Design variable of haptic display were torque profile (amount, direction, velocity, and acceleration), dial notch properties (number, position, and shape), physical dial knobs properties (shapes, materials, and weights), and this study shown that different of design variable give different sensory and affective feelings through user test.

Lee, Kwon, and Ahn (2011) conducted experiment to understand characteristics of the rotary switch needed to control emotion provided through rotary switch. This study identified the characteristics of switch manipulation according to control variable and measured toque occurred according to magnitude and width. This is expected to utilize generating intended control feel and quantification of control feel.

Table 6 Previous studies on kinesthetic feedback

Title	Author	Objective	Material	Design variable	Affective variable
Characterizing the experience of interaction: an evaluation of automotive rotary dials	Wellings et al. (2012)	empirically examines how non-visual aesthetic qualities affect the interaction experience with automotive rotary dials	automotive rotary dials		Spacing of notches Rattling sound Looseness, Effort Solidity, Positive Smoothness Clunky, Precision Clicky, Friction Notchy
Customer perception of switch-feel in luxury sports utility vehicles	Wellings et al. (2008)	holistic customer research carried out to investigate how the haptics of switches in luxury sports utility vehicles (SUVs) are perceived by customers	automotive push switch		Heavy–light Imprecise–precise Cheap–expensive Noisy–quiet Refined–unrefined Clicky–smooth Pleasant–annoying Loose–tight Flimsy–solid Interesting–dull Old fashioned–modern
Capturing the Dynamics of Mechanical Knobs	Swindells and MacLean (2007)	a novel experimental apparatus for the capture and replay of physical controls (mechanical knobs), as well as a set of acquired models and a design discussion related to the characterization approach taken here	Mechanical Knobs	detents, friction, inertia	
Designing for Feel: Contrasts between Human and Automated Parametric Capture of Knob Physics	Swindells, MacLean, and Booth (2009)	to examine a crucial aspect of a tool intended to support designing for feel: the ability of an objective physical-model	Mechanical Knobs	detents, friction, inertia	

The Role of Prototyping Tools for Haptic Behavior Design	Swindells, Maksakov, MacLean, and Chung (2006)	to introduce a custom haptic icon prototyper that includes novel interaction features, and use the lessons learnt from its development plus our experiences with a variety of haptic devices to present and argue high-level design choices for such prototyping tools in general	Mechanical Knobs	Position, Velocity, Acceleration	
Virtual prototyping of a car turn-signal switch using haptic feedback	Erdelyi and Talaba (2010)	to develop a prototyping method by which the designer can test the haptic behavior of a computer model of a switch using a haptic system	car turn-signal switch	force profile	
Haptic Models of an Automotive Turn-Signal Switch: Identification and Playback Results	Colton and Hollerbach (2007)	to develop a method to obtain haptic models of buttons and switches from experimental data.	turn-signal switch	mass, damping, stiffness, offset force	the realism of models
Haptical feeling of rotary switches	Reisinger, Wild, Mauter, and Bubb (2006)	to describes the common problems of the torque characteristics, an alternative description theory and their evaluation with tests in detail	rotary switches		
Virtual prototyping enhanced by a haptic interface	Ha et al. (2009)	to present a haptic prototyping system with a motor-actuated dial knob which is designed to add tactile/haptic feedback to conventional virtual prototyping		Torque profile (amount, direction, velocity, and acceleration) of the dial along the rotational path. Number, position, and shape of the dial notch. Physical dial knobs of different shapes, materials, and weights.	strong-weak, refined-coarse, crisp-dull

The Haptic Profile: Capturing the Feel of Switches	Weir et al. (2004)	to collect haptic data and display it in a useful and intuitive manner.	on/off type and momentary type switch	Haptic Profile	clicky, smooth, mushy
Thresholds for Dynamic Changes in a Rotary Switch	Yang et al. (2003)	to evaluate the perceptual thresholds for dynamic changes in a rotary switch	rotary switch		
Exploring Affective Design for Physical Controls	Swindells et al. (2007)	to understand how the choice of acceleration-, velocity-, and position-dependent force feedback renderings for an active physical control influences user performance		friction, inertia, and detent	valence and arousal

Chapter 3. Affective evaluation experiment – focused on real product

3.1 Overview

We have performed an evaluation of emotions related to kinesthetic sensations and an analysis of the characteristics in perceiving kinesthetic sensations with respect to the characteristics of the products. The movements of a hand during the manipulation of a target object were matched with 6 exploratory procedures of exploring objects in active haptic mode, and the experiment was modeled to investigate the characteristics of a user's perception with respect to each element (Lederman & Klatzky, 1987). Based on force-displacement graph with respect to the movement of a target object, it was also determined whether the stimulation related to object manipulation has any relationship with either movement or force. Fig. 9 shows the types of stimulation used in three experiments, the exploration procedure, image of the target object and the force-displacement graph.

In order to determine the characteristics of perception with respect to haptic feedback received from various products, an experiment was conducted to evaluate the products that have different characteristics of stimulation. The products considered in the experiment have been categorized into the elements related to force and movement that affect kinesthetic sensations based on the standards proposed in Chapter 2.1. As discussed in Chapter 2.1, the products have been observed to have three different types of characteristics: stimulation related to force elements, stimulation related to movement elements, and stimulation related to both of the force and movement elements. In addition, the movement of manipulating each product has been matched to the 6 exploratory procedures (Lederman & Klatzky, 1987) and the complex matrix (Fig. 9). Finally, the three experiments have been analyzed to determine the types of affective elements perceived from haptic feedback with respect to different characteristics of stimulation.

This chapter discusses different characteristics of haptic feedback used in each experiment in terms of force profile and explains the relationship of each element with the standards proposed in Chapter 2.1. The process of the experiments is also explained, and the affective vocabularies derived from considering the characteristic of each stimulation are discussed. In the analysis of each experiment, the main elements that affect the affective perception are analyzed to determine the influence level of the affective elements on the satisfaction of the products.

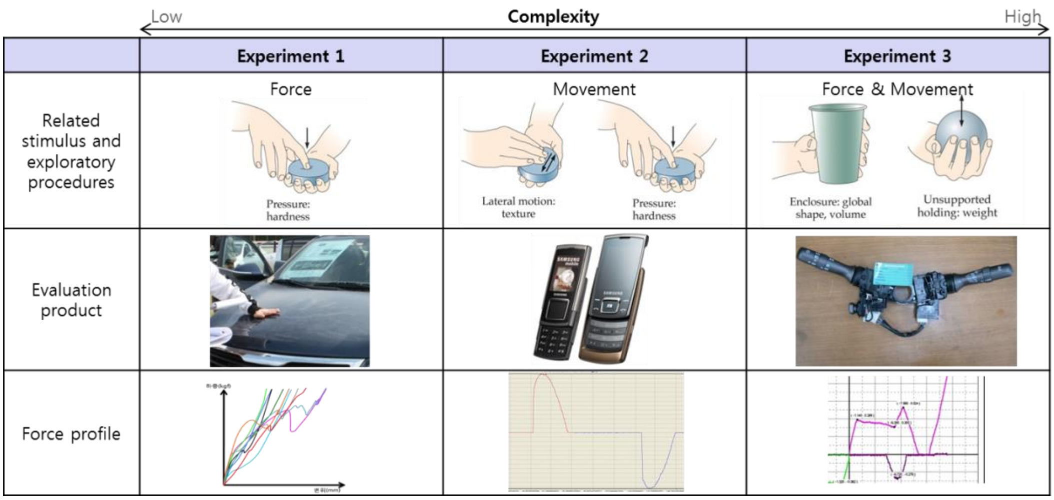


Figure 9 Overview of evaluation experiment of existing products

3.2 Experiment 1 : Automobile outside panel

3.2.1 Participants and Procedure

The experiment had a total of 54 males (25 males in 20's, 17 in 30's, 8 in 40's and 4 in 50's) to evaluate 63 different types of outside panels in seven different parts (hood, fender, front door, rear door, quarter panel, trunk lid, and roof) of 9 different kinds of automobiles. The experiment first began with the explanation of the purpose and overall process of the study. The affective evaluation was performed by randomly pressing 7 different parts of each vehicle that were labeled prior to the experiment. Experiment environments is shown in Fig. 10.

Figure 10 Experiment environments

The indices of evaluation were selected as "satisfaction," "hardness," "consistency," and "thickness," which are related to the affective perception that occur when pressing the outside panels, and each index was evaluated according to the 7-points SD scale. The details of affective variables used in the evaluation are explained in Table 7.

Table 7 Definition of affective variables in experiment 1

Affective variables	Definition
Satisfaction	Degree of satisfaction in terms of the automobile outside panel's stiffness when pressing it
Hardness	Degree of how much impact the outside panel can take when pressing it
Consistency	Degree of consistency in deformation of the automobile outside panel when pressing it
Thickness	Degree of how thick the automobile outside panel feels when pressing it

3.2.2 Materials

Experiment 1 has evaluated the senses related to the feedback received from pressing the outside panels of an automobile (Rhiu, Ryu, Jin, & Yun, 2011). The motion of pressing the outside panels with some force can be related to the pressure among the exploratory procedures. Depending on the properties of the outside panels, the slope of linear degrees, the sections where canning occurs, their linear degrees and the emotions perceived by the users may vary. In order to evaluate the affective perception of a user with respect to the pattern changes of force, different outside panels having different force patterns upon pressure have been used in the experiment as shown in Fig. 11.

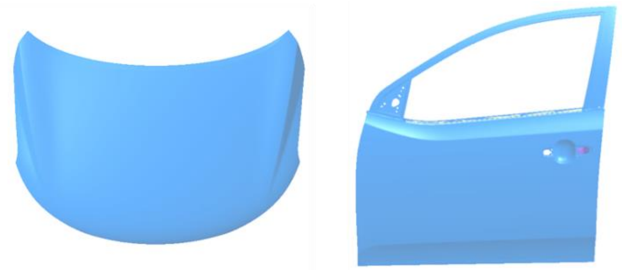


Figure 11 Outside panel

According to the force profile, the movement of the outside panels caused by pressure is no longer than 1 cm while having the force changes of 1~3 kgf when canning occurs as shown in Fig. 12, which indicates that they are more related to the force elements than the movement elements.

Force profile show that stress-strain curve have slope of force and displacement and decrease of the curve at a point (called canning). Slope of curve (displacement according force) is utilized to analyze relationship between elements of force profile and satisfaction.

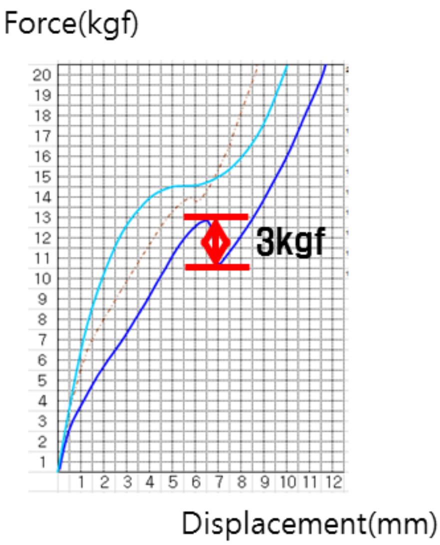


Figure 12 Force profile of experiment 1

3.2.3 Data analysis

Statistical analysis between affective element and satisfaction, satisfaction and elements of force profile is conducted to execute modeling of relationship between stiffness of outside panel and satisfaction. Through the factor analysis and correlation analysis, relationship between affective elements was checked. The relationship between the satisfaction score and affective elements was analyzed through the regression analysis, and the main affective elements were determined by affective modeling. The data analysis was performed after the normalization to remove the differences cause by user bias such as the highest and lowest scores, mean and variance. The normalization was computed by the equation (X – mean) / variance after computing the mean and the standard deviation of the evaluated scores.

3.2.4 Results

As a results of correlation analysis, every affective element have strong positive correlation (correlation coefficients among affective element are 0.74~0.79).

Table 8 Results of correlation analysis about experiment 1

	hardness	consistency	thickness	satisfaction
hardness	1	.791	.765	.746
consistency	.791	1	.734	.765
thickness	.765	.734	1	.749
satisfaction	.746	.765	.749	1

The result of factor analysis has shown that one element was explaining the data variance by 84.3%, and three different affective elements were grouped into one factor. All three elements have shown to have factor loadings higher than 0.9. As a result of factor analysis, one factor is extracted about affective element related to satisfaction of outside panel. It is thought that each affective element is related force through characteristics of force profile.

Table 9 Results of factor analysis about experiment 1

Affective vocabulary	Factor loading
	Factor 1(84.3%)
hardness	.929
consistency	.917
thickness	.907

From the result of regression analysis, the stepwise method has been used as the method of selecting variables, and all three affective elements were entered (R^2 = 0.676). Consistency has shown the highest influence level of 0.358 on the satisfaction, followed by thickness having 0.319 and hardness 0.219.

Table 10 Results of regression analysis about experiment 1

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.020	.009		2.169	.030
consistency	.320	.015	.358	21.167	.000
thickness	.319	.016	.319	19.855	.000
hardness	.215	.018	.219	12.285	.000

Slope of force profile is measured and conducted regression analysis to analyze relationship between affective satisfaction and elements of force profile. The result of regression analysis between satisfaction and slope of curve show that slope of curve affect on satisfaction (R^2 = 0.403). As slope of curve increase, thickness, hardness increase, then this affects satisfaction.

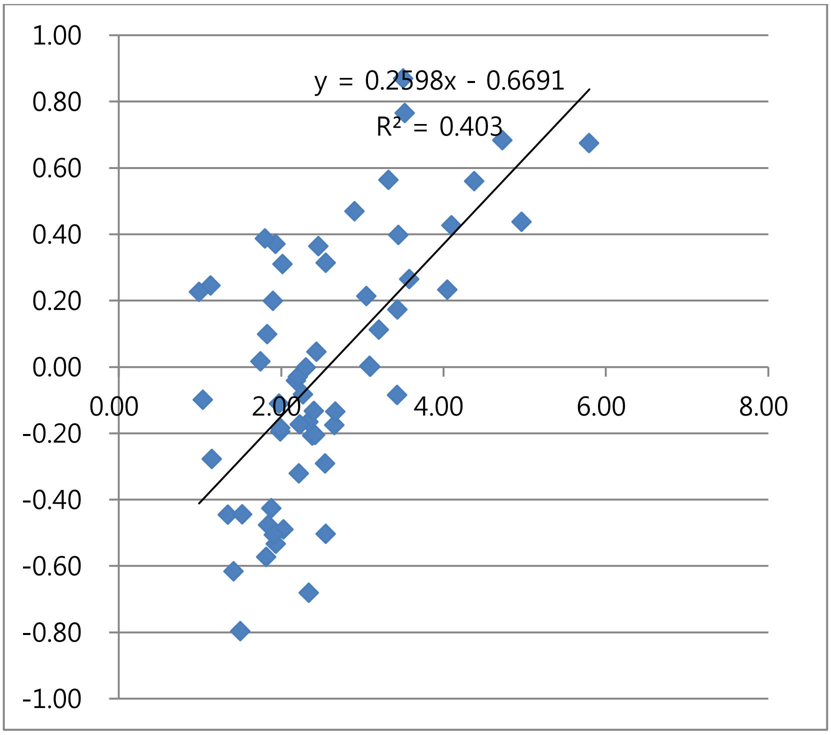


Figure 13 Scatter plot of slope of force profile and satisfaction

Force feedback evaluated in experiment 1 has simple form and not many related factor, so it is difficult to divide user perceived emotion occurred when outside panel is moved into a number of factor. Every affective element has strong positive correlation with satisfaction (correlation coefficients is more than 0.75), so there is no great difference between evaluating one factor integrated and various factor. And impact on satisfaction is not great difference according to affective element.

Satisfaction can be explained by tilt of force profile curve. Affective response on outside panel can be explained by some factor deducted from force profile unsophisticatedly because complexity of stimulus related to outside panel is not high.

3.3 Experiment 2 : Slide phone

3.3.1 Participants

The experiment was done by a total of 40 participants of having 10 males and 10 females in 20's and 10 males and 10 females in 50's. 38 of the participants had their right hands as the most skilled hand, while one of them having the left hand and another having both hands as the most skilled hand. Likewise, 31 of them have shown to use their right hands for mobile phones, and 6 of them used with the left hand and 3 of them with both hands to use the mobile phones. 29 of the participants had experiences with the slide phones for an average of 16.3 months. Table 11 shows the summary of the information of the participants.

Table 11 Characteristics of participants

Description	Category	Count	% of Total
age	21–30	20	50.0%
	51–60	20	50.0%
sex	Male	20	50.0%
	Female	20	50.0%
Preferred hand	Right	38	95.0%
	Left	1	2.5%
	both	1	2.5%
Experience with slide phones	Yes	29	72.5%
	No	11	27.5%
Total		40	100.0%

3.3.2 Materials

Experiment 2 has performed an evaluation of haptic feedback received from the moving part of the upper case reacting to a certain amount of force exerted by the spring (Bahn, Jung, Song, Kwon, & Yun, 2010). The movement of the upper case along with the force exerted on the upper case can be related to pressure and lateral motion among the exploratory procedures. The feedback received from the upper case of a mobile phone as it slides up is affected by the reaction force needed to slide up the upper case, the velocity with respect to the friction and the pattern changes of the reaction force. In order to evaluate the affective perception of a user according to the pattern changes of force, the experiment was performed with 25 different types of slide phones that have different amount of reaction force and force pattern changes with respect to the motion of sliding. Fig. 14 shows the images of the products.

Figure 14 Experiment samples

According to the force profile, there is no change in force approximately after 260 gf and after the upper case has sled up about 30 mm. This observation of having the force applied to the upper case no greater than 260 gf while the movement being approximately 30 mm tells us that they are more related to the movement elements than to the force elements.

Design variables used to analysis are deducted from force profile appeared when top of slide phone is moved, change of displacement and force in force profile that utilized to analyze perception of movement and force in literature review. Force profile has asymmetric sine wave form that force increase to peak rapidly, and then decrease slowly. Design variables are selected peak, dp1, dp2, and details of elements of force profile used in analysis are explained in Table 12.

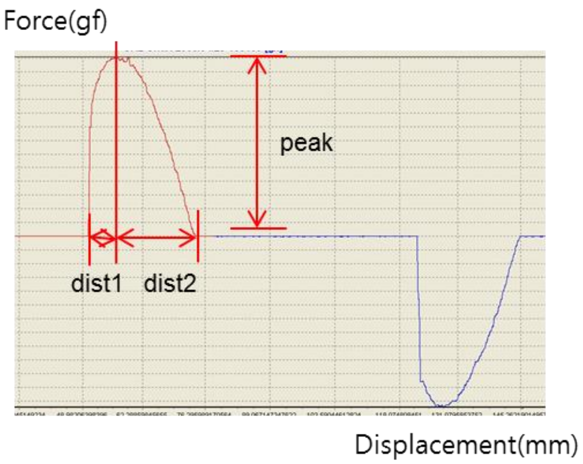


Figure 15 Force profile of experiment 2

Table 12 Definition of design variable

Design variable	Definition
peak	Maximum force occurred when upper body is moving
dist1	Distance between start point and peak
dist2	Distance between peak and end point

3.3.3 Procedure

First, the participants were briefly explained with the purpose, the subject of study and the affective elements and were asked to provide their personal information. The participants were then blindfolded and began to freely play around with various phones and feel the differences among them. In order to remove possible influence from the outside elements, the participants were asked to hold the phones inside a box and evaluate the feelings of sliding them up. Fig. 16 shows an image of the experiment.

Figure 16 Experiment environments

The affective elements that were evaluated by the users are consistency, smoothness, solidity, sleekness, liltingness and satisfaction. Satisfaction was evaluated under 100-point scale, and the rest of the elements were evaluated under 7-point Likert scale.

Table 13 Definition of affective variables in experiment 2

Affective variables	Definition
Satisfaction	Satisfaction based on feeling of sliding up a phone
Consistency	Subjective opinion on the consistency of sliding up a phone
Smoothness	Subjective opinion on the smoothness or roughness of sliding up a phone
Solidity	Subjective opinion on the hardness or looseness of sliding up a phone
Sleekness	Subjective opinion on the smoothness or roughness of sliding up a phone
Liltingness	Subjective opinion on the lightness or heaviness of sliding up a phone

3.3.4 Data analysis

In experiment 2 correlation analysis, factor analysis and regression analysis is used to analysis and data analysis was performed after the normalization of evaluation data in common with experiment 1. Quantification I analysis is utilized to analyze relationship between satisfaction and elements of force profile unlike experiment 1 because relationship between satisfaction and elements of force profile has not linearity.

We investigate descriptive statistic of affective element according to level of force profile elements and divide into 3~4 range that has similar trend or score to utilize quantification I analysis method. Then effect of each range on affective element is analyzed through quantification I analysis method.

3.3.5 Results

Results of correlation analysis between affective elements are like Table 14.

Every affective element has strong positive correlation (correlation coefficients are more than 0.35). Elasticity have most positive correlation with satisfaction (correlation coefficient is 0.54). Solidity has low correlation coefficients with rest of affective element, it means that solidity has different characteristics with rest of affective element. Smoothness, sleekness, and elasticity have strong positive correlation (correlation coefficients among smoothness, sleekness, and elasticity are more than 0.6).

Table 14 Results of correlation analysis about experiment 1

	Consis-tency	Smooth-ness	Solidity	Sleek-ness	Elasti-city	Satisfac-tion
Consis-tency	1	.594	.355	.573	.508	.456
Smooth-ness	.594	1	.240	.612	.622	.486
Solidity	.355	.240	1	.299	.268	.384
Sleek-ness	.573	.612	.299	1	.604	.477
Elasti-city	.508	.622	.268	.604	1	.540
Satisfac-tion	.456	.486	.384	.477	.540	1

The factor analysis has shown that five affective elements could be grouped by one factor with the data variance of 54.4%. Except solidity, which had a factor loading of 0.430, the rest of five elements had factor loadings higher than 0.75. As a result of factor analysis, one factor is extracted about affective element related to control feeling of slide phone although solidity has a little different with other affective element. It is thought that each affective element is related movement through characteristics of force profile.

Table 15 Results of factor analysis about experiment 2

Affective vocabulary	Factor loading Factor 1(54.4%)
Sleekness	.825
Smoothness	.801
Elasticity	.784
Consistency	.775
Solidity	.430

The result of regression analysis has shown that the stepwise method was used for the variable selection method, and the five elements were all entered ($R^2 = 0.558$). Sleekness has shown the highest influence level of 0.297 on satisfaction, followed by solidity of 0.237, smoothness of 0.2251, elasticity of 0.167 and consistency of 0.121 in order. Solidity has low correlation coefficients with satisfaction, but most effect on satisfaction next to sleekness in regression analysis result. This resulted from correlation coefficients that between other affective elements is high, but between other affective element and solidity is low. Because sleekness in affective element that correlation coefficients between each other are high explain much of satisfaction, then explanation portion of other affective elements that correlation coefficients between each other are high become smaller.

Table 16 Results of regression analysis about experiment 2

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.226	.050	.225	4.556	.000
Sleekness	.335	.043	.297	7.708	.000

Solidity	.218	.044	.237	5.017	.000
Elasticity	.169	.047	.167	3.615	.000
Consistency	.124	.050	.121	2.473	.014
Smoothness	.226	.050	.225	4.556	.000

Table 17 and 18 shows partial correlation coefficient (R) of each element of force profile and partial regression coefficient of each level of force profile elements that resulted from quantification I analysis method. R^2, indicates how well elements of force profile explain affective element, have high value, above 0.25, in every affective elements except solidity. Satisfaction and sleekness explained well by design variable (R^2 is 0.34 and 0.36) Partial correlation coefficient of dist1, effect of force profile elements on affective element, has most value in case of almost affective element. Dist1 has most effect on smoothness, sleekness, and elasticity (Partial correlation coefficient is more than 0.3). Satisfaction and consistency is effected by elements of force profile in order of dist1, dist2, and peak. But solidity that has low correlation coefficients with other affective element consistency is affected by elements of force profile in order of dist2, peak, dist1, dist1 has least effect, uniquely.

Change pattern of affective element according to level of variable can be analyzed through partial correlation coefficient, effect of force profile elements on affective element. Solidity has different change pattern in comparison of other affective elements. Level 2 has most effect on solidity in case of peak and the more level of variable is far from level 2, the more positive effect is small. Solidity has not consistent pattern affected by level of variable. As dist1 increase, positive effect of dist1on solidity increase, but other effect on affective element has not consistent pattern. Level 2 of dist1 has most positive effect on smoothness and elasticity. Level 3 of dist1 has most negative effect on other affective element, and the more level of force profile elements is far from level 3, the more negative effect is small.

Table 17 Partial correlation coefficient (R) of each force profile elements

	Satisfaction (R^2= 0.34)	Consistency (R^2= 0.28)	Smoothness (R^2= 0.29)	Solidity (R^2=0.17)	Sleekness (R^2=0.36)	Elasticity (R^2=0.25)
peak	0.13	0.10	0.27	0.22	0.13	0.14
dist1	0.23	0.18	0.34	0.20	0.31	0.32
dist2	0.18	0.17	0.17	0.32	0.12	0.07

Table 18 Partial regression coefficient of each level of force profile elements

Design variable	Level	Satisfac-tion	Consistency	Smooth-ness	Solidity	Sleekness	Elasticity
peak	1	0.04	-0.17	-0.10	0.22	0.02	0.07
	2	-0.04	0.11	0.40	-0.47	0.06	0.25
	3	0.02	-0.05	-0.32	0.34	-0.06	-0.23
	4	-0.45	-0.18	-0.22	-0.26	-0.31	0.12
dist1	1	-0.07	0.23	0.97	-0.83	0.25	0.57
	2	-0.60	-0.59	-1.22	0.35	-1.01	-1.21
	3	0.26	0.10	-0.03	0.28	0.25	0.17
	4	-0.09	-0.34	-1.16	0.97	0.09	-0.97
dist2	1	0.22	0.28	-0.10	0.32	0.17	0.03
	2	0.02	0.09	0.30	-0.33	-0.07	0.19
	3	-0.24	-0.36	-0.20	0.01	-0.10	-0.22
	4	0.57	0.40	-0.60	1.20	0.30	-0.21

Change pattern of solidity according to level of variable is different from other affective element, also. Through one factor is deducted from five affective elements as a factor analysis result, solidity can be explained another factor. This is resulted from feedback used in experiment 2 has strong relationship with movement but has some factor related with force.

3.4 Experiment 3 : Multi-function switch

3.4.1 Participants and material

Experiment 3 was performed to evaluate the haptic feedback received from twisting a bar whose end is fixed with a spring that exerts a certain amount of force on to a ball while rolling over a slanted surface. The motion involves the rotation of a bar by force and thus is related to enclosure and unsupported holding among the exploratory procedures. The experiment consisted of a total of 101 participants (mean age of 27.8) with 78 males and 23 females, and they have performed the experiment with 16 types of multifunction switch. Fig. 17 shows the image of the products.

Figure 17 Experiment samples

The force profile shows that there are two force changes with the force difference of 0.2 kgf during the rotation of the bar by 80° at the fixed end point. The first force change requires 0.4 kgf, and the next change happens with additional 0.2 kgf. Since the total angle of rotation was shown to be 80°, the feedback may seem to relate with both of the force elements and movement elements.

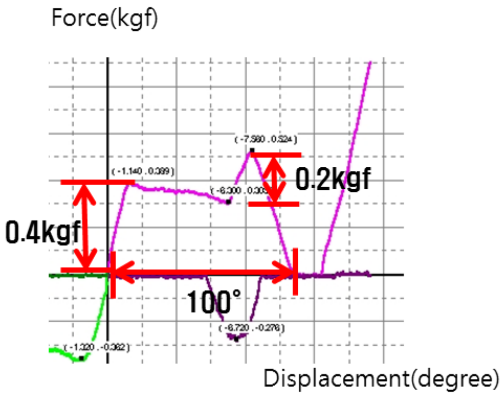


Figure 18 Force profile of experiment 3

3.4.2 Procedure

The indices of evaluating the user's affective response during the movement of the bar were selected as satisfaction, smoothness, sense of unity, perspicuity and heaviness, and each index was evaluated under the 7-point Likert scale.

3.4.3 Data analysis

In experiment 3 correlation analysis, factor analysis and regression analysis is used to analysis and data analysis was performed after the normalization of evaluation data in common with experiment 1. Statistical analysis of relationship between affective elements and elements of force profile has limitation because force profile can't be explained one or two factor and user perceived emotion is affected by various factor. In this study, elements of force profile affected on affective element are analyzed and summarized through scatter plot of affective element and factor deducted form force profile.

Factor related to degree and height is selected from force profile as design variables used to analyze, details are as follow. Force profile of multi-function switch is like Fig. 19. Switch pass two detent and section changing slope of force profile appear three times. Points that change the slope is assigned 1p, 2p, and 3p, rotation degree and height to each point is selected as design variables. Total eight variables, rotation degree and height between 0-1p, 1p-2p, 2p-3p, and of total, are utilized to analyze.

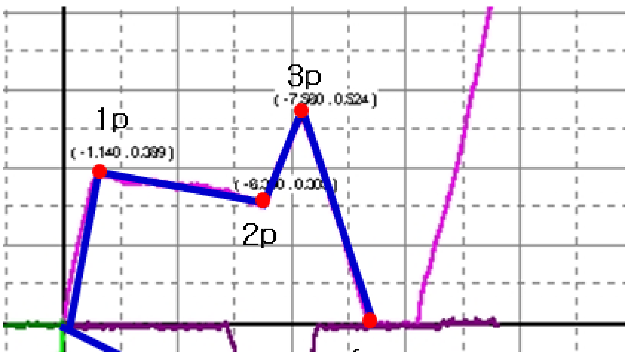


Figure 19 Point needed to define design variable

3.4.4 Results

Results of correlation analysis between affective elements are like Table 19.

As results of correlation analysis, correlation coefficients have various values in contrast with experiment 1 and 2. Smoothness has no correlation with perspicuity (correlation coefficient is 0.07) and has strong negative correlation with heaviness (correlation coefficient is -0.37). This result is related with factor analysis result that two factor is extracted. Satisfaction has strong positive correlation with affective element except heaviness (correlation coefficients are more than 0.34).

Table 19 Results of correlation analysis about experiment 3

	Smooth-ness	Sense of unity	Perspicuity	Heavi-ness	Satisfaction
Smooth-ness	1	.367	.069	-.371	.603
Sense of unity	.367	1	.199	.006	.484
Perspicuity	.069	.199	1	.165	.340
Heaviness	-.371	.006	.165	1	-.166
Satisfaction	.603	.484	.340	-.166	1

From the result of factor analysis, two elements have shown to explain 70.7% of data variance, and the four affective elements were observed to be grouped into two factors. All of the four affective elements had factor loadings higher than 0.65 for both Factor 1 and Factor 2. Smoothness and sense of unity were grouped into factor 1 while heaviness and perspicuity into factor 2 similar to correlation analysis. Factor of user perceived affective elements are more complicated contrary to experiment 1 and 2 because of complexity of force profile. Each factor can be said to be related with force and movement.

Table 20 Results of factor analysis about experiment 3

	Factor loading	
	Factor 1(38.2%)	Factor 2(31.4%)
Smoothness	**.867**	-.111
Sense of unity	**.669**	.457
Heaviness	.197	**.765**
Perspicuity	-.539	**.669**

The result of regression analysis have shown that the stepwise method was used as the method of selecting variables, and all four elements have entered (R^2 = 0.431). The effect of smoothness on satisfaction was the highest with the score of 0.430, followed by perspicuity with 0.277, sense of unity with 0.227 and heaviness with -0.106. Every affective element except heaviness has positive effect on affective element. Users prefer feedback that move smoothly and confirm change of function easily and clearly to thing that needs much power to manipulation.

Table 21 Results of regression analysis about experiment 3

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.076	.034		-2.262	.024
Smoothness	.401	.033	.430	12.270	.000
Perspicuity	.296	.033	.277	8.892	.000
Sense of unity	.240	.034	.227	7.043	.000
Heaviness	-.114	.037	-.106	-3.121	.002

Relationship analysis between affective element and elements of force profile is conducted about affective element included in two factors that has more effect on satisfaction through result of regression analysis. Smoothness in factor 1, perspicuity in factor 2 and satisfaction that perceived through integrating affective element is analyzed.

Scatter plot of total height and smoothness, perspicuity, satisfaction is like Fig. 20, 21, and 22. Change pattern of smoothness, perspicuity, and satisfaction according total height is shown similar trend. Smoothness, perspicuity, and satisfaction gets lower as total height get bigger. R^2 is 0.54, 0.47, and 0.24 in the same order as satisfaction, perspicuity, and smoothness.

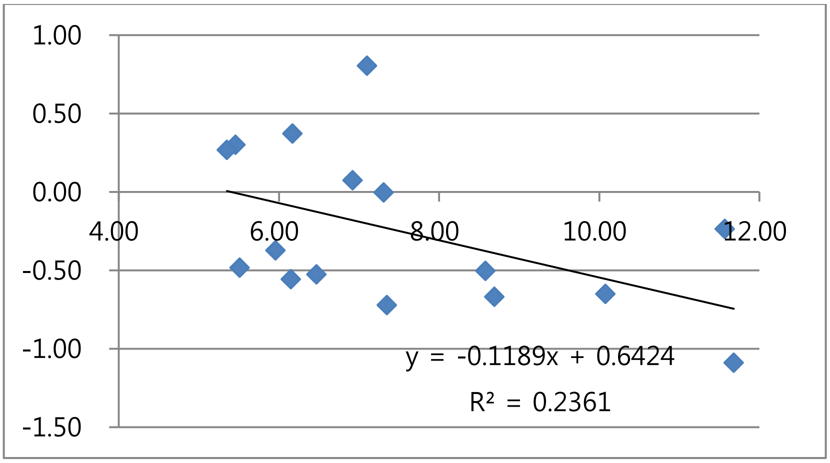


Figure 20 Scatter plot of total height and smoothness

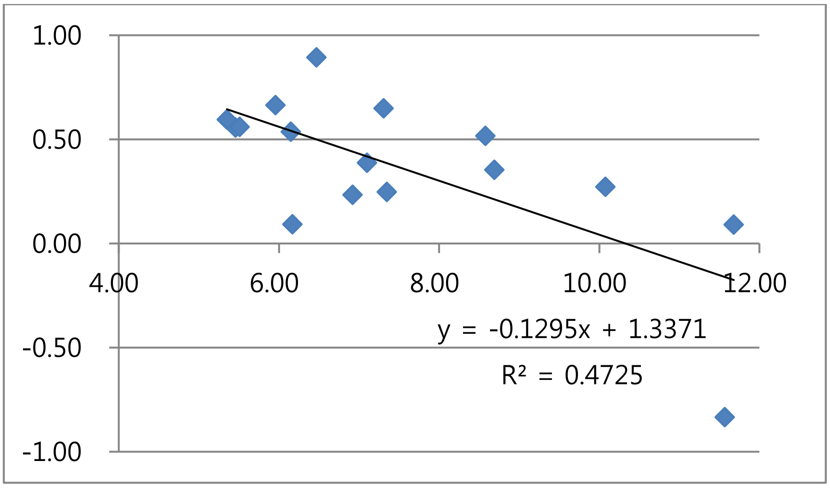


Figure 21 Scatter plot of total height and perspicuity

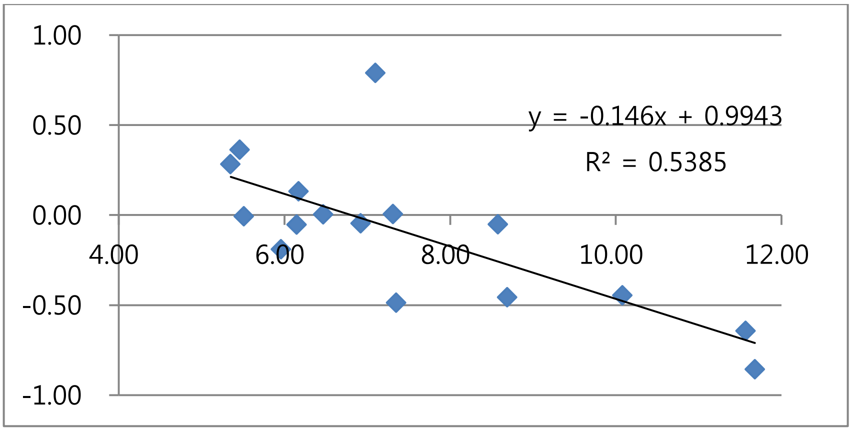


Figure 22 Scatter plot of total height and satisfaction

Scatter plot of 0-1p degree and smoothness, satisfaction is like Fig. 23 and 24. Change pattern of smoothness and satisfaction according to 0-1p degree is shown different trend. Smoothness gets lower as 0-1p degree get bigger, but satisfaction get higher.

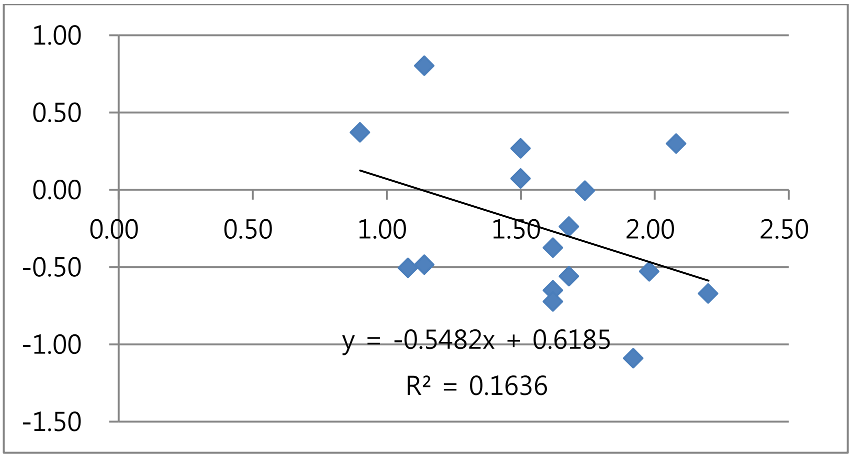


Figure 23 Scatter plot of 0-1p degree and smoothness

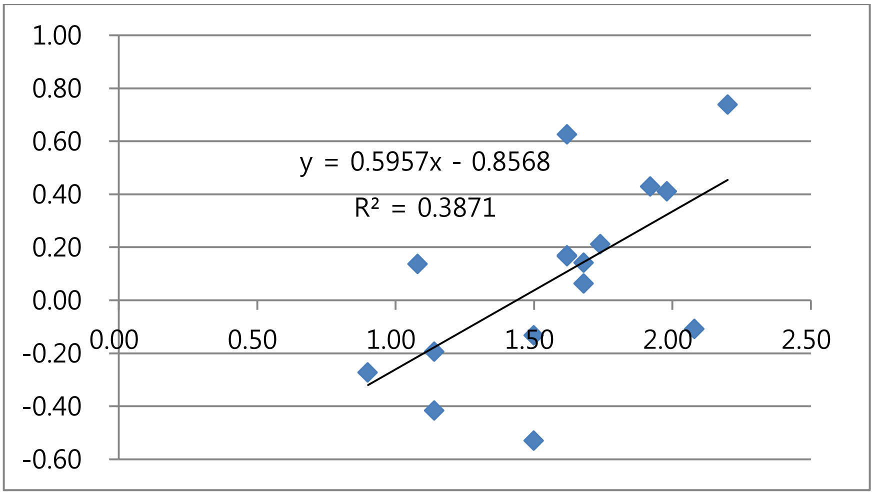


Figure 24 Scatter plot of 0-1p degree and satisfaction

Scatter plot of 2p-3p degree and perspicuity, satisfaction is like Fig. 25 and 26. Perspicuity and satisfaction get lower as 2p-3p degree get bigger. R^2 is 0.22, 0.16 in the same order as perspicuity, satisfaction.

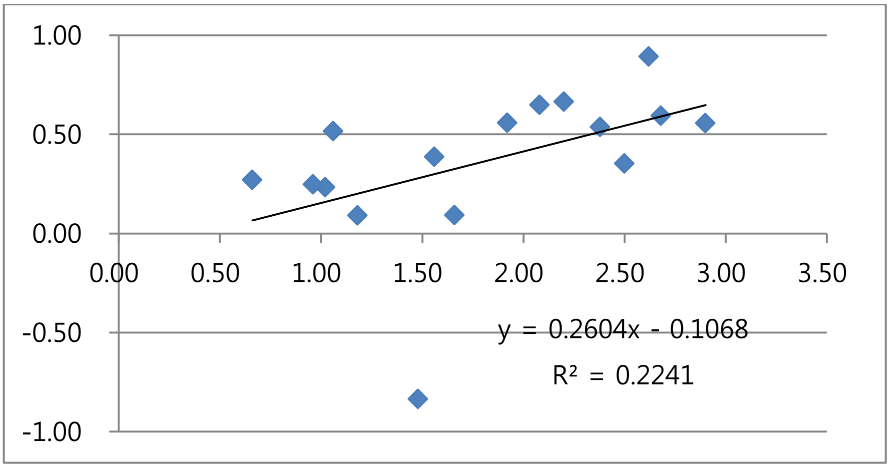


Figure 25 Scatter plot of 2p-3p degree and perspicuity

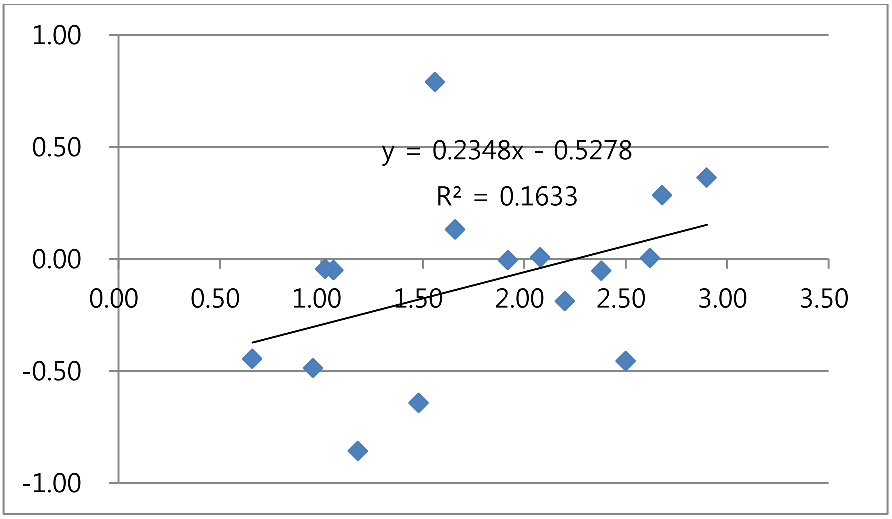


Figure 26 Scatter plot of 2p-3p degree and satisfaction

Scatter plot of 0-1p height and smoothness, perspicuity, satisfaction is like Fig. 27, 28, and 29. Change pattern of affective element according to 0-1p height is shown similar trend. Smoothness, perspicuity, and satisfaction get lower as 0-1p degree get bigger. R^2 is 0.49, 0.31, and 0.31 in the same order as satisfaction, smoothness, and perspicuity.

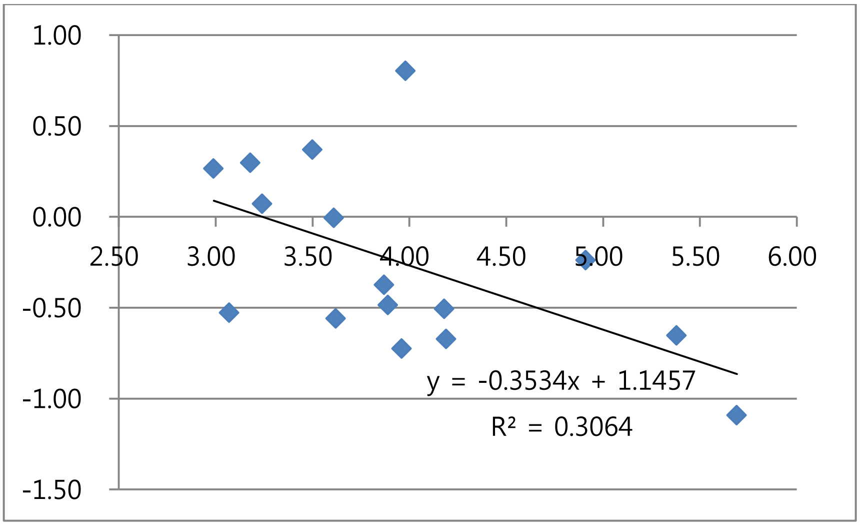


Figure 27 Scatter plot of 0-1p height and smoothness

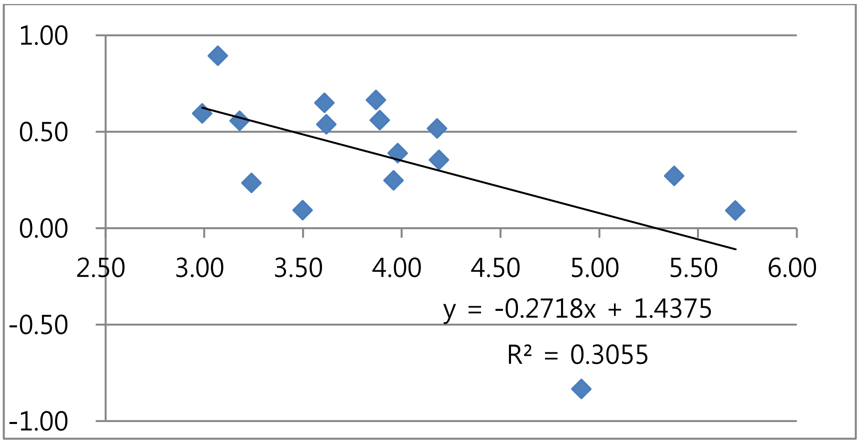


Figure 28 Scatter plot of 0-1p height and perspicuity

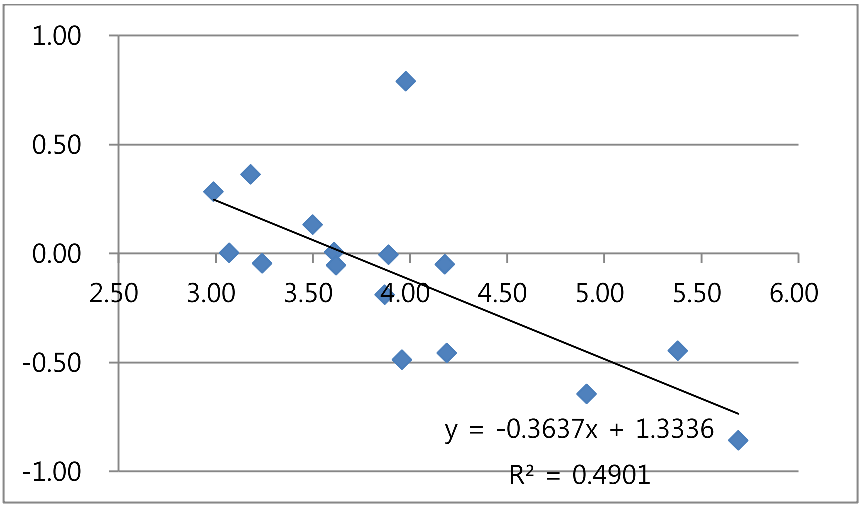


Figure 29 Scatter plot of 0-1p height and satisfaction

Scatter plot of 1p-2p height and perspicuity, satisfaction is like Fig. 30 and 31. Change pattern of affective element according to 1p-2p height is shown similar trend. Perspicuity and satisfaction get lower as 1p-2p height get bigger. R^2 is 0.39, 0.28 in the same order as perspicuity, satisfaction.

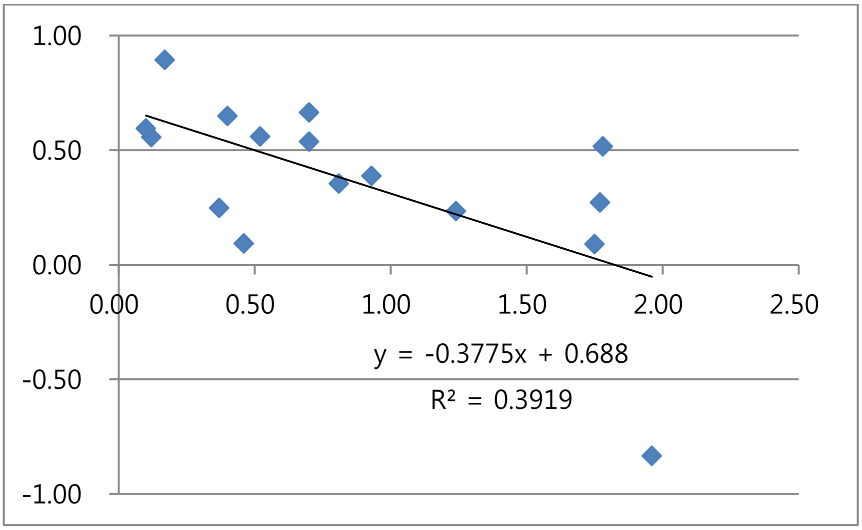


Figure 30 Scatter plot of 1p-2p height and perspicuity

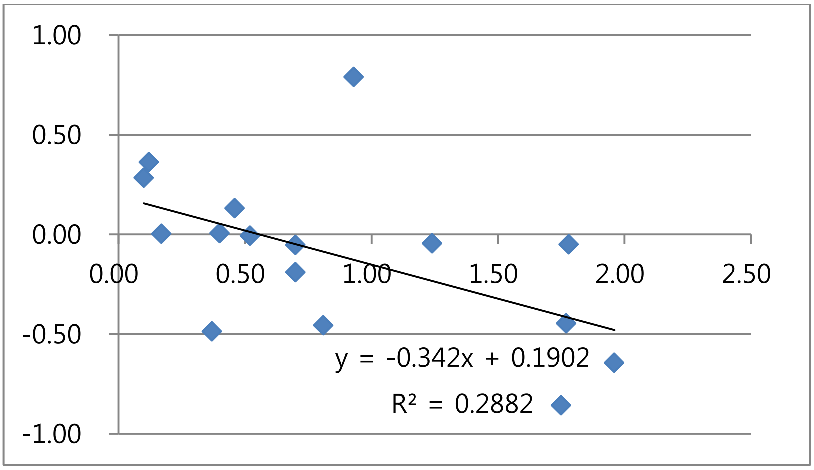


Figure 31 Scatter plot of 1p-2p height and satisfaction

Scatter plot of 2p-3p height and perspicuity, satisfaction is like Fig. 32 and 33. Change pattern of affective element according to 2p-3p height is shown similar trend. Perspicuity and satisfaction get lower as 2p-3p height get bigger. R^2 is 0.40, 0.35 in the same order as satisfaction, perspicuity.

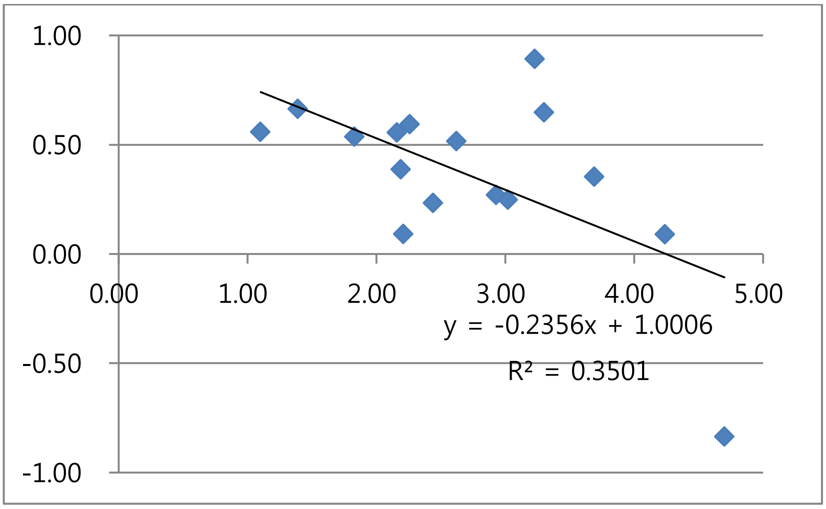


Figure 32 Scatter plot of 2p-3p height and perspicuity

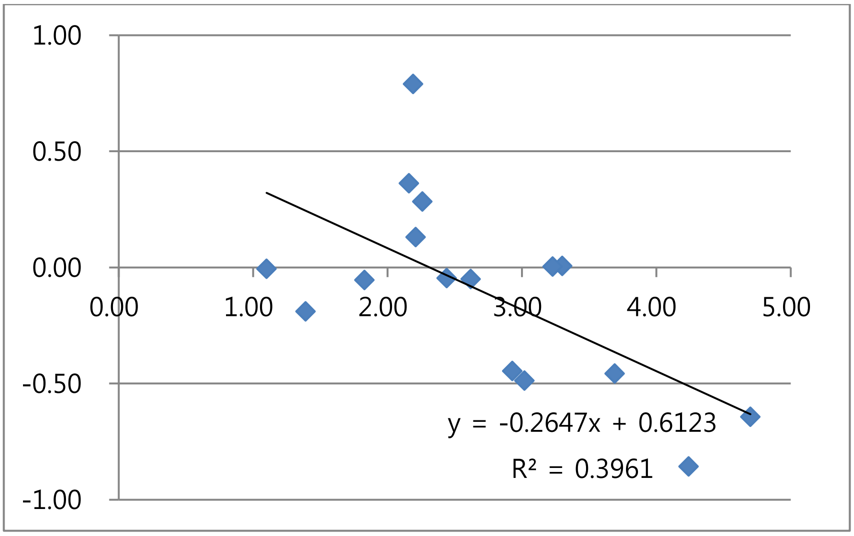


Figure 33 Scatter plot of 2p-3p height and satisfaction

Relationship between affective element and elements of force profile show that some elements of force profile and affective element have linear relationship and satisfaction is explained more than 30% by elements of force profile when elements of force profile explain smoothness or perspicuity more than 30%. As mentioned previously, haptic feedback used in experiment 3 has relatively long movement and dynamic change of force, so it is difficult that affective element explain by combination of force profile elements. But relationship between each elements of force profile and affective elements can be identified through correlation analysis and scatter plot. As a result, evaluation score of affective element has tendency to decrease as every elements of force profile except rotation degree of 2p-3p increase.

Chapter 4. Affective assessment on simulated haptic feedback

It may be possible to observe the pattern of force feedback and to distinguish the related elements from the existing product evaluations, but it is still difficult to analyze the relationship between the force profile elements and the affective elements. In order to determine the design guidelines for improving the affective satisfaction of products, the relationship between the affective elements and elements of force profile must be analyzed. However, there are certain limitation in the process and needs additional experiments in details.

First, it is difficult to define specific elements of force profile since there exists complex relationship among the force profile elements of a product. The elements of force profile that affect the affective elements must be determined and analyzed, but the force displacement graph is determined by complex relationship among various elements of force profile and it is difficult to determine the variables that act as the main factors affecting the affective elements.

Second, it is difficult to analyze the effects of variable changes since the flexibility of controlling the elements of force profile is limited. Although the elements of force profile that affect the affective elements are defined, it is still difficult to control specific variables as mentioned previously. Thus, the detailed design of the experiment is limited.

Third, there exist various noises and variations from unexpected variables and the reactions between the variables. All of the elements that affect the force profile cannot be determined, and it may be difficult to develop a product that can maintain the true intention of the force profile when the effects of different variables begin to overlap.

Therefore, the experiment needs to utilize a haptic simulator that can control the force profile. The experiment discussed in Chapter 4 uses a haptic simulator with the following characteristics. First, the force displacement graph is simplified into a sine wave graph that depicts the haptic feedback, and the main factors that affect kinesthetic sensations can be defined. Second, the design variables that explain the force profile are determined through the experiment planning, and their effects can be analyzed. Third, the controlled environment of the experiment can provide a systematic evaluation of the effects of the defined variables by eliminating unexpected factors that may affect kinesthetic sensations.

The experiments of this study attempts to determine the major affective dimensions related to kinesthetic perception among various haptic feedbacks and to analyze the patterns of affective perception with respect to the design elements related to movement. Then, the relationship between the design elements and affective elements is modeled based on the results of the experiments. Moreover, the affective perception of the feedback received from manipulating devices directly and those from manipulating indirectly are studied and compared to analyze the differences of the characteristics. The perception characteristics of the users according to the force pattern changes is analyzed by utilizing haptic simulator that can control design variables of the force profile.

4.1 Participants and product samples

The experiment consists of 33 haptic feedback provided a haptic simulator, and there were 13 male and 12 female (mean age of 25, with standard deviation of 2.5) who had participated the experiment (Fig. 34, 35). In order to analyze the pattern and characteristics of affective perception, the elements of force profile were controlled by haptic stimulator. Also, in order to analyze the perception characteristics according to the haptic mode, the experiments were divided into active haptic where the participants were directly involved with controlling devices and into passive haptic where the participants remained uninvolved. In the passive haptic, the experimenter was controlling the motor installed under the device through a software program. During the evaluation of passive haptic, the angular velocity (**π** rad/sec) of the device was set to alternate its direction every 120 degrees in order to provide stimulation similar to active haptic mode, and the participants were able to decide the number of angular motion of the device for the most accurate evaluation of the affective elements.

Figure 34 Experiment environment

Figure 35 Haptic simulator

The haptic simulator is device that utilizes haptic simulation software called Immersion Studio (http://www.immersion.com/) and it provides kinesthetic stimulation along with various feedbacks offered from force profiles. Haptic simulator allows us to simplify the design elements of the force profiles to define the elements that affect kinesthetic perception, and the defined design elements were able to be analyzed for understanding the force profiles. The feedbacks received from rotating a jog dial can be graphed as the waveforms shown in Fig. 36, and the variables Width, Magnitude, DetentType, and DetentWidth are defined in the following Table 22.

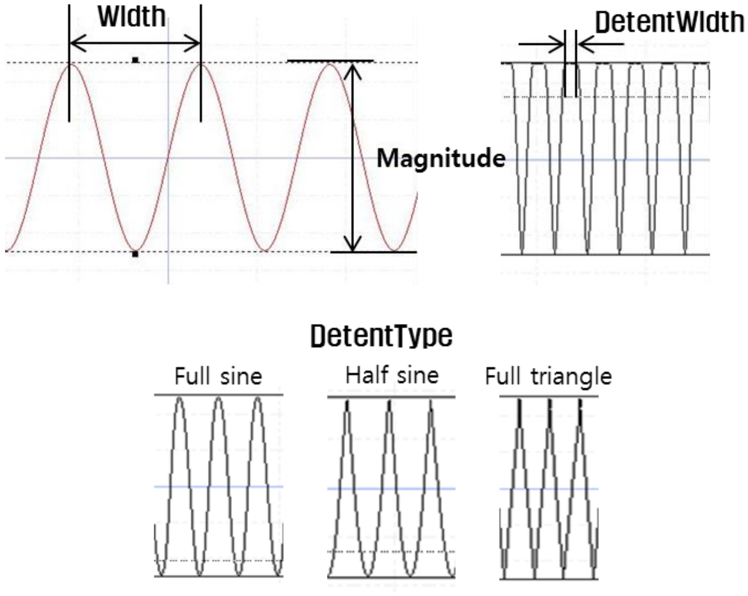


Figure 36 Shape of force profile and definition of design variable

Table 22 Definition of design variable

Design variable	Definition	Level
Haptic mode	The mode of controlling devices	Active, passive
Width	The distance between the detents	2(11~13degree), 4(21~13degree), 6(32~34degree)
Magnitude	The magnitude of force needed to pass beyond the detent peak	50(380~610gf·cm), 75(630~910gf·cm), 100(over 1000gf·cm)
DetentWidth	The distance between the detent upper peaks	60, 80, 100
DetentType	The Waveform appearing around the detents	Full sine , Half sine, Full triangle

As described previously, haptic mode refers to the mode of controlling devices as either active or passive mode where the participants may or may not involve directly with controlling the devices. The feedbacks offered by the force profiles are shown in Fig. 36, which are described by sine waves, and the controllable variables provided in Immersion Studio are as the following. The variable 'Width' refers to the distance between the lowest peaks of the sine wave, and it can be seen as a variable of vibration wave that determines the time gap between the consecutive feedbacks. The variable 'Magnitude' refers to the distance between the highest and the lowest peaks of the sine wave, and it can be considered as the force needed to pass beyond the detent peak. The variable 'DetentWidth' refers to the distance between the highest peaks, and it can be seen as the variable that affects the force feedback while passing through the detents. The variable 'DetentType' refers to the waveform, which can be decided as either Full Sine, Half Sine or Full Triangle. The experiment samples are designed by taking account of 4 variables of 3 levels and 1 variable of 2 levels and a total of 33 samples were created for the experiment by combining two $L_{27}(3^{13})$ design of experiment. Force profiles of haptic feedback are as follows (Fig. 37).

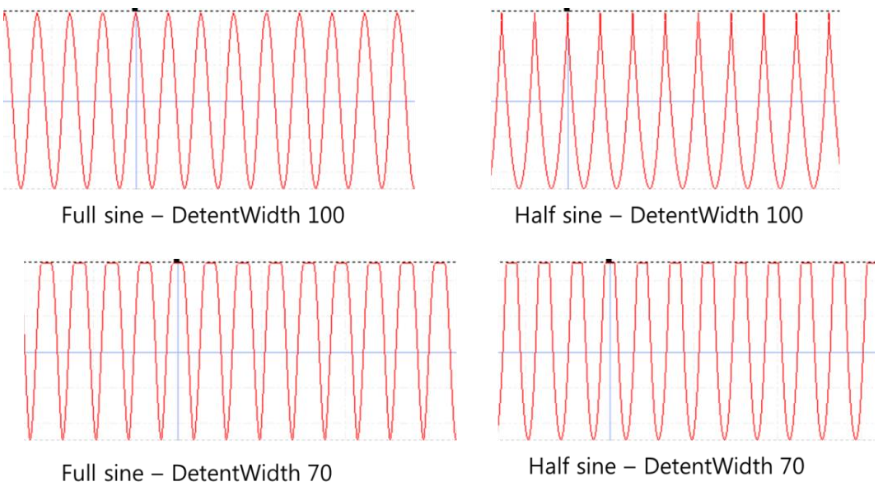


Figure 37 Force profile of haptic feedback

Table 23 Specific of evaluation samples

No	Order	haptic Type	Width	Magnitude	DetentType	DetentWidth
1	23	active	2	50	full sine	100
2	24	active	2	50	full TRI	60
3	5	active	2	50	half sine	80
4	28	active	2	75	full sine	100
5	21	active	2	100	half sine	80
6	9	active	4	50	full sine	80
7	4	active	4	75	half sine	60
8	1	active	4	100	full sine	80
9	15	active	4	100	full TRI	100
10	18	active	4	100	half sine	60
11	19	active	6	50	half sine	100
12	22	active	6	75	full sine	60
13	13	active	6	75	full TRI	80
14	12	active	6	75	half sine	100
15	8	active	6	100	full sine	60
16	7	passive	2	50	full TRI	60
17	6	passive	2	75	full sine	80
18	26	passive	2	75	full sine	100
19	11	passive	2	75	full TRI	100
20	32	passive	2	75	half sine	60
21	10	passive	2	100	half sine	80
22	25	passive	4	50	full sine	60
23	2	passive	4	50	full sine	80
24	29	passive	4	50	full TRI	80
25	31	passive	4	50	half sine	100
26	14	passive	4	75	half sine	60
27	3	passive	4	100	full TRI	100
28	30	passive	6	50	half sine	100
29	20	passive	6	75	full TRI	80
30	27	passive	6	100	full sine	60
31	16	passive	6	100	full sine	100
32	33	passive	6	100	full TRI	60
33	17	passive	6	100	half sine	80

4.2 Affective vocabulary

In order to evaluate the responses of the users on haptic feedback, we have investigated the existing research studies, the previous evaluation criteria of affective elements and expert reviews, and a total of 129 affective vocabularies have been collected (Schütte, Eklund, Axelsson, & Nagamachi, 2004). The collected affective vocabularies were then modified or neglected from our study according to the following criteria. First, the vocabularies with redundant meanings or similar concepts such as powerful and strong were combined into one. Also, the vocabularies that did not match with the purpose of our study, such as loose, were neglected from the list even though they may affect the perception of haptic feedback; this study has utilized the same device for changing feedback patterns and thus did not take account of the finishing quality of the device, and our list was narrowed down to the ones with respect to the main concern of this study which was to establish the fundamental structure of kinesthetic stimulation perception. The selected vocabularies were then paired up with those with opposite meanings. In the previous studies, the bipolar pairs (e.g., clicky – smooth) are often used in the survey questionnaire (Wellings et al., 2010), but unlike the cases where there exist two vocabularies of exactly opposite meanings such as weak and strong, there are also vocabularies with several different vocabularies of opposite meaning such as smooth vs. clicky and rough; therefore, we have decided to use the negation of the terms (i.e., X vs. non-X) for the questionnaire. The vocabularies perspicuity, smoothness, heaviness, elasticity, liltingness, and satisfaction were evaluated based on 7-point Likert Scale, and each evaluation scale was labeled as “extremely not” – “quite not” – slightly not” – “neutral”

– “slightly” – “quite” – “extremely.” The satisfactory score was evaluated under 100-point Magnitude Estimation Scale.

4.3 Data analysis

Descriptive statistics and nonparametric statistics were used to analyze the trend of the affective elements with respect to the elements of force profile. Based on the descriptive statistics, the basic results such as mean, variance and ranking were computed, and the pattern changes of affective elements with respect to the elements of force profile were analyzed. Because assumption of homogeneity of variances was not satisfied, kruskal-wallis test was used to investigate difference of affective elements with respect to elements of force profile. The data analysis was performed after the normalization to remove the differences cause by user bias such as the highest and lowest scores, mean and variance. The normalization was computed by the equation (X – mean) / standard deviation after computing the mean and the standard deviation of the evaluated scores.

In order to perform the affective modeling of affective and design elements, the following analysis was performed. Through the factor analysis, the affective elements were combined and the major affective dimensions were determined. The relationship between the satisfaction score and affective elements was analyzed through the regression analysis, and the main affective elements were determined by affective modeling. Based on the quantification I analysis, the level of effects and utility of each elements of force profile were analyzed with respect to the affective elements. The statistical analysis was performed with SAS (ver. 9.3) and SPSS (Ver. 18.0).

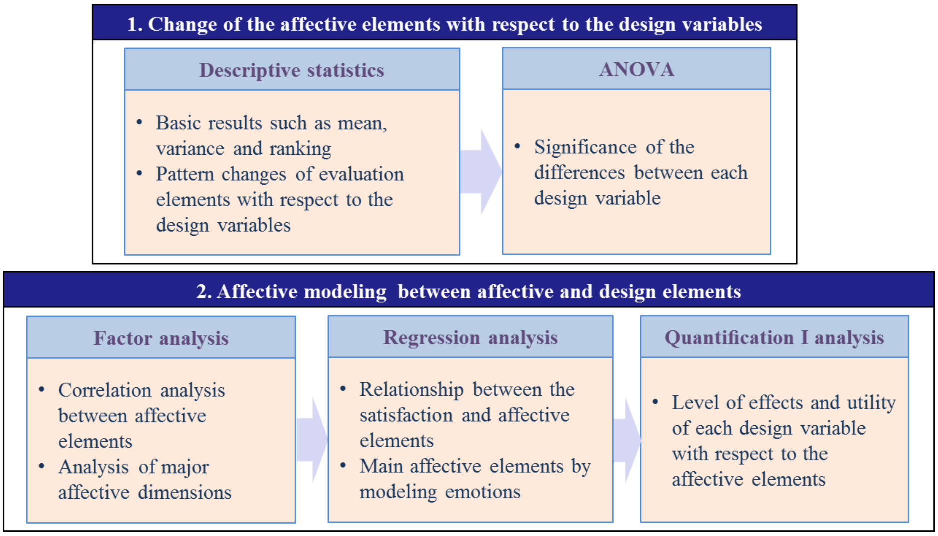


Figure 38 Analysis method

4.4 Results of active haptic mode experiment

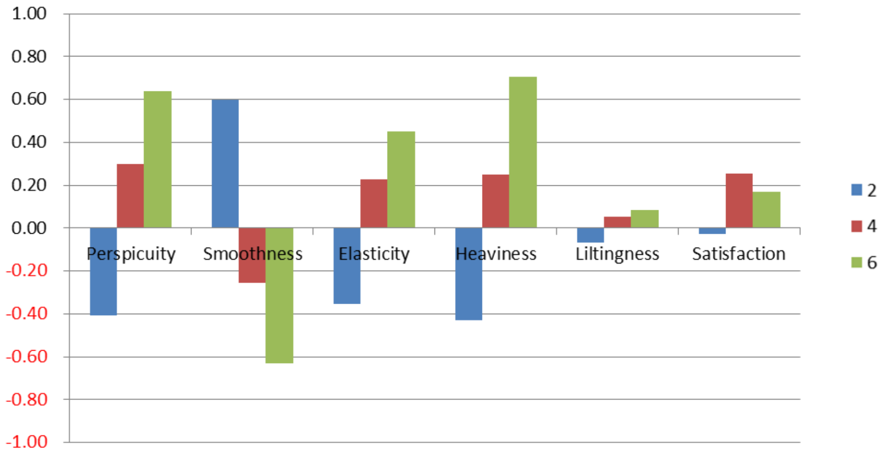
4.4.1 Trend of the affective elements according to elements of force profile

In the result of the descriptive statistics, most of the affective elements have shown significant changes with respect to the elements of force profile, except liltingness. Moreover, the terms perspicuity, heaviness and elasticity have shown similar trend with respect to the elements of force profile, whereas smoothness has shown the opposite pattern.

Table 24 Results of kruskal-wallis test about experiment 4

Design variable		Perspi-cuity	Smooth-ness	Elasti-city	Heavi-ness	Lilting-ness	Satisfac-tion
Width	Chi-Square	82.104	95.327	44.099	83.687	1.372	5.486
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.504	.064
Magni-tude	Chi-Square	91.556	65.507	47.97	76.47	11.362	19.678
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	0.003	.000
Detent-Type	Chi-Square	24.521	17.287	8.513	12.082	4.747	8.697
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	0.014	0.002	0.093	0.013
Detent-Width	Chi-Square	60.64	64.264	24.913	46.636	11.728	19.683
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	0.003	.000

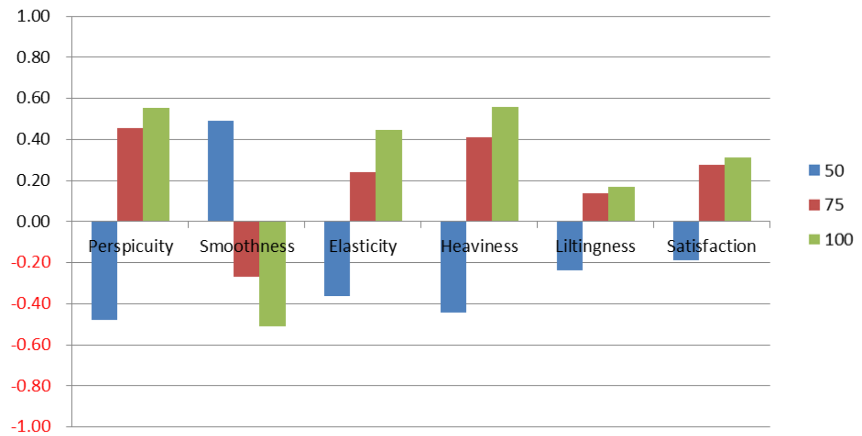
The following discusses further about the graph trend with respect to each elements of force profile. As the variable Width increase, the terms perspicuity, heaviness and elasticity all increase while smoothness decrease, but liltingness and satisfaction show no significant difference. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha < 0.05$) except liltingness and satisfaction. As the result of post hoc analysis, perspicuity, smoothness and heaviness have significant difference ($\alpha < 0.05$) among three level of width. But liltingness shows no significant difference according to level of width. Perspicuity, heaviness, and elasticity show negative value when width is 2, and show positive value when width is 4 and 6. Smoothness and heaviness evaluation score difference according to level is bigger than other affective element evaluation score.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B C	A B C	A B	A B C	A	A

Figure 39 Means of affective elements according to Width at active haptic

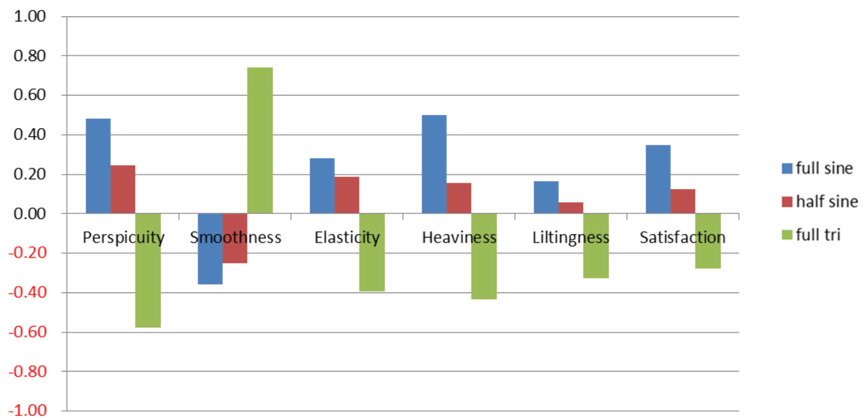
With respect to magnitude, the terms perspicuity, heaviness, elasticity and liltingness have shown positive trend while smoothness has shown negative trend. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha < 0.05$). As the result of post hoc analysis, every affective element had significant difference ($\alpha < 0.05$) between 50 and 75, 100 magnitude. Every affective element has consistency trend to get bigger or smaller as magnitude get bigger. Magnitude has something with width that smoothness has shown the opposite pattern in comparison with other affective element, and liltingness and satisfaction show no significant difference according to level of magnitude.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B

Figure 40 Means of affective elements according to Magnitude at active haptic

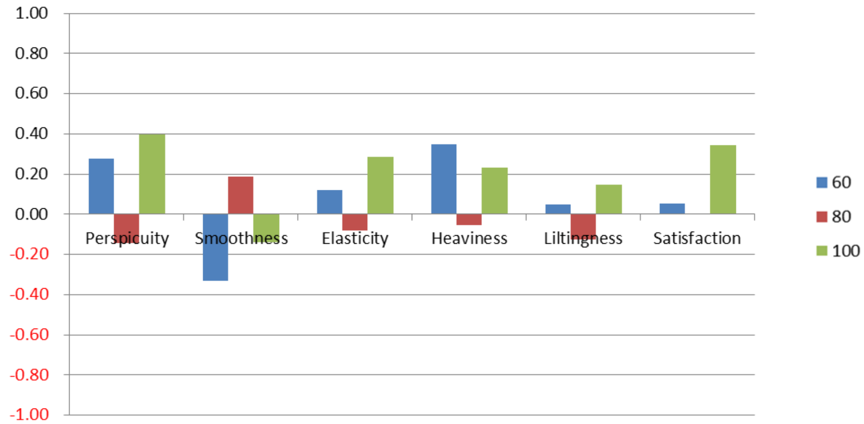
In the case of DetentType, the affective elements have shown similar evaluation score with Full Sine and Half Sine while having different evaluation score with Full Triangle. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, all affective elements except heaviness have significant difference (α< 0.05) between Full Triangle and Full Sine, Half Sine and heaviness have shown significant difference (α< 0.05) with every variable level. Perspicuity, heaviness, elasticity, liltingness and satisfaction score is higher at Full Sine, Half Sine than at Full Triangle, and smoothness score show the opposite pattern.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B C	A B	A B

Figure 41 Means of affective elements according to DetentType at active haptic

When the variable DetentWidth was set to 60 or 100, the terms perspicuity, heaviness, elasticity and liltingness have shown higher scores while smoothness with lower score than when DetentWidth was set to 80. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha < 0.05$) except liltingness. As the result of post hoc analysis, every affective element except elasticity, liltingness had significant difference ($\alpha < 0.05$) between 60, 100 and 80.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B B	A A B	A B	A B B	A	A B B

Figure 42 Means of affective elements according to DetentWidth at active haptic

4.4.2 Correlation and factor analysis of affective elements

Results of correlation analysis between affective elements are like Table 25. Perspicuity, heaviness, and elasticity have strong positive correlation (correlation coefficients among perspicuity, heaviness, and elasticity are more than 0.45). Smoothness has not correlation with liltingness and satisfaction (correlation coefficients between smoothness and liltingness, satisfaction are below 0.05) and have negative correlation with rest of affective element (correlation coefficients with rest of affective element are below -0.3). Liltingness have most positive correlation with satisfaction (correlation coefficient is 0.708)

Table 25 Results of correlation analysis about experiment 4

	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
Perspicuity	1	-.570	.624	.690	.412	.509
Smoothness	-.570	1	-.321	-.599	.040	.011
Elasticity	.624	-.321	1	.457	.490	.558
Heaviness	.690	-.599	.457	1	.208	.266
Liltingness	.412	.040	.490	.208	1	.708
Satisfaction	.509	.011	.558	.266	.708	1

The factor analysis was performed to determine the major affective dimensions. Through Principal Component Analysis, the factors were computed while the ones with the value of factor loading below 0.3 were neglected from the factor matrices for more convenient interpretation. The number of factors was determined with respect to the Eigenvalue of 1, and a total of two factors were computed (account for 79.6% of the variance). As shown in Table 26, perspicuity, heaviness and elasticity were grouped into factor 1 while liltingness and smoothness into factor 2. Factor 1 can be considered as the affective element related to force, and factor 2 to movement in consideration of meaning of affective element and research related kinesthetic sensation. And characteristics of each factor are confirmed through relationship analysis between elements of force profile.

Table 26 Results of factor analysis about experiment 4

	Factor loading	
	Factor 1(56.3%) force-related	Factor 2(23.3%) movement-related
Perspicuity	**.907**	
Elasticity	**.823**	-.284
Heaviness	**.774**	.341
Liltingness	.495	**.782**
Smoothness	-.684	**.597**

4.4.3 Relationship between affective elements and satisfaction

As the result of the regression analysis, perspicuity, elasticity, liltingness and smoothness have shown to affect the satisfaction score while heaviness has shown to be multi-collinear with perspicuity and thus was neglected from the list. With the result of F=360.187 and p-value=0.000, it has shown that the regression model was meaningful. As Adjusted R^2 being 0.61, the affective elements have shown to explain the trend of satisfaction score on controlling devices. In terms of standardized coefficients of the elements affecting satisfaction score, liltingness had the coefficient of 0.460, perspicuity 0.334, smoothness 0.248 and elasticity 0.204. Because perspicuity in affective element that correlation coefficients between each other are high explain much of satisfaction, then explanation portion of other affective elements that correlation coefficients between each other are high become smaller similar to experiment 2.

Table 27 Results of regression analysis about experiment 4

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.062	.032		1.953	.052
Liltingness	.441	.039	.460	11.381	.000
Elasticity	.201	.043	.204	4.650	.000
Perspicuity	.351	.053	.334	6.604	.000
Smoothness	.232	.040	.248	5.854	.000

4.4.4 Relationship between perspicuity and smoothness according to satisfaction score

Based on the observation that the evaluation scores of perspicuity and smoothness were high when the satisfaction score was high, the two elements that have high factor loadings for both of the factors 1 and 2 were compared with respect to the satisfaction score. The satisfaction scores were divided into the scores of lower 90% and those of higher 10%, and the means, correlation and scatter diagrams of perspicuity and smoothness were analyzed to determine the characteristics.

The satisfaction scores of perspicuity in the lower 90% and higher 10% were 0.036 and 0.976, respectively, which tells us that the higher 10% show higher score. Likewise, the satisfaction scores of smoothness in the lower 90% and higher 10% were 0.441 and 0.748, respectively, which also shows that the higher 10% have higher score. From the analysis of variance, the evaluation scores of perspicuity and smoothness in the lower 90% of satisfaction scores have shown significant differences from those in the higher 10% of satisfaction scores with the significance level of 0.05.

Table 28 Mean of perspicuity and smoothness

		Perspicuity	Smoothness
Top 10%	Mean	.976	.748
	N	82	82
	Std. D	.6681	.7927
Low 90%	Mean	.036	.441
	N	743	743
	Std. D	1.1051	.9899
Total	Mean	.129	.471
	N	825	825
	Std. D	1.1058	.9760

Table 29 ANOVA results according to satisfaction score

		Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	65.227	1	65.227	56.970	.000
	Within Groups	942.279	823	1.145		
	Total	1007.506	824			
Smoothness	Between Groups	6.944	1	6.944	7.346	.007
	Within Groups	778.001	823	.945		
	Total	784.945	824			

The coefficients of correlation show strong negative correlation (-0.648) for the lower 90% while there is no significant correlation (-0.096) for the higher

10%. The scatter diagrams show that the evaluation score of smoothness becomes lower when the evaluation score of perspicuity becomes higher for the lower 90% and that the score of smoothness becomes higher when the score of perspicuity becomes lower. For the higher 10%, the overall distribution seems to have negative correlation, but most of the scatter points have been found around the higher scores of both perspicuity and smoothness as shown in Fig. 43.

Table 30 Correlation of between perspicuity and smoothness at low 90%

Low 90%		Perspicuity	Smoothness
Perspicuity	Correlation	1	-.648**
	Sig. (2-tailed)		0
	N	743	743
Smoothness	Correlation	-.648**	1
	Sig. (2-tailed)	0	
	N	743	743

Table 31 Correlation of between perspicuity and smoothness at top 10%

Top 10%		Perspicuity	Smoothness
Perspicuity	Correlation	1	-0.096
	Sig. (2-tailed)		0.392
	N	82	82
Smoothness	Correlation	-0.096	1
	Sig. (2-tailed)	0.392	
	N	82	82

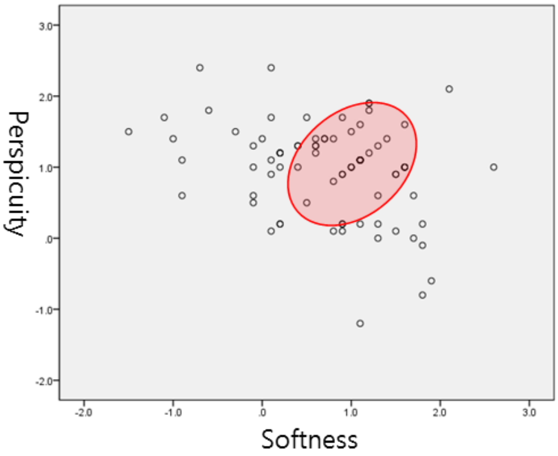


Figure 43 Scatter plot of top 10%

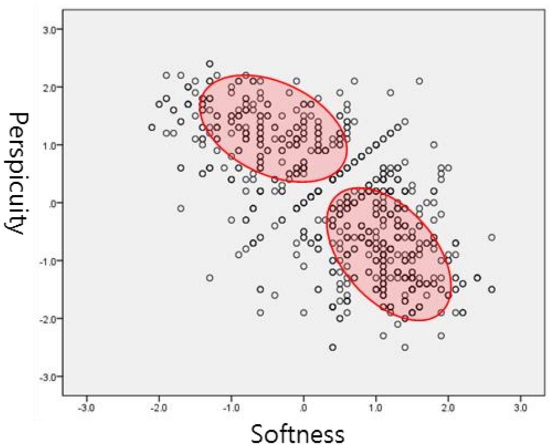


Figure 44 Scatter plot of low 90%

4.4.5 Relationship between affective elements and elements of force profile

Result of partial correlation coefficient (R) of each elements of force profile and partial regression coefficient of each level of elements of force profile is like Table 32 and 33. R^2 of every affective element except liltingness and satisfaction, a measure of how well explained affective element by elements of force profile, is above 0.25. Especially, smoothness and perspicuity explained well by elements of force profile (R^2 of smoothness and perspicuity is 0.51 and 0.60). Partial correlation coefficient of detentwidth, effect of elements of force profile on affective element, has least value in case of almost affective element, and partial correlation coefficient of width, magnitude, detent-type is different according to affective element. Perspicuity, heaviness, and elasticity have similar effect on width, magnitude, detent-type, and width and detent-type have more effect on smoothness than magnitude.

Partial regression coefficients, effect on affective element by level of force profile elements, are as follows. Change pattern of smoothness according to level of force profile elements is different from other affective element, also. Design variable has three levels, partial regression coefficient according elements of force profile is symmetry. Partial regression coefficient of almost affective element has value between -0.02 and 0.09 when magnitude is 75, absolute value of partial regression coefficient when magnitude is 50 and 100 is almost same and has different sign. According to change level of variable, width or magnitude increase, evaluation score increase or decrease consistently. But as detent-width increase, evaluation score has not consistent pattern.

Table 32 Partial correlation coefficient (R) of each force profile elements

	Satisfaction (R^2= 0.13)	Perspicuity (R^2= 0.60)	Smoothness (R^2= 0.51)	Elasticity (R^2=0.27)	Heaviness (R^2=0.48)	Liltingness (R^2= 0.06)
Width		0.45	0.48	0.29	0.45	
Magni-tude	0.27	0.53	0.39	0.32	0.43	0.19

Detent-Type	0.25	0.56	0.51	0.29	0.44	0.18
Detent-Width	0.20	0.36	0.19	0.21	0.14	0.12

Table 33 Partial regression coefficient of each level of force profile elements

Design variable	Level	Satisfaction	Perspicuity	Smoothness	Elasticity	Heaviness	Lilting-ness
Width	2		-0.40	0.54	-0.34	-0.43	
	4	-	0.01	-0.01	0.02	-0.08	-
	6		0.39	-0.53	0.32	0.50	
Magnitude	50	-0.35	-0.51	0.36	-0.36	-0.45	-0.27
	75	0.12	0.08	0.08	-0.02	0.01	0.09
	100	0.23	0.44	-0.44	0.38	0.44	0.18
Detent-Type	full sine	0.22	0.31	-0.26	0.17	0.33	0.14
	full tri	-0.41	-0.75	0.84	-0.50	-0.61	-0.35
	half sine	-0.01	0.07	-0.15	0.08	-0.02	0.03
Detent-Width	60	-0.15	-0.08	-0.06	-0.13	0.00	-0.03
	80	-0.11	-0.23	0.19	-0.13	-0.13	-0.13
	100	0.26	0.31	-0.14	0.26	0.13	0.16

4.5 Results of passive haptic mode experiment

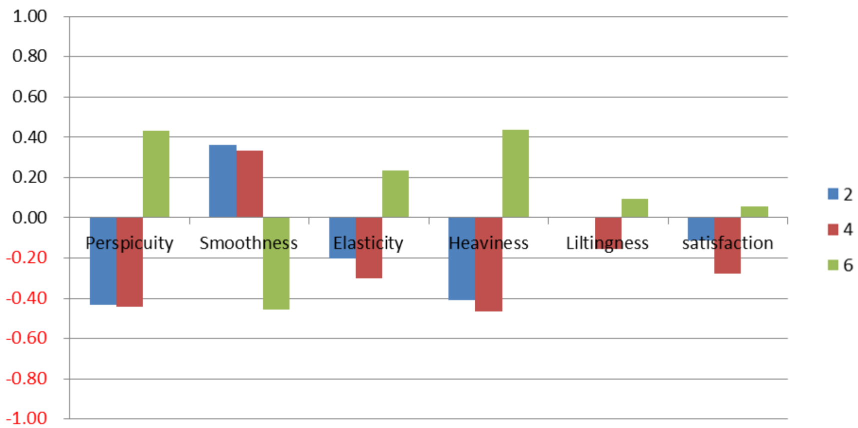
4.5.1 Trend of the affective elements according to elements of force profile

The results of the descriptive statistics are similar to active haptic mode in general. Most of the affective elements have shown significant changes with respect to the elements of force profile, except liltingness. And perspicuity, heaviness and elasticity have shown similar trend with respect to the elements of force profile, whereas smoothness has shown the opposite pattern, also. But pattern of affective element according to level of variable is different form active haptic mode.

Table 34 Results of ANOVA about experiment 5

Design variable		Perspi-cuity	Smooth-ness	Elasti-city	Heavi-ness	Lilting-ness	Satisfac-tion
Width	Chi-Square	64.415	46.411	20.446	54.460	4.109	8.617
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.128	.013
Magni-tude	Chi-Square	61.872	64.3	29.925	71.696	14.035	17.646
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	0.001	.000
Detent-Type	Chi-Square	118.531	67.314	61.449	81.62	23.619	37.46
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.000	.000
Detent-Width	Chi-Square	51.197	21.283	41.345	37.109	15.455	17.785
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.000	.000

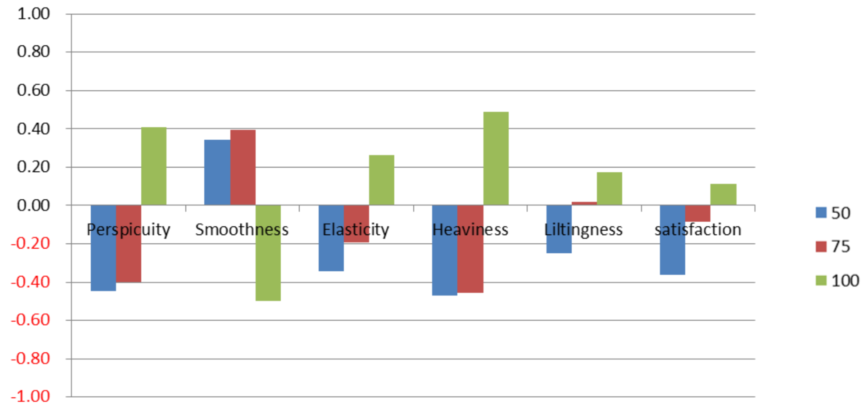
As the variable width increase, every affective element except smoothness has not consistency trend that increase or decrease according to width continuously contrary to active haptic mode. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha< 0.05$) except liltingness. As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference ($\alpha< 0.05$) between 2, 4 and 6. Affective variable evaluation score of level of 2 and 4 has not significant difference at passive haptic, this is reason that active haptic mode is more sensitivity than passive haptic mode. Liltingness showed no significant difference according to level of width in common with active haptic.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A	A B B

Figure 45 Means of affective elements according to Width at passive haptic

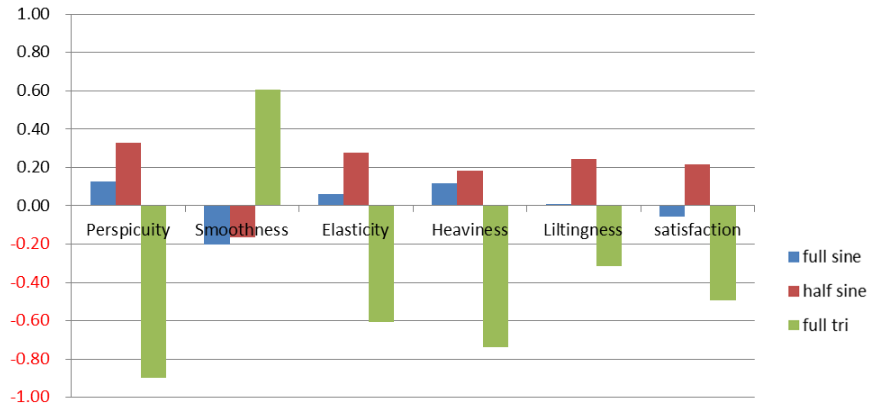
With respect to magnitude, as the variable magnitude increase, smoothness has not consistency trend that increase or decrease according to magnitude continuously contrary to active haptic mode. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference (α< 0.05) between 50, 75 and 100, and liltingness and satisfaction have significant difference (α< 0.05) between 50 and 75, 100. Affective variable evaluation score of level of 50 and 75 has not significant difference at passive haptic, this is reason that active haptic mode is more sensitivity than passive haptic mode. Liltingness showed no significant difference according to level of width in common with active haptic.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B

Figure 46 Means of affective elements according to Magnitude at passive haptic

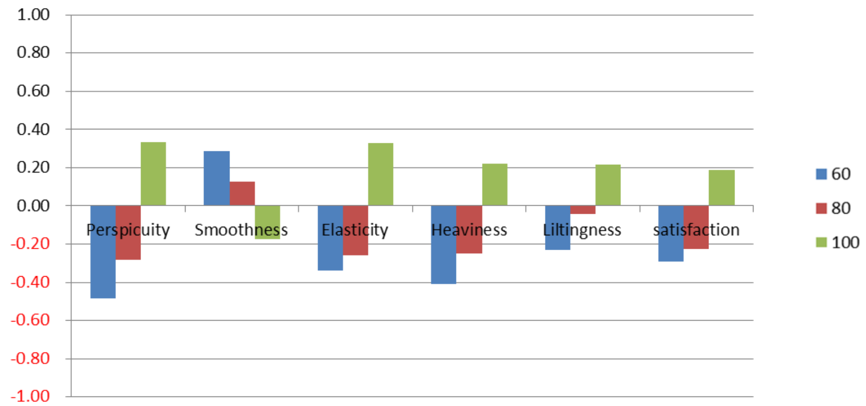
With respect to detent-type, score of perspicuity, heaviness, elasticity, liltingness and satisfaction of half sine is higher than those of full sine contrary to active haptic mode. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference (α< 0.05) between half sine, full sine and full tri. Deviation of affective variable evaluation score at passive haptic is smaller than at active haptic, this is reason that active haptic mode is more sensitivity than passive haptic mode.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B C

Figure 47 Means of affective elements according to DetentType at passive haptic

With respect to detent-width, as the variable detent-width increase, the terms perspicuity, heaviness, elasticity and liltingness all increase while smoothness decrease. Detent-width is the only variable that evaluation score has consistency trend according to variable. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference (α< 0.05) between 60, 80 and 100.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B

Figure 48 Means of affective elements according to DetentWidth at passive haptic

4.5.2 Correlation and factor analysis of affective elements

Results of correlation analysis between affective elements are like Table 35. Perspicuity, heaviness, and elasticity have strong positive correlation similar to active haptic (correlation coefficients among perspicuity, heaviness, and elasticity are more than 0.45). Smoothness has not correlation with liltingness and satisfaction (correlation coefficients between smoothness and liltingness, satisfaction are more than -0.1) but correlation coefficients is negative value in contrast with active haptic. Smoothness has negative correlation with rest of affective element (correlation coefficients with rest of affective element are below -0.4). Liltingness have most positive correlation with satisfaction (correlation coefficient is 0.758)

Table 35 Results of correlation analysis about experiment 5

	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
Perspicuity	1	-.623	.677	.776	.451	.552
Smoothness	-.623	1	-.399	-.639	-.085	-.097
Elasticity	.677	-.399	1	.578	.527	.595
Heaviness	.776	-.639	.578	1	.349	.373
Liltingness	.451	-.085	.527	.349	1	.758
Satisfaction	.552	-.097	.595	.373	.758	1

The factor analysis was performed to determine the major affective dimensions. Through Principal Component Analysis, the factors were computed while the ones with the value of factor loading below 0.3 were neglected from the factor matrices for more convenient interpretation. The number of factors was determined with respect to the Eigenvalue of 1, and a total of two factors were computed (account for 82.0% of the variance). As shown in Table 36, perspicuity, heaviness and elasticity were grouped into factor 1 while liltingness and smoothness into factor 2. Factor 1 can be considered as the affective element related to force, and factor 2 to movement in consideration of meaning of affective element and research related kinesthetic sensation. And characteristics of each factor are confirmed through relationship analysis between elements of force profile.

Table 36 Results of factor analysis about experiment 5

	Factor loading	
	Factor 1(62.1%) force-related	Factor 2(19.9%) movement-related
Perspicuity	**.918**	
Heaviness	**.873**	-.205
Elasticity	**.814**	.275
Liltingness	.574	**.737**
Smoothness	-.714	**.575**

4.5.3 Relationship between affective elements and satisfaction

As the result of the regression analysis, perspicuity, elasticity, liltingness and smoothness have shown to affect the satisfaction score while heaviness has shown to be multi-collinear with perspicuity and thus was neglected from the list. With the result of F=228.457 and p-value=0.000, it has shown that the regression model was meaningful. As Adjusted R^2 being 0.67, the affective elements have shown to explain the trend of satisfaction score on controlling devices. In terms of standardized coefficients of the elements affecting satisfaction score, liltingness had the coefficient of 0.534, perspicuity 0.331, smoothness 0.226 and elasticity 0.180. Because perspicuity in affective element that correlation coefficients between each other are high explain much of satisfaction, then explanation portion of other affective elements that correlation coefficients between each other are high become smaller similar to experiment 2.

Table 37 Results of regression analysis about experiment 5

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.056	.028		-2.009	.045
Liltingness	.545	.034	.534	15.843	.000
Perspicuity	.322	.044	.331	7.342	.000
Smoothness	.238	.038	.226	6.236	.000
Elasticity	.182	.040	.180	4.594	.000

4.5.4 Relationship between affective elements and elements of force profile

Result of partial correlation coefficient (R) of each force profile elements and partial regression coefficient of each level of force profile elements is like Table 38 and 39. R^2 of every affective element except liltingness and satisfaction is above 0.30. Especially, smoothness and perspicuity explained well by elements of force profile (R^2 of smoothness and perspicuity is 0.40 and 0.57). Partial correlation coefficient of detentwidth, effect of force profile elements on affective element, has least value in case of almost affective element, and partial correlation coefficient of width, magnitude, detent-type is different according to affective element. Perspicuity, heaviness, and elasticity have similar effect on width, magnitude, detent-type, and width and detent-type have more effect on smoothness than magnitude.

Partial regression coefficients, effect on affective element by level of force profile elements, are as follows. Change pattern of smoothness according to level of force profile elements is different from other affective element, also. Design variable has three levels, partial regression coefficient according elements of force profile is symmetry. Partial regression coefficient of almost affective element has value between -0.24 and 0.23 when magnitude is 75, absolute value of partial regression coefficient when magnitude is 50 and 100 is almost same and has different sign. According to change level of variable, width or magnitude increase, evaluation score increase or decrease consistently. But as detent-width increase, evaluation score has not consistent pattern.

Table 38 Partial correlation coefficient (R) of each force profile elements

	Satisfaction (R^2= 0.15)	Perspicuity (R^2= 0.57)	Smoothness (R^2= 0.40)	Elasticity (R^2=0.29)	Heaviness (R^2=0.48)	Liltingness (R^2= 0.11)
Width		0.34	0.26	0.14	0.29	
Magni-tude	0.20	0.31	0.32	0.19	0.36	0.18
Detent-Type	0.30	0.62	0.45	0.41	0.50	0.24
Detent-Width	0.22	0.46	0.25	0.33	0.35	0.19

Table 39 Partial regression coefficient of each level of force profile elements

Design variable	Level	Satisfac-tion	Perspicuity	Smooth-ness	Elasticity	Heaviness	Lilting-ness
Width	2	-	-0.21	0.16	-0.08	-0.14	-
	4		-0.19	0.17	-0.11	-0.21	
	6		0.40	-0.33	0.19	0.36	
Magni-tude	50	-0.25	-0.21	0.18	-0.20	-0.22	-0.23
	75	0.03	-0.15	0.23	-0.06	-0.24	0.04
	100	0.22	0.36	-0.41	0.26	0.46	0.19
Detent-Type	full sine	0.06	0.27	-0.28	0.15	0.26	0.03

	full tri	0.33	0.48	-0.24	0.37	0.33	0.27
	half sine	-0.38	-0.75	0.53	-0.52	-0.59	-0.29
Detent-Width	60	-0.18	-0.34	0.21	-0.25	-0.26	-0.21
	80	-0.12	-0.14	0.05	-0.17	-0.10	-0.02
	100	0.30	0.48	-0.25	0.42	0.37	0.24

4.6 Analysis of difference between active and passive haptic

The scores of the affective elements with respect to the mode of haptic show that all of the elements except smoothness have higher scores in active haptic than in passive haptic mode as shown in Fig. 49. The difference of the scores for perspicuity and heaviness were large while liltingness had a little difference.

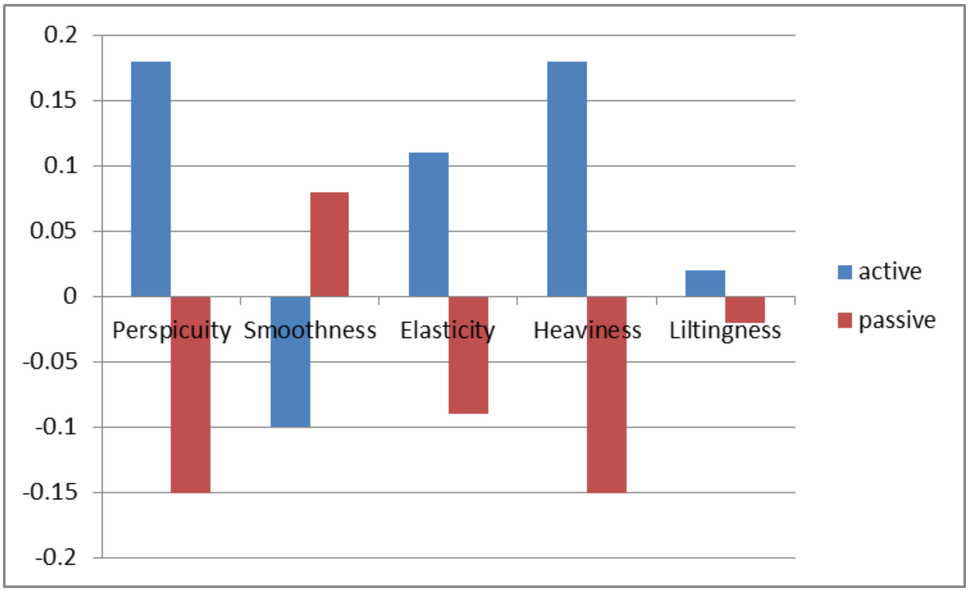


Figure 49 Means of affective elements according to haptic mode

In order to analyze the effect of mode of haptic, Width Magnitude, DetentType and DetentWidth were set to covariate while haptic mode to fixed factor, and ANCOVA was performed. The analysis has shown different results depending on the affective elements related to force and movement.

Perspicuity and heaviness have shown significant correlation with haptic mode, while smoothness, elasticity and liltingness have shown no significance ($\alpha<0.05$). Moreover, perspicuity, heaviness, elasticity and liltingness were perceived larger when the mode was set to active haptic, while smoothness was perceived larger in passive haptic. The affective elements related to force have shown greater significance with active haptic while those related to movement have shown greater significance with passive haptic, but there was no statistical difference between them.

Table 40 Results of ANCOVA

	Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	10.110	2	5.055	9.733	**.000**
Smoothness	2.672	2	1.336	2.174	.114
Elasticity	3.642	2	1.821	2.357	.095
Heaviness	11.236	2	5.618	9.791	**.000**
Liltingness	.015	2	.008	.008	.992
Satisfaction	9.246	2	4.623	5.260	**.005**

The trends of the affective elements with respect to the elements of force profile have shown the differences between those related to force and movement. The increase of Width, which is related to movement, has shown to decrease the score of smoothness in both modes of active haptic and passive haptic. On the other hand, perspicuity, heaviness and elasticity have shown to increase with respect to Width in active haptic mode while decreasing in passive haptic mode. Moreover, perspicuity, heaviness and elasticity have shown to increase with respect to Magnitude, which is related to force, in both modes of active haptic and passive haptic. However, smoothness and liltingness have shown to increase and decrease respectively with respect to Magnitude in active haptic mode while they both increased up to certain point and decreased in passive haptic mode.

In addition, the elements have shown consistent trend as either increasing or decreasing with respect to the elements of force profile in active haptic mode, but the trend was not consistent in passive haptic mode. This finding was observed in both elements related to force and movement and thus tells us that the mode of haptic affects the affective perception of the users.

The scores of the affective elements with respect to the elements of force profile were also affected by the mode of haptic. The variable Width, which is related to movement, had higher effect on smoothness, which is also related to movement, in active haptic mode while perspicuity and elasticity, which are related to force, had larger differences in passive haptic mode. The variable Magnitude, which is related to force, had higher effect on smoothness and liltingness, which are related to movement, in passive haptic mode while perspicuity, elasticityand heaviness, which are related to force, had larger differences in active haptic mode.

These observations seem to be related to the elements of force profile and the affective aspect of a user. A large difference resulted from the other elements of force profile means that the reaction to the variables is very sensitive. The affective elements related to movement react more sensitive to the elements of force profile related to movement in active haptic mode, while those related to force react more sensitive to the variables related to force in active haptic mode. However, further studies are needed to understand the exact cause of such observations.

4.7 Discussions

4.7.1 Modeling of affective element related kinesthesis

This study conducted factor analysis, regression analysis, and quantification I analysis based on user evaluation experiment of real product and simulated haptic feedback. As a result, it can be difficult and has limitations to analyze relationship between elements of force profile and affective element because of factor of force profile and noise that can’t control, but general trend of affective element according to elements of force profile can be identified.

Based on the existing studies of physiology related to evaluating product qualities, the stimulation has been categorized with respect to the characteristics of force profile. Then, the factor analysis and regression analysis were performed to determine the main factors that can group the affective elements and to analyze how much the affective elements were able to explain the satisfaction of haptic feedback. All three experiments have shown that the main factors were able to explain more than 50% of data variance, and the regression analysis has shown that each affective element had the score of explaining the satisfaction higher than 0.45. From these results, it can be observed that the feedback that is related to either force or movement was explained by one factor while the feedback related to both force and movement was explained by two factors.

Process perceived kinesthetic feedback emotionally is affected by factor related with force and movement like as physiological and psychophysical studies through evaluation of real product. This result is reasonable because affective responses are perceived and occurred based on stimulation received from receptor, but no experimental case studies which proved this relation have been reported. Chen, Shao, Barnes, Childs, and Henson (2009) has shown that affective vocabulary related with dimension studied psychophysical area effect on affective satisfaction with respect to tactile feedback. This study deducted major factor affected on kinesthetic feedback and show that these factor is related to force and movement divided in physiological and psychophysical studies like as tactile feedback through affective assessment of various product.

And relationship between affective element is change according to form of force profile. As a result, the more form of force profile is complicate, the more correlation coefficients between affective element is low and a number of deducted factor is many. This is because as complexity of force profile increase, kind of user perceived emotion increase. Deducted factor is divided into factor related with force and movement inferred from form of force profile and it is needed to evaluate and analyze based on more various product.

And relationship between affective element and elements of force profile can be analyzed using simulator that can control force-profile. Based on the results of the analyses, the affective elements have been described by the elements of force profile, and the characteristics of the elements of force profile that affect the affective elements were categorized. The quantification I analysis has shown that the effect of the elements of force profile on the affective elements can be described by the difference of their characteristics. The elements of force profile can be divided into the elements related to force and movement, and it was observed that the affective elements that were affected by the variables related to force and movement were different. The variable Magnitude, which is related to force, affected the most on perspicuity while Width, which is related to movement, affected the most on smoothness.

The elements of force profile related to force did affect both of the affective elements that are related to force and movement, but they have depicted different trends with respect to the level of each variable that affected the affective elements. As discussed in the existing physiological and psychophysical studies, it may be difficult to completely separate the perceptions related to force and movement, but this study has shown separate trend groups of affective elements related to haptic feedback with respect to force and movement, which also agrees with the existing physiological and psychophysical studies (Proske & Gandevia, 2009).

Unlike the most of the affective elements, liltingness was difficult to be described by the elements of force profile because it has shown inconsistent trend with respect to the elements of force profile. This may suggest that liltingness was not affected by the elements of force profile provided from force profile individually but rather by the elements other than the discussed variables. The results have shown different explanation for the affective elements related to kinesthetic perception with respect to individual elements of force profile and with respect to other factors that may be raised from the combination of the elements of force profile. Thus, the research needs further investigation on this matter.

It is necessary to determine the primary elements that affect the satisfaction of the users. Since the sense of satisfaction comes from the combination of various elements, there is limitation to explain the satisfaction factor in terms of the elements of force profile only. In order to provide the proper feedback stimulation as intended by the product designers, the perception of the users must be analyzed in terms of the elements of force profile. In this study, rather than analyzing the relationship between satisfaction and elements of force profile, it was shown that it was more meaningful to analyze the relationship between the major affective dimensions and elements of force profile in order to determine the characteristics of the elements of force profile in constructing feedback. The quantification I analysis has shown the satisfaction result of Adjusted R^2 as 0.13, which refers to the satisfaction score of 13%. In the case of perspicuity and smoothness, the values of Adjusted R^2 were 0.60 and 0.51 respectively, which means they can be explained by the elements of force profile by about 50%, while the result of the regression analysis has shown the value of Adjusted R^2 being higher than 0.6. These results tell us that the direct analysis between the affective elements and elements of force profile can be explained by 13% and that the relationship between each affective element and satisfaction can be explained by about 30%.

The result of affective modeling on experiment 4 and 5 is shown in Fig. 50. There are differences in weight of affective element effected on satisfaction according to mode of haptic, but the order of weight in active haptic mode is consistent with that in passive haptic mode. Most of affective elements can be explained by elements of force profile and liltingness has the largest coefficient. Based on result of affective modeling, specifications of design variable needed to provide more affective haptic feedback can be deducted in consideration of mode of haptic.

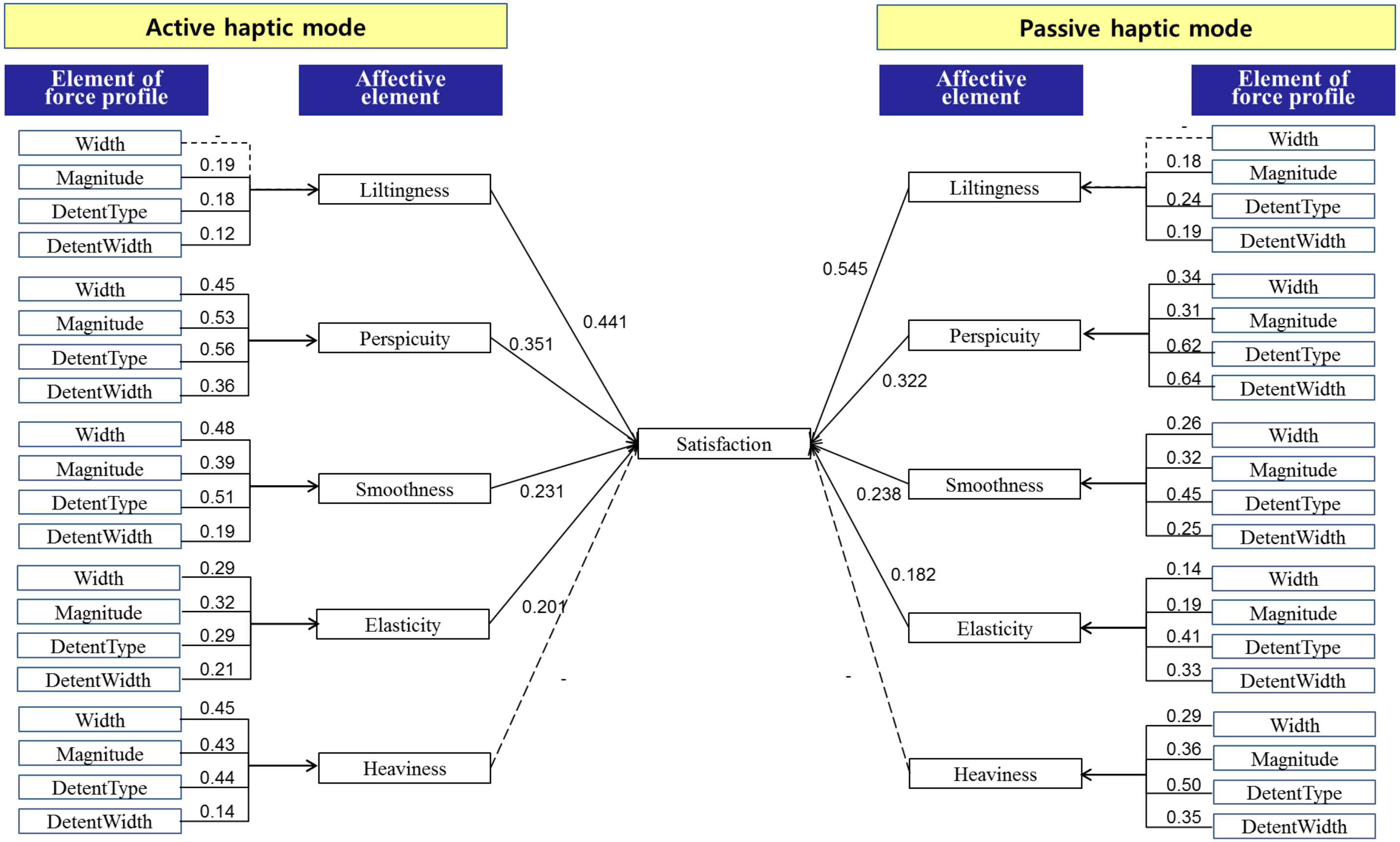


Figure 50 Results of affective modeling in experiment 4 and 5

4.7.2 Effect on affective response according to haptic mode

The effects of mode of haptic have shown the relationship between the affective elements with either force and movement. The elements related to force have shown higher score with active haptic because the active haptic required the users to physically manipulate the jog dial and thus resulted larger sensitivity of kinesthetic perception than in the passive haptic, where the users are only applying force enough to resist the feedbacks (Gandevia, McCloskey & Burke, 1992). However, the elements related to movement have not shown any significant difference with respect to mode of haptic.

The trend with respect to the elements of force profile has shown different pattern in each mode of haptic. In the case of active haptic, the trend has shown consistent pattern of increase or decrease with respect to the elements of force profile, but there was no consistent trend in the case of passive haptic. This observation can be explained by the finding discussed in the study of Lederman et al. (1999), where the range of fluctuation is large for roughness perception with respect to the change of speed in passive haptic due to the lack of information on kinesthetic perception. Moreover, this study has focused on collecting the affective responses rather than attempting to discriminate the stimulations. Thus, as suggested in the previous studies, the exploratory conditions such as methods and time duration of providing stimulation were not set equally in the active haptic and passive haptic. In turn, the result of our study can be interpreted as mentioned from the previous studies about the limitation of collecting information in passive haptic than in active haptic.

Cause of differences between active haptic mode and passive haptic mode can be explained by information to be used to percept and discriminate. On passive haptic mode, only tactile information is used to percept and discriminate, but on active haptic mode, both tactile and kinesthetic information is used. Less information is available at passive haptic mode than at active haptic mode and it has caused underestimation of perceived force and inaccurate perception at passive haptic mode.

Pattern of affective element according to elements of force profile has different trend according to related with psychophysical factor. Affective element related with force has consistent pattern according to magnitude at passive haptic, while affective element related with force has not consistent pattern according to width. And affective element related with movement has consistent pattern according to width at passive haptic, while affective element related with force has not consistent pattern according to magnitude. Although user can't discriminate stimulation exactly at passive haptic than at active haptic, relationship between elements of force profile and affective element has consistent pattern if psychophysical factor related with elements of force profile is same with that related with affective element through this results.

The result of quantification I analysis has also shown higher score of explanation for active haptic. From analyzing the elements for both modes together, the scores of explaining perspicuity has increased from 57% to 60% by analyzing the active haptic only, and smoothness from 40% to 51%. Moreover, with respect to the effect level of elements of force profile, the partial correlation coefficient of Magnitude on perspicuity has increased from 0.31 to 0.53 and those of Width on smoothness from 0.26 to 0.48 which has shown higher correlations when the mode of active haptic was analyzed separately.

Chapter 5. Conclusion

5.1 Summary of findings

This study has examined the current and future issues on haptic modality from the existing studies of the related fields. The examined issues were then analyzed in terms of the affective perception with respect to kinesthetic feedback and the effects of mode of haptic. The main findings of this study are summarized into three aspects as the following.

First, this study has organized the research related to haptic by utilizing the contents analysis and network analysis and has investigated the future research issues in the fields of human-robot interaction and virtual reality. From the results of the network analysis, the related researches were categorized in terms of technology perspective and user perspective. However, in the context of network structure, there was only a relationship between tactile display and cognitive trait of objects connecting the technology and user perspectives, and most of the studies have focused either on the technical aspects and the aspects of the users separately for understanding cognitive mechanisms and have failed to find correlation among various perspectives. If the two perspectives could be applied in the related technologies while acknowledging the relationship between them, the commercialization of the applications using haptic interaction would be feasible in the near future. In turn, there should be more research on the characteristics of haptic perception and the emotions related to kinesthetic sensations. These research topics are all oriented toward the users and mainly concern the characteristics and the effects of haptic stimulation on the user's cognition of such stimulation. Based on the fundamental research of such issues, a systematic approach of developing the technology should be further considered in order to provide more practical applications that could offer various affective experiences to the users.

Second, this study has determined the major affective dimensions that affect kinesthetic feedback perception and has analyzed the relationship between the affective elements and the elements of force profile. The affective dimensions related to kinesthetic sensation of the users can be categorized by the affective elements related to force and movement. This can also be considered as the continuation of the study suggested in the fields of physiology and psychophysics. The relationship between the affective elements and elements of force profile is determined by their characteristics. The affective elements related to force are affected by the elements of force profile related to perceiving force, and those related movement by the variables related to perceiving movement.

Third, the effects of the mode of haptic on the affective perception of the user have been also studied. The mode of haptic affects the affective elements related to perceiving force. It was observed that the presence of the user's physical force to manipulate the device affects the affective elements related to force rather than those of movement.

5.2 Contributions of this research

This study introduces thorough review of the existing research based on contents analysis and network analysis. The result of the contents analysis has allowed us to realize the current trend of the related research areas by organizing key terminologies. Then, through the network analysis, the key terminologies were re-categorized based on the network to analyze the relationship among the related research issues. As a result, the objectivity of determining the relationship among the issues was maintained. The similar insight of understanding the relationship among the related research areas would be also expected in other research fields by utilizing the proposed methodology of this study. The advanced technologies of database and data analysis have made it possible for every research field to benefit from them to investigate and analyze the current research issues of the related fields.

This study has described the emotions related to the kinesthetic sensations of the users in terms of the physiology and psychophysics research fields. The basic structure of emotion has been examined to understand and analyze different emotions, and the main affective elements have been determined. The characteristics of the affective elements and elements of force profile were categorized into force and movement, and the pattern changes of the affective elements were analyzed with respect to each elements of force profile to verify the high correlation between the elements of force profile and the affective elements.

By performing the fundamental research on the affective dimensions related to kinesthetic perception of the users and on the characteristics of feedback elements, the affective perception of complex kinesthetic perception was able to be analyzed, which in turn will allow us to build the foundation to provide the best haptic feedback to the users.

In order to improve the satisfaction of controlling products, the characteristics of the affective elements were analyzed while determining the related characteristics of the elements of force profile that may affect the affective satisfaction. It may be too early to generalize the relationship, but this study suggests the future direction of deeper research on each affective element. This study can be used as the fundamental research to define more practical design guidelines for improving the affective satisfaction related to kinesthetic sensations.

Moreover, the perception of the feedback that the users receive passively has been analyzed, which also suggests further comparative analysis with the feedbacks provided from actively interacting with devices. This study suggests the fundamental structure and elements of the characteristics of the users that need to be considered in designing kinesthetic feedback.

5.3 Limitations and further research

Limitations and further research issues are as follows.

First, the study of current literature was not sufficiently done with the contents analysis and network analysis. Although various fields of research have been examined and the analysis of their relationship has resulted in determining the current issues, the broad scope of studying the literature had the limitation of comprehending the characteristics of each research field. It is always important to see the larger picture of the literature, but further studies on each research field are also important to acknowledge the detailed issues in each field.

Since this study has allowed observing the research trend by analyzing the relationship between each field, further studies need to define the process to decide the methods of future analysis based on this study. In order to analyze the characteristics of each field and the relationship between these characteristics that may result in synergistic effects, each individual field needs to be reviewed thoroughly along with the results of this study. The results of this study may be applied not only to the research fields related to haptic technology but also to other research fields that adapt multidisciplinary approaches in order to verify and improve the methodology suggested in this study.

Second, the analysis of the relationship between the affective elements and the satisfaction score has shown that liltingness has affected the satisfaction the most while there was no elements of force profile that could explain liltingness. This result tells us that liltingness was an important element to improve the satisfaction, but it was not yet clear on how to improve liltingness. This can be understood by the possibilities of external elements that may also affect on determining the affective response beside the psychophysical factors discussed in this study.

Therefore, further research is needed to determine the factors that are related to perceiving affective elements. The psychophysical factors may not affect the affective elements linearly, while there may be also other factors beside the psychophysical factors. Although the stimulation and perception can be described with 1:1 relationship in the psychophysical aspect, they have more complicated network among various elements in the aspect of emotions.

Third, the analysis of different modes of touch has shown limitation to explain the exact cause of their effects on the affective responses. Although there are several studies on tactile sensation with respect to the mode of haptic, there are not sufficient studies related to kinesthetic sensations; thus, it was difficult to derive the explanation of the results from our study.

Therefore, there needs further studies on kinesthetic sensations in terms of the physiological changes with respect to the mode of haptic. Unlike tactile sensation, kinesthetic sensations are largely affected by the contraction of muscle and joint movements. Therefore, the changes of muscle contraction with respect to the mode of haptic should be examined to analyze its effect on the user perception. Although isometric contraction involves exerting forces, it is similar to passive haptic since the position is remained constant. On the other hand, isotonic contraction involves the force of changing forms and thus is similar to active haptic. Further research must also take account of the research fields on isometric and isotonic contractions to determine the additional elements that may affect the affective perception.

Fourth, this study has certain limitation on considering various situation and factors. In the case of the products that involve kinesthetic sensations, there are several different products, such as push-pull type and sliding type, other than the rotary type of product that was used in our study. Although they share common factors, there must also exist several different factors among them. This study has examined the fundamental structure related to kinesthetic sensations, but it still lacks in suggesting the design guidelines for improving the affective satisfaction of the products. Although this study has provided the results of the product evaluation, it was only able to discuss different types of affective elements based on the experiment. In order to analyze deeper about each product, the force profile elements that may affect the affective perception must be determined along with the detailed planning of the experiment on these elements.

The evaluation of various haptic devices that are related to kinesthetic sensations must be performed to generalize the characteristics of the affective elements and elements of force profile. Based on the characteristics of the haptic devices and force profile, the products can be grouped into similar characteristics, and the characteristics of each group needs to be further analyzed. Based on these fundamental studies, the development of more practical haptic device that provides affective feedback to the users will become feasible and thus offer commercialized haptic interaction technology to the customers in the near future.

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Appendix

A. Centrality index

A.1 Eigenvector Centrality

No.	Keyword	Eigenvec n	Eigenvec
1	haptic	0.571	80.769
2	virtual reality	0.34	48.045
3	tactile	0.337	47.624
4	touch	0.202	28.521
5	force feedback	0.189	26.704
6	tactile display	0.155	21.929
7	haptic interface	0.149	21.113
8	perception	0.141	19.886
9	vision	0.134	18.997
10	virtual environment	0.123	17.414
11	teleoperation	0.115	16.201
12	somatosensory	0.113	15.999
13	tactile feedback	0.089	12.639
14	texture	0.087	12.288
15	psychophysics	0.086	12.172
16	fmri	0.079	11.201
17	multisensory	0.077	10.858
18	haptic rendering	0.074	10.435
19	human	0.072	10.161
20	multisensory integration	0.068	9.564
21	haptic device	0.064	9.1
22	object recognition	0.064	9.023
23	tactile sensor	0.061	8.564
24	simulation	0.06	8.481
25	haptic feedback	0.059	8.37
26	vibrotactile	0.059	8.302
27	visual	0.059	8.276
28	shape	0.058	8.212
29	cross-modal	0.057	8.002
30	training	0.056	7.851

A.2 Degree Centrality

No.	Keyword	OutDegree	InDegree	NrmOutDeg	NrmInDeg
1	haptic	1857	1857	0.659	0.659
2	virtual reality	757	757	0.269	0.269
3	tactile	698	698	0.248	0.248
4	touch	561	561	0.199	0.199
5	tactile display	431	431	0.153	0.153
6	haptic interface	410	410	0.146	0.146
7	tactile sensor	376	376	0.133	0.133
8	haptic rendering	333	333	0.118	0.118
9	haptic feedback	333	333	0.118	0.118
10	perception	275	275	0.098	0.098
11	haptic device	265	265	0.094	0.094
12	force feedback	250	250	0.089	0.089
13	haptic perception	244	244	0.087	0.087
14	vision	243	243	0.086	0.086
15	psychophysics	213	213	0.076	0.076
16	tactile feedback	209	209	0.074	0.074
17	virtual environment	194	194	0.069	0.069
18	fmri	191	191	0.068	0.068
19	somatosensory	190	190	0.067	0.067
20	tactile perception	186	186	0.066	0.066
21	haptic display	175	175	0.062	0.062
22	multisensory	167	167	0.059	0.059
23	teleoperation	167	167	0.059	0.059
24	human	163	163	0.058	0.058
25	texture	159	159	0.056	0.056
26	haptic interaction	145	145	0.051	0.051
27	multisensory integration	140	140	0.05	0.05
28	blindness	131	131	0.047	0.047
29	attention	125	125	0.044	0.044
30	somatosensory cortex	118	118	0.042	0.042

A.3 Betweenness Centrality

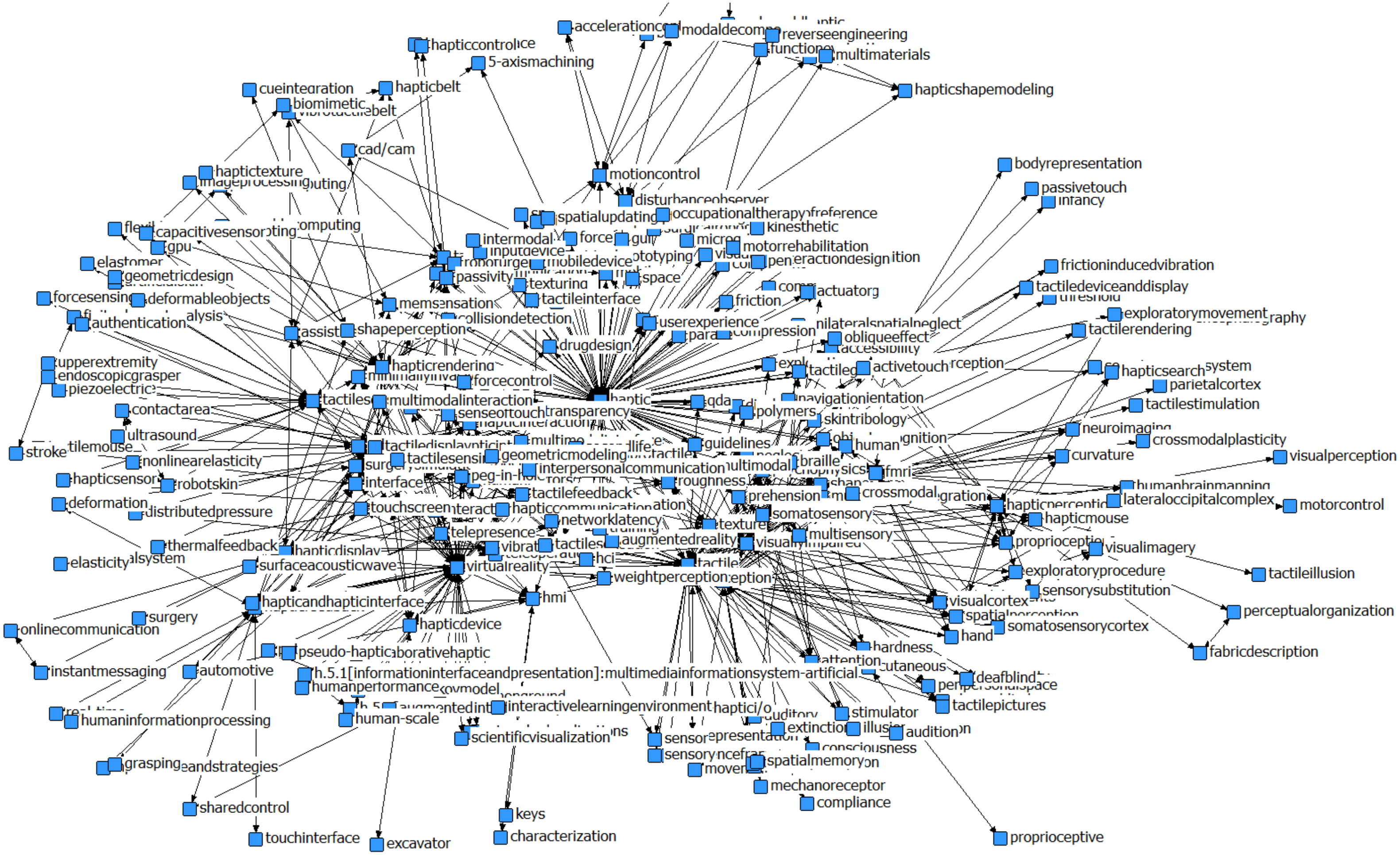
No.	Keyword	Betweenness	nBetweenness
1	haptic	3879655	29.582
2	virtual reality	1182930	9.02
3	tactile	920504.2	7.019
4	tactile sensor	872408.1	6.652
5	touch	857189.8	6.536
6	haptic interface	851106.2	6.49
7	tactile display	677545.9	5.166
8	haptic rendering	599222.9	4.569
9	haptic feedback	591827.9	4.513
10	psychophysics	470063.5	3.584
11	haptic device	415278.7	3.166
12	tactile perception	414142.2	3.158
13	haptic perception	385594.7	2.94
14	virtual environment	269557.3	2.055
15	tactile feedback	268085.9	2.044
16	neuropathic pain	265433.6	2.024
17	perception	260068.4	1.983
18	haptic display	247031.6	1.884
19	tactile sensing	232857.8	1.776
20	force feedback	230842.6	1.76
21	tactile stimulation	227787.8	1.737
22	fmri	189795.7	1.447
23	haptic interaction	180694.9	1.378
24	attention	173964.1	1.326
25	somatosensory cortex	157532	1.201
26	aging	155171.5	1.183
27	blind	142031.3	1.083
28	human	141811.2	1.081
29	rat	141374.4	1.078
30	tactile sensation	136175.8	1.038

A.4 Closeness Centrality

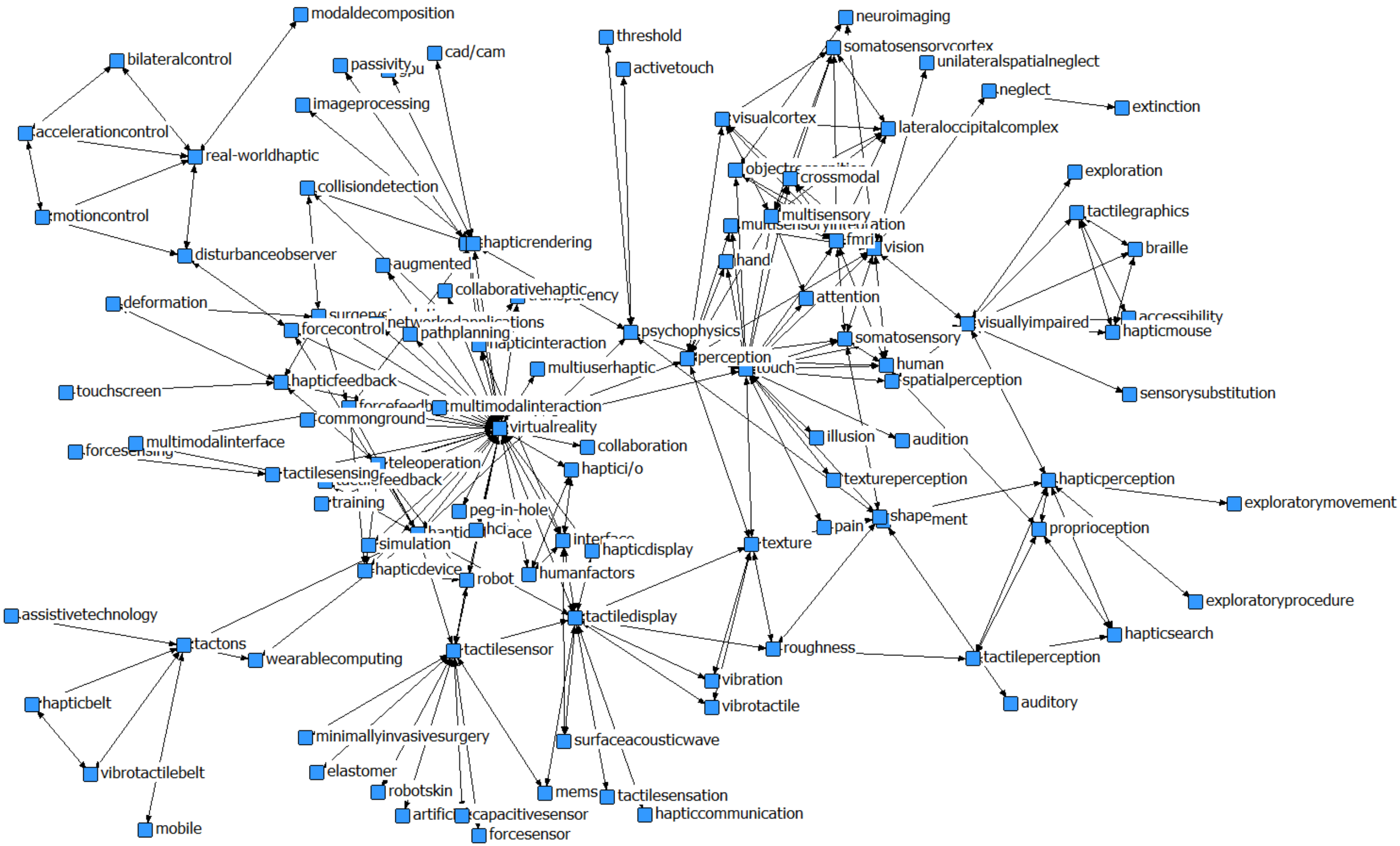
No.	Keyword	Farness	nCloseness
1	haptic	2170419	0.233
2	virtualreality	2171260	0.233
3	hapticinterface	2171796	0.232
4	touch	2171908	0.232
5	tactile	2171932	0.232
6	tactiledisplay	2171984	0.232
7	forcefeedback	2172156	0.232
8	teleoperation	2172303	0.232
9	psychophysics	2172353	0.232
10	blind	2172358	0.232
11	hapticdevice	2172484	0.232
12	tactileperception	2172507	0.232
13	perception	2172549	0.232
14	tactilefeedback	2172588	0.232
15	interface	2172603	0.232
16	tactilesensor	2172664	0.232
17	hci	2172689	0.232
18	roughness	2172694	0.232
19	vibration	2172695	0.232
20	hapticperception	2172750	0.232
21	hapticdisplay	2172779	0.232
22	human	2172824	0.232
23	crendering	2172837	0.232
24	design	2172905	0.232
25	texture	2172914	0.232
26	objectrecognition	2172921	0.232
27	robotics	2173040	0.232
28	fmri	2173055	0.232
29	hapticfeedback	2173056	0.232
30	robot	2173074	0.232

B. Network diagram

B.1 Cut off value = 2



B.2 Cut off value = 3



C. Contents analysis raw data

C.1 After 2000

No.	Keyword	Total	Title	Keyword	Abstract	Word1	Word2	Word3
1	visual	3441	405	268	2768	visual	visualization	visually
2	system	3195	299	188	2708			
3	feedback	2559	288	291	1980			
4	force	2501	140	197	2164			
5	virtual	2260	268	382	1610			
6	device	2188	167	153	1868			
7	stimulation	2073	183	55	1835	stimuli	stimulus	
8	object	1974	134	62	1778			
9	perception	1791	277	337	1177	perceptual	percepts	
10	display	1688	223	238	1227	displaying		
11	interface	1684	209	400	1075			
12	interact	1670	216	207	1247	interacting	interaction	
13	information	1663	100	96	1467			
14	model	1643	157	155	1331	modeling		
15	human	1617	183	229	1205			
16	experiment	1606	34	13	1559			
17	user	1568	22	154	1392			
18	control	1482	157	186	1139			
19	sensor	1482	221	230	1031			
20	touch	1431	119	202	1110			
21	performance	1325	60	35	1230			
22	environment	1249	137	90	1022			
23	simulation	1234	118	121	995	simulator	simulate	
24	robot	1212	197	181	834	robotic		
25	hand	1208	79	58	1071			
26	effect	1173	184	28	961	effective		
27	surface	1157	95	47	1015			
28	time	1030	73	48	909			
29	multi	1018	134	185	699	Multidimen-sional	multimodal	multiple
30	surgery	1014	152	126	736			
31	sensory	869	65	98	706			

32	vibration	833	75	96	662	vibrotactile		
33	shape	831	65	59	707			
34	modal	820	71	62	687	modality		
35	contact	791	46	38	707	contacting		
36	finger	786	72	22	692			
37	rendering	786	113	125	548			
38	spatial	770	74	79	617	spatio		
39	texture	767	77	82	608			
40	movement	755	50	29	676			
41	response	720	40	18	662			
42	sensation	712	51	58	603			
43	audio	676	90	59	527	audition	auditory	
44	integrate	656	70	64	522	integrating	integration	
45	neural	645	99	47	499	neuroimaging	neurological	Neurophy-siological
46	discriminate	637	54	50	533	discrimination		
47	measure	625	38	23	564	measurement		
48	function	621	48	41	532			
49	cue	608	52	17	539	cueing		
50	motor	594	44	69	481			
51	recognition	590	59	65	466			
52	image	587	33	41	513			
53	motion	569	43	42	484			
54	physical	552	85	18	449			
55	computer	542	110	68	364			
56	detect	539	26	51	462	detecting	detection	
57	skin	531	51	50	430			
58	blind	526	61	67	398	blindfolded	blindness	
59	representations	506	60	43	403			
60	position	503	19		484			
61	communicate	499	42	53	404	Communi-cating	Communi-cation	
62	sense	494	26	23	445			
63	mechanical	488	14	13	461			
64	actuator	482	98	38	346			
65	dynamic	476	48	32	396	dynamically		
66	behavior	474	104	13	357	behavioral		
67	feel	471	30		441	feeling		
68	tool	471	40	18	413			

69	exploratory	470	30	17	423	explore		
70	sensing	469	72	70	327			
71	guidance	466	22	22	422	guide	guidelines	
72	body	465	38	33	394			
73	experience	461	28	15	418			
74	tele	451	57	91	303	Telemani-pulation	Tele-operation	telerobotic
75	signal	440	12	14	414			
76	cortex	439	48	74	317			
77	pain	439	85	67	287			
78	manipulation	435	32	17	386	manipulate		
79	somatosensory	434	45	95	294			
80	properties	433	26	15	392			
81	network	416	49	44	323			
82	material	415	60	26	329			
83	active	406	40	45	321	actively		
84	technique	395	15	17	363			
85	space	393	39	29	325			
86	tissue	381	28	20	333			
87	brain	380	123	29	228			
88	sensibility	379	22	13	344	sensitive		
89	impaired	367	37	42	288	impairment		
90	stability	365	21	41	303			
91	map	364	11	13	340	mapping		
92	prototyping	356	19	26	311			
93	orientation	355	13	24	318			
94	field	354	11	18	325			
95	exploration	350	43	22	285			
96	pressure	345	29	32	284	press		
97	cross	340	15	59	266	crossed	crossing	crossmodal
98	assessment	338	19	13	306			
99	deformable	336	40	36	260	deformation	deformations	
100	element	330	12	23	295			
101	array	320	30	16	274			
102	kinaesthetic	320	19	11	290	kinematic	kinesthetic	
103	dimension	311	30	12	269	dimensional		
104	fingertip	306	21	11	274			
105	stiffness	303	21	23	259			
106	mobile	299	42	48	209	mobility		

107	roughness	293	28	37	228			
108	dof	292	48	11	233			
109	temporal	274	28	17	229			
110	memory	273	46	46	181			
111	friction	272	28	34	210			
112	graphic	271	25	26	220			
113	soft	269	29	22	218			
114	grasp	268	22	18	228			
115	locating	268	14		254	location		
116	affect	254	11		243	affected	affective	
117	arm	252	18	12	222			
118	assist	252	32	18	202	assistance	assistive	
119	distributed	244	13	15	216	distribution		
120	passive	244	31	16	197			
121	adaptation	240	13	12	215	adapt	adapted	
122	magnetic	235	29	47	159			
123	navigation	231	29	27	175			
124	children	229	37	14	178			
125	nerve	216	22	18	176			
126	medical	214	29	32	153			
127	primary	214	14	14	186			
128	cortical	213	30	18	165			
129	augment	207	34	33	140	augmentation	augmented	
130	cognition	205	57	16	132	cognitive		
131	interactive	205	39	18	148			
132	factor	202	12	27	163			
133	resolution	198	20	14	164			
134	product	192	27	25	140			
135	illusion	188	15	39	134			
136	bilateral	187	18	22	147			
137	presentation	185	18	47	120			
138	flexibility	182	23	15	144	flexible		
139	learn	182	46	48	88			
140	artificial	174	18	34	122			
141	elastic	172	13	16	143	elasticity		
142	fmri	169	31	40	98			
143	curvature	167		11	156	curve		
144	game	166	16	11	139			

145	threshold	166	13	19	134			
146	machine	162	13	60	89			
147	spinal	162	18	20	124			
148	invasive	159	30	27	102			
149	screen	159	14	14	131			
150	emotion	158	11	11	136	affective		
151	mouse	158	22	16	120			
152	torque	156	11	11	134			
153	inputs	155	14	24	117			
154	micro	151	27	27	97			
155	thermal	151	20	17	114			
156	braille	150	15	20	115			
157	search	149	18	13	118			
158	collaboration	147	21	30	96	collaborative		
159	compliance	146	15	11	120			
160	proprioception	146		16	130	proprioceptive		
161	assembly	144	17	18	109			
162	engineering	144	46	16	82			
163	methodology	144	29	19	96			
164	acuity	140	15	13	112			
165	limb	140	20		120			
166	transfer	139	13	14	112			
167	stroke	134	15	12	107			
168	piezoelectric	131	12	15	104			
169	injury	130	20	13	97			
170	needle	119	14	13	92			
171	shared	118	11	12	95			
172	cutaneous	115		18	97			
173	frequencies	114	13	16	85			
174	receptor	113			113			
175	media	111	12	11	88			
176	social	108	16	20	72			
177	education	107	16	15	76			
178	self	107	12	11	84			
179	dental	104	15	13	76			
180	planning	102	11	15	76			
181	optical	101	13	11	77			

C.2 Before 2000

No.	Keyword	Total	Title	Key word	Abstract	Word1	Word2	Word3
1	stimulation	2432	328	119	1985	simulator	simulate	
2	visual	1808	249	65	1494	visual	visualization	visually
3	system	1724	215	48	1461			
4	sensor	1592	364	26	1202			
5	hand	1333	176	25	1132			
6	control	1229	98	20	1111			
7	force	1182	95	49	1038			
8	surface	915	69	10	836			
9	discriminate	906	142	58	706	discrimination		
10	human	877	181	51	645			
11	sensory	869	119	69	681			
12	sensory	869	119	69	681			
13	display	795	139	29	627			
14	neural	777	89	33	655			
15	perception	754	198	48	508			
16	robot	740	161	33	546	robotic		
17	performance	738	72		666			
18	touch	730	72	43	615			
19	device	728	65	10	653			
20	finger	722	60	15	647			
21	virtual	716	114	37	565			
22	feedback	710	103	36	571			
23	interface	641	134	26	481			
24	sensitivity	641	75	29	537			
25	skin	614	55	22	537			
26	time	604	33	13	558			
27	threshold	601	31	15	555			
28	shape	593	61	8	524			

29	movement	589	55	25	509			
30	spatial	573	71	21	481			
31	cortex	538	95	85	358			
32	somatosensory	532	103	100	329			
33	blind	472	67	21	384			
34	interaction	464	59	28	377	interacting	interaction	
35	surgery	429	59	25	345			
36	user	419	20	6	393			
37	modal	399	24		375			
38	texture	387	23	12	352			
39	exploratory	382	51	8	323	exploration		
40	vibration	372	16	12	344			
41	brain	365	155	34	176			
42	pressure	330	23	23	284			
43	body	328	27	8	293			
44	impaired	318	26		292			
46	active	292	36	11	245			
47	pain	281	57	54	170			
48	affect	233	9		224			
49	cutaneous	232	25	17	190			
50	fingertip	186	12		174			
51	tele	182	8	5	169	Telemani-pulation	Teleope-ration	telerobotic
52	cognition	160	39		121			
53	arm	157	15		142			
54	passive	151	18		133			
55	stiffness	146	16		130			
56	kinaesthetic	145	21	8	116			
57	roughness	134	17	12	105			
58	feel	131			131			
59	acuity	108	15	8	85			
60	hardness	104			104			

61	deformable	93			93			
62	actuator	77	42		35			
63	forearm	50			50			
64	audio	39			39			
65	emotion	6			6			

D. Descriptive statistics and design variable

D.1 Experiment 1

Car	Area	Slope	Hardness	Consistency	Thickness	Satisfaction
Accord	Fender	2.55	-0.39	-0.60	-0.48	-0.50
Accord	Front Door	2.54	-0.25	-0.49	-0.32	-0.29
Accord	Hood	2.27	-0.18	-0.14	-0.24	-0.08
Accord	Quarter Panel	3.09	0.16	0.11	0.05	0.00
Accord	Rear Door	1.13	0.30	0.29	0.10	0.25
Accord	Roof	2.66	-0.24	-0.31	-0.33	-0.18
Accord	Trunk Lid	2.46	0.50	0.42	0.37	0.36
Avalon	Fender	3.58	0.36	0.31	0.20	0.26
Avalon	Front Door	1.82	-0.39	-0.62	-0.61	-0.57
Avalon	Hood	3.43	0.04	-0.02	-0.32	-0.08
Avalon	Quarter Panel	1.13	-0.92	-1.08	-0.96	-1.02
Avalon	Rear Door	2.03	-0.28	-0.53	-0.47	-0.49
Avalon	Roof	1.83	0.05	0.05	-0.05	0.10
Avalon	Trunk Lid	2.22	-0.19	-0.22	-0.28	-0.32
Camry	Front Door	1.98	-0.05	-0.29	-0.16	-0.11
Camry	Hood	4.38	0.79	0.69	0.58	0.56
Camry	Quarter Panel	3.21	0.26	0.05	0.16	0.11
Camry	Rear Door	3.44	0.15	-0.05	0.03	0.17
Camry	Roof	2.18	-0.12	-0.20	-0.20	-0.04
Camry	Trunk Lid	4.73	0.77	0.60	0.50	0.68
ES350	Fender	1.93	0.45	0.40	0.32	0.37
ES350	Front Door	2.21	-0.06	-0.05	-0.16	-0.03
ES350	Hood	2.67	-0.21	-0.38	-0.18	-0.13
ES350	Quarter Panel	5.80	0.79	0.70	0.61	0.67
ES350	Roof	2.91	0.51	0.51	0.51	0.47
ES350	Trunk Lid	3.53	0.95	0.98	0.78	0.77
K7	Fender	2.31	-0.02	-0.19	-0.13	0.00
K7	Front Door	2.34	-0.07	-0.11	-0.21	-0.17

K7	Hood	1.50	-0.84	-1.16	-1.02	-0.80
K7	Quarter Panel	2.38	-0.14	-0.29	-0.32	-0.21
K7	Rear Door	1.04	0.04	-0.04	0.01	-0.10
K7	Roof	1.84	-0.47	-0.56	-0.58	-0.48
K7	Trunk Lid	3.05	0.19	-0.01	0.11	0.21
Maxima	Fender	1.88	-0.44	-0.53	-0.53	-0.43
Maxima	Front Door	2.40	-0.05	-0.19	-0.18	-0.13
Maxima	Hood	1.94	-0.66	-0.77	-0.71	-0.53
Maxima	Quarter Panel	1.34	-0.55	-0.74	-0.59	-0.45
Maxima	Roof	4.05	0.33	0.27	0.29	0.23
Maxima	Trunk Lid	3.32	0.79	0.74	0.67	0.56
YF Sonata	Fender	2.55	0.38	0.38	0.26	0.31
YF Sonata	Front Door	1.80	0.57	0.32	0.31	0.39
YF Sonata	Hood	1.99	-0.26	-0.52	-0.35	-0.19
YF Sonata	Quarter Panel	2.34	-0.62	-1.01	-0.68	-0.68
YF Sonata	Rear Door	0.99	0.35	0.05	0.11	0.23
YF Sonata	Roof	1.90	0.22	0.22	0.18	0.20
YF Sonata	Trunk Lid	3.50	1.01	1.01	0.86	0.87
Insignia	Fender	4.10	0.65	0.59	0.38	0.43
Insignia	Front Door	1.99	-0.04	-0.24	-0.26	-0.18
Insignia	Hood	2.23	-0.25	-0.29	-0.36	-0.17
Insignia	Quarter Panel	2.42	-0.17	-0.33	-0.26	-0.21
Insignia	Rear Door	1.15	-0.26	-0.40	-0.40	-0.28
Insignia	Roof	1.75	-0.06	0.05	-0.06	0.02
Insignia	Trunk Lid	2.02	0.50	0.49	0.35	0.31
Torus	Fender	4.96	0.50	0.48	0.25	0.44
Torus	Front Door	1.91	-0.58	-0.73	-0.61	-0.51
Torus	Hood	2.44	0.26	0.08	0.10	0.05
Torus	Quarter Panel	3.10	0.11	-0.01	-0.15	0.00
Torus	Rear Door	1.42	-0.51	-0.64	-0.60	-0.62
Torus	Roof	1.52	-0.20	-0.28	-0.47	-0.44
Torus	Trunk Lid	3.45	0.44	0.51	0.31	0.40

D.2 Experiment 2

No	peak	dp1	dp2	Consis-tency	Smooth-ness	Solidity	Sleek-ness	Elasticity	Satisfac-tion
1	41	5.57	13.38	0.40	0.02	0.39	0.52	0.79	-0.02
2	39	1.65	19.98	0.75	0.37	0.29	0.57	0.09	0.37
3	40	5.90	14.49	-0.48	-0.78	-0.47	-0.10	-0.11	-0.76
4	40	0.18	23.03	0.31	0.05	0.26	0.41	0.71	0.35
5	39	5.56	14.36	0.44	0.43	-0.30	0.48	0.71	0.29
6	41	2.71	18.98	-0.20	0.33	-0.60	0.20	0.46	-0.17
7	39	5.64	14.37	-0.22	-0.45	0.15	-0.12	-0.54	-0.17
8	39	1.10	25.77	0.40	0.38	0.24	0.47	0.50	0.40
9	41	1.67	18.18	-1.17	-0.96	-0.63	-1.17	-0.85	-1.20
10	40	3.44	13.57	0.09	-0.66	0.42	0.16	-0.31	0.44
11	39	5.06	16.08	0.25	0.36	-0.12	0.15	0.76	0.16
12	40	0.89	19.47	0.42	0.48	0.07	0.66	0.90	0.36
13	39	4.03	16.13	-0.06	-0.14	-0.17	0.07	0.03	0.13
14	40	1.99	16.64	-1.20	-1.64	0.08	-1.62	-1.32	-1.34
15	41	4.46	19.10	0.56	-0.07	0.58	0.61	0.47	0.63
16	39	4.18	13.44	0.36	-0.23	0.72	0.38	0.23	0.63
17	40	2.17	19.00	-0.60	-0.62	-0.87	-0.75	-0.69	-0.95

D.3 Experiment 3

No.	Smooth -ness	Sense of unity	Perspi -cuity	Heavi -ness	Satisfac -tion	0-1p degree	1p-2p degree	2p-3p degree	3p-fp degree	0-1p height	1p-2p height	2p-3p height	3p-fp height
1	-0.67	-0.39	0.35	0.74	-0.46	3.00	3.00	3.00	1.00	2.00	2.00	3.00	3.00
2	0.80	0.49	0.39	-0.42	0.79	1.00	3.00	2.00	4.00	2.00	3.00	2.00	2.00
3	-0.51	-0.08	0.52	0.14	-0.05	1.00	1.00	1.00	3.00	2.00	4.00	3.00	1.00
4	0.30	0.02	0.56	-0.11	0.36	3.00	1.00	4.00	4.00	1.00	1.00	2.00	2.00
5	-1.09	-0.58	0.09	0.43	-0.86	3.00	3.00	1.00	2.00	3.00	4.00	3.00	4.00
6	-0.01	0.20	0.65	0.21	0.01	2.00	3.00	3.00	2.00	2.00	2.00	3.00	3.00
7	-0.56	-0.35	0.54	0.06	-0.05	2.00	1.00	3.00	1.00	2.00	2.00	1.00	1.00
8	-0.49	-0.24	0.56	-0.19	-0.01	1.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00
9	-0.53	-0.02	0.89	0.41	0.00	3.00	3.00	3.00	1.00	1.00	1.00	3.00	3.00
10	-0.24	0.15	-0.83	0.14	-0.64	2.00	3.00	1.00	3.00	3.00	4.00	3.00	4.00
11	0.07	0.00	0.23	-0.53	-0.05	2.00	2.00	1.00	2.00	1.00	3.00	2.00	1.00
12	-0.65	-0.03	0.27	0.62	-0.45	2.00	3.00	1.00	4.00	3.00	4.00	3.00	3.00
13	0.37	0.01	0.09	-0.27	0.13	1.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00
14	0.27	-0.26	0.59	-0.13	0.28	2.00	1.00	4.00	4.00	1.00	1.00	2.00	2.00
15	-0.37	-0.19	0.66	0.17	-0.19	2.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00
16	-0.72	-0.33	0.25	0.16	-0.49	2.00	3.00	1.00	3.00	2.00	2.00	3.00	3.00

D.4. Experiment 4 & 5

DetentType		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
full sine	Mean	4.60	4.17	3.90	3.75	3.77	63.83
	N	300	300	300	300	300	300
	Std. deviation	1.654	1.607	1.561	1.534	1.423	19.107
	Kurtosis	-.815	-.840	-.940	-.908	-.671	.588
	Skewness	-.358	-.343	-.046	.074	-.073	-1.014
full tri	Mean	2.77	5.55	2.89	2.54	3.36	57.77
	N	225	225	225	225	225	225
	Std. deviation	1.420	1.145	1.293	1.146	1.553	19.869
	Kurtosis	-.733	.980	-.186	.710	-.562	-.208
	Skewness	.453	-1.006	.434	.761	.321	-.684
half sine	Mean	4.55	4.30	4.00	3.58	3.89	64.64
	N	300	300	300	300	300	300
	Std. deviation	1.678	1.536	1.651	1.352	1.537	19.165
	Kurtosis	-.602	-.709	-.909	-.506	-.816	.477
	Skewness	-.482	-.419	-.001	.202	-.031	-.879
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

Width		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
2	Mean	3.37	5.29	3.23	2.79	3.69	61.73
	N	275	275	275	275	275	275
	Std. deviation	1.652	1.122	1.487	1.215	1.625	19.713
	Kurtosis	-.973	.120	-.721	-.373	-.922	-.387
	Skewness	.211	-.687	.365	.517	.145	-.675
4	Mean	3.91	4.68	3.59	3.19	3.64	61.93
	N	275	275	275	275	275	275
	Std. deviation	1.561	1.383	1.458	1.329	1.481	19.671
	Kurtosis	-.791	-.320	-.585	-.395	-.755	.393
	Skewness	-.109	-.462	.135	.334	.060	-.852
6	Mean	4.98	3.81	4.17	4.11	3.78	63.75
	N	275	275	275	275	275	275
	Std. deviation	1.774	1.793	1.698	1.502	1.433	19.215
	Kurtosis	-.338	-1.200	-.988	-.751	-.495	.903
	Skewness	-.809	.032	-.140	-.122	-.091	-1.062
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

Magnitude		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
50	Mean	3.30	5.19	3.15	2.76	3.41	58.82
	N	275	275	275	275	275	275
	Std. deviation	1.721	1.278	1.571	1.238	1.543	19.700
	Kurtosis	-.777	.374	-.325	-.559	-.914	-.234
	Skewness	.415	-.817	.611	.407	.195	-.598
75	Mean	4.07	4.72	3.65	3.28	3.78	63.28
	N	275	275	275	275	275	275
	Std. deviation	1.718	1.501	1.507	1.398	1.517	18.912
	Kurtosis	-.912	-.142	-.841	-.367	-.611	.609
	Skewness	-.202	-.708	.049	.459	-.011	-1.004
100	Mean	4.88	3.87	4.19	4.04	3.91	65.32
	N	275	275	275	275	275	275
	Std. deviation	1.578	1.649	1.546	1.448	1.442	19.477
	Kurtosis	-.434	-1.034	-.799	-.807	-.624	.785
	Skewness	-.593	-.050	-.105	-.019	.014	-1.046
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

Mode of haptic		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
active	Mean	4.38	4.45	3.83	3.60	3.72	63.93
	N	375	375	375	375	375	375
	Std. deviation	1.674	1.601	1.600	1.429	1.528	19.247
	Kurtosis	-.674	-.631	-.830	-.682	-.726	.571
	Skewness	-.416	-.505	.022	.192	.046	-.946
passive	Mean	3.84	4.71	3.53	3.16	3.69	61.26
	N	450	450	450	450	450	450
	Std. deviation	1.852	1.553	1.585	1.459	1.505	19.705
	Kurtosis	-1.133	-.470	-.793	-.469	-.762	.035
	Skewness	.103	-.601	.288	.477	.047	-.790
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

E. ANOVA Table of experiment 4 & 5

DetentType		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	535.100	2	267.550	104.125	.000
	Within Groups	2112.129	822	2.569		
	Total	2647.229	824			
smoothness	Between Groups	284.066	2	142.033	65.921	.000
	Within Groups	1771.090	822	2.155		
	Total	2055.156	824			
Elasticity	Between Groups	186.907	2	93.453	40.064	.000
	Within Groups	1917.416	822	2.333		
	Total	2104.322	824			
Heaviness	Between Groups	213.488	2	106.744	56.807	.000
	Within Groups	1544.592	822	1.879		
	Total	1758.080	824			
Liltingness	Between Groups	37.874	2	18.937	8.403	.000
	Within Groups	1852.369	822	2.253		
	Total	1890.242	824			
satisfaction	Between Groups	6928.034	2	3464.017	9.263	.000
	Within Groups	307407.547	822	373.975		
	Total	314335.581	824			

Width		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	369.913	2	184.956	66.760	.000
	Within Groups	2277.316	822	2.770		
	Total	2647.229	824			
smoothness	Between Groups	305.804	2	152.902	71.847	.000
	Within Groups	1749.353	822	2.128		
	Total	2055.156	824			
Elasticity	Between Groups	126.112	2	63.056	26.201	.000
	Within Groups	1978.211	822	2.407		
	Total	2104.322	824			
Heaviness	Between Groups	251.629	2	125.815	68.651	.000
	Within Groups	1506.451	822	1.833		
	Total	1758.080	824			
Liltingness	Between Groups	2.868	2	1.434	.625	.536
	Within Groups	1887.375	822	2.296		
	Total	1890.242	824			
satisfaction	Between Groups	674.955	2	337.478	.884	.413
	Within Groups	313660.625	822	381.582		
	Total	314335.581	824			

Magnitude		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	344.182	2	172.091	61.422	.000
	Within Groups	2303.047	822	2.802		
	Total	2647.229	824			
smoothness	Between Groups	245.331	2	122.665	55.713	.000
	Within Groups	1809.825	822	2.202		
	Total	2055.156	824			
Elasticity	Between Groups	150.868	2	75.434	31.742	.000
	Within Groups	1953.455	822	2.376		
	Total	2104.322	824			
Heaviness	Between Groups	227.920	2	113.960	61.219	.000
	Within Groups	1530.160	822	1.862		
	Total	1758.080	824			
Liltingness	Between Groups	36.686	2	18.343	8.135	.000
	Within Groups	1853.556	822	2.255		
	Total	1890.242	824			
satisfaction	Between Groups	6066.839	2	3033.419	8.089	.000
	Within Groups	308268.742	822	375.023		
	Total	314335.581	824			

Mode of haptic		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	58.765	1	58.765	18.684	.000
	Within Groups	2588.464	823	3.145		
	Total	2647.229	824			
smoothness	Between Groups	13.875	1	13.875	5.594	.018
	Within Groups	2041.282	823	2.480		
	Total	2055.156	824			
Elasticity	Between Groups	18.409	1	18.409	7.263	.007
	Within Groups	2085.913	823	2.535		
	Total	2104.322	824			
Heaviness	Between Groups	38.725	1	38.725	18.536	.000
	Within Groups	1719.355	823	2.089		
	Total	1758.080	824			
Liltingness	Between Groups	.198	1	.198	.086	.769
	Within Groups	1890.044	823	2.297		
	Total	1890.242	824			
satisfaction	Between Groups	1458.427	1	1458.427	3.836	.050
	Within Groups	312877.154	823	380.167		
	Total	314335.581	824			

F. Questionnaire

F.1 Experiment 1

자동차 외판 강성 감성 평가 실험

본 평가 실험에 참여해 주셔서 대단히 감사합니다. **서울대학교 휴먼인터페이스시스템 연구실은 사용자가 자동차 외판과의 접촉에서 느끼는 감성에 대한 연구**를 진행하고 있습니다. 사용자는 자동차 외판과 자주 접촉하게 되고, 외판의 강도(외판의 딱딱함 또는 부드러움)에 따라 차에 대한 고급스러움 또는 저급함을 느낄 수 있습니다. 이에 본 실험은 자동차 외판의 강도에 대한 사용자의 느낌(감성)을 파악하여 사용자가 선호하는 외판의 강도가 어느 정도인지 파악하고자 합니다. 귀하의 평가는 자동차 외판에 대한 사용자 만족감을 향상시키고 원가를 절감하는 외판 설계에 많은 도움이 될 것입니다. 본 평가 실험에 **한 시간**이 소요되며, 귀하께 소정의 평가비가 지급됩니다. 본 조사 질문의 응답내용은 통계법 제8조에 의거하여 제품의 개선 및 개발의 목적으로만 사용됩니다.

기본 인적 사항

1. 귀하는 다음 중 어느 나이 구간에 해당하나요?
   ① 20 ~ 29세 ② 30 ~ 39세 ③ 40 ~ 49세 ④ 50 ~ 59 세

2. 귀하의 직업은 다음 중 어디에 해당하나요?
   ① 학생 ② 직장인 ③ 기타

3. 귀하는 한 달에 몇 번 정도 직접 세차 또는 외판 관리를 하시나요?
   ① 월 1회 미만 ② 월 1 ~ 2회 ③ 월 2 ~ 3회 ④ 월 4회 이상

4. 귀하는 현재까지 자동차 외판의 꿀렁임*을 얼마나 자주 경험하셨나요?
   ① 경험 못함 ② 조금 경험함 ③ 자주 경험함

   *** 외판에 힘을 가했을 때 외판이 일정하게 변형되다가 어느 시점에서 급격히 변형되는 느낌**

5. 운전 경력은 대략적으로 얼마나 되시나요?
   ① 1년 이하 ② 1 ~ 5년 ③ 5 ~ 10년 ④ 10년 이상

6. 차량 구매 시 자동차의 외판 강성을 어느 정도 고려하시나요?
   ① 전혀 고려하지 않음 ② 조금 고려함 ③ 많이 고려함

평가 시나리오 및 평가 설문 문항

자동차 외판 강성 관련 감성 평가 시나리오

다음은 자동차 외판의 사용자 감성 평가를 위한 평가 시나리오(가정된 상황)입니다. 귀하는 자동차를 세차하거나 자동차에 기대다가 아래 그림과 같이 7개의 외판 부위에서 약한 부위들을 발견하게 되었습니다(각 차량의 외판 부위 중 표시된 곳). 이를 이상하게 여겨 이 부위를 손바닥으로 힘껏 눌러보았습니다. 이러한 상황을 가정하시고 평가할 차의 외판 부위를 **주로 사용하는 손의 손바닥**으로 **힘껏 5-10 회** 눌러본 후 아래 표의 문항들을 평가해 주시기 바랍니다.

외판 평가 부위

귀하는 본 평가실험에서 다음과 같이 자동차 외판의 부위를 평가하게 됩니다.

자동차 외판 강성 관련 감성 평가 문항

귀하께서는 다음 문항들을 외판 부위를 눌러본 후 평가해야 합니다. 천천히 읽어 이해하신 후 다음 페이지를 이용하여 평가해 주세요. 의문점이 있으시다면 실험 진행자에게 문의하세요.

No.	설문 문항	형용사 pair
1	자동차 외판이 강한 충격에 견디는 단단한 정도가 손바닥으로 누를 때 얼마나 된다고 느껴지십니까?	약한 ↔ 단단한
2	자동차의 외판을 손바닥으로 누를 때 외판이 들어가는 느낌은 어떻습니까?	*꿀렁거리는 ↔ 일정한
3	자동차 외판을 손바닥으로 누를 때 외판 자체의 만족스러운 정도가 얼마나 느껴지십니까?	불만족한 ↔ 만족한
4	자동차 외판을 손바닥으로 누를 때 느껴지는 외판의 두께 정도는 어느 정도로 느껴지십니까?	얇은 ↔ 두꺼운
5	자동차 외판을 손바닥으로 누를 때 외판이 누르는 방향으로 얼마나 들어간다고 느껴지십니까?	cm

*** 외판에 힘을 가했을 때 외판이 일정하게 변형되다가 어느 시점에서 급격히 변형되는 느낌**

평가 양식

차 이름: ____________

차 번호에 맞는 차량에 대하여 다음 평가 양식에 따라 평가해주세요. 아래의 평가 작성 예시를 참조하여 작성하십시오. 평가 시 유의 사항은 다음과 같습니다.

1. 브랜드는 가급적 배제하시고 평가해주세요.
2. 조립 불량에 의한 소리는 무시하시고 외판 자체의 느낌을 평가해주세요.
3. 다른 차량과 비교하지 말고 해당 차량에서 받은 느낌의 정도를 평가하세요.

<평가 체크 예시>

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
			O				
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
					O		
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
				O			
4	매우 얇다	←		보통이다	→		매우 두껍다
						O	
5	5 cm						

1. Hood

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

2. Fender

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

3. Front Door

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

4. Rear Door

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

5. Quarter Panel

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

6. Trunk Lid

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

7. Roof

문항	3	2	1	0	1	2	3
1	매우 약하다	←		보통이다	→		매우 단단하다
2	매우 꿀렁거리다	←		보통이다	→		매우 일정하다
3	매우 불만족스럽다	←		보통이다	→		매우 만족스럽다
4	매우 얇다	←		보통이다	→		매우 두껍다
5	cm						

F.2 Experiment 2

핸드폰 슬라이드 조작 감성 평가

안녕하십니까? 본 설문지는 삼성전자㈜와 서울대학교 HIS연구실에서 함께 진행하고 있는 "슬라이드 조작 감성 평가 및 표준화 방안 연구" 과제 중 조작 감성 평가 pilot test를 위한 것입니다. 본 조사 질문의 응답내용은 통계법 제8조에 의거하여 제품의 개선 및 개발의 목적으로만 사용될 것이며, 신상에 어떠한 불이익도 따르지 않을 것임을 약속 드립니다. 조사에 성실히 답변해 주시면 감사하겠습니다.

문의처: 서울대학교 산업공학과 HIS 연구실 (Tel. 02-885-1403)

평가자 연령	
평가자 성별	남 여

슬라이드 사용 경험	
휴대폰 사용 정도	
슬라이드 선호 모델	

평가자 손 너비	
평가자 손 길이	

HISL.

1

평가대상 번호 _____

1. 다음 내용들은 휴대폰 슬라이드 조작에 대한 사용자 감성 측면의 평가를 위한 설문 항목입니다. 각 문항에 대해 평가 대상에 대한 생각을 문항별로 표시해 주시기 바랍니다. 불만족스러운 경우 comment 란에 불만족사항에 대해 기입하여 주시기 바랍니다.

빈 문항이 없이 <u>모든 문제에</u> <u>하나의 번호를</u> 표시해 주시기 바랍니다. (답변 수정의 경우 확실히 표시)

< 평가 변수 >

1. [혁신적임] 슬라이드 조작 시에 기존의 것과는 다른 혁신적인 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

2. [고급스러움] 슬라이드 조작 시에 품질이 좋으며 수준이 높아 고급스럽다는 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

3. [경쾌함] 슬라이드 조작 시에 가볍고 상쾌한 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

4. [안정감] 슬라이드 조작 시에 느낌이 달라지지 않고 일정한 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

HTSL

2

F.3 Experiment 4 & 5

조그 다이얼의 조작감 연구 조사

안녕하십니까? 서울대학교 휴먼인터페이스시스템 연구실에서 '조그다이얼의 조작감에 대한 연구'를 진행하고 있습니다.

본 조사 질문의 응답내용은 통계법 제8조에 의거하여 제품의 개선 및 개발의 목적으로만 사용될 것이며, 신상에 어떠한 불이익도 따르지 않을 것임을 약속 드립니다. 본 평가와 관련하여 문의사항이나 궁금한 점이 있으시면 아래로 연락하시기 바랍니다.

서울대학교 공과대학 산업공학과 휴먼인터페이스 시스템 연구실
송주봉 (shedtwin@naver.com)

기본 인적 사항

질문1. 귀하의 성별은 무엇입니까? ① 남자 ② 여자

질문2. 귀하는 올해 만으로 몇 세입니까? 만 ________세

질문3. 주로 사용하는 손은 어느 손입니까? ① 왼손 ② 오른손

질문4. 손길이

질문5. 손너비

평가 샘플 번호 :

1. 조그다이얼을 조작할 때 다이얼을 회전하면서 단계가 넘어갈 때 느껴지는 느낌이 명확합니까?

매우 명확하지 않다	← 명확하지 않다	←	보통이다	→	명확하다	→ 매우 명확하다
①	②	③	④	⑤	⑥	⑦

2. 조그다이얼을 조작할 때 다이얼을 회전하면서 느껴지는 움직임의 부드러움은 어느 정도입니까?

매우 부드럽지 않다	← 부드럽지 않다	←	보통이다	→	부드럽다	→ 매우 부드럽다
①	②	③	④	⑤	⑥	⑦

3. 조그다이얼을 조작할 때 다이얼을 회전하면서 느껴지는 움직임의 탄력적인 정도 어떻습니까?

매우 탄력적이지 않다	← 탄력적이지 않다	←	보통이다	→ 탄력적이다	→	매우 탄력적이다
①	②	③	④	⑤	⑥	⑦

4. 조그다이얼을 조작할 때 필요한 힘에 대한 느낌은 어떻습니까?

매우 약하다	←	약하다 ←	보통이다	→	세다	→ 매우 세다
①	②	③	④	⑤	⑥	⑦

5. 조그다이얼을 조작할 때 다이얼을 회전하면서 느껴지는 움직임의 경쾌한 정도 어떻습니까?

매우 경쾌하지 않다	← 경쾌하지 않다	←	보통이다	→	경쾌하다	→ 매우 경쾌하다
①	②	③	④	⑤	⑥	⑦

6. 전체적으로 조그 다이얼을 조작해 보았을 때 느껴지는 고급감을 0 점 - 100 점 사이로 평가하여 주시기 바랍니다. ____________ 점

G. Glossary

Term	Definition	Reference
Active touch	Touch in which a person actively explores an object, usually with fingers and hands	Grunwald (2008), Goldstein (2009)
Affective touch	Touch may be divided into discriminatory functions (how large, soft, hot etc an object is, for instance), but also how pleasant it is. This pleasant, emotional or affective dimension is often encountered within a more social affiliative context.	Grunwald (2008)
Cutaneous information	The cutaneous class of sensations refers to those which arise through direct contact with the skin surface. Cutaneous stimulation can be further subdivided in to the sensations of pressure, stretch, vibration, and heat. In some instances pain is also referred to as a separate sensation, though excessive stimulation of the other detectable parameters will lead to a feeling of pain	Wall & Brewster (2006)
Cutaneous senses	Which are responsible for perceptions such as touch and pain that are usually caused by stimulation of the skin	Goldstein (2009)
Force feedback	The area of haptics that deals with devices that interact with the muscles and tendons that give the human a sensation of a force being applied.	Grunwald (2008), Smith (1997)
Golgi tendon organs	Tension receptors at the juncture between skeletal muscle and tendon	Grunwald (2008)
Haptic feedback	Information for a system or user i.e. whether an item is firmly grasped or sliding or of the elasticity of an object touched in a virtual environment.	Grunwald (2008)
Haptic interaction	The haptic transmission of information	Kern (2009)
Haptic interface	A haptic device permitting a haptic interaction, whereby the transmitted information is subject to change and a measure of the haptic interaction is	Kern (2009)

	acquired	
Haptic perception	Refers to the integration of cutaneous surface sensing with kinesthetic data derived from the position and movement variables of the manipulator system	Grunwald (2008), Lee & Nicholls (1999)
Haptic simulator	A system enabling to control design variable of haptic feedback and to interact with a virtual object	Kern (2009)
Haptic profile	A plot of the data that seem to correlate with the human perception appeared with three axis, force, position, and velocity when device, switch, jog dial etc., is moving. It is used to emphasizes aspects of the feel of a switch as it is actuated, while minimizing the variability due to human actuation	Weir et al., (2004)
Haptics	The science of all biological and psychological aspects of the sensory as well as the motor capabilities within the skin, joints, muscles and tendons	Grunwald (2008), Kern (2009)
Kinesthesis	The ability to sense the movement of the body and limbs perceived by muscles and joints.	Goldstein (2009), Grunwald (2008), Kern (2009)
Kinesthetic information	Kinesthetic information refers to the sensation of positions, velocities, forces and constraints that arises from the muscle spindles and tendons. Force feedback haptic interfaces appeal to the kinesthetic senses by presenting computer controlled resistive forces to create the illusion of contact with a rigid surface.	Wall, Brewster (2006), Jones (2000)
Mechano-receptors	Receptors that respond to mechanical stimulation such as pressure, stretching, and vibration, compression, bending, stretching of cells, pressure, proprioception, and balance	Goldstein (2009)
Muscle spindle	Mechanoreceptors embedded between muscle fibers in skeletal muscle monitoring muscle length.	Grunwald (2008)
Passive touch	Refers to a non-moving observer that obtains tactile information passively from cutaneous sources only	Grunwald (2008), Goldstein (2009)

Proprio-ception	The ability to sense the position of the body and limbs	Goldstein (2009)
Roughness	A measurement of small-scale variations in the height of a physical surface. Usually, spacing, size and density of raised elements are crucial factors that determine texture perception	Grunwald (2008)
Somato-sensory system	A term referring to body senses which includes the cutaneous senses, proprioception, and kinesthesis related to the sense of temperature, pain, proprioception, mechanoreception and itch.	Goldstein (2009), Grunwald (2008)
Stiffness	Stiffness of a contact describes the rigidity of a contact in terms of a relation between the penetration depth and the reflecting force.	
Tactile	The mechanical interaction with the skin	Kern (2009)
Tactile feedback	Tactile feedback deals with the devices that interact with the nerve endings in the skin which indicate heat, pressure, and texture.	Grunwald (2008), Smith (1997)
Texture	The contribution of static characteristics of skin deformation, such as depth of penetration, volume of skin deformed, skin tension and skin stretch are the defining factors in perception of roughness.	Katz (1970), Lederman & Taylor (1972), Lederman, Loomis, Williams (1982)
The sense of force or tension	The process by which we perceive forces generated through the muscles	Taylor (2009)
The sense of joint movement	The process by which we perceive movements of parts of the body relative to one another. It includes detection of movements and perception of their direction, velocity, distance, and timing.	Taylor (2009)
The sense of joint position	The process by which we perceive the current positions of parts of the body relative to one another.	Taylor (2009)

국문초록

사람-로봇 상호작용, 가상 현실 등에서 멀티모달, 실감 인터페이스에 대한 관심이 많아지면서 촉각에 대한 연구가 다양한 분야에서 이루어지고 있다. 하지만 아직까지 멀티모달 인터랙션 구현을 위해 필요한 기술 자체에 대한 연구와 개발된 기술을 적용하여 어떻게 활용할 것인가에 대한 연구는 부족한 실정이다. 햅틱기술 적용을 위해서는 햅틱 자극의 특성을 정확하게 이해하고 사용자 측면에서 어떻게 인지하는지에 대한 체계적인 연구가 필요하다. 본 연구의 목적은 1) 운동감각과 관련된 햅틱 피드백의 특성을 도출하고 각 특성들이 사용자가 인지하는 감성에 미치는 영향에 대한 연구, 2)mode of haptic 가 운동감각 인지에 미치는 영향에 대한 분석, 두 가지이다. 본 연구에서는 width, magnitude, detent type, detent width 로 정의된 사인파 형태로 표현되는 총 33 개의 햅틱 피드백을 시뮬레이터를 이용하여 제공하였다. 25 명의 피험자가 6 가지 감성어휘(명확함, 부드러움, 조작력, 탄력감, 경쾌함, 만족도)에 대한 평가를 수행하였다. 실험은 조그 다이얼을 대상으로 햅틱 피드백이 제공되는 상황을 사용자가 조그 다이얼을 직접 조작하면서 자극이 제공되는 active haptic 와 사용자는 가만히 있고 조그 다이얼이 움직이면서 자극이 제공되는 passive haptic 로 나누어 진행하였다. 감성요소와 만족도 사이의 관계를 회귀분석으로, 감성요소와 설계변수 사이의 관계를 수량화 1 류 분석으로 수행하고 감성 모델을 도출하였다. 요인분석을 통하여 감성요소들은 힘과 관련된 감성요소, 움직임과 관련된 감성요소로 나누어 볼 수 있었고 만족도를 감성요소를 통하여 설명할 수 있었다(R^2=0.6). 그리고 각 세부 감성요소들을 설계 변수들을 통하여 설명할 수 있었다(R^2=0.2~0.5). 상황에 따라 사용자가 인지하는 차이를 분석하기 위하여 ANOVA 를 통하여 각 상황의 평균을 비교하고 force profile 요소에 따른 감성의 변화 경향을 조사하였다. 분석 결과 명확함과 조작력은 active haptic 일 때, 부드러움은 passive haptic 일 때를 통계적으로 유의하게 더 크게 평가하였다. force profile 요소에 따른 변화 경향을 살펴보면 active haptic 일 때는 force profile 요소와 선형적인 관계를 보인 반면 passive haptic 일 때는 그렇지 않은 것으로 나타났다. 실험결과를 통하여 힘의 차이와 관련된 요소를 passive haptic 일 때보다 active haptic 일 때 더 크게 평가하는 것과 passive haptic 일 때는 자극의 차이에 대한 일관적인 평가가 이루어지지 않는 것을 알 수 있었다. 사용자들이 인지하는 운동감각과 관련된 감성을 파악하기 위한 감성 차원 및 피드백 요소의 특성에 대한 기초 연구를 수행함으로써 보다 복잡한 운동감각에 대한 감성인지를 분석하고 사용자가 원하는 햅틱 피드백을 제공할 수 있는 토대를 마련할 수 있을 것으로 기대된다. 또한 실감 재현과 관련하여 사용자가 수동적으로 제공받는 피드백에 대한 인지 특성을 분석함으로써 능동적으로 사물을 조작하면서 느끼는 피드백과 다른 점을 고려해 볼 수 있었다.

주요어 : Haptic perception, Kinesthetic feedback, Force profile, Affective engineering, Mode of haptic
학 번 : 2006-23023

공학박사학위논문

Analysis of Affective Response to Kinesthetic Stimulation

운동감각 자극에 대한 감성 반응 분석 연구

2014년 2월

서울대학교 대학원

산업공학과 인간공학전공

송 주 봉

Abstract

Analysis of Affective Response to Kinesthetic Stimulation

Joobong Song

Department of Industrial Engineering

The Graduate School

Seoul National University

Although the degree of freedom is increasing in technological perspective related to haptic, more research on the technology itself and the method of technology application is still needed to actualize the haptic interaction. The necessity of researches using systematic approach to explore application method considering haptic perception characteristics of user to implement affective experience and social message is becoming a rising topic. This study consists of two: (1) study on affective response related to kinesthetic feedback and (2) analysis of the perception characteristics according to mode of haptic. In this study, thirdty three force profiles represented by specific sine wave having width, magnitude, detent type, and detent width were used as stimuli. Six affective variables such as perspicuity, smoothness, heaviness, elasticity, liltingness, and satisfaction of each stimulus were evaluated on 7-point likert scale and 100-point magnitude estimation scale by 25 subjects. The experiments with jog dial were divided into active haptic where the participants were directly involved with controlling devices and into passive haptic where the participants remained uninvolved. A statistical model has been developed to describe the relationship between satisfaction and affective variable using regression analysis. Also, the relationship between affective variables and elements of force profile as design variables has been found by quantification I analysis. Based on factor analysis, affective variables could be classified into force-related variables and movement-related variables. Affective elements and satisfaction had high relationship level (R^2=0.6). Also, each affective variables could be explained by design variables (R^2=0.2~0.5). In order to analyze the perception characteristics according to haptic mode, averages of affective elements in each mode were compared and change pattern according to force profiles parameter was investigated through statistical analysis. As a result, perspicuity, heaviness and elasticity were perceived larger when the mode was set to active haptic, while smoothness was perceived larger in passive haptic, and perspicuity and heaviness have shown significant difference according to haptic mode ($\alpha<0.05$). When it comes to change pattern of affective elements caused by force profiles parameter, it has linear relationship in active mode, but it doesn't in passive mode. Experiment result shows that the affective elements related with force are largely evaluated in active haptic than in passive haptic and assessment according to magnitude of stimuli was not consistent in passive haptic. This study investigates research issues that need to provide affective response utilizing haptic technology in human–robot interaction and virtual reality. By performing the fundamental research on the affective dimensions related to kinesthetic perception of the users and on the characteristics of feedback elements, the affective perception of complex kinesthetic perception was able to be analyzed, which in turn will allow us to build the foundation to provide the best haptic feedback to the users. Moreover, the perception of the feedback that the users receive passively has been analyzed, which also suggests further comparative analysis with the feedbacks provided from actively interacting with devices.

Keywords: Haptic perception, Kinesthetic feedback, Force profile, Affective engineering, Mode of haptic
Student Number: 2006-23023

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Chapter 1. Introduction

1.1 Research background

As the importance of multimodal interaction in the field of HCI has been acknowledged, haptic technology has gained greater attention and its various studies have been introduced (Bolt, 1980; Hayward, 2008; Shimoga, 1993; Tähkäpää and Raisamo, 2002). The existing studies have applied haptic technology in a form of multimodal interaction to improve the presence and performance, while proving its benefits for the cases limited major modality such as vision and auditory (Chellali et al., 2011; Chouvardas et al., 2008; Qian et al., 2011). However, the practical usage of the technology still stays limited with the mobile device applications (Raisamo et al., 2009). The technical aspect of the major limitations of the haptic technology is being improved as the recent actuators, which provide haptic stimulation, offer better performance with smaller size and lower price (Hayward et al., 2004; Wall and Brewster, 2006). While such limitation has been improved for greater degree of freedom in technical aspects, the current literature still lacks the research on the practical application of the technologies developed from the implementation of such multimodal interaction.

Haptic perception has significant differences from the other major modality such as vision and auditory in two aspects. First, the mechanism of perceiving stimulation is different from the other modality. While vision and auditory occur at specific sensory organs, which are the eyes and ears, haptic perception occurs through various somatic receptors that are spread throughout the body. The perception is not one-to-one interaction between a receptor and the stimulation but is occurred through combining various information received from more than one receptor

(Bleyenheuft and Thonnard, 2009; Kim, 2008). It is also important to decide which part of the body should be studied since the characteristics, distribution and density of receptors vary throughout the body (Shimoga, 1993).

The second difference is the characteristic of the delivered messages. The messages are delivered in the aspects of cognition and emotion through all of the senses, but delivering elements show differences between them. This can be seen as the difference between verbal communication and nonverbal communication. Vision and auditory are mainly occupied with delivering specific information, whereas haptic perception is often involved with simple information and other emotions such as affection, warmth and friendliness (Andersen and Guerrero, 2008). The examples of delivering affective messages through haptic sensation can be seen from a baby inside the bosom of the mother or from the physical touch between two lovers (Gallace and Spence, 2010). Moreover, the messages delivered through haptic perception are not explicit and thus may convey different meanings in the context of different cultures and situations (Knapp and Hall, 2009). Because of these unique characteristics of haptic perception, there are many researches on developing haptic feedback to provide the users with various social interaction and affective involvements (Tsetserukou, 2010; Yohanan and MacLean, 2011).

As technology has advanced, haptic technology has been adapted into various fields such as human-robot, human-device and telecommunication interactions (Bolt, 1980; Lederman and Klatzky, 2009b; Raisamo et al., 2009). Due to its technical limitations, the previous haptic technology had primarily been utilized to provide simple haptic feedback information. However, as the recent technologies have advanced and as various research on user perception characteristics have been conducted, the range of haptic technology has been extended to providing haptic experiences such as emotion and feelings, as well as to the fields of Human-Robot

Interaction and virtual reality. The recent focus of the technology is being geared toward applying haptic perception for better delivery of affective and social interactions through the tactile senses (Raisamo et al., 2009; Smith, 1997; Tan et al., 1994).

1.2 Haptic sensational dimension & research keyword

This study categorizes the important topics found in the existing research of haptic technology and its applications as the following: types of stimulation as cutaneous sensations and kinesthetic sensations, haptic modes as active haptic and passive haptic, dimensions of information characteristics as cognition and emotion (Gibson, 1962; Loomis and Lederman, 1984).

The perception of haptic stimulation can be divided into two categories. First, cutaneous (tactile) sensations are spread throughout the body at skin level that perceives information related to roughness, pressure and temperature. Second, kinesthetic (deep, proprioceptive or force) sensations are located around the muscles, bones and joints and perceive information related to force and movement. The details are discussed in Chapter 2.1.1.

The modes of touch in terms of haptic stimulation are also divided into two categories: active and passive touch. Active touch refers to the haptic perception that occurs during physical and direct manipulation/exploration of target objects, whereas passive touch refers to the perception that occurs through physical contacts of the objects without the user's intention. The details are discussed in Chapter 2.1.2.

The characteristics of information delivered through haptic perception are divided into two categories. Cognition is the information related to the method and effect of feedback provided for discriminating stimulation. Emotion is the information related to affective communication through affective responses and physical contacts of haptic feedback. The details are discussed in Chapter 2.1.3.

This study focuses on kinesthetic aspect of stimulation, two modes of active and passive haptic, and emotions from the characteristic of information. In other words, this study examines the differences of the emotions between two modes of haptic (active and passive) perceived through the kinesthetic sensations in interaction with objects.

Type of sensation		**Mode of haptic**		Information characteristic	
Cutaneous	**Kinesthetic**	Active haptic	Passive haptic	Cognition	**Emotion**

Figure 1 Research keyword

1.3 Motivation

As the fields of Human-Robot Interaction and Virtual Reality become more notably importance and their related technologies have advanced, the performance of presence has been improved while the interest on haptic modality for providing stimulation has recently increased (Gallace & Spence, 2010; Raisamo et al., 2009). The technologies on providing haptic stimulation can be used in various applications such as haptic feedback during device control and tactile stimulation during interaction with virtual object through virtual reality. The process of constructing haptic interface must consider and allow the users to recognize properly on the primary purpose of feedback design, and in order to accomplish this, various elements such as technical properties, user perception properties and environment of providing stimulation must be all considered together (Robles-De-

La-Torre, 2008; Song, Lim, & Yun, 2012).

In this respect, many studies on the perception of haptic stimulation have been conducted, but there had been few studies considering affective aspects in haptic. To perform haptic research in respect to emotion, combinations of perceptual properties and their effects on users' affective responses should be analyzed (Chen et al., 2009). But existing studies are limited in investigating single perceptual properties such as roughness and hardness rather than considering combination of perceptual properties due to difficulties in design of experiment.

Haptic perception includes sensation activated via tactile stimulation and kinesthetic stimulation. In terms of tactile stimulation, the existing research has been focused on surface and material properties which would influence tactile sensation. There are studies demonstrated the relationship between physical properties and various properties of tactile perception such as roughness, stiffness, texture and vibration and effects of physical properties on users' perception (Hollins, Bensmaļa, & Roy, 2002; Lederman & Taylor, 1972). The studies that considered affective responses of tactile stimulation includes investigation of single perceptual properties (Hwang & Hwang, 2010; Salminen et al., 2008) and perceptual properties related to materials of touched object (Chen et al., 2009).

The studies on the perception of kinesthetic stimulation have been investigating the force, movement and position. The related studies attempted to identify elements that influence the perception of stimulation such as force, movement and position, as well as the psychophysical aspects of both absolute and relative sensitivity in the kinesthetic sensation (Kern, 2009; Tan et al., 1994). The studies on affective responses in relation to kinesthetic stimulation include a design research on switch (Wellings, Williams, & Tennant, 2010) and an experimental study on affective responses toward physical controls such as knobs (Swindells et al., 2007). In addition, there are other studies on the design attributes that could affect perception of kinesthetic stimulation (Weir et al., 2004).

However, there are few studies that investigate the relationship between kinesthetic perception and physical properties which influences on emotion on the specific experience. Similar to the studies related to tactile stimulation, the studies related to kinesthetic stimulation need to be conducted to deduct the dimensions of haptic perception and to consider combination of perceptual properties to investigate the affective response on real-life product. In order to analyze affective response related to kinesthetic sensation, a structure of recognizing emotions must be suggested while deriving meaningful dimensions of haptic perception. Then analysis of relationships between subjective response to a haptic stimulus (satisfaction or likeness), dimensions of perception, and design variables are necessary.

The research related to affective engineering have concerned various aspects of vision, auditory and tactile modalities. However, the existing studies still lack the understanding of the connection between the user's affective responses to the physiological process and have not been able to answer the entire process of affective perception. In order to overcome this limitation, a systematic modeling scheme that builds from the basic process of physiological phenomenon must be considered.

Also, the context of providing haptic feedback needs to be studied in respect for its effect on haptic experience. Acknowledging the increase of various applications using Virtual Reality and Human-Robot Interaction, we must consider the passive interaction as well as the active one which user actively explore the haptic stimulus. As we have seen the existing studies that observed the effect of the mode of haptic in shape and texture perception (Heller, 1984; Lederman, 1981; Smith et al., 2009), further research on the effects of the mode of haptic is necessary in the context of affective perception through kinesthetic feedback (Song et al., 2012).

1.4 Objective of this study

The aims of this study are 1) to confirm dimension of affective perception related to kinesthetic feedback and relation between affective element and design variable and 2) to analyze difference of perception according to mode of haptic.

This study has hypothesized that the affective elements based on the characteristics of proprioceptor that recognizes kinesthetic perception were affected by the types of stimulation, and the experiment was performed by utilizing a simulator that can create specific haptic feedbacks to verify the hypothesis. In order to verify that the affective responses of the users can be divided into the elements of force and movement, the design variables from the existing psychophysical research have been categorized to analyze the relationship with the affective elements.

We have also investigated the differences seen in the evaluation of the mode of haptic in terms of affective responses, and the existing studies that compare the superiority of time and preciseness have been used to analyze the related causes of the differences.

The main elements discussed in this study are shown in Fig. 2, and this study has attempted to find the relationship among the elements. In this study, elements of force profile are utilized as design variable to analyze characteristics of user perceived emotion based on literature review.

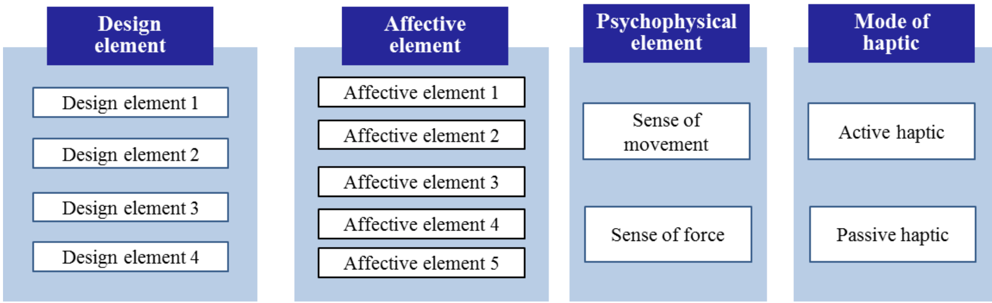


Figure 2 Elements related to this study

Research questions are as follows.

- Determining the major affective dimensions: Which elements affect the emotions related to kinesthetic sensations, and what is the relationship with the elements categorized in the aspect of physiological and psychophysical studies?
- Analyzing the relationship between affective elements and design variables: What is the relationship between the affective elements and the variables that can describe the pattern changes of haptic feedback?
- Comparing difference of perceptions characteristic between active and passive haptic: How are the perceptions different with the haptic feedback received from manipulating the devices directly with hands and the feedback received without any active movement?

Affective evaluation of real product feedback and simulated feedback is conducted to modeling of affective element related kinesthesis and to analyze difference between haptic modes.

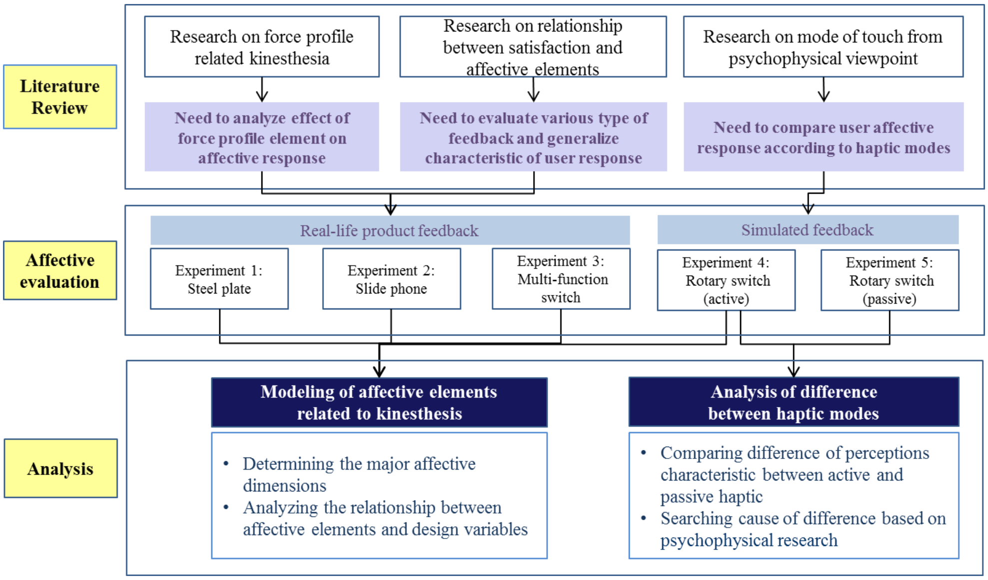


Figure 3 Overview of this study

1.5 Organization of the thesis

This study consists of three sections: 1) affective evaluation of kinesthetic sensations from the existing products, 2) user affective assessment experiment with a haptic feedback simulator, and 3) the analysis of user perception characteristics with respect to the conditions of providing feedback. The details of each section are as the following.

In Chapter 2, the research on the types of haptic stimulation and the related receptors have been examined to analyze the characteristics of affective perception on kinesthetic sensations. Then, the characteristics and effects of mode of haptic were studied while investigating the existing studies of emotions related to haptic. And characteristics and limitation of affective engineering research on kinesthetic sensations is summarized.

In Chapter 3, various designs of exploratory procedures of hands in manipulating products and the types of stimulation have been constructed for the evaluation of the users in order to analyze the characteristics of stimulation with respect to each design attribute and to analyze the affective elements that affect the satisfaction of the users through kinesthetic sensations.

In Chapter 4, a hypothesis has been proposed based on the result of Chapter 4 and the characteristics of proprioceptors, and the characteristics of the affective perception on kinesthetic sensations have been analyzed by utilizing a simulator. In turn, the main dimensions that affect the emotions related to kinesthetic sensations were determined, and the relationship between the affective elements and design variables was analyzed. And the effect of mode of haptic on kinesthetic feedback perception has been analyzed. The same haptic feedback was provided through active mode and passive mode to analyze the changes of the affective elements between the two modes.

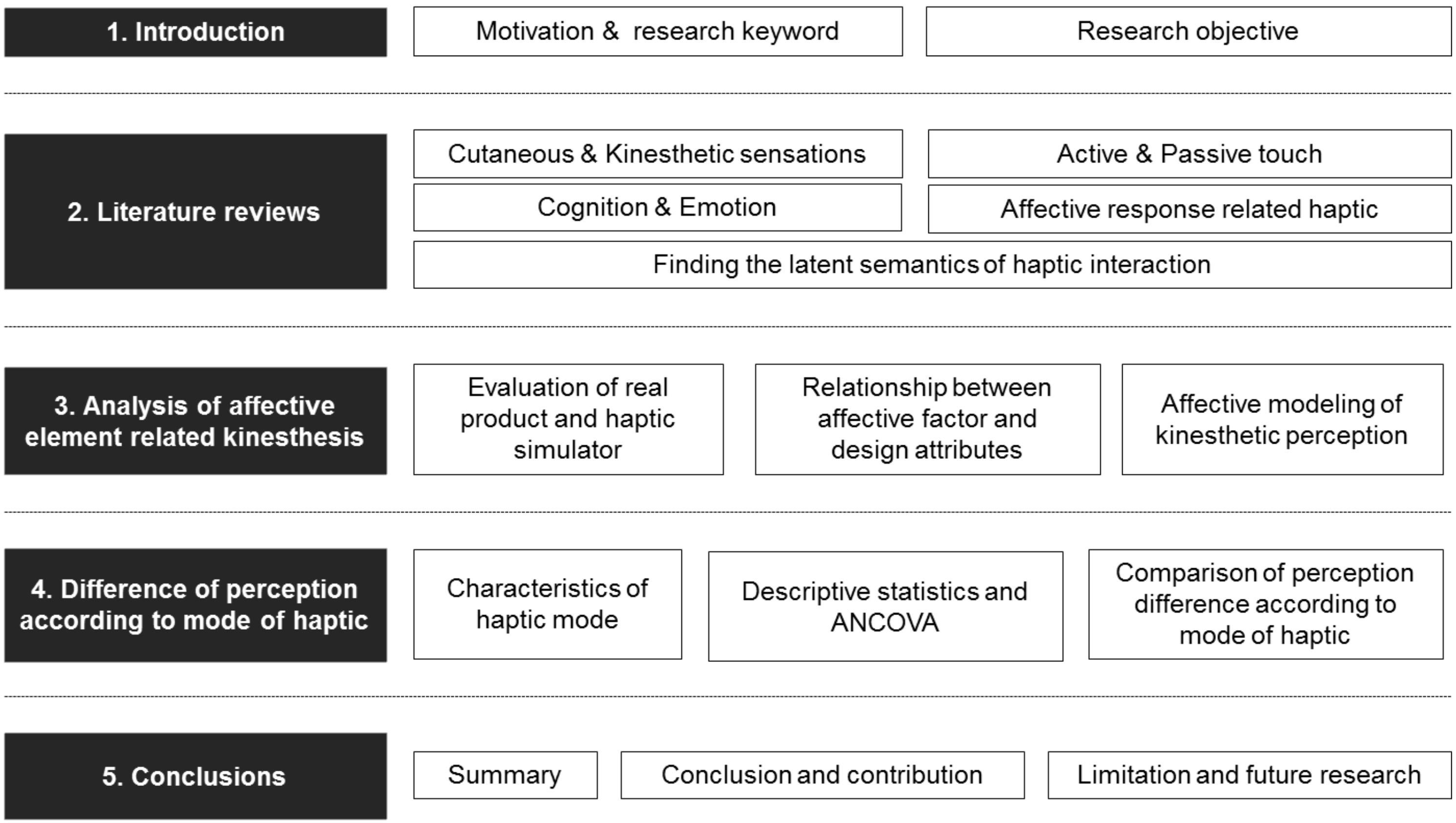


Figure 4 Structure of thesis

Chapter 2. Literature review

2.1 Haptic sensational dimension

2.1.1 Cutaneous and kinesthetic sensations

The perceptions of somatosensory system can be divided into cutaneous sensations and kinesthetic sensations (Bear et al., 2007; Goldstein, 2009; Smith, 1997). The roughness and the vibration of an object touching human skin are recognized through cutaneous sensations, while kinesthetic sensations recognize the force, movement and position of an object in manipulation. The cutaneous sensations perceive the senses related to the contact of an object on the human skin such as pressure, vibration, and heat through the mechanoreceptors. The receptors are categorized according to the characteristics of reactions to the stimulation, the scope of reception, and adaptation speed, and there are four categories of the mechanoreceptors: meissner corpuscles, merkel receptor, pacinian corpuscles and ruffini endings. The kinesthetic sensations relate to the senses of recognizing the movements around the body and the limbs, which are perceived through the muscle spindle, golgi tendon organ and joint capsule. The feedback of the kinesthetic sensations consists of the information of the tension and the length of the muscles (Powers and Howley, 2011).

The studies on the cutaneous sensations related to psychophysics mainly focus on the two-point discrimination threshold and point localization of tactile acuity (Kaczmarek 1995; Tan et al., 1994; Taylor-Clarke et al., 2004), while those of the kinesthetic sensations on force, sensations and joint angle (Burdea and Brooks, 1996; Tan et al., 1994). The existing studies on stimulation and sensations have often focused on the hand but still lack the research on the other parts of the body (Kern, 2009). Previously, the hands had been the main part of the body for manipulating an object; thus, the previous studies on the sensations have been mainly around the hands. However, as the research interests of HRI and tele-communication have been recently increased for the interactions between the users and other devices present in different locations, and the research on the characteristics of the haptic perception for the other parts of the body have obtained a greater attention (Lemmens et al., 2009; Tsetserukou, 2010; Yohanan and MacLean, 2011). Moreover, there have been a number of studies on the quantitative analysis of thresholds in the fields of psychophysics, and their research scope is slowly expanding to analyze the characteristics of stimulation and the perception system that determines the relationship among the users.

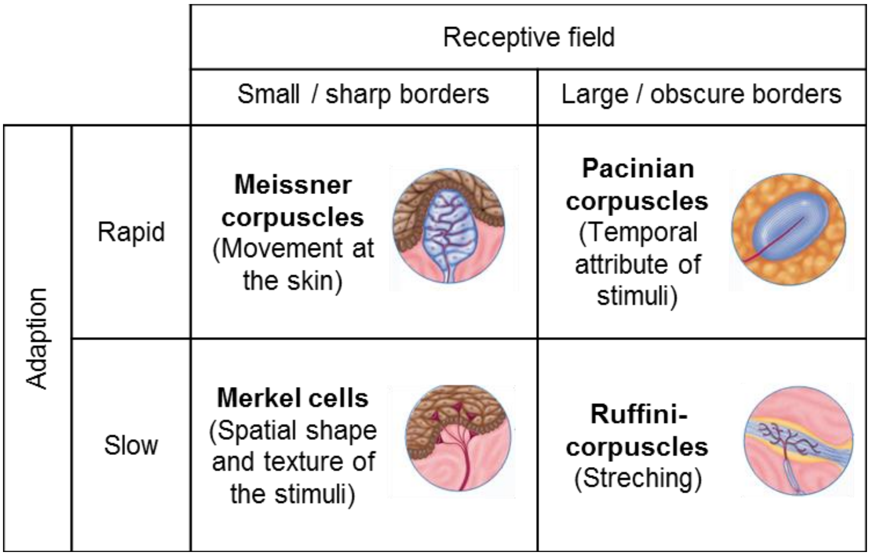


Figure 5 Characteristics of somatic sensory receptor

Table 1 Psychophysical research related to haptic sensations (Adapted from Kern (2009))

Characteristic value	Body part	Value
Skin-deformation, absolute value	Fingertip	10 μm
Two-point threshold (Spatial resolution)	Fingertip	2-3mm
	Palm	10-11mm
Force, absolute threshold	Fingertip	0.8mN
	Palm	1.5mN
Pressure, Absolute threshold	Fingertip	0.2N/cm^2
Force, Difference-Limen (DL)	Total body	5-10%
Pressure, Difference-limen (DL)	Wrist	4-19%
Maximum force	Index finger	40-50N
	Wrist	35-65N
Position-resolution, Difference-limen (DL)	Finger joint	2.5 ◦
	Wrist	2.0 ◦

Kinesthetic perceptions include perceptions of a sense of joint movement, a sense of joint position, a sense of muscle force and a sense of a sense of muscle tension, and they can be divided into the senses of joint movements and muscle forces (Proske, 2005; Proske & Gandevia, 2009). A sense of movement recognizes direction, velocity, distance and timing through relative position of body parts and perceives its movement. A sense of force recognizes and distinguishes the weight and its applied force by perceiving the force exerted from muscle contraction and relaxation.

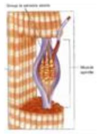
	Information
Muscle spindle	Muscle length and velocity information 
Golgi tendon organ	Tension information 
Joint capsule	Joint angle and angular velocity information

Figure 6 Characteristics of proprioceptor

Kinesthetic sensations occur with the combination of stimulation received from various receptors, and the characteristic of each receptor is described as the following (Bear, Connors, & Paradiso, 2007; Jones & Lederman, 2006). Muscle spindle consists of 14 bundles having the lengths of 4~10 mm, and they have two types of sensory nerve endings. Muscle spindle reacts to the extension of the muscle and provides the information of muscle length. Golgi tendon organ is an encapsulated receptor having the lengths of 0.2~1 mm and the radius of 0.1 mm, and it is directly connected with muscle spindle at the meeting point of muscle tendon and extrafusal muscle fibers. Muscle spindle reacts to the passive stretch throughout the muscle but is more sensitive to the force exerted at the muscle fibers connected with Golgi tendon organ. Joint capsule provides the information of joint movement, but it often reacts around the ends of the joint and is limited to recognize the direction of the movement as it lacks the sensitivity in the middle part. Skin receptor reacts to the stretch of skin from angular motion of joints and to the pressure exerted by holding an object with a hand, and it provides the information of location and movement of the joint, as well as the object's weight.

Kinesthetic perception can recognize stimulation through the receptors such as muscle spindle, golgi tendon organ, joint capsule and skin receptor (Bear et al., 2007; Jones & Lederman, 2006). Since kinesthetic perception usually combines various stimulations such as muscle length, joint angle and stretch of skin through each receptor, it may be difficult to distinguish movement, position, force and tension, but we can categorize them as the following based on the existing research. The studies on movement often focus on measuring the smallest imposed movement that can be recognized by the subjects, and it was discovered that the size of threshold is affected by speed (Proske, 2006). The studies on the sensation of position and movement mainly deal with the recognition of each joint's angular velocity and angle differences. Based on these studies, among the affective elements of kinesthetic perception that are recognized from touching switch or moving parts, the elements related to movement among those may be described by the movement beyond the threshold of a joint angle. Meanwhile, the sensations of force and tension are perceived by the force of muscle contraction and relaxation, and the affective elements related to force can be described by the force that are recognized from beyond the threshold of force.

Although there are some studies related to the resolution and differential threshold of movement and force (Jones, 2000), there still lacks the appropriate standard of the minimum threshold for recognizing the user's emotion. This study has determined the minimum thresholds as 2 cm of movement for the stimulation related to movement and 20% of force change for the stimulation related to force.

2.1.2 Active and passive touch

The tactile interaction with an object in contact can be categorized into active touch and passive touch (Gibson, 1962; Heller, 1984; Hughes and Jansson, 1994; Loomis and Lederman, 1984). The active touch refers to the senses aroused during active movements of manipulating or searching for an object, while the passive touch to the senses from a contact with an object without the person's intention. The two types of touch can be distinguished by the objectivity and the context. The active touch often has a purpose of obtaining information and involves the movements of the hands (Prescott et al., 2011). In the past, the related studies have focused on the movement of manipulating or searching an object (Lederman, 1981; Lederman and Klatzky, 1987; Smith et al., 2009), but the recent studies are also taking account of the emotions aroused from the manipulation of the object (Weir et al., 2004). On the other hand, the passive touch does not involve a purpose and is not only limited to the hands but also the rest of the bodies. Since it is a group of sensations aroused from passive movements, it mainly uses cutaneous sensations as opposed to the active touch that uses both the cutaneous sensations and kinesthetic sensations (Loomis and Lederman, 1984).

The research related tactile senses are mainly divided into active touch and passive touch for interacting targets (Gibson, 1962; Loomis & Lederman, 1984). The research related to perception characteristics with respect of mode of touch can be also divided into tactile and kinesthetic studies. The studies of tactile perception attempt to understand the superiority between the two modes in terms of efficiency, and their main concern is focused on the perception characteristics of textual roughness (Heller, 1984; Lederman, 1981; Lederman, Klatzky, Hamilton, & Ramsay, 1999). The studies of the differences between the modes of touch related to superiority have shown different trend for different methods and types of tasks to provide stimulation (Loomis & Lederman, 1984).

Table 2 Attribute of active & passive touch

	Active touch	Passive touch
The experience of touch	The object being touched	The sensation experienced in the skin
The type of information	Cutaneous and proprioceptive information	Cutaneous information
The degree of control	Control	No control
Major recognition parts	Fingertip & palm	Upper and forearms
Purpose	To acquire information and to manipulate their environments	To acquire feeling

The explanations of having different trends for different experimental conditions are as the following. The active touch mode often involves voluntary movement and thus is able to improve the performance by utilizing motor strategy (Chapman, 1994); the users are able to take as much time as desired when needed to obtain the kinesthetic information at any point of the task. Therefore, in order to determine the effects of the mode of touch more systematically, the exploratory conditions such as stimulation, position of stimulation and exploration time should be equally set and be analyzed. Under the same exploratory conditions, the experiment has shown lower performance in the case of active touch due to the movement-related suppression of the sensory inputs (Smith et al., 2009). When effect of motor strategy brought different results, the mode of active touch turned out to be more superior. In the case of the decrease of movement-related suppression, either they remained the same or the passive touch mode became more superior.

The studies on the effects of the mode of touch related to kinesthetic perception have shown that the active touch mode had higher sensitivity than the passive touch mode. In the study of Gandevia, McCloskey, and Bruke (1992), the threshold for detection of passive movement was shown to be 10 times larger than in the case of active movement, and the study of Taylor and McCloskey (1992) has shown smaller detection thresholds to maintain active flexion movement than in the case of passive limb.

2.1.3 Cognition and emotion

Among the research related to haptic, Raisamo et al. (2009) has suggested two categories: cognitive sensation for obtaining information through the tactile senses and affective sensation aroused from actions involving the tactile senses, such as comfort from a hug. Meanwhile, Essick et al. (2010) has proposed the affective responses of tactile stimulation as affective touch and quantitative judgment of tactile stimulation as discriminative touch. Likewise, the majority of the research studies related to haptic can be categorized into the fields of cognition and emotion.

(1) Research on cognition

The research studies that focus on cognition can be categorized into the studies on the discrimination of stimulation and on providing information through different feedbacks and effects, and they are mainly focusing on the tactile information obtained from active movements of hands for searching for objects. This can be related to the terms cutaneous sensations, active touch and hands from the previous section.

The research studies related to the discrimination of stimulation often focus on the stimulation that are recognized through cutaneous sensations such as vibration and roughness, and their main topics are the elements of stimulation, absolute and relative acuities and the characteristics of receptors (Hollins et al., 2002; Lederman and Taylor, 1972; Verrillo, 1963). The recent trend also realizes the influences of materialistic characteristics, such as texture, weight and compliance, and of geometric characteristics, such as curvature, orientation and size, on searching and recognizing objects (Ballesteros and Heller, 2008); therefore, the related studies take account of not only cutaneous sensations but also of kinesthetic sensations (Drewing and Ernst, 2006; Frisoli et al., 2011; Overvliet et al., 2008; Sanders and Kappers, 2009).

The research studies related to feedback information mainly focus on the characteristics of tactile modality for improving the effectiveness of haptic feedback. The characteristics of tactile modality offer more direct delivery of the information than the other senses such as visual and auditory, and they can also provide haptic feedbacks to help certain situations where other senses are limited. In other words, the tactile modality can be characterized by the fact that the delivery of information occurs directly through tactile senses without other senses. Due to such characteristics that require physical contact with the devices, there seems to appear active research on the touch screens of mobile devices. Brewster et al., (2007) has suggested a way of reducing errors while typing texts in mobile devices by providing haptic feedbacks. Moreover, in the research of Tähkäpää and Raisamo (2002), a tactile mouse was proposed to offer more effective task operation and work satisfaction by providing haptic feedbacks during target selection tasks.

(2) Research on emotion

The research studies on emotion can be categorized into the affective responses from haptic feedback and sentimental interaction through tactile contacts. The affective responses may be aroused from the force feedback of clicking a switch or from touching different clothing materials such as velvet and cotton, and they are related to the terms cutaneous sensations, kinesthetic sensations, active touch and hands that were mentioned in the previous section. The sentimental interactions can be described through the examples of pet robots and telecommunication, which offer remote contacts between the users, and they are related to the terms cutaneous sensations, passive touch, forearm and chest.

The research studies on haptic feedback that are related to affective responses can be divided into those of the affective changes in relation with the elements of haptic feedback and the others concerning the elements that affect the haptic perception. Such studies of haptic perception often focus on the affective responses of the vibration and texture related to the tactile feedback. The scope of the existing research covers from the psychophysical aspects of discriminating vibration and texture to studying the trend of the affective responses of the frequency and amplitude of the vibration(Hwang and Hwang, 2010; Salminen et al., 2008). Essick et al. (2010) has shown the tendency of the users having more pleasant feelings with soft and comforting materials such as velvet, cotton and plastic mesh than with hard and rough materials. In order to investigate such elements of haptic perception, Weir et al. (2004) has shown a graph of affective changes in his study to analyze the possible elements related to the changes in force. However, the major concern of the research studies related to emotions is about the user's responses through cutaneous sensations, and the kinesthetic sensations related to switches and alike are still lacking in the current literature. Other studies that conduct research on object recognition and detection consider both of the sensations, but affective aspects are still neglected in such studies (Drewing and Ernst, 2006; Frisoli et al., 2011; Overvliet et al., 2008).

The research studies that concern the sentimental interactions mainly focus on the emotions occur during the communication among the users or between the users and devices, as well as the similar interactions in the fields of virtual reality and robotics. Hertenstein et al., (2006) has shown the possibility of affective interactions through tactile contacts without visual information in his experiments. Also, he has also shown in his experiment that a person is able to recognize the other person’s affective intention through tactile contacts around the arms, and there were 6 basic emotions that could be also recognized through facial expressions and voices. In Bailenson et al., (2007), force-feedback haptic devices for virtual interpersonal touch was used to recognize the affective intention of the other person, and the patterns of expressive motions were categorized. In Tsetserukou (2010) for developing devices that offer affective interactions, haptic displays were proposed to provide emotions that are aroused from hugging the other person in online communication. Moreover, Yohanan and MacLean (2011) has conducted an experiment among the robot pet owners to analyze the affective interactions with the touch-centric social robot. Those studies have shown us the possibility of affective communication through tactile contacts and have proposed the implementation of certain devices, but there still lacks the research on the detailed analysis of the touch patterns that stimulates emotions (Field, 2011). Therefore, the related research fields also need to conduct research on the fundamental methodologies of implementing devices for specific purposes of affective delivery.

2.2 Finding the latent semantics of haptic interaction research

This chapter focuses on the review of various research studies on haptic while investigating different issues on the implementation of haptic technology for virtual reality and human-robot interaction. Therefore, the overall review of the fields related to haptic has been conducted to investigate the relationship between each field. Through the contents analysis, the common terminologies were extracted to categorize each field, and the network analysis was used to study the relationship between the terminologies as the reference for the categorization. Lastly, the frequency of each term and the centrality index were used to quantify the importance of each field.

2.2.1 Contents analysis results

Major area related to haptic research is medicine, neuroscience before 2000, but change to engineering, computer science after 2001 (Table 3). As a result, it is confirmed that research topic has been changed from basic perceptual mechanisms and characteristics associated with haptic perception to the implementation of multi-modal equipment by utilizing haptic feedback and sensing technology. And the number of published papers has been steadily growing from 2001. Major areas of study are to be roughly classified into research related technology to provide haptic stimuli and research related user characteristic to percept haptic stimuli.

Table 3 shows the terms with the highest frequencies that are categorized into different characteristics. The research areas related to haptic are field of application, relationship between the visual modality, cognitive trait of objects, body site, physiology of haptic sensation, mode of touch and more. The detailed characteristics are as the following:

- **Field of application :** the terms that are related to the research areas that focus on developing devices and systems with the haptic technologies such as virtual reality, human-robot interaction and haptic displays (e.g., virtual, robot, interface, display)
- **Haptic stimulation :** the terms that are related to stimulation via tactile senses (e.g., feedback, touch, and force)
- **Performance :** the terms that are related to the performance of haptic stimulation (e.g., control, time, and performance)
- **Relationship between the visual modality:** the terms that are related to the reactions of haptic stimulation in the cases of limited sight or visual stimulation (e.g., blind and visual)
- **Cognitive trait of objects :** the terms that are related to the characteristics of a target object such as vibration, texture and shape, which can be recognized through haptic stimulation (e.g., shape, texture, surface, and vibration)
- **Body site:** the terms that are related to the body site of haptic stimulation (e.g., hand, finger, and fingertip)
- **Physiology of haptic sensation :** the terms that are related to the neural senses and receptors that receive stimulation (e.g., cortex, neural, and brain)
- **Haptic search :** the terms that are related to the movement of a hand for recognizing the properties of a target (e.g., exploration and movement)
- **Mode of touch :** the terms that are related to the ways of contacting

the target (e.g., active and passive)

- **Haptic perception characteristics :** the terms that are related to the information and characteristics of perception via haptic stimulation (e.g., cognition and emotion)

The frequency of each term appearing in a paper was counted separately for the title, keywords and abstract. The keyword frequency was then computed for the years before 2000 and after 2001. Taking account of the ratio difference of the overall frequencies between the two time periods being 1.6, the relative ratio was computed as (frequency after 2001) / (frequency before 2000 x 1.6). The relative ratio greater than 1.0 represents the increase of the frequency of a term appearing in the texts over time between years before 2000 and after 2001. As the result, the frequencies of the keywords appearing in the context of the field of application and users have shown to be increased, while those of the body site and physiology have decreased. The detailed discussion of the research texts and the characteristics of changes in each category are shown in the following sections.

Table 3 appearance frequency and relative ratio of keyword

Category	Word	After 2001				Before 2000				Relative ratio			
		total	title	key word	abs tract	total	title	key word	abs tract	total	title	key word	abs tract
Field of application	virtual	2260	268	382	1610	716	114	37	565	2.0	1.9	2.7	1.9
	system	3195	299	188	2708	1724	215	48	1461	1.2	1.1	1.0	1.2
	device	2188	167	153	1868	728	65	10	653	1.9	2.1	4.1	1.9
	interface	1684	209	400	1075	641	134	26	481	1.7	1.3	4.1	1.5
	display	1688	223	238	1227	795	139	29	627	1.3	1.3	2.2	1.3
	interaction	1670	216	207	1247	464	59	28	377	2.3	3.0	2.0	2.2
	sensor	1482	221	230	1031	1592	364	26	1202	0.6	0.5	2.4	0.6
	robot	1212	197	181	834	740	161	33	546	1.0	1.0	1.5	1.0
	surgery	1014	152	126	736	429	59	25	345	1.5	2.1	1.3	1.4
	actuator	482	98	38	346	77	42		35	3.9	1.9	0.0	6.4
	tele	451	57	91	303	182	8	5	169	1.6	5.9	4.8	1.2
	subtotal	17326	2107	2234	12985	8088	1360	267	6461	1.4	1.3	2.2	1.3
Haptic stimulation	feedback	2559	288	291	1980	710	103	36	571	2.3	2.3	2.2	2.3
	touch	1431	119	202	1110	730	72	43	615	1.2	1.4	1.3	1.2
	cutaneous	115		18	97	232	25	17	190	0.3	0.0	0.3	0.3
	force	2501	140	197	2164	1182	95	49	1038	1.3	1.2	1.1	1.4
	kinesthetic	320	19	11	290	145	21	8	116	1.4	0.7	0.4	1.6
	perception	1791	277	337	1177	754	198	48	508	1.5	1.2	1.9	1.5
	spatial	770	74	79	617	573	71	21	481	0.8	0.9	1.0	0.8

	stimulation	2073	183	55	1835	2432	328	119	1985	0.5	0.5	0.1	0.6
	subtotal	11560	1100	1190	9270	6758	913	341	5504	1.1	1.0	0.9	1.1
Cognitive trait of objects	surface	1157	95	47	1015	915	69	10	836	0.8	1.1	1.3	0.8
	shape	831	65	59	707	593	61	8	524	0.9	0.9	2.0	0.9
	texture	767	77	82	608	387	23	12	352	1.2	2.8	1.8	1.1
	vibration	833	75	96	662	372	16	12	344	1.4	3.9	2.1	1.3
	pressure	345	29	32	284	330	23	23	284	0.7	1.0	0.4	0.7
	roughness	293	28	37	228	134	17	12	105	1.4	1.4	0.8	1.4
	stiffness	303	21	23	259	146	16		130	1.3	1.1	0.0	1.3
	hardness	87		13	74	104			104	0.5	0.0	0.0	0.5
	pain	439	85	67	287	281	57	54	170	1.0	1.2	0.3	1.1
	subtotal	5055	475	456	4124	3262	282	131	2849	1.0	1.4	0.9	0.9
Performance	control	1482	157	186	1139	1229	98	20	1111	0.8	1.3	2.5	0.7
	time	1030	73	48	909	604	33	13	558	1.1	1.8	1.0	1.1
	performance	1325	60	35	1230	738	72		666	1.1	0.7	0.0	1.2
	discriminate	637	54	50	533	906	142	58	706	0.4	0.3	0.2	0.5
	subtotal	4474	344	319	3811	3477	345	91	3041	0.8	0.8	0.9	0.8
Relationship between visual modality	visual	3441	405	268	2768	1808	249	65	1494	1.2	1.3	1.1	1.2
	blind	526	61	67	398	472	67	21	384	0.7	0.8	0.8	0.7
	subtotal	3967	466	335	3166	2280	316	86	1878	1.1	1.2	1.0	1.1
Related body site	hand	1208	79	58	1071	1333	176	25	1132	0.6	0.4	0.6	0.6
	finger	786	72	22	692	722	60	15	647	0.7	1.0	0.4	0.7
	fingertip	306	21	11	274	186	12		174	1.0	1.4	0.0	1.0

	body	465	38	33	394	328	27	8	293	0.9	1.2	1.1	0.9
	arm	252	18	12	222	157	15		142	1.0	1.0	0.0	1.0
	forearm	32			32	50			50	0.4	0.0	0.0	0.4
	skin	531	51	50	430	614	55	22	537	0.5	0.8	0.6	0.5
	subtotal	3580	279	186	3115	3390	345	70	2975	0.7	0.7	0.7	0.7
Physiology of haptic sensation	brain	380	123	29	228	365	155	34	176	0.7	0.7	0.2	0.8
	cortex	439	48	74	317	538	95	85	358	0.5	0.4	0.2	0.6
	neural	645	99	47	499	777	89	33	655	0.5	0.9	0.4	0.5
	sensory	869	65	98	706	869	119	69	681	0.6	0.5	0.4	0.7
	sensitivity	379	22	13	344	641	75	29	537	0.4	0.2	0.1	0.4
	threshold	166	13	19	134	601	31	15	555	0.2	0.3	0.3	0.2
	acuity	140	15	13	112	108	15	8	85	0.8	0.8	0.4	0.9
	somatosensory	434	45	95	294	532	103	100	329	0.5	0.4	0.3	0.6
	subtotal	3452	430	388	2634	4431	682	373	3376	0.5	0.5	0.3	0.5
User	human	1617	183	229	1205	877	181	51	645	1.2	0.8	1.2	1.2
	user	1568	22	154	1392	419	20	6	393	2.4	0.9	6.8	2.3
	subtotal	3185	205	383	2597	1296	201	57	1038	1.5	0.8	1.8	1.6
Haptic search	exploratory	820	73	39	708	382	51	8	323	1.4	1.2	1.3	1.4
	movement	755	50	29	676	589	55	25	509	0.8	0.8	0.3	0.9
	subtotal	1575	123	68	1384	971	106	33	832	1.0	1.0	0.5	1.1
Haptic perception characteris	affect	254	11		243	233	9		224	0.7	1.0	0.0	0.7
	feel	471	30		441	131			131	2.3	0.0	0.0	2.2
	cognition	205	57	16	132	160	39		121	0.8	1.2	0.0	0.7

tics	emotion	158	11	11	136	6			6	16.6	0.0	0.0	14.8
	subtotal	1088	109	27	952	530	48	0	482	1.3	1.9	0.0	1.3
Mode of touch	active	406	40	45	321	292	36	11	245	0.9	0.9	1.1	0.9
	passive	244	31	16	197	151	18		133	1.0	1.4	0.0	1.0
	subtotal	650	71	61	518	443	54	11	378	0.9	1.1	1.5	0.9
Total		56781	5774	5745	45262	35795	4771	1529	29495	1.0	1.0	1.0	

(1) Field of application

In the context of the field of application, the overall frequency of the appearance of the terms was the largest, while showing the increase of the frequency from the years before 2000 and after 2001 by the relative ratio of 1.4. Among them, the relative ratios of the terms 'virtual' and 'interaction' were 2.0 and 2.3, showing large changes. Such findings could be explained by the current research studies' tendency of focusing on the application of haptic device in virtual reality and robotics using haptic stimulation. The relative ratio of the terms 'device' and 'interface' appeared in the keywords came out to be 4.1, which was two times larger than their overall frequency ratios (1.9 and 1.7, respectively). Such trend of seeing the terms 'device' and 'interface' more frequently explains the increasing number of the research studies on the development of the devices that implement virtual reality and related user interactions. Moreover, although the overall frequency of the terms with the suffix 'tele-' such as telemanipulation, teleoperation and telerobotics was rather lower, the relative ratio of the terms found in titles was 5.9, which tells us that there is a large increase in such research studies that focus on haptic stimulation or other related haptic feedbacks for operating devices from the distance. In cases of remote operation between users or the users and virtual objects, haptic modality has become quite important in providing feedbacks for precise manipulation as if done in physical contact. In cases of the terms 'display' and 'sensor', which play roles as the components of haptic devices, the term 'display' showed an increase in the appearance by the relative ratio of 1.3 while sensor decreased by the ratio of 0.6. Especially for the 'actuator', a type of displays, the relative ratio was shown to be 3.9. This finding is relevant to the increase of the interest in providing stimulation and emotions to the users.

(2) Haptic stimulation

The overall relative ratio of the terms related to haptic stimulation was 1.0, which shows the consistency between the years before 2000 and after 2001. However, the relative ratio of the term ‘feedback’ showed an increase by 2.3. Haptic stimulation can be divided into cutaneous and kinesthetic, and when these two terms were compared, the terms ‘force’ and ‘kinesthetic’ showed higher frequency than the terms ‘touch’ and ‘cutaneous’, whose relative ratios were 1.3 and 1.4 respectively, during the years after 2001. Such findings tell us the trend in the research is leaning toward kinesthetic sensation from cutaneous sensation. On the other hand, the terms ‘spatial’ and ‘stimulation’, which are related to stimulation and the characteristics of stimulation, were shown to appear less after the year 2001.

(3) Performance

The terms related to performance showed the relative ratio of 0.8. More specifically, the terms ‘time’ and ‘performance’, which are related to the performance improvement of providing haptic stimulation, have increased by the ratio of 1.1 while the term ‘discriminate’ for evaluating the efficiency of stimulation has decreased by 0.4. From this, we can learn that the research studies are continuously focusing on improving the effectiveness of providing information based on modality characteristics of tactile senses as the feedback information, while the interest in the discrimination of stimulation is decreasing. The research studies related to the performance have previously focused on the usability during the interaction between a user and a device and now focuses on various characteristics related to interaction, while being expected to stay in fundamental issues.

(4) User

Although the terms related to user does not necessarily focus on a specific research area, the relative ratio of the term came out to be 1.5. Particularly, the term appearing in keywords showed the relative ratio of 6.8, which suggests the increase of attention in developing technologies that are oriented toward the users. Moreover, this finding agrees strongly with the findings in the previous section of field of application, which discussed the importance of the characteristics of a user in developing haptic devices for virtual reality and robotics.

(5) Body site & physiology of haptic sensation

The terms related to body site and physiology of haptic sensation have shown the overall relative ratio as 0.7 and 0.5, respectively. Although each body site has different characteristics of the receptors and distribution, the existing studies have mainly focused on hands and fingers for the body sites. Also, the terms related to the physiological mechanisms of the tactile senses have appeared less in the articles after the year 2001. Therefore, a wider range of body sites should be considered in the research related physiological characteristics.

(6) Haptic perception characteristics

In the case of haptic perception characteristics, the overall relative ratio of the terms ‘affect’ and ‘cognition’ came out to be 1.0, while the term ‘emotion’ have shown a significant increase by the ratio of 16.7. Although the current literature lacks the research on emotion, we have noticed a positive increase since the year 2000.

2.2.2 Network analysis results

Fig. 7 shows the visualization of the results of the network analysis on the keywords. As shown in Fig. 7, the research studies related to haptic can be divided into the technology perspective related to application of haptic technology and the user perspective related to haptic perception. In these two categories, we find ‘virtual reality’ being at the center of the technology perspective whereas ‘touch’ at the center of the user perspective, and they are connected to several other different groups around them. The groups related to virtual reality include display, sensor, haptic interface, haptic feedback and haptic rendering, and they all relate to providing haptic stimulation to the users based on haptic information collected from the virtual reality environment. The groups related to touch include cortex, visual impaired, cognitive trait of objects and haptic search, which all related to the user’s process of recognizing the target.

In the groups related to cortex, many research studies have focused on analyzing the stimulation through more than one modality such as visual senses and other activated parts of the cortex by utilizing fMRI. Various fields of study on the fundamental mechanism of recognizing haptic stimulation are expected in the near future as the neural technology is rapidly being advanced.

The research fields related to vision often focus on the reaction in the brain to recognizing objects through visual and tactile senses, and the studies related to visually impaired consider various possibilities of applying haptic technology to replace the visual information with haptic feedbacks for those who are not able to see properly. In the case of 'vision', the studies are related to 'multisensory', 'fMRI', 'perception' and 'objective cognition', while studies on 'visually impaired' relate to 'braille', 'haptic mouse' and 'tactile graphics'. Moreover, the research related to visually impaired are connected to haptic perception, which is included in the haptic search group, and often focus on analyzing the process of haptic perception without being able to see.

As shown in the network of Fig. 7, 'exploratory procedure', 'exploratory movement' and 'proprioception' are categorized under the haptic search, whose center is the 'haptic perception'. This tells us the that trend of the related research often focuses on studying different senses for haptic perception and different procedures and movements of searching for an object through tactile senses.

The groups related to cognitive trait of objects include 'texture', 'vibration', 'shape' and 'roughness'. The focuses of each haptic search group vary depending on the type of cognitive trait of objects, which is connected to the types of the senses during haptic search. Moreover, 'shape', which requires both kinesthetic sensation and cutaneous sensation, is closely related to the 'haptic perception', while 'roughness', which only requires cutaneous sensation, is related to the 'tactile perception'.

The groups related to tactile display are mainly connected with the terms related to cognitive trait of objects. The terms that connect technology perspective and user perspective are only display group and cognitive trait of objects group beside from virtual reality and touch. This is due to the fact that the characteristics of a desired stimulation must be thoroughly considered in order to implement tactile displays. The architecture of a display can be more effective and efficient if the process of a person recognizing stimulation is well known beforehand.

The groups related to haptic interface often concern the characteristics necessary for the user's tactile interaction, which include 'tactile display', 'tactile sensor', 'force feedback', 'force control' and 'tactile feedback'. The tie strength for each node of 'haptic interface' shows the ratio between 'tactile display' and 'tactile sensor' as 5:3, which reveals closer relationship with display than sensor. However, this result is not necessarily caused by the frequency difference, as seen from the frequency ratio of 1:1 between display and sensor appearing in the keywords. Meanwhile, the tie strength ratio between 'force feedback' and 'tactile feedback' is 9:4, which shows closer connection with the feedbacks related to kinesthetic sensation than with those of cutaneous sensation. Moreover, 'tacton' – a type of a haptic interface – is also related to haptic interface groups and is often used in mobile devices for providing feedbacks through a belt approach of vibration.

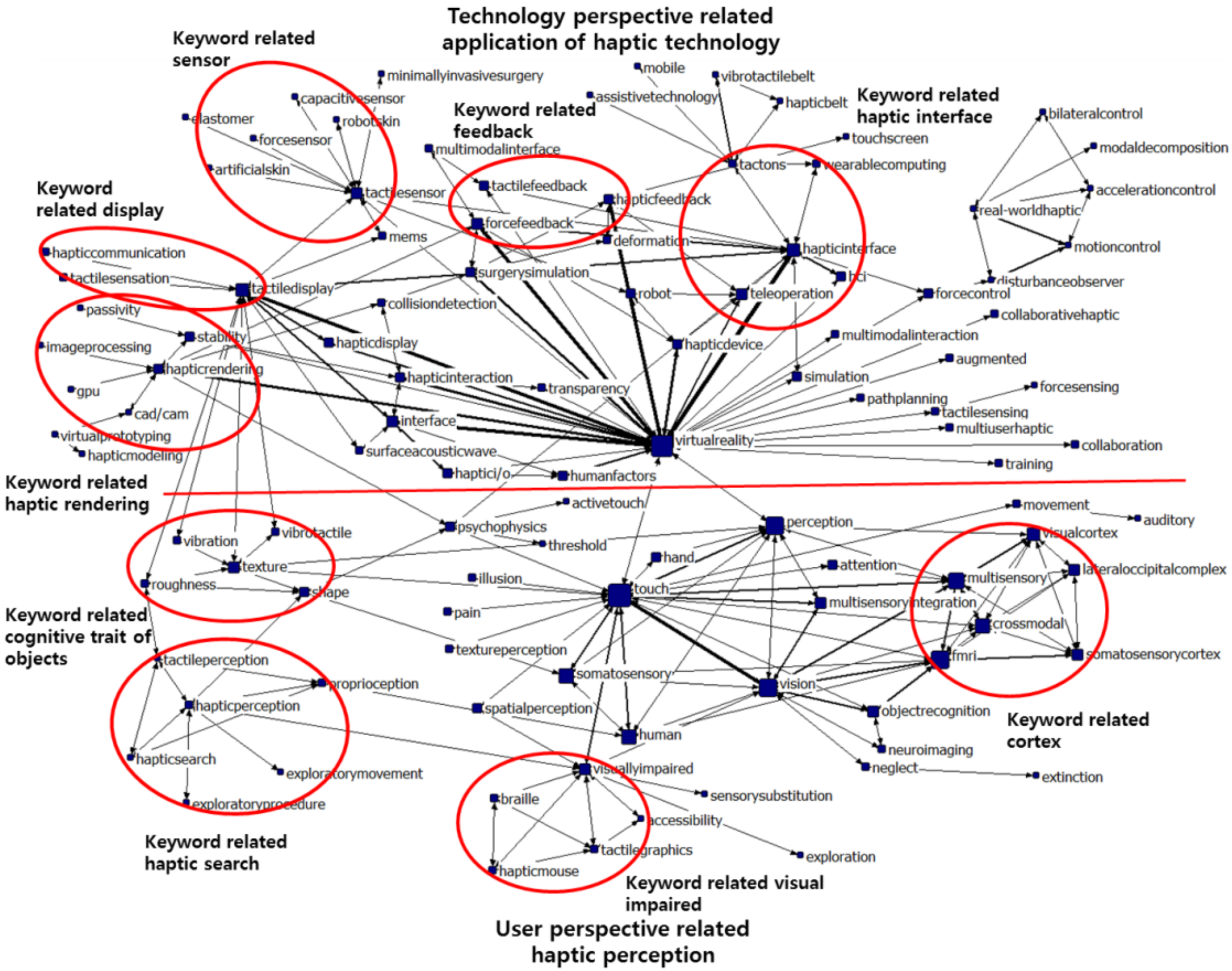


Figure 7 Visualization of network analysis results

The centrality indices are shown in Table 4. The centrality analysis was performed in terms of degree centrality, closeness centrality, betweenness centrality and eigenvector centrality. In order to compute the centrality, the ranking of each index was computed and added up to assign the scores for each term. Table 4 shows the top 25 terms with the highest scores. The result shows 14 terms related to the technology perspective and 11 terms for the user perspective; thus, the terms related to the technology perspective show higher centrality. The top two terms are ‘virtual reality’ and ‘touch’, which lie in the middle of the technology perspective and user perspective.

Although the centrality index shows a similar characteristic as the frequency ratio in the contents analysis, the terms can be analyzed in various aspects by comparing each centrality of the terms. The correlation coefficient of eigenvector centrality and betweenness centrality is 0.248, which is lower than the correlation coefficients of the other centralities, while the ranking of the terms according to eigenvector centrality and betweenness centrality showed a larger difference in the index rankings of the terms. The terms with higher betweenness centrality than eigenvector centrality are haptic device, tactile sensor, haptic display, and tactile perception, while the terms with higher rankings of eigenvector than betweenness are ‘force feedback’, ‘perception’, ‘teleoperation’, ‘interface’ and ‘vision’.

Table 4 Centrality index of keyword

No	Keyword	Degree		Eigenvec		Betweenness		Closeness	
		Value	rank	Value	rank	Value	rank	Value	rank
1	virtual reality	976	1	0.43	1	1433982.6	1	2171260	1
2	touch	543	2	0.17	3	777328.3	3	2171908	3
3	haptic interface	436	3	0.17	4	847591.4	2	2171796	2
4	tactile display	431	4	0.16	5	625137.8	5	2171984	4
5	force feedback	294	8	0.21	2	258312.2	15	2172156	5
6	perception	272	9	0.12	7	246993.2	16	2172549	11
7	haptic device	265	10	0.07	16	410433.7	9	2172484	9
8	visually impaired	247	12	0.09	11	346153.0	13	2172358	8
9	psychophysics	213	16	0.08	14	425713.5	8	2172353	7
10	tactile sensor	380	5	0.06	23	877187.9	4	2172664	14
11	haptic rendering	333	7	0.08	13	555692.8	7	2172837	21
12	teleoperation	190	18	0.11	8	146401.1	24	2172303	6
13	haptic feedback	334	6	0.07	18	557438.3	6	2173056	27
14	interface	213	15	0.14	6	150355.3	23	2172603	13
15	tactile feedback	209	17	0.09	12	245478.9	17	2172588	12
16	fmri	253	11	0.08	15	373865.3	11	2173055	26
17	human	180	22	0.06	21	145809.3	25	2172824	20
18	haptic display	179	23	0.05	30	243308.3	18	2172779	19
19	vision	228	14	0.11	9	107776.6	38	2173129	31
20	tactile perception	186	20	0.03	53	374830.4	10	2172507	10
21	texture	161	25	0.07	17	121930.8	31	2172914	23
22	hci	120	30	0.07	19	121720.3	32	2172689	15
23	haptic interaction	180	21	0.07	20	235969.4	19	2173229	37
24	haptic perception	244	13	0.03	56	362449.6	12	2172750	18
25	vibration	142	26	0.06	26	126912.9	30	2172695	17

Eigenvector centrality is an index that computes the number of ties connected to other nodes while considering the importance weight of each node. Betweenness centrality is an index that computes the number of the shortest paths between two other nodes goes through a certain node. The terms with higher eigenvector centrality than betweenness centrality are often connected with a large body of terms that have higher importance, but these terms rarely provide the connections among themselves. The terms 'force feedback', 'perception', 'teleoperation', 'interface' and 'vision', which have shown similar characteristics as mentioned above, have the tie strength with the terms 'virtual reality' and 'touch', which score higher importance, two times higher than the other terms. However, such terms are not located in the center of the network and thus are not connected with each of the nodes; thus, they have shown lower betweenness centrality.

The terms with higher betweenness centrality than eigenvector centrality are either connected with smaller number of the terms or with the terms having lower importance, but the terms often provide the shortest paths for the other terms. 'Haptic device' is one of the terms having such characteristics and was located in the center of the network, but it lacked the number of nodes connected to it and had lower tie strengths. Also, the term 'tactile sensor' also showed lower tie strengths among the other nodes but showed higher betweenness centrality since it was located in a position providing shortest paths between many other nodes.

There were also the terms with large differences in the rankings between closeness centrality and betweenness centrality. In such cases, the terms were considered to provide relatively lower number of shortest connections to the other nodes even though they were located closer to the most of the terms.

The terms with such characteristics are ‘haptic rendering’, ‘haptic feedback’ and ‘fMRI’, which were located in a position connecting to many other nodes but were not necessarily located in the center.

2.2.3 Comparison of analysis results

In order to view the related research areas in a broader perspective, we have taken the contents analysis and network analysis into account. The two methodologies follow an approach of analyzing unstructured data, which is advantageous in terms of providing insights about the research areas through quantitative indices. Although there exist a few differences between the two methodologies, more meaningful insights could be discovered through understanding and analyzing such differences in the process.

Since the elements that are considered in the contents analysis and network analysis cover different aspects, it may be possible to obtain more meaningful issues and insights by taking account of the both analyses together. Table 5 shows the results and the current issues obtained from the two analyses.

First, the results of the analyses on the application, both of the two analyses have shown high importance in various applications such as virtual reality and interfaces. In the contents analysis, the terms related to application fields have shown the highest percentage of the appearance frequency, among which the terms ‘virtual’ and ‘interaction’ had the highest increase ratio. In the network analysis, the terms ‘virtual reality’ and ‘interface’ have shown high centrality, which indicates an important position in the network among the terms.

Table 5 Implication by comparing of analysis results

Category	Contents analysis results	Network analysis results	Implication
Field of application	• High increase ratio for the terms virtual and interaction	• High centrality of the terms virtual reality and interface	• Increase of the interest in applying haptic technology in the fields of VR and HRI
Component of haptic system	• Increase in display while decrease in sensor • Similar overall frequency for display and sensor • Increase in actuator, as a type of display	• The groups related to tactile display often linked with the terms related to object cognitive trait – which is the only link between technology perspective and user perspective • Closer relationship between Haptic interface and sensor than with display • Closer relationship between haptic interface and force feedback than with tactile feedback	• Increase of the interest in display
Haptic stimulation	• Higher increase ratio and frequency of force and kinesthetic than those of touch and cutaneous	• The term force display not appearing in the network	• Research on force and its application of display needed
Vision	• One group for vision and blind	• Separate groups for vision and blind	• Objective analysis of relationship among research areas through network analysis
Related body site	• Lack of research on various body sites	• Hand as the only term related to perception	• More research on physiological characteristics of various body sites needed in the future
Physiology of haptic sensation	• Rapid decrease of the terms related to physiological research	• Various research on reactions of different cortex through fMRI and the characteristics of modality and stimulation	
User	• Increase of realizing the important of user-oriented research	• Appearance of the terms human and human factor	• User-oriented research on emotion related to display needed
Haptic perception characteristics	• Increase in ratio despite its lack of research before 2000	• None of direct appearance of the terms related to perception characteristics	

The issues related to display can be found in the studies on haptic stimulation and device components. Between the terms ‘display’ and ‘sensor’, ‘display’ has shown higher importance than ‘sensor’, while kinesthetic sensations than cutaneous sensations in the context of sensations. In the contents analysis, the overall frequencies for both terms came out to be similar, but the term ‘display’ has shown to appear more frequently after the year 2000 while the term ‘sensor’ has shown the opposite trend. In the network analysis, the centrality index of ‘display’ was also larger than that of ‘sensor’. Moreover, ‘display’ has shown a closer relationship with ‘haptic interface’ than ‘sensor’, as well as ‘force feedback’ than ‘tactile feedback’. In the contents analysis, there seems to have an increase in the number of studies on kinesthetic sensation. Also, while the term ‘sensor’ has appeared often with the terms ‘tactile sensor’ and ‘force sensor’, the term ‘display’ has appeared only with the term cutaneous sensation (‘tactile display’) and not with kinesthetic sensation (‘force or kinesthetic display’). This may be due to the complexity in implementation of kinesthetic sensation is higher than that of cutaneous sensation. Moreover, there are more studies related to cutaneous sensation in the context of user perspective than those related to kinesthetic sensation.

In the case of the body site and physiology of haptic sensation, the current research topics mainly focus on the fingers and the hands, while the research trend is showing a decrease in the interest of such topics on physiology of haptic sensations. However, we may expect to see more demands of the studies on the physiological characteristics of different body sites since the targets of the haptic stimulation in the fields of virtual reality and HRI can vary beside the hands. Moreover, in order to develop haptic displays for kinesthetic sensation, the current research studies must expand their interests from physiological studies on cutaneous sensation to physiological mechanisms on kinesthetic sensation.

In taking account of the increase ratio of the terms related user and haptic perception characteristics, we may also realize that the affective aspects of the users are becoming more important than before. Such trend is commonly discovered throughout the fields of HRI, including the fields of haptic (Arkin et al., 2003; Breazeal and Brooks, 2005; Kwon et al., 2007). This finding can be also regarded in relation with the display issues for the future development of haptic displays.

2.3 Research related perception of kinesthetic feedback

To analyze feeling of kinesthetic feedback, there have been various researches on force-profile such as thresholds about force and displacement of switch movement, properties of force-profile affected to switch feeling, effect of properties on feeling, and so on.

In Yang, Tan, Buttolo, Johnston, and Pizlo (2003), perceptual thresholds of feedback factor felt through manipulation of rotary-switch were measured. User perceived torque thresholds was investigated based on torque vs. travel (angular position) profiles that is being used traditionally according to switch movement.

Swindells and MacLean (2007) made the knob-model and measured information of acceleration, friction, position to capture and replay dynamics of mechanical knobs. And model’s accuracy was tested through comparing real knobs with simulated test knobs made by knob-model.

Weir et al. (2004) was utilized a graphical representation technique called the “haptic profile” to define and measure haptic properties that can explain feel of switches. Feel of switches is divided into clicky, smooth, and mushy, then characteristics of haptic profile were investigated. Haptic-profile was deducted with three axles, force, position, and velocity like Fig. 8, graph projected to force-position, position-velocity, and force-velocity was used to analyze characteristics of haptic profile. Characteristics of user perceived switch-feel can be understood through Weir et al. (2004), but investigation of major factor affected on switch-feel and pattern and extent of change according to factor was lack.

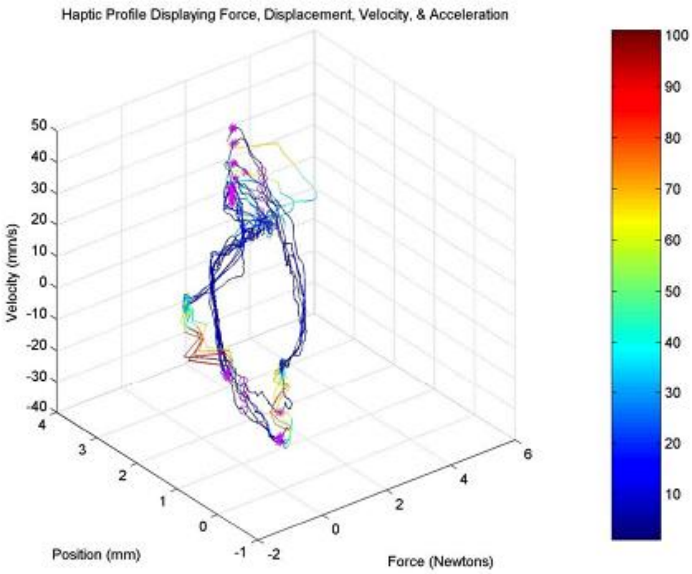


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Figure 8 Haptic profile for analyzing switch feel (adapted from Weir et al. (2004))

Research related to characteristics of force profile show that force, position, and velocity affect on user perceived switch feel and factor of force profile can explain characteristics of kinesthetic feedback.

Summary of research on affective response of kinesthetic feedback are as follows.

Swindells, MacLean, Booth, and Meitner (2007) has analyzed the change of performance of a target acquisition task and visceral emotional responses according to friction, inertia, and detent. It can be identified that position-, velocity-, and acceleration-based effects affected on user affective responses through user evaluation and bio-signal measurement on seven test knobs. But this study has limitation on systematic analysis because independent variable was just one, and level of variable was two. And there were limitation that user evaluation was conducted based on valence, not various affective elements though bio-signal such as EMG, skin conductance was measured, so this study can't analyze which affective element and how much affect on final affective satisfaction.

Wellings and his company investigated about effect of multisensory integration such as visual, auditory, and haptic, etc., on hedonic qualities on user perception of switches in automotive.

Wellings, Williams, and Pitts (2008) and Wellings, Williams, and Tennant (2010) looked at user perception of automotive switches from a holistic perspective. Perceived visual, auditory, and haptic stimulation, when users see and manipulate automotive switches, was evaluated, and then factor analysis is conducted to identify how many and what major factors are deducted. These researches conducted evaluation on stimulation perceived by various modalities as well as haptic stimulation of switch, and deducted the major factors of switch-feel perception. As a results, feeling or image integrated various modalities was deducted as major factor rather than being integrated each modality such as overall image of product, build quality related to precise or finish, and clickiness related to feeling and sound occurred when switch click.

Wellings, Pitts, and Williams (2012) has a different research scope from previous two studies, investigated effect of non-visual aesthetic qualities on experience of interaction except factor related to visual stimulation. And effect of major factors deducted from regression analysis on likeness was analyzed. As a results, four factor, unrefined loudness, positivity/precision, stiffness, and looseness/rattling, were deducted as major factors and positivity/precision and unrefined loudness is affected on likeness.

But systematic diversification of specific product properties was difficult in Wellings and his company’s studies because of evaluation of real product to increase the ecological validity. And number of sample was not enough to conduct systematic analysis. Effect of product properties on affective element couldn’t be identified because of these limitations. These study conducted analysis of effect of aesthetic qualities on the interaction experience and user perception, but relationship between aesthetic qualities and design variable needed to develop product couldn’t be analyzed.

Ha, Kim, Park, Jun, and Rho (2009) and Kim, Han, Shin, and Park (2008) aimed to develop haptic prototyping system to provide hands-on experiences, developed virtual prototype and conducted user test. Virtual prototype provided experience like using and manipulating real product to user using multimodal display utilized visual, aural and haptic modalities. Design variable of haptic display were torque profile (amount, direction, velocity, and acceleration), dial notch properties (number, position, and shape), physical dial knobs properties (shapes, materials, and weights), and this study shown that different of design variable give different sensory and affective feelings through user test.

Lee, Kwon, and Ahn (2011) conducted experiment to understand characteristics of the rotary switch needed to control emotion provided through rotary switch. This study identified the characteristics of switch manipulation according to control variable and measured toque occurred according to magnitude and width. This is expected to utilize generating intended control feel and quantification of control feel.

Table 6 Previous studies on kinesthetic feedback

Title	Author	Objective	Material	Design variable	Affective variable
Characterizing the experience of interaction: an evaluation of automotive rotary dials	Wellings et al. (2012)	empirically examines how non-visual aesthetic qualities affect the interaction experience with automotive rotary dials	automotive rotary dials		Spacing of notches Rattling sound Looseness, Effort Solidity, Positive Smoothness Clunky, Precision Clicky, Friction Notchy
Customer perception of switch-feel in luxury sports utility vehicles	Wellings et al. (2008)	holistic customer research carried out to investigate how the haptics of switches in luxury sports utility vehicles (SUVs) are perceived by customers	automotive push switch		Heavy–light Imprecise–precise Cheap–expensive Noisy–quiet Refined–unrefined Clicky–smooth Pleasant–annoying Loose–tight Flimsy–solid Interesting–dull Old fashioned–modern
Capturing the Dynamics of Mechanical Knobs	Swindells and MacLean (2007)	a novel experimental apparatus for the capture and replay of physical controls (mechanical knobs), as well as a set of acquired models and a design discussion related to the characterization approach taken here	Mechanical Knobs	detents, friction, inertia	
Designing for Feel: Contrasts between Human and Automated Parametric Capture of Knob Physics	Swindells, MacLean, and Booth (2009)	to examine a crucial aspect of a tool intended to support designing for feel: the ability of an objective physical-model	Mechanical Knobs	detents, friction, inertia	

The Role of Prototyping Tools for Haptic Behavior Design	Swindells, Maksakov, MacLean, and Chung (2006)	to introduce a custom haptic icon prototyper that includes novel interaction features, and use the lessons learnt from its development plus our experiences with a variety of haptic devices to present and argue high-level design choices for such prototyping tools in general	Mechanical Knobs	Position, Velocity, Acceleration	
Virtual prototyping of a car turn-signal switch using haptic feedback	Erdelyi and Talaba (2010)	to develop a prototyping method by which the designer can test the haptic behavior of a computer model of a switch using a haptic system	car turn-signal switch	force profile	
Haptic Models of an Automotive Turn-Signal Switch: Identification and Playback Results	Colton and Hollerbach (2007)	to develop a method to obtain haptic models of buttons and switches from experimental data.	turn-signal switch	mass, damping, stiffness, offset force	the realism of models
Haptical feeling of rotary switches	Reisinger, Wild, Mauter, and Bubb (2006)	to describes the common problems of the torque characteristics, an alternative description theory and their evaluation with tests in detail	rotary switches		
Virtual prototyping enhanced by a haptic interface	Ha et al. (2009)	to present a haptic prototyping system with a motor-actuated dial knob which is designed to add tactile/haptic feedback to conventional virtual prototyping		Torque profile (amount, direction, velocity, and acceleration) of the dial along the rotational path. Number, position, and shape of the dial notch. Physical dial knobs of different shapes, materials, and weights.	strong-weak, refined-coarse, crisp-dull

The Haptic Profile: Capturing the Feel of Switches	Weir et al. (2004)	to collect haptic data and display it in a useful and intuitive manner.	on/off type and momentary type switch	Haptic Profile	clicky, smooth, mushy
Thresholds for Dynamic Changes in a Rotary Switch	Yang et al. (2003)	to evaluate the perceptual thresholds for dynamic changes in a rotary switch	rotary switch		
Exploring Affective Design for Physical Controls	Swindells et al. (2007)	to understand how the choice of acceleration-, velocity-, and position-dependent force feedback renderings for an active physical control influences user performance		friction, inertia, and detent	valence and arousal

Chapter 3. Affective evaluation experiment – focused on real product

3.1 Overview

We have performed an evaluation of emotions related to kinesthetic sensations and an analysis of the characteristics in perceiving kinesthetic sensations with respect to the characteristics of the products. The movements of a hand during the manipulation of a target object were matched with 6 exploratory procedures of exploring objects in active haptic mode, and the experiment was modeled to investigate the characteristics of a user's perception with respect to each element (Lederman & Klatzky, 1987). Based on force-displacement graph with respect to the movement of a target object, it was also determined whether the stimulation related to object manipulation has any relationship with either movement or force. Fig. 9 shows the types of stimulation used in three experiments, the exploration procedure, image of the target object and the force-displacement graph.

In order to determine the characteristics of perception with respect to haptic feedback received from various products, an experiment was conducted to evaluate the products that have different characteristics of stimulation. The products considered in the experiment have been categorized into the elements related to force and movement that affect kinesthetic sensations based on the standards proposed in Chapter 2.1. As discussed in Chapter 2.1, the products have been observed to have three different types of characteristics: stimulation related to force elements, stimulation related to movement elements, and stimulation related to both of the force and movement elements. In addition, the movement of manipulating each product has been matched to the 6 exploratory procedures (Lederman & Klatzky, 1987) and the complex matrix (Fig. 9). Finally, the three experiments have been analyzed to determine the types of affective elements perceived from haptic feedback with respect to different characteristics of stimulation.

This chapter discusses different characteristics of haptic feedback used in each experiment in terms of force profile and explains the relationship of each element with the standards proposed in Chapter 2.1. The process of the experiments is also explained, and the affective vocabularies derived from considering the characteristic of each stimulation are discussed. In the analysis of each experiment, the main elements that affect the affective perception are analyzed to determine the influence level of the affective elements on the satisfaction of the products.

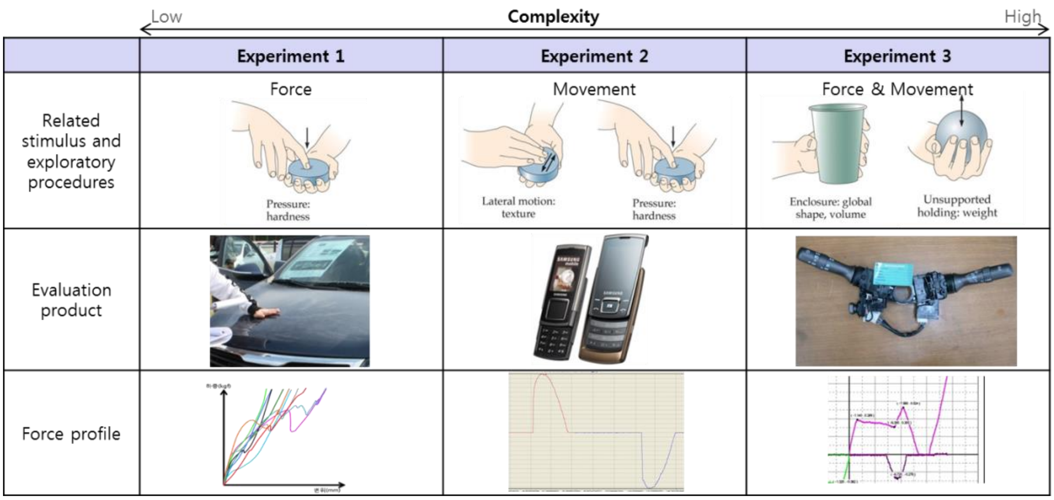


Figure 9 Overview of evaluation experiment of existing products

3.2 Experiment 1 : Automobile outside panel

3.2.1 Participants and Procedure

The experiment had a total of 54 males (25 males in 20's, 17 in 30's, 8 in 40's and 4 in 50's) to evaluate 63 different types of outside panels in seven different parts (hood, fender, front door, rear door, quarter panel, trunk lid, and roof) of 9 different kinds of automobiles. The experiment first began with the explanation of the purpose and overall process of the study. The affective evaluation was performed by randomly pressing 7 different parts of each vehicle that were labeled prior to the experiment. Experiment environments is shown in Fig. 10.

Figure 10 Experiment environments

The indices of evaluation were selected as "satisfaction," "hardness," "consistency," and "thickness," which are related to the affective perception that occur when pressing the outside panels, and each index was evaluated according to the 7-points SD scale. The details of affective variables used in the evaluation are explained in Table 7.

Table 7 Definition of affective variables in experiment 1

Affective variables	Definition
Satisfaction	Degree of satisfaction in terms of the automobile outside panel’s stiffness when pressing it
Hardness	Degree of how much impact the outside panel can take when pressing it
Consistency	Degree of consistency in deformation of the automobile outside panel when pressing it
Thickness	Degree of how thick the automobile outside panel feels when pressing it

3.2.2 Materials

Experiment 1 has evaluated the senses related to the feedback received from pressing the outside panels of an automobile (Rhiu, Ryu, Jin, & Yun, 2011). The motion of pressing the outside panels with some force can be related to the pressure among the exploratory procedures. Depending on the properties of the outside panels, the slope of linear degrees, the sections where canning occurs, their linear degrees and the emotions perceived by the users may vary. In order to evaluate the affective perception of a user with respect to the pattern changes of force, different outside panels having different force patterns upon pressure have been used in the experiment as shown in Fig. 11.

Figure 11 Outside panel

According to the force profile, the movement of the outside panels caused by pressure is no longer than 1 cm while having the force changes of 1~3 kgf when canning occurs as shown in Fig. 12, which indicates that they are more related to the force elements than the movement elements.

Force profile show that stress-strain curve have slope of force and displacement and decrease of the curve at a point (called canning). Slope of curve (displacement according force) is utilized to analyze relationship between elements of force profile and satisfaction.

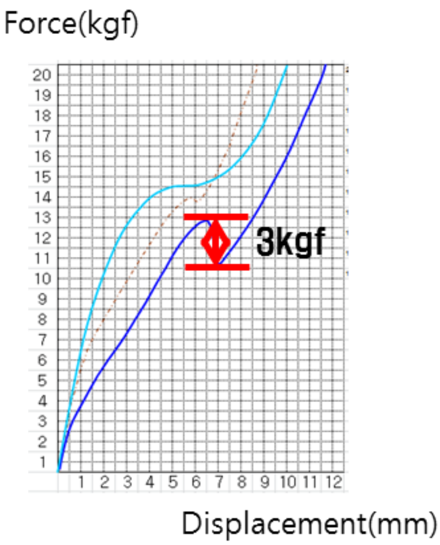


Figure 12 Force profile of experiment 1

3.2.3 Data analysis

Statistical analysis between affective element and satisfaction, satisfaction and elements of force profile is conducted to execute modeling of relationship between stiffness of outside panel and satisfaction. Through the factor analysis and correlation analysis, relationship between affective elements was checked. The relationship between the satisfaction score and affective elements was analyzed through the regression analysis, and the main affective elements were determined by affective modeling. The data analysis was performed after the normalization to remove the differences cause by user bias such as the highest and lowest scores, mean and variance. The normalization was computed by the equation (X – mean) / variance after computing the mean and the standard deviation of the evaluated scores.

3.2.4 Results

As a results of correlation analysis, every affective element have strong positive correlation (correlation coefficients among affective element are 0.74~0.79).

Table 8 Results of correlation analysis about experiment 1

	hardness	consistency	thickness	satisfaction
hardness	1	.791	.765	.746
consistency	.791	1	.734	.765
thickness	.765	.734	1	.749
satisfaction	.746	.765	.749	1

The result of factor analysis has shown that one element was explaining the data variance by 84.3%, and three different affective elements were grouped into one factor. All three elements have shown to have factor loadings higher than 0.9. As a result of factor analysis, one factor is extracted about affective element related to satisfaction of outside panel. It is thought that each affective element is related force through characteristics of force profile.

Table 9 Results of factor analysis about experiment 1

Affective vocabulary	Factor loading
	Factor 1(84.3%)
hardness	.929
consistency	.917
thickness	.907

From the result of regression analysis, the stepwise method has been used as the method of selecting variables, and all three affective elements were entered (R^2 = 0.676). Consistency has shown the highest influence level of 0.358 on the satisfaction, followed by thickness having 0.319 and hardness 0.219.

Table 10 Results of regression analysis about experiment 1

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.020	.009		2.169	.030
consistency	.320	.015	.358	21.167	.000
thickness	.319	.016	.319	19.855	.000
hardness	.215	.018	.219	12.285	.000

Slope of force profile is measured and conducted regression analysis to analyze relationship between affective satisfaction and elements of force profile. The result of regression analysis between satisfaction and slope of curve show that slope of curve affect on satisfaction (R^2 = 0.403). As slope of curve increase, thickness, hardness increase, then this affects satisfaction.

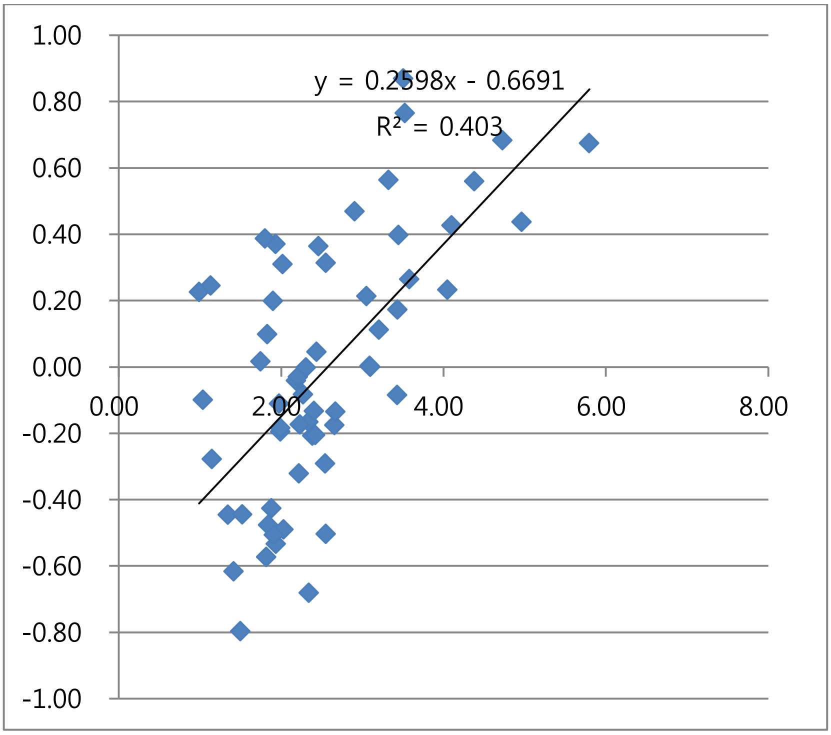


Figure 13 Scatter plot of slope of force profile and satisfaction

Force feedback evaluated in experiment 1 has simple form and not many related factor, so it is difficult to divide user perceived emotion occurred when outside panel is moved into a number of factor. Every affective element has strong positive correlation with satisfaction (correlation coefficients is more than 0.75), so there is no great difference between evaluating one factor integrated and various factor. And impact on satisfaction is not great difference according to affective element.

Satisfaction can be explained by tilt of force profile curve. Affective response on outside panel can be explained by some factor deducted from force profile unsophisticatedly because complexity of stimulus related to outside panel is not high.

3.3 Experiment 2 : Slide phone

3.3.1 Participants

The experiment was done by a total of 40 participants of having 10 males and 10 females in 20's and 10 males and 10 females in 50's. 38 of the participants had their right hands as the most skilled hand, while one of them having the left hand and another having both hands as the most skilled hand. Likewise, 31 of them have shown to use their right hands for mobile phones, and 6 of them used with the left hand and 3 of them with both hands to use the mobile phones. 29 of the participants had experiences with the slide phones for an average of 16.3 months. Table 11 shows the summary of the information of the participants.

Table 11 Characteristics of participants

Description	Category	Count	% of Total
age	21–30	20	50.0%
	51–60	20	50.0%
sex	Male	20	50.0%
	Female	20	50.0%
Preferred hand	Right	38	95.0%
	Left	1	2.5%
	both	1	2.5%
Experience with slide phones	Yes	29	72.5%
	No	11	27.5%
Total		40	100.0%

3.3.2 Materials

Experiment 2 has performed an evaluation of haptic feedback received from the moving part of the upper case reacting to a certain amount of force exerted by the spring (Bahn, Jung, Song, Kwon, & Yun, 2010). The movement of the upper case along with the force exerted on the upper case can be related to pressure and lateral motion among the exploratory procedures. The feedback received from the upper case of a mobile phone as it slides up is affected by the reaction force needed to slide up the upper case, the velocity with respect to the friction and the pattern changes of the reaction force. In order to evaluate the affective perception of a user according to the pattern changes of force, the experiment was performed with 25 different types of slide phones that have different amount of reaction force and force pattern changes with respect to the motion of sliding. Fig. 14 shows the images of the products.

Figure 14 Experiment samples

According to the force profile, there is no change in force approximately after 260 gf and after the upper case has sled up about 30 mm. This observation of having the force applied to the upper case no greater than 260 gf while the movement being approximately 30 mm tells us that they are more related to the movement elements than to the force elements.

Design variables used to analysis are deducted from force profile appeared when top of slide phone is moved, change of displacement and force in force profile that utilized to analyze perception of movement and force in literature review. Force profile has asymmetric sine wave form that force increase to peak rapidly, and then decrease slowly. Design variables are selected peak, dp1, dp2, and details of elements of force profile used in analysis are explained in Table 12.

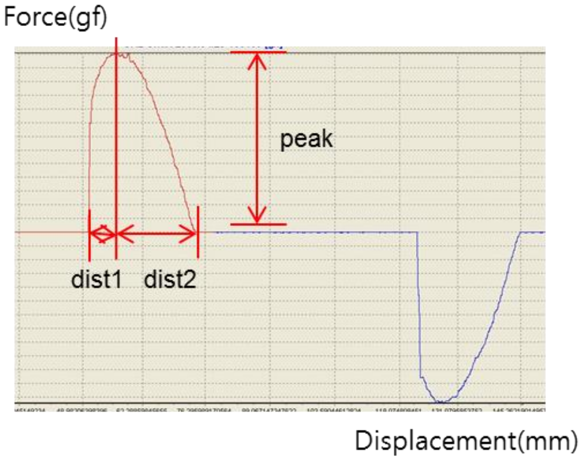


Figure 15 Force profile of experiment 2

Table 12 Definition of design variable

Design variable	Definition
peak	Maximum force occurred when upper body is moving
dist1	Distance between start point and peak
dist2	Distance between peak and end point

3.3.3 Procedure

First, the participants were briefly explained with the purpose, the subject of study and the affective elements and were asked to provide their personal information. The participants were then blindfolded and began to freely play around with various phones and feel the differences among them. In order to remove possible influence from the outside elements, the participants were asked to hold the phones inside a box and evaluate the feelings of sliding them up. Fig. 16 shows an image of the experiment.

Figure 16 Experiment environments

The affective elements that were evaluated by the users are consistency, smoothness, solidity, sleekness, liltingness and satisfaction. Satisfaction was evaluated under 100-point scale, and the rest of the elements were evaluated under 7-point Likert scale.

Table 13 Definition of affective variables in experiment 2

Affective variables	Definition
Satisfaction	Satisfaction based on feeling of sliding up a phone
Consistency	Subjective opinion on the consistency of sliding up a phone
Smoothness	Subjective opinion on the smoothness or roughness of sliding up a phone
Solidity	Subjective opinion on the hardness or looseness of sliding up a phone
Sleekness	Subjective opinion on the smoothness or roughness of sliding up a phone
Liltingness	Subjective opinion on the lightness or heaviness of sliding up a phone

3.3.4 Data analysis

In experiment 2 correlation analysis, factor analysis and regression analysis is used to analysis and data analysis was performed after the normalization of evaluation data in common with experiment 1. Quantification I analysis is utilized to analyze relationship between satisfaction and elements of force profile unlike experiment 1 because relationship between satisfaction and elements of force profile has not linearity.

We investigate descriptive statistic of affective element according to level of force profile elements and divide into 3~4 range that has similar trend or score to utilize quantification I analysis method. Then effect of each range on affective element is analyzed through quantification I analysis method.

3.3.5 Results

Results of correlation analysis between affective elements are like Table 14.

Every affective element has strong positive correlation (correlation coefficients are more than 0.35). Elasticity have most positive correlation with satisfaction (correlation coefficient is 0.54). Solidity has low correlation coefficients with rest of affective element, it means that solidity has different characteristics with rest of affective element. Smoothness, sleekness, and elasticity have strong positive correlation (correlation coefficients among smoothness, sleekness, and elasticity are more than 0.6).

Table 14 Results of correlation analysis about experiment 1

	Consis-tency	Smooth-ness	Solidity	Sleek-ness	Elasti-city	Satisfac-tion
Consis-tency	1	.594	.355	.573	.508	.456
Smooth-ness	.594	1	.240	.612	.622	.486
Solidity	.355	.240	1	.299	.268	.384
Sleek-ness	.573	.612	.299	1	.604	.477
Elasti-city	.508	.622	.268	.604	1	.540
Satisfac-tion	.456	.486	.384	.477	.540	1

The factor analysis has shown that five affective elements could be grouped by one factor with the data variance of 54.4%. Except solidity, which had a factor loading of 0.430, the rest of five elements had factor loadings higher than 0.75. As a result of factor analysis, one factor is extracted about affective element related to control feeling of slide phone although solidity has a little different with other affective element. It is thought that each affective element is related movement through characteristics of force profile.

Table 15 Results of factor analysis about experiment 2

Affective vocabulary	Factor loading Factor 1(54.4%)
Sleekness	.825
Smoothness	.801
Elasticity	.784
Consistency	.775
Solidity	.430

The result of regression analysis has shown that the stepwise method was used for the variable selection method, and the five elements were all entered (R^2 = 0.558). Sleekness has shown the highest influence level of 0.297 on satisfaction, followed by solidity of 0.237, smoothness of 0.2251, elasticity of 0.167 and consistency of 0.121 in order. Solidity has low correlation coefficients with satisfaction, but most effect on satisfaction next to sleekness in regression analysis result. This resulted from correlation coefficients that between other affective elements is high, but between other affective element and solidity is low. Because sleekness in affective element that correlation coefficients between each other are high explain much of satisfaction, then explanation portion of other affective elements that correlation coefficients between each other are high become smaller.

Table 16 Results of regression analysis about experiment 2

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.226	.050	.225	4.556	.000
Sleekness	.335	.043	.297	7.708	.000

Solidity	.218	.044	.237	5.017	.000
Elasticity	.169	.047	.167	3.615	.000
Consistency	.124	.050	.121	2.473	.014
Smoothness	.226	.050	.225	4.556	.000

Table 17 and 18 shows partial correlation coefficient (R) of each element of force profile and partial regression coefficient of each level of force profile elements that resulted from quantification I analysis method. R^2, indicates how well elements of force profile explain affective element, have high value, above 0.25, in every affective elements except solidity. Satisfaction and sleekness explained well by design variable (R^2 is 0.34 and 0.36) Partial correlation coefficient of dist1, effect of force profile elements on affective element, has most value in case of almost affective element. Dist1 has most effect on smoothness, sleekness, and elasticity (Partial correlation coefficient is more than 0.3). Satisfaction and consistency is effected by elements of force profile in order of dist1, dist2, and peak. But solidity that has low correlation coefficients with other affective element consistency is affected by elements of force profile in order of dist2, peak, dist1, dist1 has least effect, uniquely.

Change pattern of affective element according to level of variable can be analyzed through partial correlation coefficient, effect of force profile elements on affective element. Solidity has different change pattern in comparison of other affective elements. Level 2 has most effect on solidity in case of peak and the more level of variable is far from level 2, the more positive effect is small. Solidity has not consistent pattern affected by level of variable. As dist1 increase, positive effect of dist1on solidity increase, but other effect on affective element has not consistent pattern. Level 2 of dist1 has most positive effect on smoothness and elasticity. Level 3 of dist1 has most negative effect on other affective element, and the more level of force profile elements is far from level 3, the more negative effect is small.

Table 17 Partial correlation coefficient (R) of each force profile elements

	Satisfaction (R^2= 0.34)	Consistency (R^2= 0.28)	Smoothness (R^2= 0.29)	Solidity (R^2=0.17)	Sleekness (R^2=0.36)	Elasticity (R^2=0.25)
peak	0.13	0.10	0.27	0.22	0.13	0.14
dist1	0.23	0.18	0.34	0.20	0.31	0.32
dist2	0.18	0.17	0.17	0.32	0.12	0.07

Table 18 Partial regression coefficient of each level of force profile elements

Design variable	Level	Satisfac-tion	Consistency	Smooth-ness	Solidity	Sleekness	Elasticity
peak	1	0.04	-0.17	-0.10	0.22	0.02	0.07
	2	-0.04	0.11	0.40	-0.47	0.06	0.25
	3	0.02	-0.05	-0.32	0.34	-0.06	-0.23
	4	-0.45	-0.18	-0.22	-0.26	-0.31	0.12
dist1	1	-0.07	0.23	0.97	-0.83	0.25	0.57
	2	-0.60	-0.59	-1.22	0.35	-1.01	-1.21
	3	0.26	0.10	-0.03	0.28	0.25	0.17
	4	-0.09	-0.34	-1.16	0.97	0.09	-0.97
dist2	1	0.22	0.28	-0.10	0.32	0.17	0.03
	2	0.02	0.09	0.30	-0.33	-0.07	0.19
	3	-0.24	-0.36	-0.20	0.01	-0.10	-0.22
	4	0.57	0.40	-0.60	1.20	0.30	-0.21

Change pattern of solidity according to level of variable is different from other affective element, also. Through one factor is deducted from five affective elements as a factor analysis result, solidity can be explained another factor. This is resulted from feedback used in experiment 2 has strong relationship with movement but has some factor related with force.

3.4 Experiment 3 : Multi-function switch

3.4.1 Participants and material

Experiment 3 was performed to evaluate the haptic feedback received from twisting a bar whose end is fixed with a spring that exerts a certain amount of force on to a ball while rolling over a slanted surface. The motion involves the rotation of a bar by force and thus is related to enclosure and unsupported holding among the exploratory procedures. The experiment consisted of a total of 101 participants (mean age of 27.8) with 78 males and 23 females, and they have performed the experiment with 16 types of multifunction switch. Fig. 17 shows the image of the products.

Figure 17 Experiment samples

The force profile shows that there are two force changes with the force difference of 0.2 kgf during the rotation of the bar by 80^{o} at the fixed end point. The first force change requires 0.4 kgf, and the next change happens with additional 0.2 kgf. Since the total angle of rotation was shown to be 80°, the feedback may seem to relate with both of the force elements and movement elements.

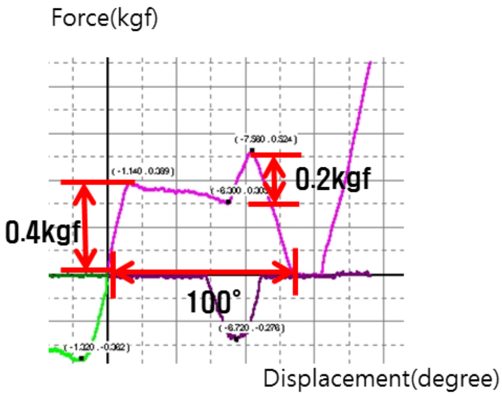


Figure 18 Force profile of experiment 3

3.4.2 Procedure

The indices of evaluating the user's affective response during the movement of the bar were selected as satisfaction, smoothness, sense of unity, perspicuity and heaviness, and each index was evaluated under the 7-point Likert scale.

3.4.3 Data analysis

In experiment 3 correlation analysis, factor analysis and regression analysis is used to analysis and data analysis was performed after the normalization of evaluation data in common with experiment 1. Statistical analysis of relationship between affective elements and elements of force profile has limitation because force profile can't be explained one or two factor and user perceived emotion is affected by various factor. In this study, elements of force profile affected on affective element are analyzed and summarized through scatter plot of affective element and factor deducted form force profile.

Factor related to degree and height is selected from force profile as design variables used to analyze, details are as follow. Force profile of multi-function switch is like Fig. 19. Switch pass two detent and section changing slope of force profile appear three times. Points that change the slope is assigned 1p, 2p, and 3p, rotation degree and height to each point is selected as design variables. Total eight variables, rotation degree and height between 0-1p, 1p-2p, 2p-3p, and of total, are utilized to analyze.

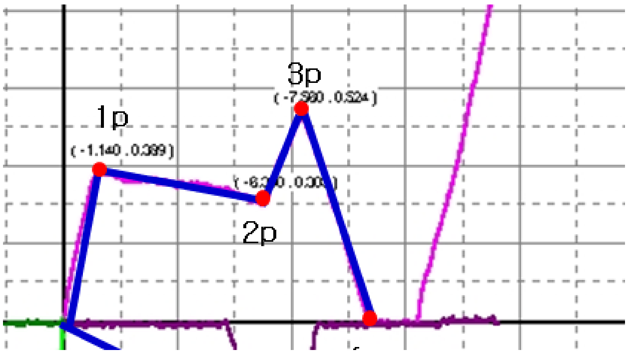


Figure 19 Point needed to define design variable

3.4.4 Results

Results of correlation analysis between affective elements are like Table 19.

As results of correlation analysis, correlation coefficients have various values in contrast with experiment 1 and 2. Smoothness has no correlation with perspicuity (correlation coefficient is 0.07) and has strong negative correlation with heaviness (correlation coefficient is -0.37). This result is related with factor analysis result that two factor is extracted. Satisfaction has strong positive correlation with affective element except heaviness (correlation coefficients are more than 0.34).

Table 19 Results of correlation analysis about experiment 3

	Smooth-ness	Sense of unity	Perspicuity	Heavi-ness	Satisfaction
Smooth-ness	1	.367	.069	-.371	.603
Sense of unity	.367	1	.199	.006	.484
Perspicuity	.069	.199	1	.165	.340
Heaviness	-.371	.006	.165	1	-.166
Satisfaction	.603	.484	.340	-.166	1

From the result of factor analysis, two elements have shown to explain 70.7% of data variance, and the four affective elements were observed to be grouped into two factors. All of the four affective elements had factor loadings higher than 0.65 for both Factor 1 and Factor 2. Smoothness and sense of unity were grouped into factor 1 while heaviness and perspicuity into factor 2 similar to correlation analysis. Factor of user perceived affective elements are more complicated contrary to experiment 1 and 2 because of complexity of force profile. Each factor can be said to be related with force and movement.

Table 20 Results of factor analysis about experiment 3

	Factor loading	
	Factor 1(38.2%)	Factor 2(31.4%)
Smoothness	**.867**	-.111
Sense of unity	**.669**	.457
Heaviness	.197	**.765**
Perspicuity	-.539	**.669**

The result of regression analysis have shown that the stepwise method was used as the method of selecting variables, and all four elements have entered ($R^2 = 0.431$). The effect of smoothness on satisfaction was the highest with the score of 0.430, followed by perspicuity with 0.277, sense of unity with 0.227 and heaviness with -0.106. Every affective element except heaviness has positive effect on affective element. Users prefer feedback that move smoothly and confirm change of function easily and clearly to thing that needs much power to manipulation.

Table 21 Results of regression analysis about experiment 3

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.076	.034		-2.262	.024
Smoothness	.401	.033	.430	12.270	.000
Perspicuity	.296	.033	.277	8.892	.000
Sense of unity	.240	.034	.227	7.043	.000
Heaviness	-.114	.037	-.106	-3.121	.002

Relationship analysis between affective element and elements of force profile is conducted about affective element included in two factors that has more effect on satisfaction through result of regression analysis. Smoothness in factor 1, perspicuity in factor 2 and satisfaction that perceived through integrating affective element is analyzed.

Scatter plot of total height and smoothness, perspicuity, satisfaction is like Fig. 20, 21, and 22. Change pattern of smoothness, perspicuity, and satisfaction according total height is shown similar trend. Smoothness, perspicuity, and satisfaction gets lower as total height get bigger. R^2 is 0.54, 0.47, and 0.24 in the same order as satisfaction, perspicuity, and smoothness.

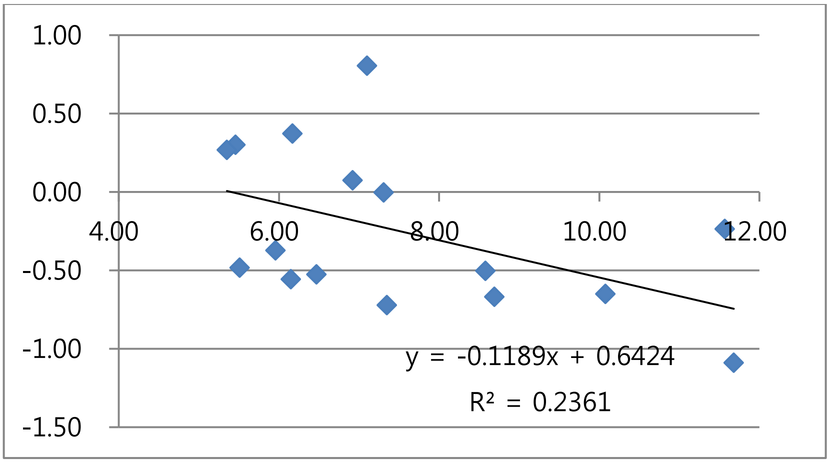


Figure 20 Scatter plot of total height and smoothness

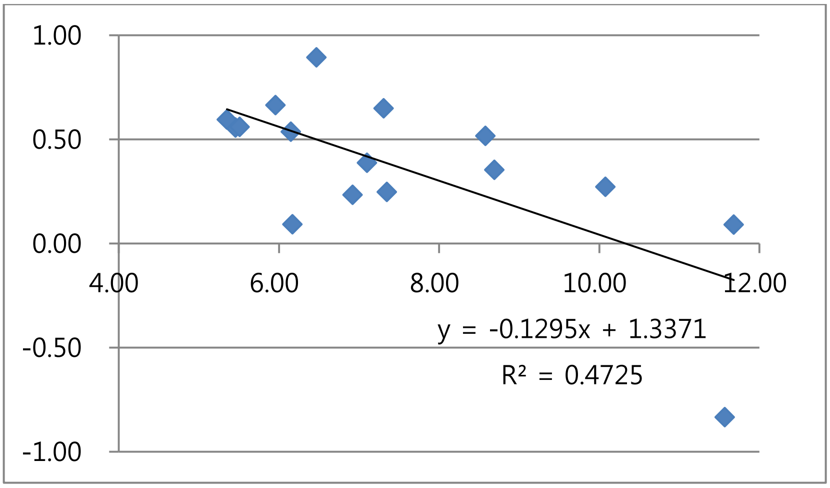


Figure 21 Scatter plot of total height and perspicuity

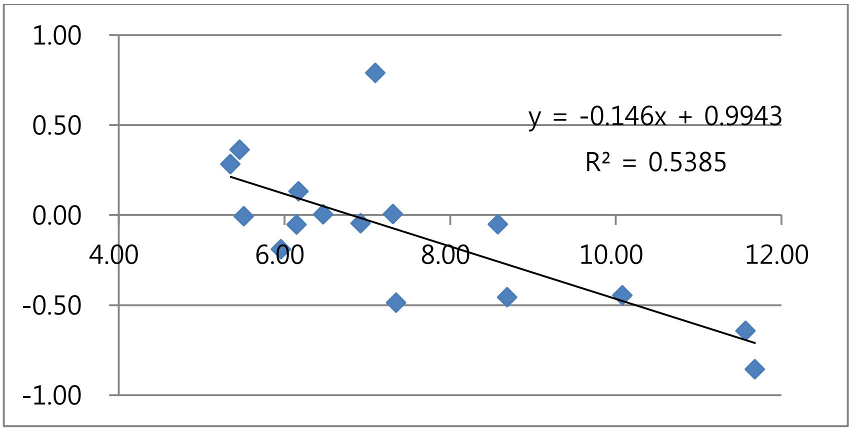


Figure 22 Scatter plot of total height and satisfaction

Scatter plot of 0-1p degree and smoothness, satisfaction is like Fig. 23 and 24. Change pattern of smoothness and satisfaction according to 0-1p degree is shown different trend. Smoothness gets lower as 0-1p degree get bigger, but satisfaction get higher.

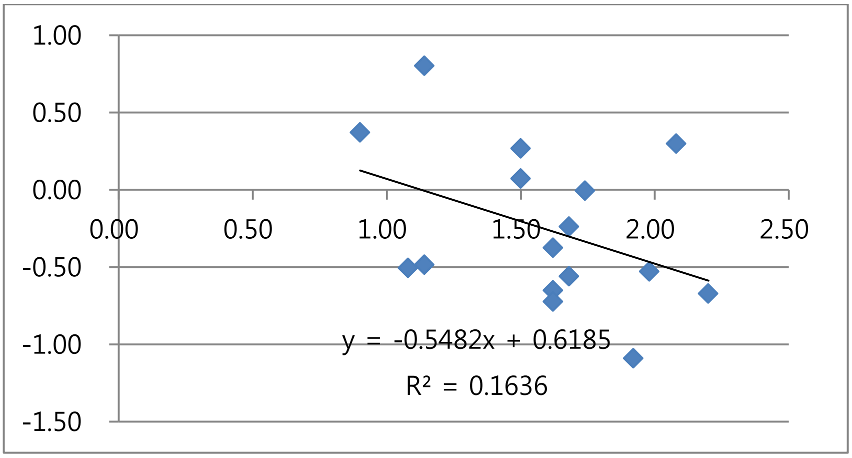


Figure 23 Scatter plot of 0-1p degree and smoothness

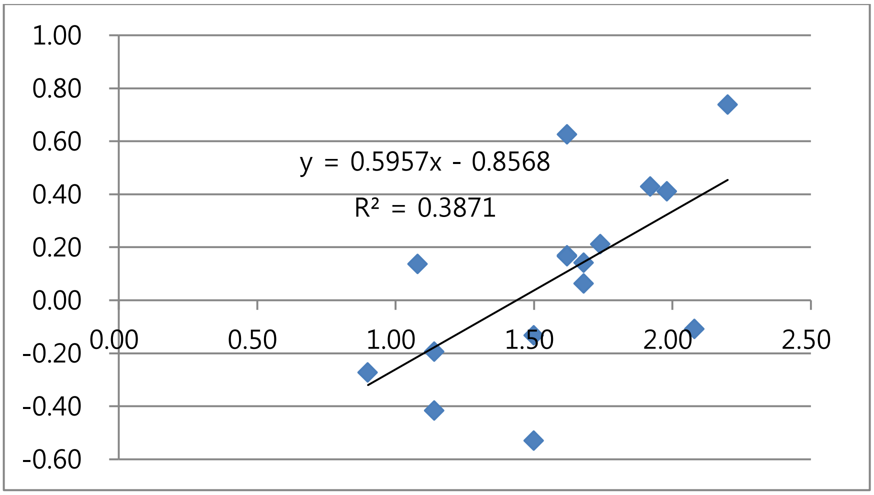


Figure 24 Scatter plot of 0-1p degree and satisfaction

Scatter plot of 2p-3p degree and perspicuity, satisfaction is like Fig. 25 and 26. Perspicuity and satisfaction get lower as 2p-3p degree get bigger. R^2 is 0.22, 0.16 in the same order as perspicuity, satisfaction.

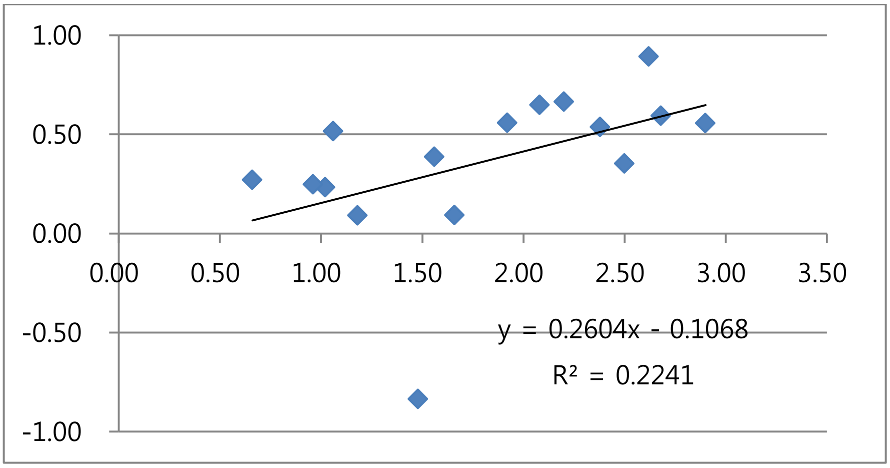


Figure 25 Scatter plot of 2p-3p degree and perspicuity

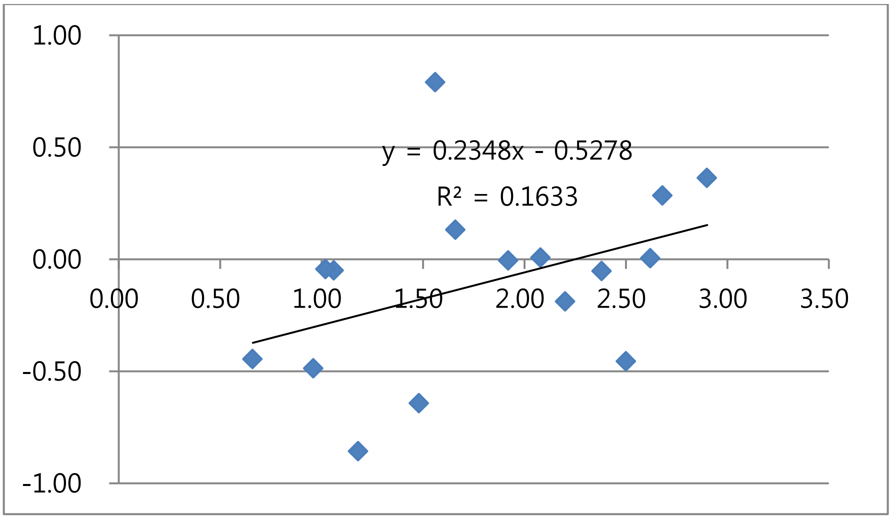


Figure 26 Scatter plot of 2p-3p degree and satisfaction

Scatter plot of 0-1p height and smoothness, perspicuity, satisfaction is like Fig. 27, 28, and 29. Change pattern of affective element according to 0-1p height is shown similar trend. Smoothness, perspicuity, and satisfaction get lower as 0-1p degree get bigger. R^2 is 0.49, 0.31, and 0.31 in the same order as satisfaction, smoothness, and perspicuity.

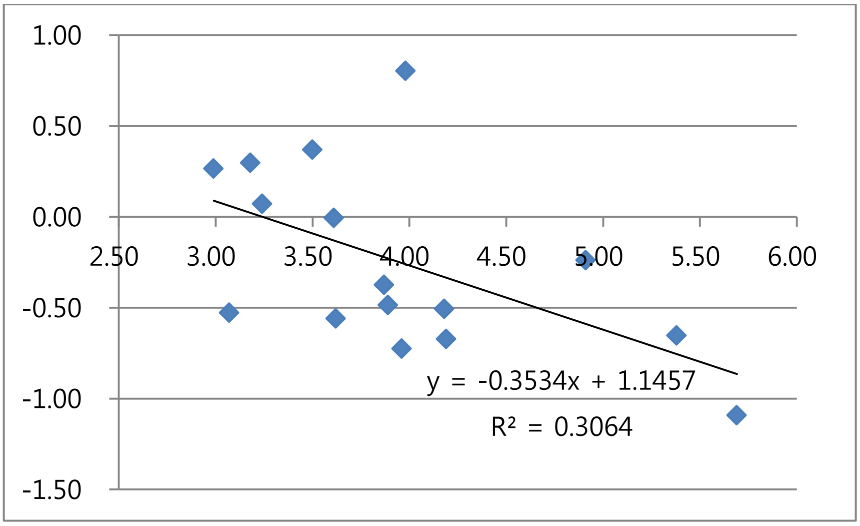


Figure 27 Scatter plot of 0-1p height and smoothness

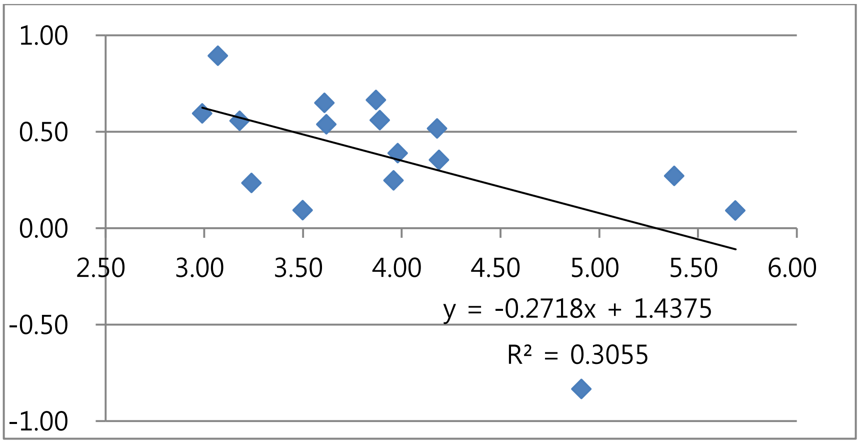


Figure 28 Scatter plot of 0-1p height and perspicuity

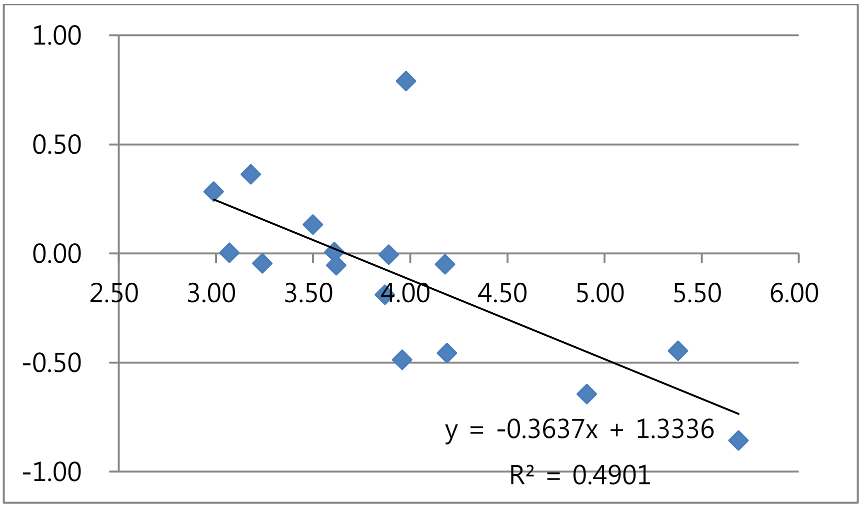


Figure 29 Scatter plot of 0-1p height and satisfaction

Scatter plot of 1p-2p height and perspicuity, satisfaction is like Fig. 30 and 31. Change pattern of affective element according to 1p-2p height is shown similar trend. Perspicuity and satisfaction get lower as 1p-2p height get bigger. R^2 is 0.39, 0.28 in the same order as perspicuity, satisfaction.

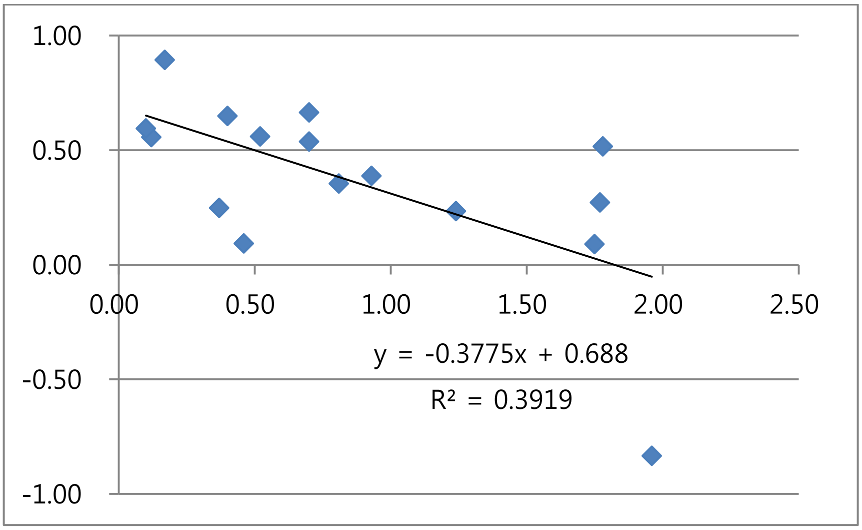


Figure 30 Scatter plot of 1p-2p height and perspicuity

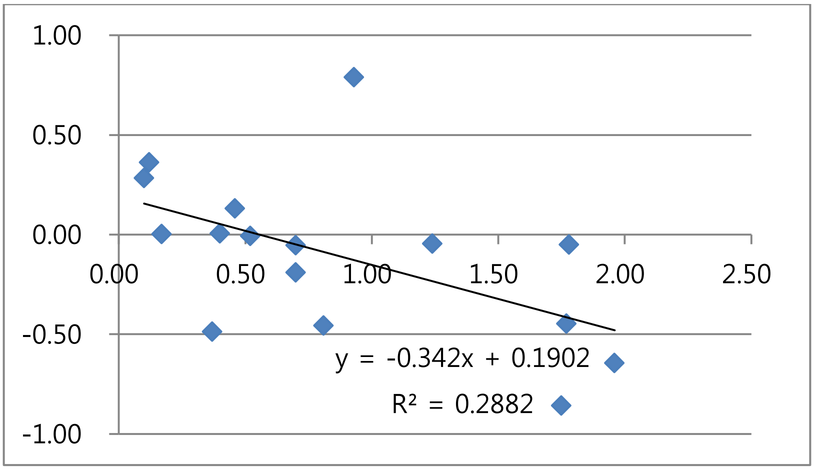


Figure 31 Scatter plot of 1p-2p height and satisfaction

Scatter plot of 2p-3p height and perspicuity, satisfaction is like Fig. 32 and 33. Change pattern of affective element according to 2p-3p height is shown similar trend. Perspicuity and satisfaction get lower as 2p-3p height get bigger. R^2 is 0.40, 0.35 in the same order as satisfaction, perspicuity.

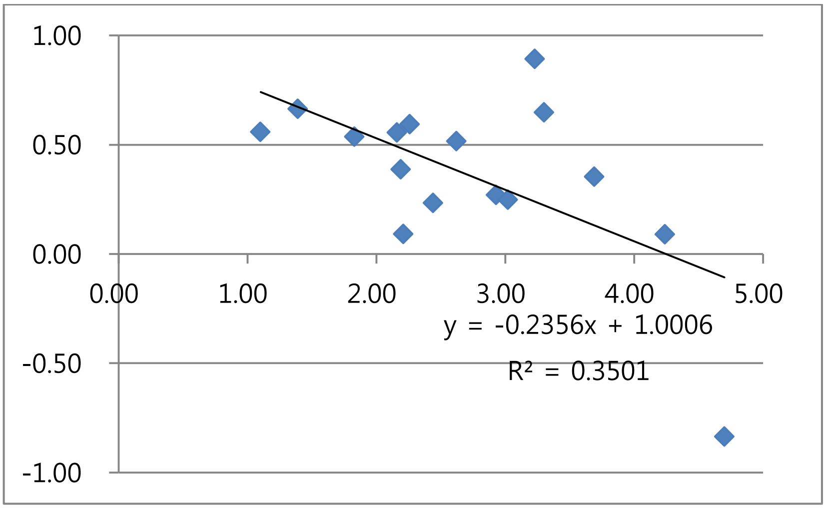


Figure 32 Scatter plot of 2p-3p height and perspicuity

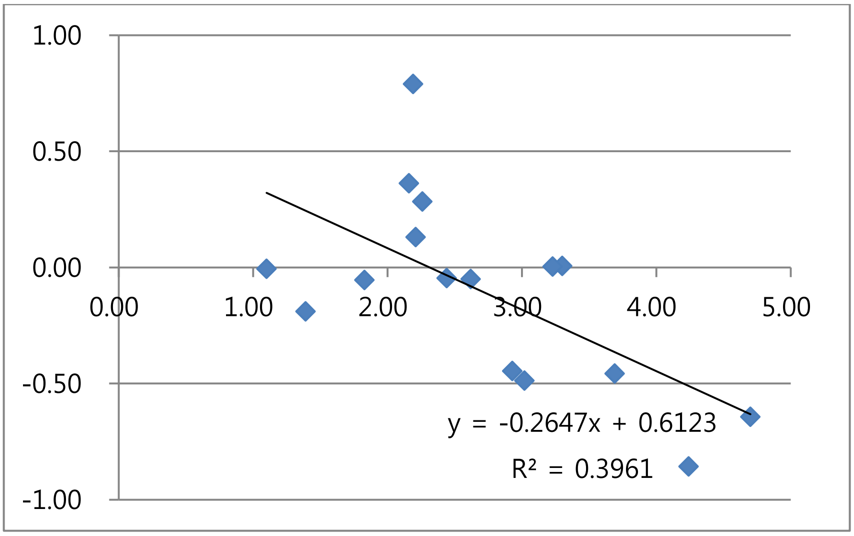


Figure 33 Scatter plot of 2p-3p height and satisfaction

Relationship between affective element and elements of force profile show that some elements of force profile and affective element have linear relationship and satisfaction is explained more than 30% by elements of force profile when elements of force profile explain smoothness or perspicuity more than 30%. As mentioned previously, haptic feedback used in experiment 3 has relatively long movement and dynamic change of force, so it is difficult that affective element explain by combination of force profile elements. But relationship between each elements of force profile and affective elements can be identified through correlation analysis and scatter plot. As a result, evaluation score of affective element has tendency to decrease as every elements of force profile except rotation degree of 2p-3p increase.

Chapter 4. Affective assessment on simulated haptic feedback

It may be possible to observe the pattern of force feedback and to distinguish the related elements from the existing product evaluations, but it is still difficult to analyze the relationship between the force profile elements and the affective elements. In order to determine the design guidelines for improving the affective satisfaction of products, the relationship between the affective elements and elements of force profile must be analyzed. However, there are certain limitation in the process and needs additional experiments in details.

First, it is difficult to define specific elements of force profile since there exists complex relationship among the force profile elements of a product. The elements of force profile that affect the affective elements must be determined and analyzed, but the force displacement graph is determined by complex relationship among various elements of force profile and it is difficult to determine the variables that act as the main factors affecting the affective elements.

Second, it is difficult to analyze the effects of variable changes since the flexibility of controlling the elements of force profile is limited. Although the elements of force profile that affect the affective elements are defined, it is still difficult to control specific variables as mentioned previously. Thus, the detailed design of the experiment is limited.

Third, there exist various noises and variations from unexpected variables and the reactions between the variables. All of the elements that affect the force profile cannot be determined, and it may be difficult to develop a product that can maintain the true intention of the force profile when the effects of different variables begin to overlap.

Therefore, the experiment needs to utilize a haptic simulator that can control the force profile. The experiment discussed in Chapter 4 uses a haptic simulator with the following characteristics. First, the force displacement graph is simplified into a sine wave graph that depicts the haptic feedback, and the main factors that affect kinesthetic sensations can be defined. Second, the design variables that explain the force profile are determined through the experiment planning, and their effects can be analyzed. Third, the controlled environment of the experiment can provide a systematic evaluation of the effects of the defined variables by eliminating unexpected factors that may affect kinesthetic sensations.

The experiments of this study attempts to determine the major affective dimensions related to kinesthetic perception among various haptic feedbacks and to analyze the patterns of affective perception with respect to the design elements related to movement. Then, the relationship between the design elements and affective elements is modeled based on the results of the experiments. Moreover, the affective perception of the feedback received from manipulating devices directly and those from manipulating indirectly are studied and compared to analyze the differences of the characteristics. The perception characteristics of the users according to the force pattern changes is analyzed by utilizing haptic simulator that can control design variables of the force profile.

4.1 Participants and product samples

The experiment consists of 33 haptic feedback provided a haptic simulator, and there were 13 male and 12 female (mean age of 25, with standard deviation of 2.5) who had participated the experiment (Fig. 34, 35). In order to analyze the pattern and characteristics of affective perception, the elements of force profile were controlled by haptic stimulator. Also, in order to analyze the perception characteristics according to the haptic mode, the experiments were divided into active haptic where the participants were directly involved with controlling devices and into passive haptic where the participants remained uninvolved. In the passive haptic, the experimenter was controlling the motor installed under the device through a software program. During the evaluation of passive haptic, the angular velocity (**π** rad/sec) of the device was set to alternate its direction every 120 degrees in order to provide stimulation similar to active haptic mode, and the participants were able to decide the number of angular motion of the device for the most accurate evaluation of the affective elements.

Figure 34 Experiment environment

Figure 35 Haptic simulator

The haptic simulator is device that utilizes haptic simulation software called Immersion Studio (http://www.immersion.com/) and it provides kinesthetic stimulation along with various feedbacks offered from force profiles. Haptic simulator allows us to simplify the design elements of the force profiles to define the elements that affect kinesthetic perception, and the defined design elements were able to be analyzed for understanding the force profiles. The feedbacks received from rotating a jog dial can be graphed as the waveforms shown in Fig. 36, and the variables Width, Magnitude, DetentType, and DetentWidth are defined in the following Table 22.

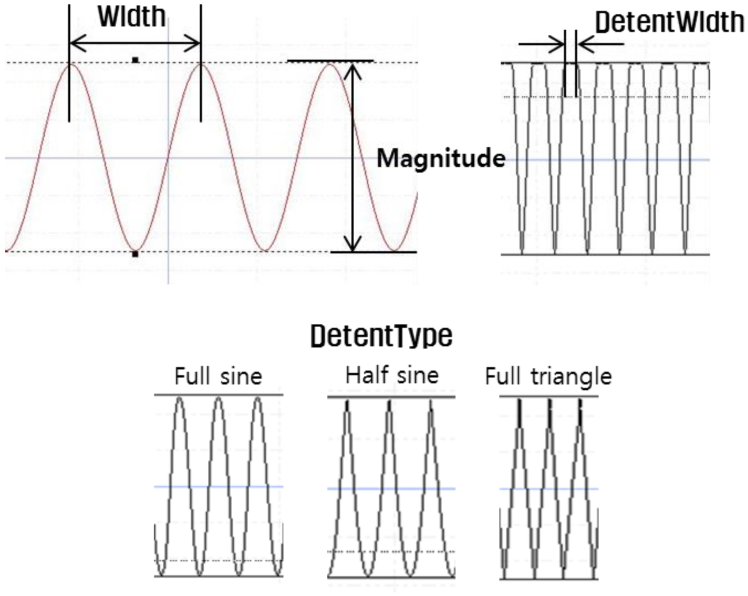


Figure 36 Shape of force profile and definition of design variable

Table 22 Definition of design variable

Design variable	Definition	Level
Haptic mode	The mode of controlling devices	Active, passive
Width	The distance between the detents	2(11~13degree), 4(21~13degree), 6(32~34degree)
Magnitude	The magnitude of force needed to pass beyond the detent peak	50(380~610gf·cm), 75(630~910gf·cm), 100(over 1000gf·cm)
DetentWidth	The distance between the detent upper peaks	60, 80, 100
DetentType	The Waveform appearing around the detents	Full sine , Half sine, Full triangle

As described previously, haptic mode refers to the mode of controlling devices as either active or passive mode where the participants may or may not involve directly with controlling the devices. The feedbacks offered by the force profiles are shown in Fig. 36, which are described by sine waves, and the controllable variables provided in Immersion Studio are as the following. The variable ‘Width’ refers to the distance between the lowest peaks of the sine wave, and it can be seen as a variable of vibration wave that determines the time gap between the consecutive feedbacks. The variable ‘Magnitude’ refers to the distance between the highest and the lowest peaks of the sine wave, and it can be considered as the force needed to pass beyond the detent peak. The variable ‘DetentWidth’ refers to the distance between the highest peaks, and it can be seen as the variable that affects the force feedback while passing through the detents. The variable ‘DetentType’ refers to the waveform, which can be decided as either Full Sine, Half Sine or Full Triangle. The experiment samples are designed by taking account of 4 variables of 3 levels and 1 variable of 2 levels and a total of 33 samples were created for the experiment by combining two $L_{27}(3^{13})$ design of experiment. Force profiles of haptic feedback are as follows (Fig. 37).

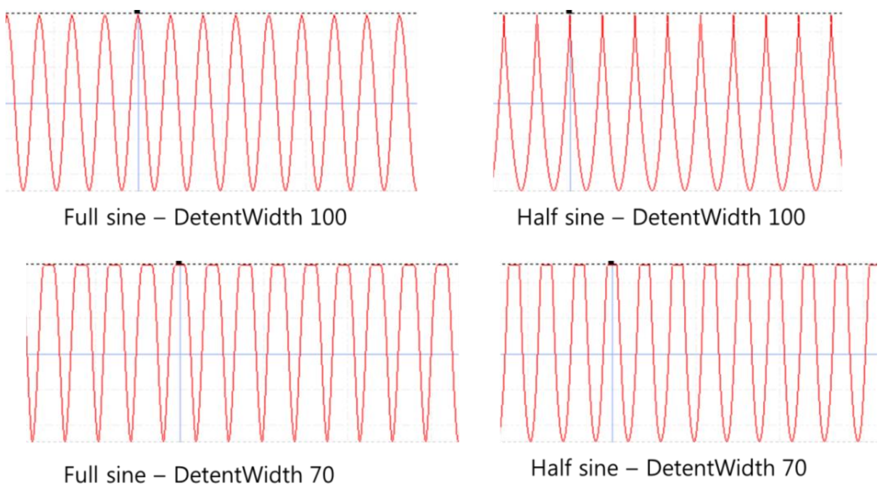


Figure 37 Force profile of haptic feedback

Table 23 Specific of evaluation samples

No	Order	haptic Type	Width	Magnitude	DetentType	DetentWidth
1	23	active	2	50	full sine	100
2	24	active	2	50	full TRI	60
3	5	active	2	50	half sine	80
4	28	active	2	75	full sine	100
5	21	active	2	100	half sine	80
6	9	active	4	50	full sine	80
7	4	active	4	75	half sine	60
8	1	active	4	100	full sine	80
9	15	active	4	100	full TRI	100
10	18	active	4	100	half sine	60
11	19	active	6	50	half sine	100
12	22	active	6	75	full sine	60
13	13	active	6	75	full TRI	80
14	12	active	6	75	half sine	100
15	8	active	6	100	full sine	60
16	7	passive	2	50	full TRI	60
17	6	passive	2	75	full sine	80
18	26	passive	2	75	full sine	100
19	11	passive	2	75	full TRI	100
20	32	passive	2	75	half sine	60
21	10	passive	2	100	half sine	80
22	25	passive	4	50	full sine	60
23	2	passive	4	50	full sine	80
24	29	passive	4	50	full TRI	80
25	31	passive	4	50	half sine	100
26	14	passive	4	75	half sine	60
27	3	passive	4	100	full TRI	100
28	30	passive	6	50	half sine	100
29	20	passive	6	75	full TRI	80
30	27	passive	6	100	full sine	60
31	16	passive	6	100	full sine	100
32	33	passive	6	100	full TRI	60
33	17	passive	6	100	half sine	80

4.2 Affective vocabulary

In order to evaluate the responses of the users on haptic feedback, we have investigated the existing research studies, the previous evaluation criteria of affective elements and expert reviews, and a total of 129 affective vocabularies have been collected (Schütte, Eklund, Axelsson, & Nagamachi, 2004). The collected affective vocabularies were then modified or neglected from our study according to the following criteria. First, the vocabularies with redundant meanings or similar concepts such as powerful and strong were combined into one. Also, the vocabularies that did not match with the purpose of our study, such as loose, were neglected from the list even though they may affect the perception of haptic feedback; this study has utilized the same device for changing feedback patterns and thus did not take account of the finishing quality of the device, and our list was narrowed down to the ones with respect to the main concern of this study which was to establish the fundamental structure of kinesthetic stimulation perception. The selected vocabularies were then paired up with those with opposite meanings. In the previous studies, the bipolar pairs (e.g., clicky – smooth) are often used in the survey questionnaire (Wellings et al., 2010), but unlike the cases where there exist two vocabularies of exactly opposite meanings such as weak and strong, there are also vocabularies with several different vocabularies of opposite meaning such as smooth vs. clicky and rough; therefore, we have decided to use the negation of the terms (i.e., X vs. non-X) for the questionnaire. The vocabularies perspicuity, smoothness, heaviness, elasticity, liltingness, and satisfaction were evaluated based on 7-point Likert Scale, and each evaluation scale was labeled as “extremely not” – “quite not” – slightly not” – “neutral”

– “slightly” – “quite” – “extremely.” The satisfactory score was evaluated under 100-point Magnitude Estimation Scale.

4.3 Data analysis

Descriptive statistics and nonparametric statistics were used to analyze the trend of the affective elements with respect to the elements of force profile. Based on the descriptive statistics, the basic results such as mean, variance and ranking were computed, and the pattern changes of affective elements with respect to the elements of force profile were analyzed. Because assumption of homogeneity of variances was not satisfied, kruskal-wallis test was used to investigate difference of affective elements with respect to elements of force profile. The data analysis was performed after the normalization to remove the differences cause by user bias such as the highest and lowest scores, mean and variance. The normalization was computed by the equation (X – mean) / standard deviation after computing the mean and the standard deviation of the evaluated scores.

In order to perform the affective modeling of affective and design elements, the following analysis was performed. Through the factor analysis, the affective elements were combined and the major affective dimensions were determined. The relationship between the satisfaction score and affective elements was analyzed through the regression analysis, and the main affective elements were determined by affective modeling. Based on the quantification I analysis, the level of effects and utility of each elements of force profile were analyzed with respect to the affective elements. The statistical analysis was performed with SAS (ver. 9.3) and SPSS (Ver. 18.0).

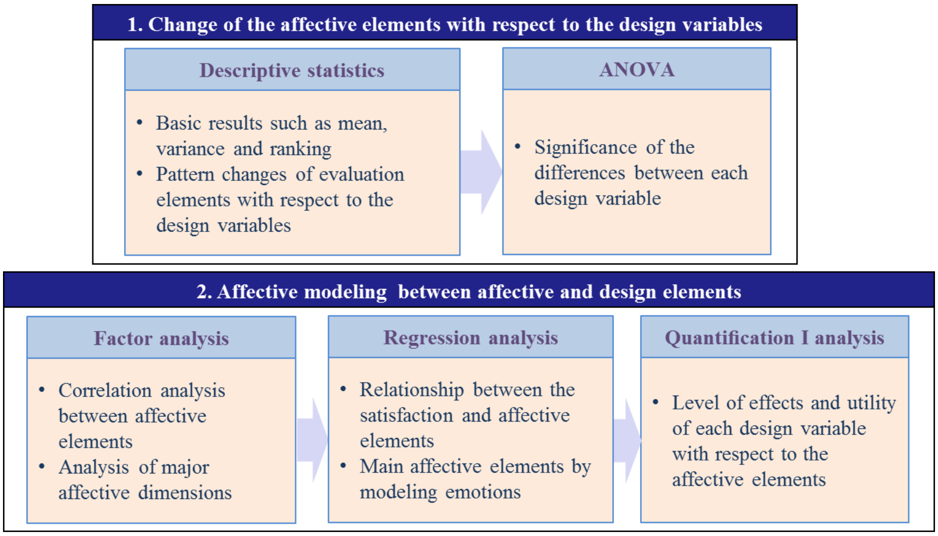


Figure 38 Analysis method

4.4 Results of active haptic mode experiment

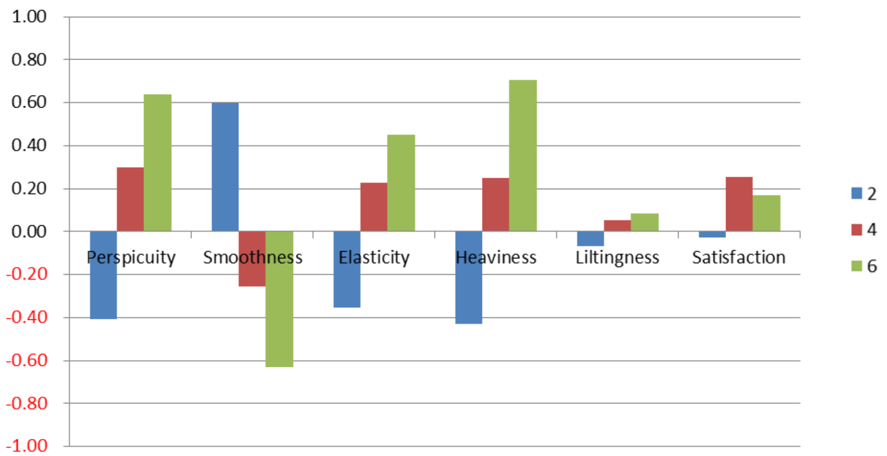
4.4.1 Trend of the affective elements according to elements of force profile

In the result of the descriptive statistics, most of the affective elements have shown significant changes with respect to the elements of force profile, except liltingness. Moreover, the terms perspicuity, heaviness and elasticity have shown similar trend with respect to the elements of force profile, whereas smoothness has shown the opposite pattern.

Table 24 Results of kruskal-wallis test about experiment 4

Design variable		Perspi-cuity	Smooth-ness	Elasti-city	Heavi-ness	Lilting-ness	Satisfac-tion
Width	Chi-Square	82.104	95.327	44.099	83.687	1.372	5.486
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.504	.064
Magni-tude	Chi-Square	91.556	65.507	47.97	76.47	11.362	19.678
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	0.003	.000
Detent-Type	Chi-Square	24.521	17.287	8.513	12.082	4.747	8.697
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	0.014	0.002	0.093	0.013
Detent-Width	Chi-Square	60.64	64.264	24.913	46.636	11.728	19.683
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	0.003	.000

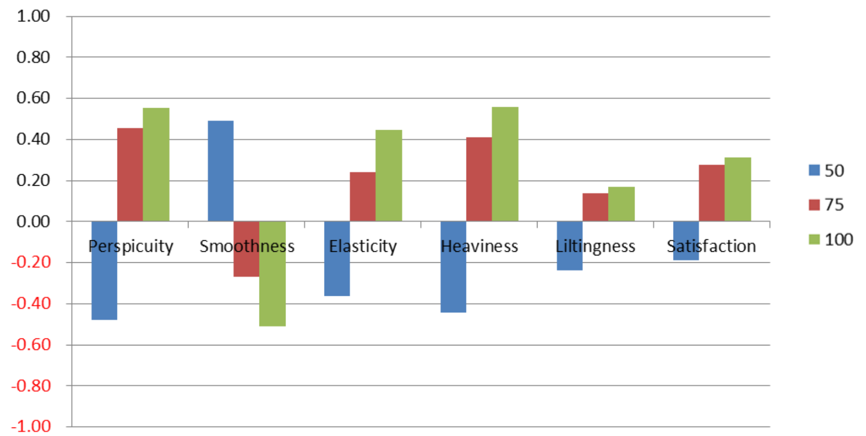
The following discusses further about the graph trend with respect to each elements of force profile. As the variable Width increase, the terms perspicuity, heaviness and elasticity all increase while smoothness decrease, but liltingness and satisfaction show no significant difference. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha < 0.05$) except liltingness and satisfaction. As the result of post hoc analysis, perspicuity, smoothness and heaviness have significant difference ($\alpha < 0.05$) among three level of width. But liltingness shows no significant difference according to level of width. Perspicuity, heaviness, and elasticity show negative value when width is 2, and show positive value when width is 4 and 6. Smoothness and heaviness evaluation score difference according to level is bigger than other affective element evaluation score.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B C	A B C	A B	A B C	A	A

Figure 39 Means of affective elements according to Width at active haptic

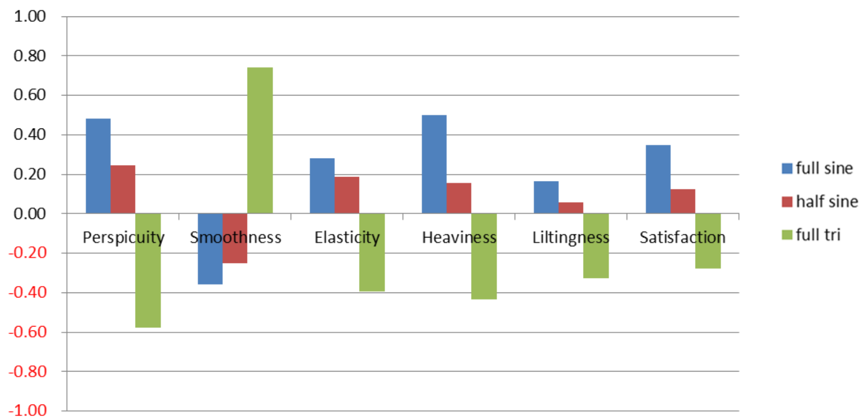
With respect to magnitude, the terms perspicuity, heaviness, elasticity and liltingness have shown positive trend while smoothness has shown negative trend. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha < 0.05$). As the result of post hoc analysis, every affective element had significant difference ($\alpha < 0.05$) between 50 and 75, 100 magnitude. Every affective element has consistency trend to get bigger or smaller as magnitude get bigger. Magnitude has something with width that smoothness has shown the opposite pattern in comparison with other affective element, and liltingness and satisfaction show no significant difference according to level of magnitude.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	B A	A B	A B	A B	A B

Figure 40 Means of affective elements according to Magnitude at active haptic

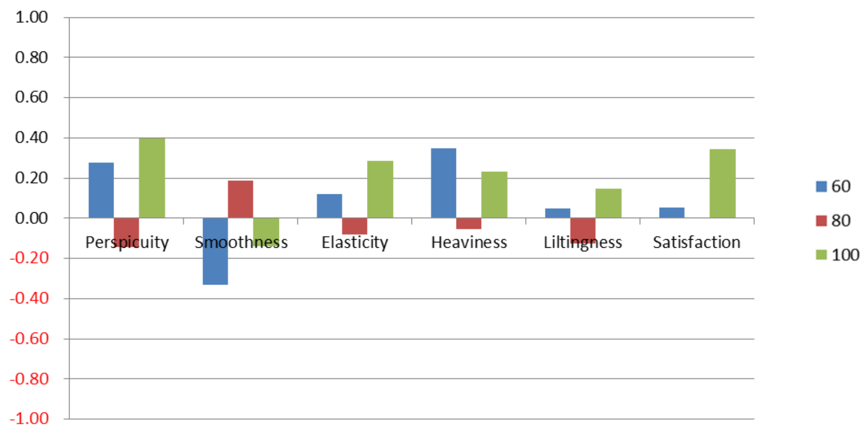
In the case of DetentType, the affective elements have shown similar evaluation score with Full Sine and Half Sine while having different evaluation score with Full Triangle. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, all affective elements except heaviness have significant difference (α< 0.05) between Full Triangle and Full Sine, Half Sine and heaviness have shown significant difference (α< 0.05) with every variable level. Perspicuity, heaviness, elasticity, liltingness and satisfaction score is higher at Full Sine, Half Sine than at Full Triangle, and smoothness score show the opposite pattern.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B C	A B	A B

Figure 41 Means of affective elements according to DetentType at active haptic

When the variable DetentWidth was set to 60 or 100, the terms perspicuity, heaviness, elasticity and liltingness have shown higher scores while smoothness with lower score than when DetentWidth was set to 80. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05) except liltingness. As the result of post hoc analysis, every affective element except elasticity, liltingness had significant difference (α< 0.05) between 60, 100 and 80.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B B	A A B	A B	A B B	A	A B B

Figure 42 Means of affective elements according to DetentWidth at active haptic

4.4.2 Correlation and factor analysis of affective elements

Results of correlation analysis between affective elements are like Table 25. Perspicuity, heaviness, and elasticity have strong positive correlation (correlation coefficients among perspicuity, heaviness, and elasticity are more than 0.45). Smoothness has not correlation with liltingness and satisfaction (correlation coefficients between smoothness and liltingness, satisfaction are below 0.05) and have negative correlation with rest of affective element (correlation coefficients with rest of affective element are below -0.3). Liltingness have most positive correlation with satisfaction (correlation coefficient is 0.708)

Table 25 Results of correlation analysis about experiment 4

	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
Perspicuity	1	-.570	.624	.690	.412	.509
Smoothness	-.570	1	-.321	-.599	.040	.011
Elasticity	.624	-.321	1	.457	.490	.558
Heaviness	.690	-.599	.457	1	.208	.266
Liltingness	.412	.040	.490	.208	1	.708
Satisfaction	.509	.011	.558	.266	.708	1

The factor analysis was performed to determine the major affective dimensions. Through Principal Component Analysis, the factors were computed while the ones with the value of factor loading below 0.3 were neglected from the factor matrices for more convenient interpretation. The number of factors was determined with respect to the Eigenvalue of 1, and a total of two factors were computed (account for 79.6% of the variance). As shown in Table 26, perspicuity, heaviness and elasticity were grouped into factor 1 while liltingness and smoothness into factor 2. Factor 1 can be considered as the affective element related to force, and factor 2 to movement in consideration of meaning of affective element and research related kinesthetic sensation. And characteristics of each factor are confirmed through relationship analysis between elements of force profile.

Table 26 Results of factor analysis about experiment 4

	Factor loading	
	Factor 1(56.3%) force-related	Factor 2(23.3%) movement-related
Perspicuity	**.907**	
Elasticity	**.823**	-.284
Heaviness	**.774**	.341
Liltingness	.495	**.782**
Smoothness	-.684	**.597**

4.4.3 Relationship between affective elements and satisfaction

As the result of the regression analysis, perspicuity, elasticity, liltingness and smoothness have shown to affect the satisfaction score while heaviness has shown to be multi-collinear with perspicuity and thus was neglected from the list. With the result of F=360.187 and p-value=0.000, it has shown that the regression model was meaningful. As Adjusted R^2 being 0.61, the affective elements have shown to explain the trend of satisfaction score on controlling devices. In terms of standardized coefficients of the elements affecting satisfaction score, liltingness had the coefficient of 0.460, perspicuity 0.334, smoothness 0.248 and elasticity 0.204. Because perspicuity in affective element that correlation coefficients between each other are high explain much of satisfaction, then explanation portion of other affective elements that correlation coefficients between each other are high become smaller similar to experiment 2.

Table 27 Results of regression analysis about experiment 4

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	.062	.032		1.953	.052
Liltingness	.441	.039	.460	11.381	.000
Elasticity	.201	.043	.204	4.650	.000
Perspicuity	.351	.053	.334	6.604	.000
Smoothness	.232	.040	.248	5.854	.000

4.4.4 Relationship between perspicuity and smoothness according to satisfaction score

Based on the observation that the evaluation scores of perspicuity and smoothness were high when the satisfaction score was high, the two elements that have high factor loadings for both of the factors 1 and 2 were compared with respect to the satisfaction score. The satisfaction scores were divided into the scores of lower 90% and those of higher 10%, and the means, correlation and scatter diagrams of perspicuity and smoothness were analyzed to determine the characteristics.

The satisfaction scores of perspicuity in the lower 90% and higher 10% were 0.036 and 0.976, respectively, which tells us that the higher 10% show higher score. Likewise, the satisfaction scores of smoothness in the lower 90% and higher 10% were 0.441 and 0.748, respectively, which also shows that the higher 10% have higher score. From the analysis of variance, the evaluation scores of perspicuity and smoothness in the lower 90% of satisfaction scores have shown significant differences from those in the higher 10% of satisfaction scores with the significance level of 0.05.

Table 28 Mean of perspicuity and smoothness

		Perspicuity	Smoothness
Top 10%	Mean	.976	.748
	N	82	82
	Std. D	.6681	.7927
Low 90%	Mean	.036	.441
	N	743	743
	Std. D	1.1051	.9899
Total	Mean	.129	.471
	N	825	825
	Std. D	1.1058	.9760

Table 29 ANOVA results according to satisfaction score

		Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	65.227	1	65.227	56.970	.000
	Within Groups	942.279	823	1.145		
	Total	1007.506	824			
Smoothness	Between Groups	6.944	1	6.944	7.346	.007
	Within Groups	778.001	823	.945		
	Total	784.945	824			

The coefficients of correlation show strong negative correlation (-0.648) for the lower 90% while there is no significant correlation (-0.096) for the higher

10%. The scatter diagrams show that the evaluation score of smoothness becomes lower when the evaluation score of perspicuity becomes higher for the lower 90% and that the score of smoothness becomes higher when the score of perspicuity becomes lower. For the higher 10%, the overall distribution seems to have negative correlation, but most of the scatter points have been found around the higher scores of both perspicuity and smoothness as shown in Fig. 43.

Table 30 Correlation of between perspicuity and smoothness at low 90%

Low 90%		Perspicuity	Smoothness
Perspicuity	Correlation	1	-.648**
	Sig. (2-tailed)		0
	N	743	743
Smoothness	Correlation	-.648**	1
	Sig. (2-tailed)	0	
	N	743	743

Table 31 Correlation of between perspicuity and smoothness at top 10%

Top 10%		Perspicuity	Smoothness
Perspicuity	Correlation	1	-0.096
	Sig. (2-tailed)		0.392
	N	82	82
Smoothness	Correlation	-0.096	1
	Sig. (2-tailed)	0.392	
	N	82	82

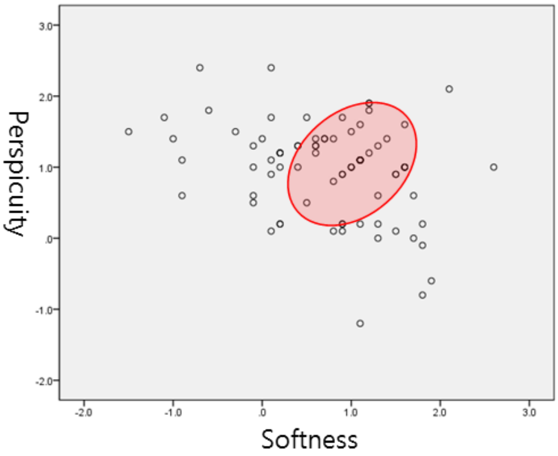


Figure 43 Scatter plot of top 10%

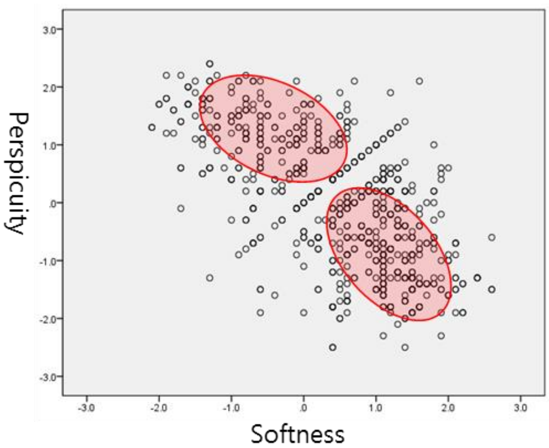


Figure 44 Scatter plot of low 90%

4.4.5 Relationship between affective elements and elements of force profile

Result of partial correlation coefficient (R) of each elements of force profile and partial regression coefficient of each level of elements of force profile is like Table 32 and 33. R^2 of every affective element except liltingness and satisfaction, a measure of how well explained affective element by elements of force profile, is above 0.25. Especially, smoothness and perspicuity explained well by elements of force profile (R^2 of smoothness and perspicuity is 0.51 and 0.60). Partial correlation coefficient of detentwidth, effect of elements of force profile on affective element, has least value in case of almost affective element, and partial correlation coefficient of width, magnitude, detent-type is different according to affective element. Perspicuity, heaviness, and elasticity have similar effect on width, magnitude, detent-type, and width and detent-type have more effect on smoothness than magnitude.

Partial regression coefficients, effect on affective element by level of force profile elements, are as follows. Change pattern of smoothness according to level of force profile elements is different from other affective element, also. Design variable has three levels, partial regression coefficient according elements of force profile is symmetry. Partial regression coefficient of almost affective element has value between -0.02 and 0.09 when magnitude is 75, absolute value of partial regression coefficient when magnitude is 50 and 100 is almost same and has different sign. According to change level of variable, width or magnitude increase, evaluation score increase or decrease consistently. But as detent-width increase, evaluation score has not consistent pattern.

Table 32 Partial correlation coefficient (R) of each force profile elements

	Satisfaction (R^2= 0.13)	Perspicuity (R^2= 0.60)	Smoothness (R^2= 0.51)	Elasticity (R^2=0.27)	Heaviness (R^2=0.48)	Liltingness (R^2= 0.06)
Width		0.45	0.48	0.29	0.45	
Magni-tude	0.27	0.53	0.39	0.32	0.43	0.19

Detent-Type	0.25	0.56	0.51	0.29	0.44	0.18
Detent-Width	0.20	0.36	0.19	0.21	0.14	0.12

Table 33 Partial regression coefficient of each level of force profile elements

Design variable	Level	Satisfac-tion	Perspicuity	Smooth-ness	Elasticity	Heaviness	Lilting-ness
Width	2	-	-0.40	0.54	-0.34	-0.43	-
	4		0.01	-0.01	0.02	-0.08	
	6		0.39	-0.53	0.32	0.50	
Magni-tude	50	-0.35	-0.51	0.36	-0.36	-0.45	-0.27
	75	0.12	0.08	0.08	-0.02	0.01	0.09
	100	0.23	0.44	-0.44	0.38	0.44	0.18
Detent-Type	full sine	0.22	0.31	-0.26	0.17	0.33	0.14
	full tri	-0.41	-0.75	0.84	-0.50	-0.61	-0.35
	half sine	-0.01	0.07	-0.15	0.08	-0.02	0.03
Detent-Width	60	-0.15	-0.08	-0.06	-0.13	0.00	-0.03
	80	-0.11	-0.23	0.19	-0.13	-0.13	-0.13
	100	0.26	0.31	-0.14	0.26	0.13	0.16

4.5 Results of passive haptic mode experiment

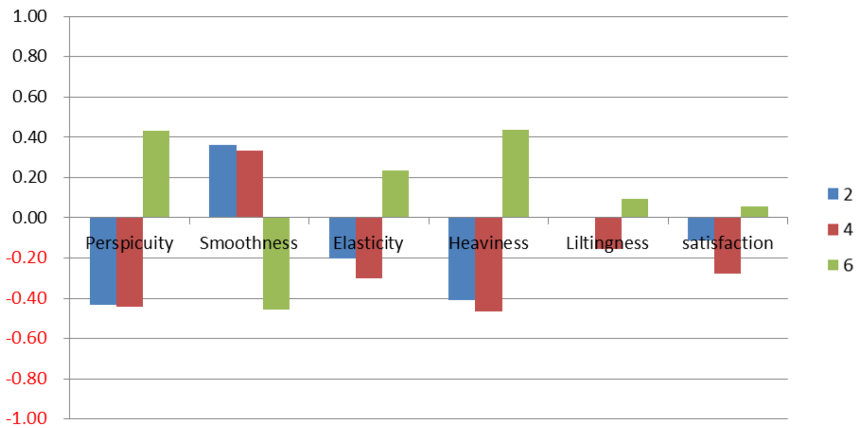
4.5.1 Trend of the affective elements according to elements of force profile

The results of the descriptive statistics are similar to active haptic mode in general. Most of the affective elements have shown significant changes with respect to the elements of force profile, except liltingness. And perspicuity, heaviness and elasticity have shown similar trend with respect to the elements of force profile, whereas smoothness has shown the opposite pattern, also. But pattern of affective element according to level of variable is different form active haptic mode.

Table 34 Results of ANOVA about experiment 5

Design variable		Perspi-cuity	Smooth-ness	Elasti-city	Heavi-ness	Lilting-ness	Satisfac-tion
Width	Chi-Square	64.415	46.411	20.446	54.460	4.109	8.617
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.128	.013
Magni-tude	Chi-Square	61.872	64.3	29.925	71.696	14.035	17.646
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	0.001	.000
Detent-Type	Chi-Square	118.531	67.314	61.449	81.62	23.619	37.46
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.000	.000
Detent-Width	Chi-Square	51.197	21.283	41.345	37.109	15.455	17.785
	df	2	2	2	2	2	2
	Asymp. Sig.	.000	.000	.000	.000	.000	.000

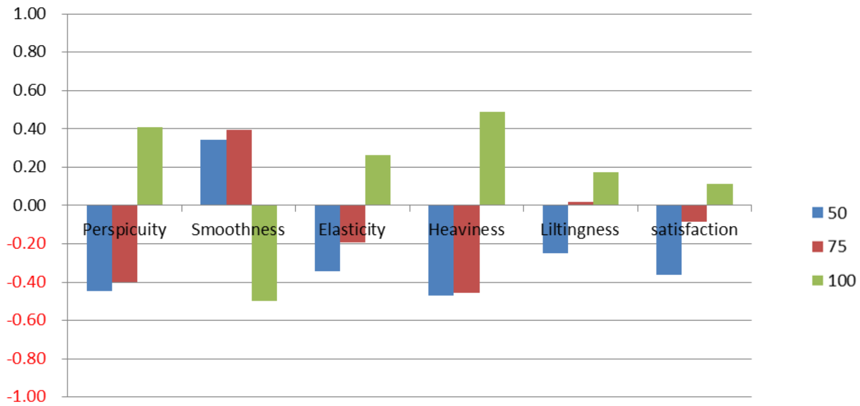
As the variable width increase, every affective element except smoothness has not consistency trend that increase or decrease according to width continuously contrary to active haptic mode. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05) except liltingness. As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference (α< 0.05) between 2, 4 and 6. Affective variable evaluation score of level of 2 and 4 has not significant difference at passive haptic, this is reason that active haptic mode is more sensitivity than passive haptic mode. Liltingness showed no significant difference according to level of width in common with active haptic.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A	A B B

Figure 45 Means of affective elements according to Width at passive haptic

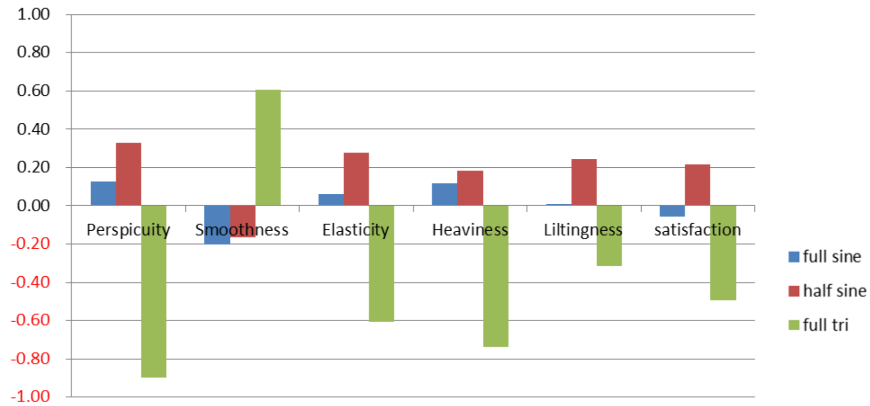
With respect to magnitude, as the variable magnitude increase, smoothness has not consistency trend that increase or decrease according to magnitude continuously contrary to active haptic mode. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference (α< 0.05) between 50, 75 and 100, and liltingness and satisfaction have significant difference (α< 0.05) between 50 and 75, 100. Affective variable evaluation score of level of 50 and 75 has not significant difference at passive haptic, this is reason that active haptic mode is more sensitivity than passive haptic mode. Liltingness showed no significant difference according to level of width in common with active haptic.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B

Figure 46 Means of affective elements according to Magnitude at passive haptic

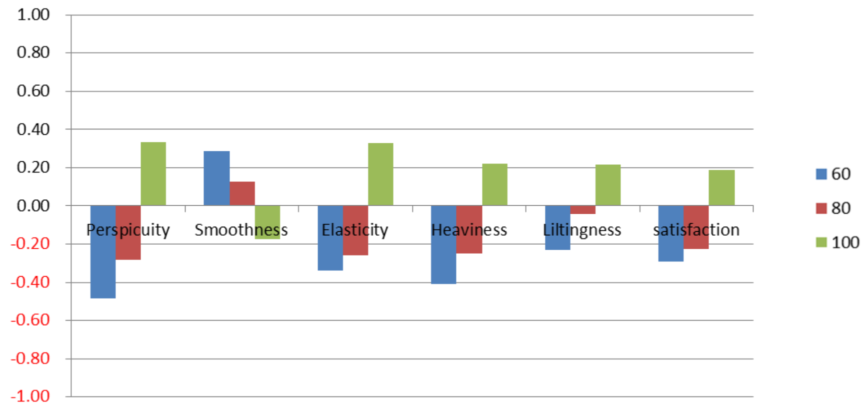
With respect to detent-type, score of perspicuity, heaviness, elasticity, liltingness and satisfaction of half sine is higher than those of full sine contrary to active haptic mode. As the result of ANOVA, all of the affective elements have shown significant difference ($\alpha < 0.05$). As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference ($\alpha < 0.05$) between half sine, full sine and full tri. Deviation of affective variable evaluation score at passive haptic is smaller than at active haptic, this is reason that active haptic mode is more sensitivity than passive haptic mode.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B C

Figure 47 Means of affective elements according to DetentType at passive haptic

With respect to detent-width, as the variable detent-width increase, the terms perspicuity, heaviness, elasticity and liltingness all increase while smoothness decrease. Detent-width is the only variable that evaluation score has consistency trend according to variable. As the result of ANOVA, all of the affective elements have shown significant difference (α< 0.05). As the result of post hoc analysis, perspicuity, smoothness, elasticity, and heaviness have significant difference (α< 0.05) between 60, 80 and 100.



Affective elements	Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	Satisfaction
post-hoc comparison (Tukey test using ranks)	A B	A B	A B	A B	A B	A B

Figure 48 Means of affective elements according to DetentWidth at passive haptic

4.5.2 Correlation and factor analysis of affective elements

Results of correlation analysis between affective elements are like Table 35. Perspicuity, heaviness, and elasticity have strong positive correlation similar to active haptic (correlation coefficients among perspicuity, heaviness, and elasticity are more than 0.45). Smoothness has not correlation with liltingness and satisfaction (correlation coefficients between smoothness and liltingness, satisfaction are more than -0.1) but correlation coefficients is negative value in contrast with active haptic. Smoothness has negative correlation with rest of affective element (correlation coefficients with rest of affective element are below -0.4). Liltingness have most positive correlation with satisfaction (correlation coefficient is 0.758)

Table 35 Results of correlation analysis about experiment 5

	Perspi-cuity	Smooth-ness	Elasticity	Heavi-ness	Lilting-ness	Satisfac-tion
Perspi-cuity	1	-.623	.677	.776	.451	.552
Smooth-ness	-.623	1	-.399	-.639	-.085	-.097
Elasticity	.677	-.399	1	.578	.527	.595
Heavi-ness	.776	-.639	.578	1	.349	.373
Lilting-ness	.451	-.085	.527	.349	1	.758
Satisfac-tion	.552	-.097	.595	.373	.758	1

The factor analysis was performed to determine the major affective dimensions. Through Principal Component Analysis, the factors were computed while the ones with the value of factor loading below 0.3 were neglected from the factor matrices for more convenient interpretation. The number of factors was determined with respect to the Eigenvalue of 1, and a total of two factors were computed (account for 82.0% of the variance). As shown in Table 36, perspicuity, heaviness and elasticity were grouped into factor 1 while liltingness and smoothness into factor 2. Factor 1 can be considered as the affective element related to force, and factor 2 to movement in consideration of meaning of affective element and research related kinesthetic sensation. And characteristics of each factor are confirmed through relationship analysis between elements of force profile.

Table 36 Results of factor analysis about experiment 5

	Factor loading	
	Factor 1(62.1%) force-related	Factor 2(19.9%) movement-related
Perspicuity	**.918**	
Heaviness	**.873**	-.205
Elasticity	**.814**	.275
Liltingness	.574	**.737**
Smoothness	-.714	**.575**

4.5.3 Relationship between affective elements and satisfaction

As the result of the regression analysis, perspicuity, elasticity, liltingness and smoothness have shown to affect the satisfaction score while heaviness has shown to be multi-collinear with perspicuity and thus was neglected from the list. With the result of F=228.457 and p-value=0.000, it has shown that the regression model was meaningful. As Adjusted R^2 being 0.67, the affective elements have shown to explain the trend of satisfaction score on controlling devices. In terms of standardized coefficients of the elements affecting satisfaction score, liltingness had the coefficient of 0.534, perspicuity 0.331, smoothness 0.226 and elasticity 0.180. Because perspicuity in affective element that correlation coefficients between each other are high explain much of satisfaction, then explanation portion of other affective elements that correlation coefficients between each other are high become smaller similar to experiment 2.

Table 37 Results of regression analysis about experiment 5

	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	-.056	.028		-2.009	.045
Liltingness	.545	.034	.534	15.843	.000
Perspicuity	.322	.044	.331	7.342	.000
Smoothness	.238	.038	.226	6.236	.000
Elasticity	.182	.040	.180	4.594	.000

4.5.4 Relationship between affective elements and elements of force profile

Result of partial correlation coefficient (R) of each force profile elements and partial regression coefficient of each level of force profile elements is like Table 38 and 39. R^2 of every affective element except liltingness and satisfaction is above 0.30. Especially, smoothness and perspicuity explained well by elements of force profile (R^2 of smoothness and perspicuity is 0.40 and 0.57). Partial correlation coefficient of detentwidth, effect of force profile elements on affective element, has least value in case of almost affective element, and partial correlation coefficient of width, magnitude, detent-type is different according to affective element. Perspicuity, heaviness, and elasticity have similar effect on width, magnitude, detent-type, and width and detent-type have more effect on smoothness than magnitude.

Partial regression coefficients, effect on affective element by level of force profile elements, are as follows. Change pattern of smoothness according to level of force profile elements is different from other affective element, also. Design variable has three levels, partial regression coefficient according elements of force profile is symmetry. Partial regression coefficient of almost affective element has value between -0.24 and 0.23 when magnitude is 75, absolute value of partial regression coefficient when magnitude is 50 and 100 is almost same and has different sign. According to change level of variable, width or magnitude increase, evaluation score increase or decrease consistently. But as detent-width increase, evaluation score has not consistent pattern.

Table 38 Partial correlation coefficient (R) of each force profile elements

	Satisfaction (R^2= 0.15)	Perspicuity (R^2= 0.57)	Smoothness (R^2= 0.40)	Elasticity (R^2=0.29)	Heaviness (R^2=0.48)	Liltingness (R^2= 0.11)
Width		0.34	0.26	0.14	0.29	
Magni-tude	0.20	0.31	0.32	0.19	0.36	0.18
Detent-Type	0.30	0.62	0.45	0.41	0.50	0.24
Detent-Width	0.22	0.46	0.25	0.33	0.35	0.19

Table 39 Partial regression coefficient of each level of force profile elements

Design variable	Level	Satisfac-tion	Perspicuity	Smooth-ness	Elasticity	Heaviness	Lilting-ness
Width	2	-	-0.21	0.16	-0.08	-0.14	-
	4		-0.19	0.17	-0.11	-0.21	
	6		0.40	-0.33	0.19	0.36	
Magni-tude	50	-0.25	-0.21	0.18	-0.20	-0.22	-0.23
	75	0.03	-0.15	0.23	-0.06	-0.24	0.04
	100	0.22	0.36	-0.41	0.26	0.46	0.19
Detent-Type	full sine	0.06	0.27	-0.28	0.15	0.26	0.03

	full tri	0.33	0.48	-0.24	0.37	0.33	0.27
	half sine	-0.38	-0.75	0.53	-0.52	-0.59	-0.29
Detent-Width	60	-0.18	-0.34	0.21	-0.25	-0.26	-0.21
	80	-0.12	-0.14	0.05	-0.17	-0.10	-0.02
	100	0.30	0.48	-0.25	0.42	0.37	0.24

4.6 Analysis of difference between active and passive haptic

The scores of the affective elements with respect to the mode of haptic show that all of the elements except smoothness have higher scores in active haptic than in passive haptic mode as shown in Fig. 49. The difference of the scores for perspicuity and heaviness were large while liltingness had a little difference.

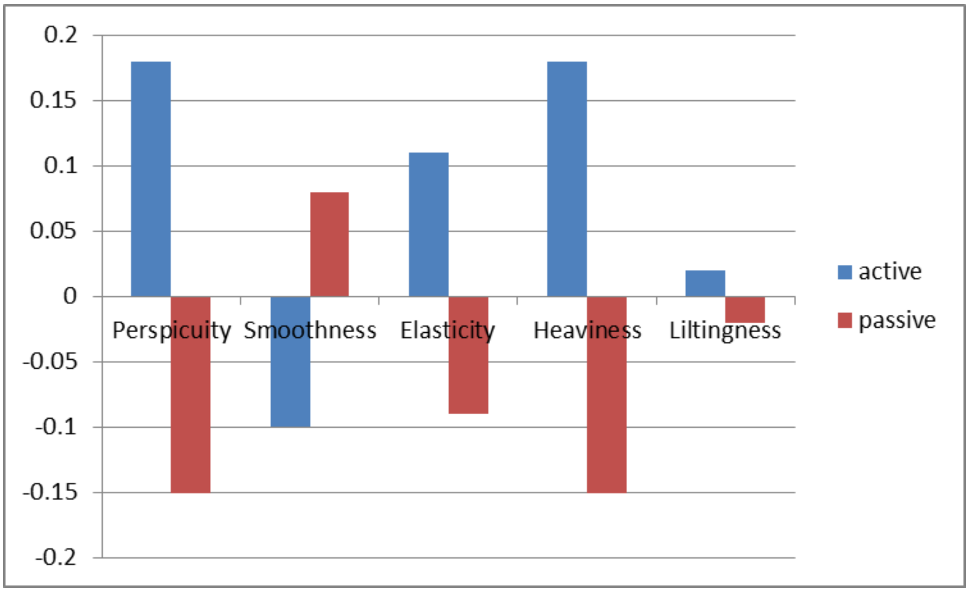


Figure 49 Means of affective elements according to haptic mode

In order to analyze the effect of mode of haptic, Width Magnitude, DetentType and DetentWidth were set to covariate while haptic mode to fixed factor, and ANCOVA was performed. The analysis has shown different results depending on the affective elements related to force and movement.

Perspicuity and heaviness have shown significant correlation with haptic mode, while smoothness, elasticity and liltingness have shown no significance ($\alpha<0.05$). Moreover, perspicuity, heaviness, elasticity and liltingness were perceived larger when the mode was set to active haptic, while smoothness was perceived larger in passive haptic. The affective elements related to force have shown greater significance with active haptic while those related to movement have shown greater significance with passive haptic, but there was no statistical difference between them.

Table 40 Results of ANCOVA

	Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	10.110	2	5.055	9.733	**.000**
Smoothness	2.672	2	1.336	2.174	.114
Elasticity	3.642	2	1.821	2.357	.095
Heaviness	11.236	2	5.618	9.791	**.000**
Liltingness	.015	2	.008	.008	.992
Satisfaction	9.246	2	4.623	5.260	**.005**

The trends of the affective elements with respect to the elements of force profile have shown the differences between those related to force and movement. The increase of Width, which is related to movement, has shown to decrease the score of smoothness in both modes of active haptic and passive haptic. On the other hand, perspicuity, heaviness and elasticity have shown to increase with respect to Width in active haptic mode while decreasing in passive haptic mode. Moreover, perspicuity, heaviness and elasticity have shown to increase with respect to Magnitude, which is related to force, in both modes of active haptic and passive haptic. However, smoothness and liltingness have shown to increase and decrease respectively with respect to Magnitude in active haptic mode while they both increased up to certain point and decreased in passive haptic mode.

In addition, the elements have shown consistent trend as either increasing or decreasing with respect to the elements of force profile in active haptic mode, but the trend was not consistent in passive haptic mode. This finding was observed in both elements related to force and movement and thus tells us that the mode of haptic affects the affective perception of the users.

The scores of the affective elements with respect to the elements of force profile were also affected by the mode of haptic. The variable Width, which is related to movement, had higher effect on smoothness, which is also related to movement, in active haptic mode while perspicuity and elasticity, which are related to force, had larger differences in passive haptic mode. The variable Magnitude, which is related to force, had higher effect on smoothness and liltingness, which are related to movement, in passive haptic mode while perspicuity, elasticityand heaviness, which are related to force, had larger differences in active haptic mode.

These observations seem to be related to the elements of force profile and the affective aspect of a user. A large difference resulted from the other elements of force profile means that the reaction to the variables is very sensitive. The affective elements related to movement react more sensitive to the elements of force profile related to movement in active haptic mode, while those related to force react more sensitive to the variables related to force in active haptic mode. However, further studies are needed to understand the exact cause of such observations.

4.7 Discussions

4.7.1 Modeling of affective element related kinesthesis

This study conducted factor analysis, regression analysis, and quantification I analysis based on user evaluation experiment of real product and simulated haptic feedback. As a result, it can be difficult and has limitations to analyze relationship between elements of force profile and affective element because of factor of force profile and noise that can't control, but general trend of affective element according to elements of force profile can be identified.

Based on the existing studies of physiology related to evaluating product qualities, the stimulation has been categorized with respect to the characteristics of force profile. Then, the factor analysis and regression analysis were performed to determine the main factors that can group the affective elements and to analyze how much the affective elements were able to explain the satisfaction of haptic feedback. All three experiments have shown that the main factors were able to explain more than 50% of data variance, and the regression analysis has shown that each affective element had the score of explaining the satisfaction higher than 0.45. From these results, it can be observed that the feedback that is related to either force or movement was explained by one factor while the feedback related to both force and movement was explained by two factors.

Process perceived kinesthetic feedback emotionally is affected by factor related with force and movement like as physiological and psychophysical studies through evaluation of real product. This result is reasonable because affective responses are perceived and occurred based on stimulation received from receptor, but no experimental case studies which proved this relation have been reported. Chen, Shao, Barnes, Childs, and Henson (2009) has shown that affective vocabulary related with dimension studied psychophysical area effect on affective satisfaction with respect to tactile feedback. This study deducted major factor affected on kinesthetic feedback and show that these factor is related to force and movement divided in physiological and psychophysical studies like as tactile feedback through affective assessment of various product.

And relationship between affective element is change according to form of force profile. As a result, the more form of force profile is complicate, the more correlation coefficients between affective element is low and a number of deducted factor is many. This is because as complexity of force profile increase, kind of user perceived emotion increase. Deducted factor is divided into factor related with force and movement inferred from form of force profile and it is needed to evaluate and analyze based on more various product.

And relationship between affective element and elements of force profile can be analyzed using simulator that can control force-profile. Based on the results of the analyses, the affective elements have been described by the elements of force profile, and the characteristics of the elements of force profile that affect the affective elements were categorized. The quantification I analysis has shown that the effect of the elements of force profile on the affective elements can be described by the difference of their characteristics. The elements of force profile can be divided into the elements related to force and movement, and it was observed that the affective elements that were affected by the variables related to force and movement were different. The variable Magnitude, which is related to force, affected the most on perspicuity while Width, which is related to movement, affected the most on smoothness.

The elements of force profile related to force did affect both of the affective elements that are related to force and movement, but they have depicted different trends with respect to the level of each variable that affected the affective elements. As discussed in the existing physiological and psychophysical studies, it may be difficult to completely separate the perceptions related to force and movement, but this study has shown separate trend groups of affective elements related to haptic feedback with respect to force and movement, which also agrees with the existing physiological and psychophysical studies (Proske & Gandevia, 2009).

Unlike the most of the affective elements, liltingness was difficult to be described by the elements of force profile because it has shown inconsistent trend with respect to the elements of force profile. This may suggest that liltingness was not affected by the elements of force profile provided from force profile individually but rather by the elements other than the discussed variables. The results have shown different explanation for the affective elements related to kinesthetic perception with respect to individual elements of force profile and with respect to other factors that may be raised from the combination of the elements of force profile. Thus, the research needs further investigation on this matter.

It is necessary to determine the primary elements that affect the satisfaction of the users. Since the sense of satisfaction comes from the combination of various elements, there is limitation to explain the satisfaction factor in terms of the elements of force profile only. In order to provide the proper feedback stimulation as intended by the product designers, the perception of the users must be analyzed in terms of the elements of force profile. In this study, rather than analyzing the relationship between satisfaction and elements of force profile, it was shown that it was more meaningful to analyze the relationship between the major affective dimensions and elements of force profile in order to determine the characteristics of the elements of force profile in constructing feedback. The quantification I analysis has shown the satisfaction result of Adjusted R^2 as 0.13, which refers to the satisfaction score of 13%. In the case of perspicuity and smoothness, the values of Adjusted R^2 were 0.60 and 0.51 respectively, which means they can be explained by the elements of force profile by about 50%, while the result of the regression analysis has shown the value of Adjusted R^2 being higher than 0.6. These results tell us that the direct analysis between the affective elements and elements of force profile can be explained by 13% and that the relationship between each affective element and satisfaction can be explained by about 30%.

The result of affective modeling on experiment 4 and 5 is shown in Fig. 50. There are differences in weight of affective element effected on satisfaction according to mode of haptic, but the order of weight in active haptic mode is consistent with that in passive haptic mode. Most of affective elements can be explained by elements of force profile and liltingness has the largest coefficient. Based on result of affective modeling, specifications of design variable needed to provide more affective haptic feedback can be deducted in consideration of mode of haptic.

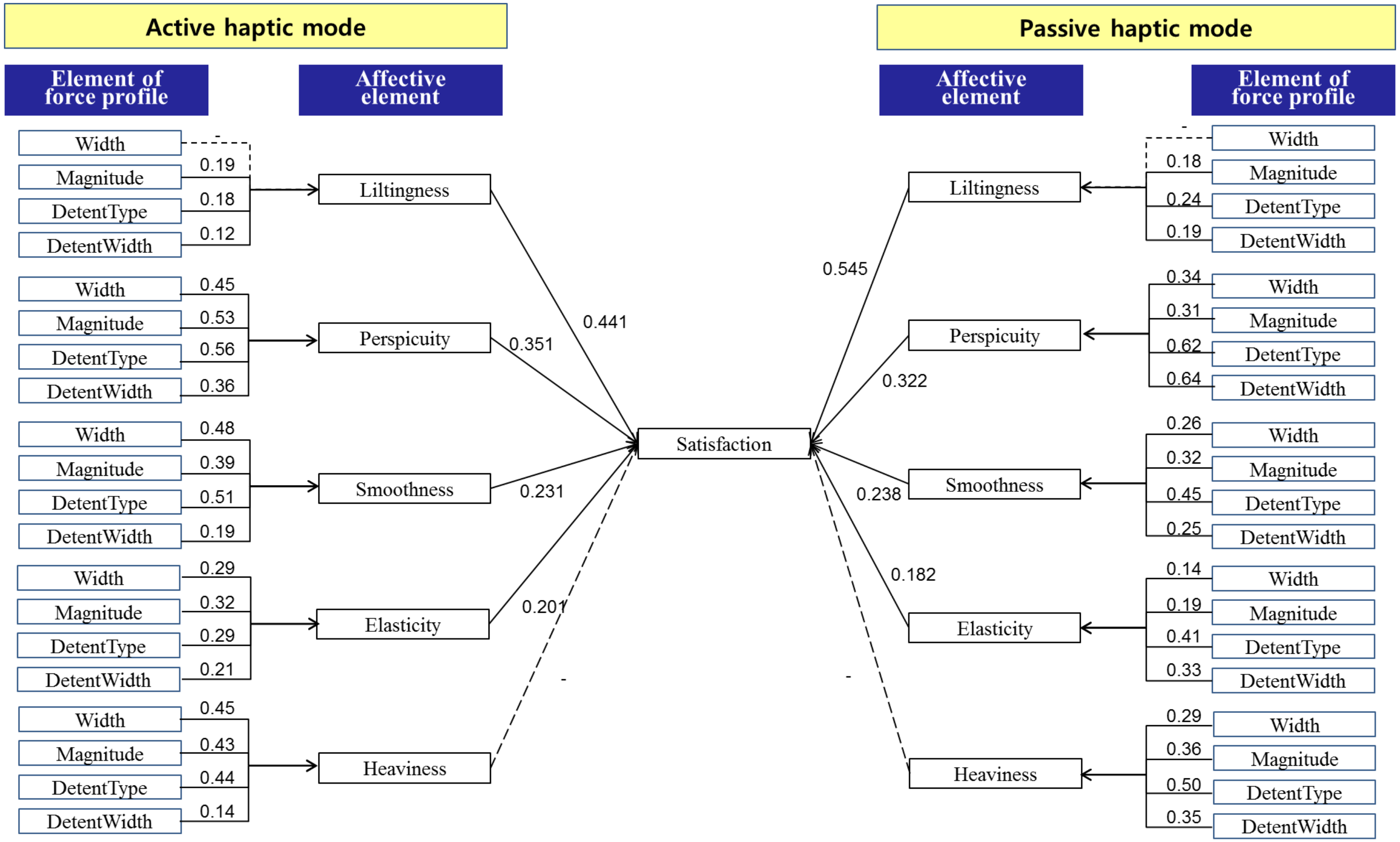


Figure 50 Results of affective modeling in experiment 4 and 5

4.7.2 Effect on affective response according to haptic mode

The effects of mode of haptic have shown the relationship between the affective elements with either force and movement. The elements related to force have shown higher score with active haptic because the active haptic required the users to physically manipulate the jog dial and thus resulted larger sensitivity of kinesthetic perception than in the passive haptic, where the users are only applying force enough to resist the feedbacks (Gandevia, McCloskey & Burke, 1992). However, the elements related to movement have not shown any significant difference with respect to mode of haptic.

The trend with respect to the elements of force profile has shown different pattern in each mode of haptic. In the case of active haptic, the trend has shown consistent pattern of increase or decrease with respect to the elements of force profile, but there was no consistent trend in the case of passive haptic. This observation can be explained by the finding discussed in the study of Lederman et al. (1999), where the range of fluctuation is large for roughness perception with respect to the change of speed in passive haptic due to the lack of information on kinesthetic perception. Moreover, this study has focused on collecting the affective responses rather than attempting to discriminate the stimulations. Thus, as suggested in the previous studies, the exploratory conditions such as methods and time duration of providing stimulation were not set equally in the active haptic and passive haptic. In turn, the result of our study can be interpreted as mentioned from the previous studies about the limitation of collecting information in passive haptic than in active haptic.

Cause of differences between active haptic mode and passive haptic mode can be explained by information to be used to percept and discriminate. On passive haptic mode, only tactile information is used to percept and discriminate, but on active haptic mode, both tactile and kinesthetic information is used. Less information is available at passive haptic mode than at active haptic mode and it has caused underestimation of perceived force and inaccurate perception at passive haptic mode.

Pattern of affective element according to elements of force profile has different trend according to related with psychophysical factor. Affective element related with force has consistent pattern according to magnitude at passive haptic, while affective element related with force has not consistent pattern according to width. And affective element related with movement has consistent pattern according to width at passive haptic, while affective element related with force has not consistent pattern according to magnitude. Although user can't discriminate stimulation exactly at passive haptic than at active haptic, relationship between elements of force profile and affective element has consistent pattern if psychophysical factor related with elements of force profile is same with that related with affective element through this results.

The result of quantification I analysis has also shown higher score of explanation for active haptic. From analyzing the elements for both modes together, the scores of explaining perspicuity has increased from 57% to 60% by analyzing the active haptic only, and smoothness from 40% to 51%. Moreover, with respect to the effect level of elements of force profile, the partial correlation coefficient of Magnitude on perspicuity has increased from 0.31 to 0.53 and those of Width on smoothness from 0.26 to 0.48 which has shown higher correlations when the mode of active haptic was analyzed separately.

Chapter 5. Conclusion

5.1 Summary of findings

This study has examined the current and future issues on haptic modality from the existing studies of the related fields. The examined issues were then analyzed in terms of the affective perception with respect to kinesthetic feedback and the effects of mode of haptic. The main findings of this study are summarized into three aspects as the following.

First, this study has organized the research related to haptic by utilizing the contents analysis and network analysis and has investigated the future research issues in the fields of human-robot interaction and virtual reality. From the results of the network analysis, the related researches were categorized in terms of technology perspective and user perspective. However, in the context of network structure, there was only a relationship between tactile display and cognitive trait of objects connecting the technology and user perspectives, and most of the studies have focused either on the technical aspects and the aspects of the users separately for understanding cognitive mechanisms and have failed to find correlation among various perspectives. If the two perspectives could be applied in the related technologies while acknowledging the relationship between them, the commercialization of the applications using haptic interaction would be feasible in the near future. In turn, there should be more research on the characteristics of haptic perception and the emotions related to kinesthetic sensations. These research topics are all oriented toward the users and mainly concern the characteristics and the effects of haptic stimulation on the user's cognition of such stimulation. Based on the fundamental research of such issues, a systematic approach of developing the technology should be further considered in order to provide more practical applications that could offer various affective experiences to the users.

Second, this study has determined the major affective dimensions that affect kinesthetic feedback perception and has analyzed the relationship between the affective elements and the elements of force profile. The affective dimensions related to kinesthetic sensation of the users can be categorized by the affective elements related to force and movement. This can also be considered as the continuation of the study suggested in the fields of physiology and psychophysics. The relationship between the affective elements and elements of force profile is determined by their characteristics. The affective elements related to force are affected by the elements of force profile related to perceiving force, and those related movement by the variables related to perceiving movement.

Third, the effects of the mode of haptic on the affective perception of the user have been also studied. The mode of haptic affects the affective elements related to perceiving force. It was observed that the presence of the user's physical force to manipulate the device affects the affective elements related to force rather than those of movement.

5.2 Contributions of this research

This study introduces thorough review of the existing research based on contents analysis and network analysis. The result of the contents analysis has allowed us to realize the current trend of the related research areas by organizing key terminologies. Then, through the network analysis, the key terminologies were re-categorized based on the network to analyze the relationship among the related research issues. As a result, the objectivity of determining the relationship among the issues was maintained. The similar insight of understanding the relationship among the related research areas would be also expected in other research fields by utilizing the proposed methodology of this study. The advanced technologies of database and data analysis have made it possible for every research field to benefit from them to investigate and analyze the current research issues of the related fields.

This study has described the emotions related to the kinesthetic sensations of the users in terms of the physiology and psychophysics research fields. The basic structure of emotion has been examined to understand and analyze different emotions, and the main affective elements have been determined. The characteristics of the affective elements and elements of force profile were categorized into force and movement, and the pattern changes of the affective elements were analyzed with respect to each elements of force profile to verify the high correlation between the elements of force profile and the affective elements.

By performing the fundamental research on the affective dimensions related to kinesthetic perception of the users and on the characteristics of feedback elements, the affective perception of complex kinesthetic perception was able to be analyzed, which in turn will allow us to build the foundation to provide the best haptic feedback to the users.

In order to improve the satisfaction of controlling products, the characteristics of the affective elements were analyzed while determining the related characteristics of the elements of force profile that may affect the affective satisfaction. It may be too early to generalize the relationship, but this study suggests the future direction of deeper research on each affective element. This study can be used as the fundamental research to define more practical design guidelines for improving the affective satisfaction related to kinesthetic sensations.

Moreover, the perception of the feedback that the users receive passively has been analyzed, which also suggests further comparative analysis with the feedbacks provided from actively interacting with devices. This study suggests the fundamental structure and elements of the characteristics of the users that need to be considered in designing kinesthetic feedback.

5.3 Limitations and further research

Limitations and further research issues are as follows.

First, the study of current literature was not sufficiently done with the contents analysis and network analysis. Although various fields of research have been examined and the analysis of their relationship has resulted in determining the current issues, the broad scope of studying the literature had the limitation of comprehending the characteristics of each research field. It is always important to see the larger picture of the literature, but further studies on each research field are also important to acknowledge the detailed issues in each field.

Since this study has allowed observing the research trend by analyzing the relationship between each field, further studies need to define the process to decide the methods of future analysis based on this study. In order to analyze the characteristics of each field and the relationship between these characteristics that may result in synergistic effects, each individual field needs to be reviewed thoroughly along with the results of this study. The results of this study may be applied not only to the research fields related to haptic technology but also to other research fields that adapt multidisciplinary approaches in order to verify and improve the methodology suggested in this study.

Second, the analysis of the relationship between the affective elements and the satisfaction score has shown that liltingness has affected the satisfaction the most while there was no elements of force profile that could explain liltingness. This result tells us that liltingness was an important element to improve the satisfaction, but it was not yet clear on how to improve liltingness. This can be understood by the possibilities of external elements that may also affect on determining the affective response beside the psychophysical factors discussed in this study.

Therefore, further research is needed to determine the factors that are related to perceiving affective elements. The psychophysical factors may not affect the affective elements linearly, while there may be also other factors beside the psychophysical factors. Although the stimulation and perception can be described with 1:1 relationship in the psychophysical aspect, they have more complicated network among various elements in the aspect of emotions.

Third, the analysis of different modes of touch has shown limitation to explain the exact cause of their effects on the affective responses. Although there are several studies on tactile sensation with respect to the mode of haptic, there are not sufficient studies related to kinesthetic sensations; thus, it was difficult to derive the explanation of the results from our study.

Therefore, there needs further studies on kinesthetic sensations in terms of the physiological changes with respect to the mode of haptic. Unlike tactile sensation, kinesthetic sensations are largely affected by the contraction of muscle and joint movements. Therefore, the changes of muscle contraction with respect to the mode of haptic should be examined to analyze its effect on the user perception. Although isometric contraction involves exerting forces, it is similar to passive haptic since the position is remained constant. On the other hand, isotonic contraction involves the force of changing forms and thus is similar to active haptic. Further research must also take account of the research fields on isometric and isotonic contractions to determine the additional elements that may affect the affective perception.

Fourth, this study has certain limitation on considering various situation and factors. In the case of the products that involve kinesthetic sensations, there are several different products, such as push-pull type and sliding type, other than the rotary type of product that was used in our study. Although they share common factors, there must also exist several different factors among them. This study has examined the fundamental structure related to kinesthetic sensations, but it still lacks in suggesting the design guidelines for improving the affective satisfaction of the products. Although this study has provided the results of the product evaluation, it was only able to discuss different types of affective elements based on the experiment. In order to analyze deeper about each product, the force profile elements that may affect the affective perception must be determined along with the detailed planning of the experiment on these elements.

The evaluation of various haptic devices that are related to kinesthetic sensations must be performed to generalize the characteristics of the affective elements and elements of force profile. Based on the characteristics of the haptic devices and force profile, the products can be grouped into similar characteristics, and the characteristics of each group needs to be further analyzed. Based on these fundamental studies, the development of more practical haptic device that provides affective feedback to the users will become feasible and thus offer commercialized haptic interaction technology to the customers in the near future.

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Appendix

A. Centrality index

A.1 Eigenvector Centrality

No.	Keyword	Eigenvec n	Eigenvec
1	haptic	0.571	80.769
2	virtual reality	0.34	48.045
3	tactile	0.337	47.624
4	touch	0.202	28.521
5	force feedback	0.189	26.704
6	tactile display	0.155	21.929
7	haptic interface	0.149	21.113
8	perception	0.141	19.886
9	vision	0.134	18.997
10	virtual environment	0.123	17.414
11	teleoperation	0.115	16.201
12	somatosensory	0.113	15.999
13	tactile feedback	0.089	12.639
14	texture	0.087	12.288
15	psychophysics	0.086	12.172
16	fmri	0.079	11.201
17	multisensory	0.077	10.858
18	haptic rendering	0.074	10.435
19	human	0.072	10.161
20	multisensory integration	0.068	9.564
21	haptic device	0.064	9.1
22	object recognition	0.064	9.023
23	tactile sensor	0.061	8.564
24	simulation	0.06	8.481
25	haptic feedback	0.059	8.37
26	vibrotactile	0.059	8.302
27	visual	0.059	8.276
28	shape	0.058	8.212
29	cross-modal	0.057	8.002
30	training	0.056	7.851

A.2 Degree Centrality

No.	Keyword	OutDegree	InDegree	NrmOutDeg	NrmInDeg
1	haptic	1857	1857	0.659	0.659
2	virtual reality	757	757	0.269	0.269
3	tactile	698	698	0.248	0.248
4	touch	561	561	0.199	0.199
5	tactile display	431	431	0.153	0.153
6	haptic interface	410	410	0.146	0.146
7	tactile sensor	376	376	0.133	0.133
8	haptic rendering	333	333	0.118	0.118
9	haptic feedback	333	333	0.118	0.118
10	perception	275	275	0.098	0.098
11	haptic device	265	265	0.094	0.094
12	force feedback	250	250	0.089	0.089
13	haptic perception	244	244	0.087	0.087
14	vision	243	243	0.086	0.086
15	psychophysics	213	213	0.076	0.076
16	tactile feedback	209	209	0.074	0.074
17	virtual environment	194	194	0.069	0.069
18	fmri	191	191	0.068	0.068
19	somatosensory	190	190	0.067	0.067
20	tactile perception	186	186	0.066	0.066
21	haptic display	175	175	0.062	0.062
22	multisensory	167	167	0.059	0.059
23	teleoperation	167	167	0.059	0.059
24	human	163	163	0.058	0.058
25	texture	159	159	0.056	0.056
26	haptic interaction	145	145	0.051	0.051
27	multisensory integration	140	140	0.05	0.05
28	blindness	131	131	0.047	0.047
29	attention	125	125	0.044	0.044
30	somatosensory cortex	118	118	0.042	0.042

A.3 Betweenness Centrality

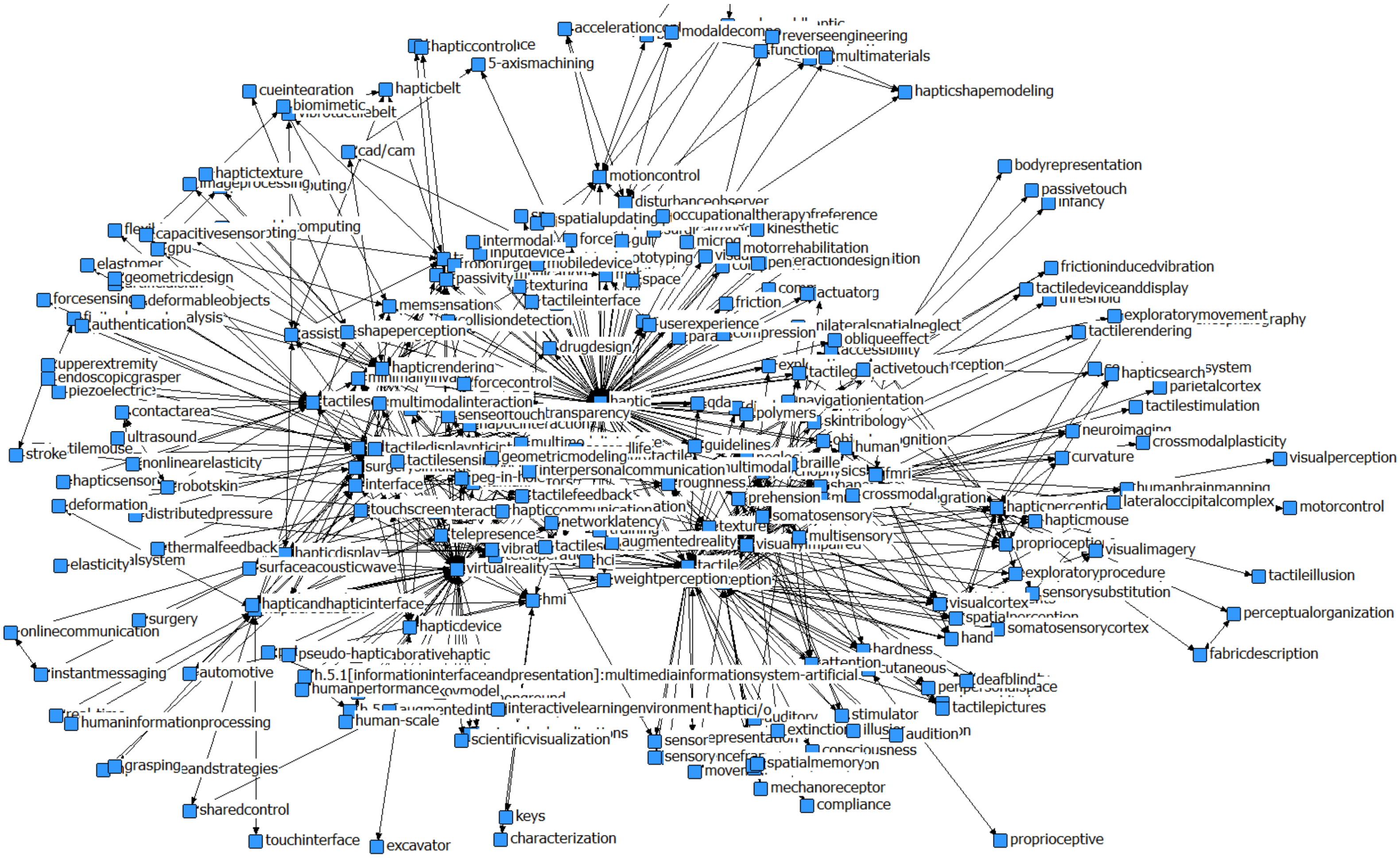
No.	Keyword	Betweenness	nBetweenness
1	haptic	3879655	29.582
2	virtual reality	1182930	9.02
3	tactile	920504.2	7.019
4	tactile sensor	872408.1	6.652
5	touch	857189.8	6.536
6	haptic interface	851106.2	6.49
7	tactile display	677545.9	5.166
8	haptic rendering	599222.9	4.569
9	haptic feedback	591827.9	4.513
10	psychophysics	470063.5	3.584
11	haptic device	415278.7	3.166
12	tactile perception	414142.2	3.158
13	haptic perception	385594.7	2.94
14	virtual environment	269557.3	2.055
15	tactile feedback	268085.9	2.044
16	neuropathic pain	265433.6	2.024
17	perception	260068.4	1.983
18	haptic display	247031.6	1.884
19	tactile sensing	232857.8	1.776
20	force feedback	230842.6	1.76
21	tactile stimulation	227787.8	1.737
22	fmri	189795.7	1.447
23	haptic interaction	180694.9	1.378
24	attention	173964.1	1.326
25	somatosensory cortex	157532	1.201
26	aging	155171.5	1.183
27	blind	142031.3	1.083
28	human	141811.2	1.081
29	rat	141374.4	1.078
30	tactile sensation	136175.8	1.038

A.4 Closeness Centrality

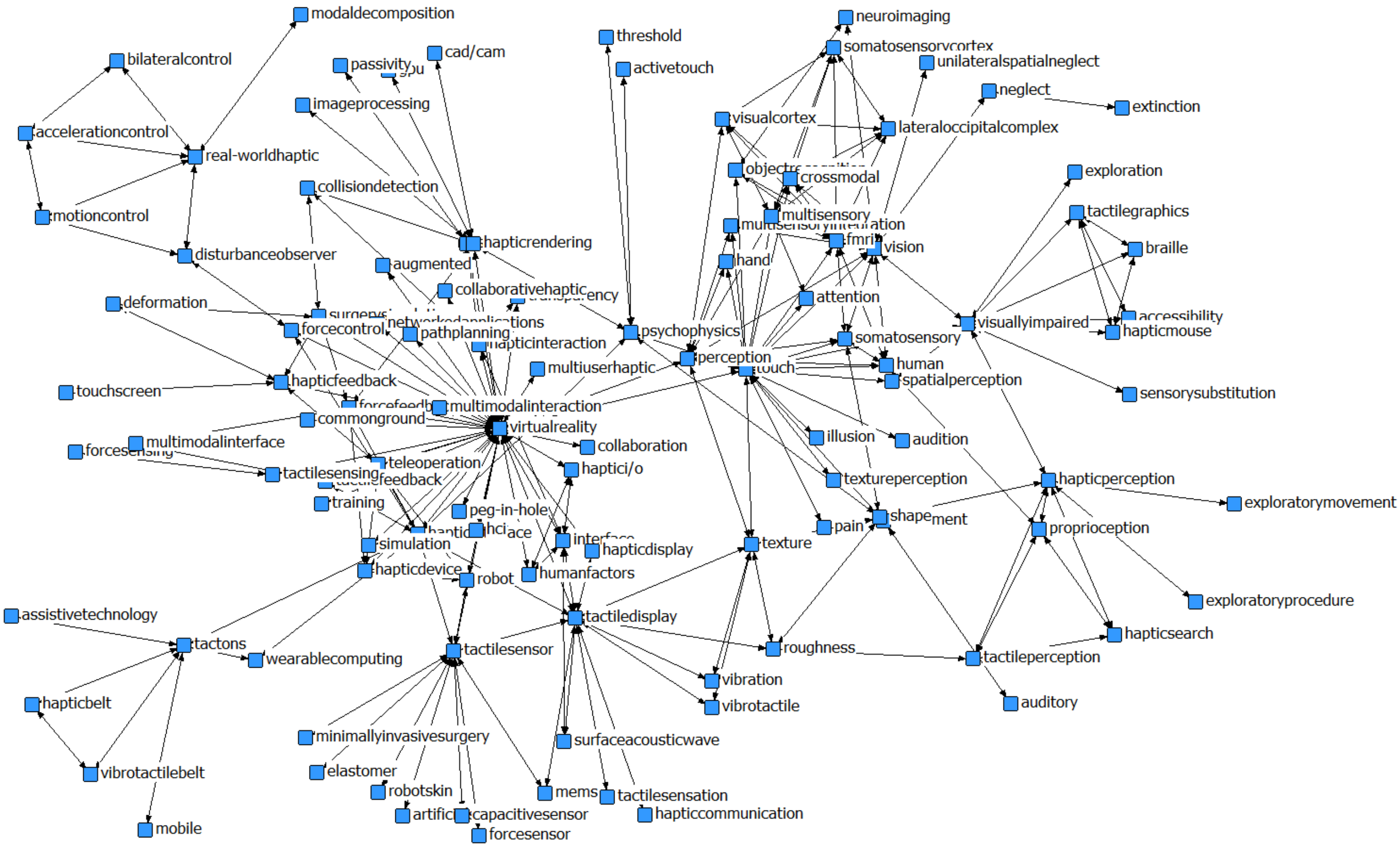
No.	Keyword	Farness	nCloseness
1	haptic	2170419	0.233
2	virtualreality	2171260	0.233
3	hapticinterface	2171796	0.232
4	touch	2171908	0.232
5	tactile	2171932	0.232
6	tactiledisplay	2171984	0.232
7	forcefeedback	2172156	0.232
8	teleoperation	2172303	0.232
9	psychophysics	2172353	0.232
10	blind	2172358	0.232
11	hapticdevice	2172484	0.232
12	tactileperception	2172507	0.232
13	perception	2172549	0.232
14	tactilefeedback	2172588	0.232
15	interface	2172603	0.232
16	tactilesensor	2172664	0.232
17	hci	2172689	0.232
18	roughness	2172694	0.232
19	vibration	2172695	0.232
20	hapticperception	2172750	0.232
21	hapticdisplay	2172779	0.232
22	human	2172824	0.232
23	crendering	2172837	0.232
24	design	2172905	0.232
25	texture	2172914	0.232
26	objectrecognition	2172921	0.232
27	robotics	2173040	0.232
28	fmri	2173055	0.232
29	hapticfeedback	2173056	0.232
30	robot	2173074	0.232

B. Network diagram

B.1 Cut off value = 2



B.2 Cut off value = 3



C. Contents analysis raw data

C.1 After 2000

No.	Keyword	Total	Title	Keyword	Abstract	Word1	Word2	Word3
1	visual	3441	405	268	2768	visual	visualization	visually
2	system	3195	299	188	2708			
3	feedback	2559	288	291	1980			
4	force	2501	140	197	2164			
5	virtual	2260	268	382	1610			
6	device	2188	167	153	1868			
7	stimulation	2073	183	55	1835	stimuli	stimulus	
8	object	1974	134	62	1778			
9	perception	1791	277	337	1177	perceptual	percepts	
10	display	1688	223	238	1227	displaying		
11	interface	1684	209	400	1075			
12	interact	1670	216	207	1247	interacting	interaction	
13	information	1663	100	96	1467			
14	model	1643	157	155	1331	modeling		
15	human	1617	183	229	1205			
16	experiment	1606	34	13	1559			
17	user	1568	22	154	1392			
18	control	1482	157	186	1139			
19	sensor	1482	221	230	1031			
20	touch	1431	119	202	1110			
21	performance	1325	60	35	1230			
22	environment	1249	137	90	1022			
23	simulation	1234	118	121	995	simulator	simulate	
24	robot	1212	197	181	834	robotic		
25	hand	1208	79	58	1071			
26	effect	1173	184	28	961	effective		
27	surface	1157	95	47	1015			
28	time	1030	73	48	909			
29	multi	1018	134	185	699	Multidimen-sional	multimodal	multiple
30	surgery	1014	152	126	736			
31	sensory	869	65	98	706			

32	vibration	833	75	96	662	vibrotactile		
33	shape	831	65	59	707			
34	modal	820	71	62	687	modality		
35	contact	791	46	38	707	contacting		
36	finger	786	72	22	692			
37	rendering	786	113	125	548			
38	spatial	770	74	79	617	spatio		
39	texture	767	77	82	608			
40	movement	755	50	29	676			
41	response	720	40	18	662			
42	sensation	712	51	58	603			
43	audio	676	90	59	527	audition	auditory	
44	integrate	656	70	64	522	integrating	integration	
45	neural	645	99	47	499	neuroimaging	neurological	Neurophy-siological
46	discriminate	637	54	50	533	discrimination		
47	measure	625	38	23	564	measurement		
48	function	621	48	41	532			
49	cue	608	52	17	539	cueing		
50	motor	594	44	69	481			
51	recognition	590	59	65	466			
52	image	587	33	41	513			
53	motion	569	43	42	484			
54	physical	552	85	18	449			
55	computer	542	110	68	364			
56	detect	539	26	51	462	detecting	detection	
57	skin	531	51	50	430			
58	blind	526	61	67	398	blindfolded	blindness	
59	representations	506	60	43	403			
60	position	503	19		484			
61	communicate	499	42	53	404	Communi-cating	Communi-cation	
62	sense	494	26	23	445			
63	mechanical	488	14	13	461			
64	actuator	482	98	38	346			
65	dynamic	476	48	32	396	dynamically		
66	behavior	474	104	13	357	behavioral		
67	feel	471	30		441	feeling		
68	tool	471	40	18	413			

69	exploratory	470	30	17	423	explore		
70	sensing	469	72	70	327			
71	guidance	466	22	22	422	guide	guidelines	
72	body	465	38	33	394			
73	experience	461	28	15	418			
74	tele	451	57	91	303	Telemani-pulation	Tele-operation	telerobotic
75	signal	440	12	14	414			
76	cortex	439	48	74	317			
77	pain	439	85	67	287			
78	manipulation	435	32	17	386	manipulate		
79	somatosensory	434	45	95	294			
80	properties	433	26	15	392			
81	network	416	49	44	323			
82	material	415	60	26	329			
83	active	406	40	45	321	actively		
84	technique	395	15	17	363			
85	space	393	39	29	325			
86	tissue	381	28	20	333			
87	brain	380	123	29	228			
88	sensibility	379	22	13	344	sensitive		
89	impaired	367	37	42	288	impairment		
90	stability	365	21	41	303			
91	map	364	11	13	340	mapping		
92	prototyping	356	19	26	311			
93	orientation	355	13	24	318			
94	field	354	11	18	325			
95	exploration	350	43	22	285			
96	pressure	345	29	32	284	press		
97	cross	340	15	59	266	crossed	crossing	crossmodal
98	assessment	338	19	13	306			
99	deformable	336	40	36	260	deformation	deformations	
100	element	330	12	23	295			
101	array	320	30	16	274			
102	kinaesthetic	320	19	11	290	kinematic	kinesthetic	
103	dimension	311	30	12	269	dimensional		
104	fingertip	306	21	11	274			
105	stiffness	303	21	23	259			
106	mobile	299	42	48	209	mobility		

107	roughness	293	28	37	228			
108	dof	292	48	11	233			
109	temporal	274	28	17	229			
110	memory	273	46	46	181			
111	friction	272	28	34	210			
112	graphic	271	25	26	220			
113	soft	269	29	22	218			
114	grasp	268	22	18	228			
115	locating	268	14		254	location		
116	affect	254	11		243	affected	affective	
117	arm	252	18	12	222			
118	assist	252	32	18	202	assistance	assistive	
119	distributed	244	13	15	216	distribution		
120	passive	244	31	16	197			
121	adaptation	240	13	12	215	adapt	adapted	
122	magnetic	235	29	47	159			
123	navigation	231	29	27	175			
124	children	229	37	14	178			
125	nerve	216	22	18	176			
126	medical	214	29	32	153			
127	primary	214	14	14	186			
128	cortical	213	30	18	165			
129	augment	207	34	33	140	augmentation	augmented	
130	cognition	205	57	16	132	cognitive		
131	interactive	205	39	18	148			
132	factor	202	12	27	163			
133	resolution	198	20	14	164			
134	product	192	27	25	140			
135	illusion	188	15	39	134			
136	bilateral	187	18	22	147			
137	presentation	185	18	47	120			
138	flexibility	182	23	15	144	flexible		
139	learn	182	46	48	88			
140	artificial	174	18	34	122			
141	elastic	172	13	16	143	elasticity		
142	fmri	169	31	40	98			
143	curvature	167		11	156	curve		
144	game	166	16	11	139			

145	threshold	166	13	19	134			
146	machine	162	13	60	89			
147	spinal	162	18	20	124			
148	invasive	159	30	27	102			
149	screen	159	14	14	131			
150	emotion	158	11	11	136	affective		
151	mouse	158	22	16	120			
152	torque	156	11	11	134			
153	inputs	155	14	24	117			
154	micro	151	27	27	97			
155	thermal	151	20	17	114			
156	braille	150	15	20	115			
157	search	149	18	13	118			
158	collaboration	147	21	30	96	collaborative		
159	compliance	146	15	11	120			
160	proprioception	146		16	130	proprioceptive		
161	assembly	144	17	18	109			
162	engineering	144	46	16	82			
163	methodology	144	29	19	96			
164	acuity	140	15	13	112			
165	limb	140	20		120			
166	transfer	139	13	14	112			
167	stroke	134	15	12	107			
168	piezoelectric	131	12	15	104			
169	injury	130	20	13	97			
170	needle	119	14	13	92			
171	shared	118	11	12	95			
172	cutaneous	115		18	97			
173	frequencies	114	13	16	85			
174	receptor	113			113			
175	media	111	12	11	88			
176	social	108	16	20	72			
177	education	107	16	15	76			
178	self	107	12	11	84			
179	dental	104	15	13	76			
180	planning	102	11	15	76			
181	optical	101	13	11	77			

C.2 Before 2000

No.	Keyword	Total	Title	Key word	Abstract	Word1	Word2	Word3
1	stimulation	2432	328	119	1985	simulator	simulate	
2	visual	1808	249	65	1494	visual	visualization	visually
3	system	1724	215	48	1461			
4	sensor	1592	364	26	1202			
5	hand	1333	176	25	1132			
6	control	1229	98	20	1111			
7	force	1182	95	49	1038			
8	surface	915	69	10	836			
9	discriminate	906	142	58	706	discrimination		
10	human	877	181	51	645			
11	sensory	869	119	69	681			
12	sensory	869	119	69	681			
13	display	795	139	29	627			
14	neural	777	89	33	655			
15	perception	754	198	48	508			
16	robot	740	161	33	546	robotic		
17	performance	738	72		666			
18	touch	730	72	43	615			
19	device	728	65	10	653			
20	finger	722	60	15	647			
21	virtual	716	114	37	565			
22	feedback	710	103	36	571			
23	interface	641	134	26	481			
24	sensitivity	641	75	29	537			
25	skin	614	55	22	537			
26	time	604	33	13	558			
27	threshold	601	31	15	555			
28	shape	593	61	8	524			

29	movement	589	55	25	509			
30	spatial	573	71	21	481			
31	cortex	538	95	85	358			
32	somatosensory	532	103	100	329			
33	blind	472	67	21	384			
34	interaction	464	59	28	377	interacting	interaction	
35	surgery	429	59	25	345			
36	user	419	20	6	393			
37	modal	399	24		375			
38	texture	387	23	12	352			
39	exploratory	382	51	8	323	exploration		
40	vibration	372	16	12	344			
41	brain	365	155	34	176			
42	pressure	330	23	23	284			
43	body	328	27	8	293			
44	impaired	318	26		292			
46	active	292	36	11	245			
47	pain	281	57	54	170			
48	affect	233	9		224			
49	cutaneous	232	25	17	190			
50	fingertip	186	12		174			
51	tele	182	8	5	169	Telemani-pulation	Teleope-ration	telerobotic
52	cognition	160	39		121			
53	arm	157	15		142			
54	passive	151	18		133			
55	stiffness	146	16		130			
56	kinaesthetic	145	21	8	116			
57	roughness	134	17	12	105			
58	feel	131			131			
59	acuity	108	15	8	85			
60	hardness	104			104			

61	deformable	93			93			
62	actuator	77	42		35			
63	forearm	50			50			
64	audio	39			39			
65	emotion	6			6			

D. Descriptive statistics and design variable

D.1 Experiment 1

Car	Area	Slope	Hardness	Consistency	Thickness	Satisfaction
Accord	Fender	2.55	-0.39	-0.60	-0.48	-0.50
Accord	Front Door	2.54	-0.25	-0.49	-0.32	-0.29
Accord	Hood	2.27	-0.18	-0.14	-0.24	-0.08
Accord	Quarter Panel	3.09	0.16	0.11	0.05	0.00
Accord	Rear Door	1.13	0.30	0.29	0.10	0.25
Accord	Roof	2.66	-0.24	-0.31	-0.33	-0.18
Accord	Trunk Lid	2.46	0.50	0.42	0.37	0.36
Avalon	Fender	3.58	0.36	0.31	0.20	0.26
Avalon	Front Door	1.82	-0.39	-0.62	-0.61	-0.57
Avalon	Hood	3.43	0.04	-0.02	-0.32	-0.08
Avalon	Quarter Panel	1.13	-0.92	-1.08	-0.96	-1.02
Avalon	Rear Door	2.03	-0.28	-0.53	-0.47	-0.49
Avalon	Roof	1.83	0.05	0.05	-0.05	0.10
Avalon	Trunk Lid	2.22	-0.19	-0.22	-0.28	-0.32
Camry	Front Door	1.98	-0.05	-0.29	-0.16	-0.11
Camry	Hood	4.38	0.79	0.69	0.58	0.56
Camry	Quarter Panel	3.21	0.26	0.05	0.16	0.11
Camry	Rear Door	3.44	0.15	-0.05	0.03	0.17
Camry	Roof	2.18	-0.12	-0.20	-0.20	-0.04
Camry	Trunk Lid	4.73	0.77	0.60	0.50	0.68
ES350	Fender	1.93	0.45	0.40	0.32	0.37
ES350	Front Door	2.21	-0.06	-0.05	-0.16	-0.03
ES350	Hood	2.67	-0.21	-0.38	-0.18	-0.13
ES350	Quarter Panel	5.80	0.79	0.70	0.61	0.67
ES350	Roof	2.91	0.51	0.51	0.51	0.47
ES350	Trunk Lid	3.53	0.95	0.98	0.78	0.77
K7	Fender	2.31	-0.02	-0.19	-0.13	0.00
K7	Front Door	2.34	-0.07	-0.11	-0.21	-0.17

K7	Hood	1.50	-0.84	-1.16	-1.02	-0.80
K7	Quarter Panel	2.38	-0.14	-0.29	-0.32	-0.21
K7	Rear Door	1.04	0.04	-0.04	0.01	-0.10
K7	Roof	1.84	-0.47	-0.56	-0.58	-0.48
K7	Trunk Lid	3.05	0.19	-0.01	0.11	0.21
Maxima	Fender	1.88	-0.44	-0.53	-0.53	-0.43
Maxima	Front Door	2.40	-0.05	-0.19	-0.18	-0.13
Maxima	Hood	1.94	-0.66	-0.77	-0.71	-0.53
Maxima	Quarter Panel	1.34	-0.55	-0.74	-0.59	-0.45
Maxima	Roof	4.05	0.33	0.27	0.29	0.23
Maxima	Trunk Lid	3.32	0.79	0.74	0.67	0.56
YF Sonata	Fender	2.55	0.38	0.38	0.26	0.31
YF Sonata	Front Door	1.80	0.57	0.32	0.31	0.39
YF Sonata	Hood	1.99	-0.26	-0.52	-0.35	-0.19
YF Sonata	Quarter Panel	2.34	-0.62	-1.01	-0.68	-0.68
YF Sonata	Rear Door	0.99	0.35	0.05	0.11	0.23
YF Sonata	Roof	1.90	0.22	0.22	0.18	0.20
YF Sonata	Trunk Lid	3.50	1.01	1.01	0.86	0.87
Insignia	Fender	4.10	0.65	0.59	0.38	0.43
Insignia	Front Door	1.99	-0.04	-0.24	-0.26	-0.18
Insignia	Hood	2.23	-0.25	-0.29	-0.36	-0.17
Insignia	Quarter Panel	2.42	-0.17	-0.33	-0.26	-0.21
Insignia	Rear Door	1.15	-0.26	-0.40	-0.40	-0.28
Insignia	Roof	1.75	-0.06	0.05	-0.06	0.02
Insignia	Trunk Lid	2.02	0.50	0.49	0.35	0.31
Torus	Fender	4.96	0.50	0.48	0.25	0.44
Torus	Front Door	1.91	-0.58	-0.73	-0.61	-0.51
Torus	Hood	2.44	0.26	0.08	0.10	0.05
Torus	Quarter Panel	3.10	0.11	-0.01	-0.15	0.00
Torus	Rear Door	1.42	-0.51	-0.64	-0.60	-0.62
Torus	Roof	1.52	-0.20	-0.28	-0.47	-0.44
Torus	Trunk Lid	3.45	0.44	0.51	0.31	0.40

D.2 Experiment 2

No	peak	dp1	dp2	Consis-tency	Smooth-ness	Solidity	Sleek-ness	Elasticity	Satisfac-tion
1	41	5.57	13.38	0.40	0.02	0.39	0.52	0.79	-0.02
2	39	1.65	19.98	0.75	0.37	0.29	0.57	0.09	0.37
3	40	5.90	14.49	-0.48	-0.78	-0.47	-0.10	-0.11	-0.76
4	40	0.18	23.03	0.31	0.05	0.26	0.41	0.71	0.35
5	39	5.56	14.36	0.44	0.43	-0.30	0.48	0.71	0.29
6	41	2.71	18.98	-0.20	0.33	-0.60	0.20	0.46	-0.17
7	39	5.64	14.37	-0.22	-0.45	0.15	-0.12	-0.54	-0.17
8	39	1.10	25.77	0.40	0.38	0.24	0.47	0.50	0.40
9	41	1.67	18.18	-1.17	-0.96	-0.63	-1.17	-0.85	-1.20
10	40	3.44	13.57	0.09	-0.66	0.42	0.16	-0.31	0.44
11	39	5.06	16.08	0.25	0.36	-0.12	0.15	0.76	0.16
12	40	0.89	19.47	0.42	0.48	0.07	0.66	0.90	0.36
13	39	4.03	16.13	-0.06	-0.14	-0.17	0.07	0.03	0.13
14	40	1.99	16.64	-1.20	-1.64	0.08	-1.62	-1.32	-1.34
15	41	4.46	19.10	0.56	-0.07	0.58	0.61	0.47	0.63
16	39	4.18	13.44	0.36	-0.23	0.72	0.38	0.23	0.63
17	40	2.17	19.00	-0.60	-0.62	-0.87	-0.75	-0.69	-0.95

D.3 Experiment 3

No.	Smooth -ness	Sense of unity	Perspi -cuity	Heavi -ness	Satisfac -tion	0-1p degree	1p-2p degree	2p-3p degree	3p-fp degree	0-1p height	1p-2p height	2p-3p height	3p-fp height
1	-0.67	-0.39	0.35	0.74	-0.46	3.00	3.00	3.00	1.00	2.00	2.00	3.00	3.00
2	0.80	0.49	0.39	-0.42	0.79	1.00	3.00	2.00	4.00	2.00	3.00	2.00	2.00
3	-0.51	-0.08	0.52	0.14	-0.05	1.00	1.00	1.00	3.00	2.00	4.00	3.00	1.00
4	0.30	0.02	0.56	-0.11	0.36	3.00	1.00	4.00	4.00	1.00	1.00	2.00	2.00
5	-1.09	-0.58	0.09	0.43	-0.86	3.00	3.00	1.00	2.00	3.00	4.00	3.00	4.00
6	-0.01	0.20	0.65	0.21	0.01	2.00	3.00	3.00	2.00	2.00	2.00	3.00	3.00
7	-0.56	-0.35	0.54	0.06	-0.05	2.00	1.00	3.00	1.00	2.00	2.00	1.00	1.00
8	-0.49	-0.24	0.56	-0.19	-0.01	1.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00
9	-0.53	-0.02	0.89	0.41	0.00	3.00	3.00	3.00	1.00	1.00	1.00	3.00	3.00
10	-0.24	0.15	-0.83	0.14	-0.64	2.00	3.00	1.00	3.00	3.00	4.00	3.00	4.00
11	0.07	0.00	0.23	-0.53	-0.05	2.00	2.00	1.00	2.00	1.00	3.00	2.00	1.00
12	-0.65	-0.03	0.27	0.62	-0.45	2.00	3.00	1.00	4.00	3.00	4.00	3.00	3.00
13	0.37	0.01	0.09	-0.27	0.13	1.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00
14	0.27	-0.26	0.59	-0.13	0.28	2.00	1.00	4.00	4.00	1.00	1.00	2.00	2.00
15	-0.37	-0.19	0.66	0.17	-0.19	2.00	1.00	3.00	3.00	2.00	2.00	1.00	1.00
16	-0.72	-0.33	0.25	0.16	-0.49	2.00	3.00	1.00	3.00	2.00	2.00	3.00	3.00

D.4. Experiment 4 & 5

DetentType		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
full sine	Mean	4.60	4.17	3.90	3.75	3.77	63.83
	N	300	300	300	300	300	300
	Std. deviation	1.654	1.607	1.561	1.534	1.423	19.107
	Kurtosis	-.815	-.840	-.940	-.908	-.671	.588
	Skewness	-.358	-.343	-.046	.074	-.073	-1.014
full tri	Mean	2.77	5.55	2.89	2.54	3.36	57.77
	N	225	225	225	225	225	225
	Std. deviation	1.420	1.145	1.293	1.146	1.553	19.869
	Kurtosis	-.733	.980	-.186	.710	-.562	-.208
	Skewness	.453	-1.006	.434	.761	.321	-.684
half sine	Mean	4.55	4.30	4.00	3.58	3.89	64.64
	N	300	300	300	300	300	300
	Std. deviation	1.678	1.536	1.651	1.352	1.537	19.165
	Kurtosis	-.602	-.709	-.909	-.506	-.816	.477
	Skewness	-.482	-.419	-.001	.202	-.031	-.879
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

Width		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
2	Mean	3.37	5.29	3.23	2.79	3.69	61.73
	N	275	275	275	275	275	275
	Std. deviation	1.652	1.122	1.487	1.215	1.625	19.713
	Kurtosis	-.973	.120	-.721	-.373	-.922	-.387
	Skewness	.211	-.687	.365	.517	.145	-.675
4	Mean	3.91	4.68	3.59	3.19	3.64	61.93
	N	275	275	275	275	275	275
	Std. deviation	1.561	1.383	1.458	1.329	1.481	19.671
	Kurtosis	-.791	-.320	-.585	-.395	-.755	.393
	Skewness	-.109	-.462	.135	.334	.060	-.852
6	Mean	4.98	3.81	4.17	4.11	3.78	63.75
	N	275	275	275	275	275	275
	Std. deviation	1.774	1.793	1.698	1.502	1.433	19.215
	Kurtosis	-.338	-1.200	-.988	-.751	-.495	.903
	Skewness	-.809	.032	-.140	-.122	-.091	-1.062
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

Magnitude		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
50	Mean	3.30	5.19	3.15	2.76	3.41	58.82
	N	275	275	275	275	275	275
	Std. deviation	1.721	1.278	1.571	1.238	1.543	19.700
	Kurtosis	-.777	.374	-.325	-.559	-.914	-.234
	Skewness	.415	-.817	.611	.407	.195	-.598
75	Mean	4.07	4.72	3.65	3.28	3.78	63.28
	N	275	275	275	275	275	275
	Std. deviation	1.718	1.501	1.507	1.398	1.517	18.912
	Kurtosis	-.912	-.142	-.841	-.367	-.611	.609
	Skewness	-.202	-.708	.049	.459	-.011	-1.004
100	Mean	4.88	3.87	4.19	4.04	3.91	65.32
	N	275	275	275	275	275	275
	Std. deviation	1.578	1.649	1.546	1.448	1.442	19.477
	Kurtosis	-.434	-1.034	-.799	-.807	-.624	.785
	Skewness	-.593	-.050	-.105	-.019	.014	-1.046
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

Mode of haptic		Perspicuity	Smoothness	Elasticity	Heaviness	Liltingness	satisfaction
active	Mean	4.38	4.45	3.83	3.60	3.72	63.93
	N	375	375	375	375	375	375
	Std. deviation	1.674	1.601	1.600	1.429	1.528	19.247
	Kurtosis	-.674	-.631	-.830	-.682	-.726	.571
	Skewness	-.416	-.505	.022	.192	.046	-.946
passive	Mean	3.84	4.71	3.53	3.16	3.69	61.26
	N	450	450	450	450	450	450
	Std. deviation	1.852	1.553	1.585	1.459	1.505	19.705
	Kurtosis	-1.133	-.470	-.793	-.469	-.762	.035
	Skewness	.103	-.601	.288	.477	.047	-.790
Total	Mean	4.08	4.59	3.66	3.36	3.70	62.47
	N	825	825	825	825	825	825
	Std. deviation	1.792	1.579	1.598	1.461	1.515	19.531
	Kurtosis	-1.046	-.549	-.847	-.628	-.747	.244
	Skewness	-.135	-.556	.165	.332	.047	-.855

E. ANOVA Table of experiment 4 & 5

DetentType		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	535.100	2	267.550	104.125	.000
	Within Groups	2112.129	822	2.569		
	Total	2647.229	824			
smoothness	Between Groups	284.066	2	142.033	65.921	.000
	Within Groups	1771.090	822	2.155		
	Total	2055.156	824			
Elasticity	Between Groups	186.907	2	93.453	40.064	.000
	Within Groups	1917.416	822	2.333		
	Total	2104.322	824			
Heaviness	Between Groups	213.488	2	106.744	56.807	.000
	Within Groups	1544.592	822	1.879		
	Total	1758.080	824			
Liltingness	Between Groups	37.874	2	18.937	8.403	.000
	Within Groups	1852.369	822	2.253		
	Total	1890.242	824			
satisfaction	Between Groups	6928.034	2	3464.017	9.263	.000
	Within Groups	307407.547	822	373.975		
	Total	314335.581	824			

Width		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	369.913	2	184.956	66.760	.000
	Within Groups	2277.316	822	2.770		
	Total	2647.229	824			
smoothness	Between Groups	305.804	2	152.902	71.847	.000
	Within Groups	1749.353	822	2.128		
	Total	2055.156	824			
Elasticity	Between Groups	126.112	2	63.056	26.201	.000
	Within Groups	1978.211	822	2.407		
	Total	2104.322	824			
Heaviness	Between Groups	251.629	2	125.815	68.651	.000
	Within Groups	1506.451	822	1.833		
	Total	1758.080	824			
Liltingness	Between Groups	2.868	2	1.434	.625	.536
	Within Groups	1887.375	822	2.296		
	Total	1890.242	824			
satisfaction	Between Groups	674.955	2	337.478	.884	.413
	Within Groups	313660.625	822	381.582		
	Total	314335.581	824			

Magnitude		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	344.182	2	172.091	61.422	.000
	Within Groups	2303.047	822	2.802		
	Total	2647.229	824			
smoothness	Between Groups	245.331	2	122.665	55.713	.000
	Within Groups	1809.825	822	2.202		
	Total	2055.156	824			
Elasticity	Between Groups	150.868	2	75.434	31.742	.000
	Within Groups	1953.455	822	2.376		
	Total	2104.322	824			
Heaviness	Between Groups	227.920	2	113.960	61.219	.000
	Within Groups	1530.160	822	1.862		
	Total	1758.080	824			
Liltingness	Between Groups	36.686	2	18.343	8.135	.000
	Within Groups	1853.556	822	2.255		
	Total	1890.242	824			
satisfaction	Between Groups	6066.839	2	3033.419	8.089	.000
	Within Groups	308268.742	822	375.023		
	Total	314335.581	824			

Mode of haptic		Type III Sum of Squares	df	Mean Square	F	Sig.
Perspicuity	Between Groups	58.765	1	58.765	18.684	.000
	Within Groups	2588.464	823	3.145		
	Total	2647.229	824			
smoothness	Between Groups	13.875	1	13.875	5.594	.018
	Within Groups	2041.282	823	2.480		
	Total	2055.156	824			
Elasticity	Between Groups	18.409	1	18.409	7.263	.007
	Within Groups	2085.913	823	2.535		
	Total	2104.322	824			
Heaviness	Between Groups	38.725	1	38.725	18.536	.000
	Within Groups	1719.355	823	2.089		
	Total	1758.080	824			
Liltingness	Between Groups	.198	1	.198	.086	.769
	Within Groups	1890.044	823	2.297		
	Total	1890.242	824			
satisfaction	Between Groups	1458.427	1	1458.427	3.836	.050
	Within Groups	312877.154	823	380.167		
	Total	314335.581	824			

F. Questionnaire

F.1 Experiment 1

자동차 외판 강성 감성 평가 실험

본 평가 실험에 참여해 주셔서 대단히 감사합니다. **서울대학교 휴먼인터페이스시스템 연구실은 사용자가 자동차 외판과의 접촉에서 느끼는 감성에 대한 연구**를 진행하고 있습니다. 사용자는 자동차 외판과 자주 접촉하게 되고, 외판의 강도(외판의 딱딱함 또는 부드러움)에 따라 차에 대한 고급스러움 또는 저급함을 느낄 수 있습니다. 이에 본 실험은 자동차 외판의 강도에 대한 사용자의 느낌(감성)을 파악하여 사용자가 선호하는 외판의 강도가 어느 정도인지 파악하고자 합니다. 귀하의 평가는 자동차 외판에 대한 사용자 만족감을 향상시키고 원가를 절감하는 외판 설계에 많은 도움이 될 것입니다. 본 평가 실험에 **한 시간**이 소요되며, 귀하께 소정의 평가비가 지급됩니다. 본 조사 질문의 응답내용은 통계법 제8조에 의거하여 제품의 개선 및 개발의 목적으로만 사용됩니다.

기본 인적 사항

1. 귀하는 다음 중 어느 나이 구간에 해당하나요?
   ① 20 ~ 29세 ② 30 ~ 39세 ③ 40 ~ 49세 ④ 50 ~ 59 세

2. 귀하의 직업은 다음 중 어디에 해당하나요?
   ① 학생 ② 직장인 ③ 기타

3. 귀하는 한 달에 몇 번 정도 직접 세차 또는 외판 관리를 하시나요?
   ① 월 1회 미만 ② 월 1 ~ 2회 ③ 월 2 ~ 3회 ④ 월 4회 이상

4. 귀하는 현재까지 자동차 외판의 꿀렁임*을 얼마나 자주 경험하셨나요?
   ① 경험 못함 ② 조금 경험함 ③ 자주 경험함

   *** 외판에 힘을 가했을 때 외판이 일정하게 변형되다가 어느 시점에서 급격히 변형되는 느낌**

5. 운전 경력은 대략적으로 얼마나 되시나요?
   ① 1년 이하 ② 1 ~ 5년 ③ 5 ~ 10년 ④ 10년 이상

6. 차량 구매 시 자동차의 외판 강성을 어느 정도 고려하시나요?
   ① 전혀 고려하지 않음 ② 조금 고려함 ③ 많이 고려함

평가 시나리오 및 평가 설문 문항

자동차 외판 강성 관련 감성 평가 시나리오

다음은 자동차 외판의 사용자 감성 평가를 위한 평가 시나리오(가정된 상황)입니다. 귀하는 자동차를 세차하거나 자동차에 기대다가 아래 그림과 같이 7개의 외판 부위에서 약한 부위들을 발견하게 되었습니다(각 차량의 외판 부위 중 표시된 곳). 이를 이상하게 여겨 이 부위를 손바닥으로 힘껏 눌러보았습니다. 이러한 상황을 가정하시고 평가할 차의 외판 부위를 **주로 사용하는 손의 손바닥**으로 **힘껏 5-10 회** 눌러본 후 아래 표의 문항들을 평가해 주시기 바랍니다.

외판 평가 부위

귀하는 본 평가실험에서 다음과 같이 자동차 외판의 부위를 평가하게 됩니다.

자동차 외판 강성 관련 감성 평가 문항

귀하께서는 다음 문항들을 외판 부위를 눌러본 후 평가해야 합니다. 천천히 읽어 이해하신 후 다음 페이지를 이용하여 평가해 주세요. 의문점이 있으시다면 실험 진행자에게 문의하세요.

No.	설문 문항	형용사 pair
1	자동차 외판이 강한 충격에 견디는 단단한 정도가 손바닥으로 누를 때 얼마나 된다고 느껴지십니까?	약한 ↔ 단단한
2	자동차의 외판을 손바닥으로 누를 때 외판이 들어가는 느낌은 어떻습니까?	*꿀렁거리는 ↔ 일정한
3	자동차 외판을 손바닥으로 누를 때 외판 자체의 만족스러운 정도가 얼마나 느껴지십니까?	불만족한 ↔ 만족한
4	자동차 외판을 손바닥으로 누를 때 느껴지는 외판의 두께 정도는 어느 정도로 느껴지십니까?	얇은 ↔ 두꺼운
5	자동차 외판을 손바닥으로 누를 때 외판이 누르는 방향으로 얼마나 들어간다고 느껴지십니까?	cm

* 외판에 힘을 가했을 때 외판이 일정하게 변형되다가 어느 시점에서 급격히 변형되는 느낌

평가 양식

차 이름: ____________________

자 번호에 맞는 차량에 대하여 다음 평가 양식에 따라 평가해주세요. 아래의 평가 작성 예시를 참조하여 작성하십시오. 평가 시 유의 사항은 다음과 같습니다.

1. 브랜드는 가급적 배제하시고 평가해주세요.
2. 조립 불량에 의한 소리는 무시하시고 외판 자체의 느낌을 평가해주세요.
3. 다른 차량과 비교하지 말고 해당 차량에서 받은 느낌의 정도를 평가하세요.

<평가 체크 예시>

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
			O				
2	매우 꿀렁거리다			보통이다			매우 일정하다
					O		
3	매우 불만족스럽다			보통이다			매우 만족스럽다
				O			
4	매우 얇다			보통이다			매우 두껍다
						O	
5	5 cm						

1. Hood

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

2. Fender

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

3. Front Door

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

4. Rear Door

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

5. Quarter Panel

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

6. Trunk Lid

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

7. Roof

문항	3	2	1	0	1	2	3
1	매우 약하다			보통이다			매우 단단하다
2	매우 꿀렁거리다			보통이다			매우 일정하다
3	매우 불만족스럽다			보통이다			매우 만족스럽다
4	매우 얇다			보통이다			매우 두껍다
5	cm						

F.2 Experiment 2

핸드폰 슬라이드 조작 감성 평가

안녕하십니까? 본 설문지는 삼성전자㈜와 서울대학교 HIS연구실에서 함께 진행하고 있는 "슬라이드 조작 감성 평가 및 표준화 방안 연구" 과제 중 조작 감성 평가 pilot test를 위한 것입니다. 본 조사 질문의 응답내용은 통계법 제8조에 의거하여 제품의 개선 및 개발의 목적으로만 사용될 것이며, 신상에 어떠한 불이익도 따르지 않을 것임을 약속 드립니다. 조사에 성실히 답변해 주시면 감사하겠습니다.

문의처: 서울대학교 산업공학과 HIS 연구실 (Tel. 02-885-1403)

평가자 연령	
평가자 성별	남 여

슬라이드 사용 경험	
휴대폰 사용 정도	
슬라이드 선호 모델	

평가자 손 너비	
평가자 손 길이	

HISL.

1

평가대상 번호 _____

1. 다음 내용들은 휴대폰 슬라이드 조작에 대한 사용자 감성 측면의 평가를 위한 설문 항목입니다. 각 문항에 대해 평가 대상에 대한 생각을 문항별로 표시해 주시기 바랍니다. 불만족스러운 경우 comment 란에 불만족사항에 대해 기입하여 주시기 바랍니다.

빈 문항이 없이 모든 문제에 하나의 번호를 표시해 주시기 바랍니다. (답변 수정의 경우 확실히 표시)

< 평가 변수 >

1. [혁신적임] 슬라이드 조작 시에 기존의 것과는 다른 혁신적인 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

2. [고급스러움] 슬라이드 조작 시에 품질이 좋으며 수준이 높아 고급스럽다는 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

3. [경쾌함] 슬라이드 조작 시에 가볍고 상쾌한 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

4. [안정감] 슬라이드 조작 시에 느낌이 달라지지 않고 일정한 느낌이 드는가?

전혀 그렇지 않다 ~	그렇지 않다 ~	조금 그렇지 않다 ~	보통이다 ~	조금 그렇다 ~	그렇다 ~	매우 그렇다
○	○	○	○	○	○	○

Comment ____

HTSL

2

F.3 Experiment 4 & 5

조그 다이얼의 조작감 연구 조사

안녕하십니까? 서울대학교 휴먼인터페이스시스템 연구실에서 '조그다이얼의 조작감에 대한 연구'를 진행하고 있습니다.
본 조사 질문의 응답내용은 통계법 제8조에 의거하여 제품의 개선 및 개발의 목적으로만 사용될 것이며, 신상에 어떠한 불이익도 따르지 않을 것임을 약속드립니다. 본 평가와 관련하여 문의사항이나 궁금한 점이 있으시면 아래로 연락하시기 바랍니다.

서울대학교 공과대학 산업공학과 휴먼인터페이스 시스템 연구실
송주봉 (shedtwin@naver.com)

기본 인적 사항

질문1. 귀하의 성별은 무엇입니까? ① 남자 ② 여자

질문2. 귀하는 올해 만으로 몇 세입니까? **만 _______세**

질문3. 주로 사용하는 손은 어느 손입니까? ① 왼손 ② 오른손

질문4. 손길이

질문5. 손너비

평가 샘플 번호 :

1. 조그다이얼을 조작할 때 다이얼을 회전하면서 단계가 넘어갈 때 느껴지는 느낌이 명확합니까?

매우 명확하지 않다 ←	명확하지 않다 ←		보통이다 →		명확하다 →	매우 명확하다
①	②	③	④	⑤	⑥	⑦

2. 조그다이얼을 조작할 때 다이얼을 회전하면서 느껴지는 움직임의 부드러움은 어느 정도입니까?

매우 부드럽지 않다 ←	부드럽지 않다 ←		보통이다 →		부드럽다 →	매우 부드럽다
①	②	③	④	⑤	⑥	⑦

3. 조그다이얼을 조작할 때 다이얼을 회전하면서 느껴지는 움직임의 탄력적인 정도 어떻습니까?

매우 탄력적이지 않다 ←	탄력적이지 않다 ←		보통이다 →	탄력적이다 →		매우 탄력적이다
①	②	③	④	⑤	⑥	⑦

4. 조그다이얼을 조작할 때 필요한 힘에 대한 느낌은 어떻습니까?

매우 약하다 ←	약하다 ←		보통이다 →		세다 →	매우 세다
①	②	③	④	⑤	⑥	⑦

5. 조그다이얼을 조작할 때 다이얼을 회전하면서 느껴지는 움직임의 경쾌한 정도 어떻습니까?

매우 경쾌하지 않다 ←	경쾌하지 않다 ←		보통이다 →		경쾌하다 →	매우 경쾌하다
①	②	③	④	⑤	⑥	⑦

6. 전체적으로 조그 다이얼을 조작해 보았을 때 느껴지는 고급감을 0 점 - 100 점 사이로 평가하여 주시기 바랍니다. ______________ 점

G. Glossary

Term	Definition	Reference
Active touch	Touch in which a person actively explores an object, usually with fingers and hands	Grunwald (2008), Goldstein (2009)
Affective touch	Touch may be divided into discriminatory functions (how large, soft, hot etc an object is, for instance), but also how pleasant it is. This pleasant, emotional or affective dimension is often encountered within a more social affiliative context.	Grunwald (2008)
Cutaneous information	The cutaneous class of sensations refers to those which arise through direct contact with the skin surface. Cutaneous stimulation can be further subdivided in to the sensations of pressure, stretch, vibration, and heat. In some instances pain is also referred to as a separate sensation, though excessive stimulation of the other detectable parameters will lead to a feeling of pain	Wall & Brewster (2006)
Cutaneous senses	Which are responsible for perceptions such as touch and pain that are usually caused by stimulation of the skin	Goldstein (2009)
Force feedback	The area of haptics that deals with devices that interact with the muscles and tendons that give the human a sensation of a force being applied.	Grunwald (2008), Smith (1997)
Golgi tendon organs	Tension receptors at the juncture between skeletal muscle and tendon	Grunwald (2008)
Haptic feedback	Information for a system or user i.e. whether an item is firmly grasped or sliding or of the elasticity of an object touched in a virtual environment.	Grunwald (2008)
Haptic interaction	The haptic transmission of information	Kern (2009)
Haptic interface	A haptic device permitting a haptic interaction, whereby the transmitted information is subject to change and a measure of the haptic interaction is	Kern (2009)

	acquired	
Haptic perception	Refers to the integration of cutaneous surface sensing with kinesthetic data derived from the position and movement variables of the manipulator system	Grunwald (2008), Lee & Nicholls (1999)
Haptic simulator	A system enabling to control design variable of haptic feedback and to interact with a virtual object	Kern (2009)
Haptic profile	A plot of the data that seem to correlate with the human perception appeared with three axis, force, position, and velocity when device, switch, jog dial etc., is moving. It is used to emphasizes aspects of the feel of a switch as it is actuated, while minimizing the variability due to human actuation	Weir et al., (2004)
Haptics	The science of all biological and psychological aspects of the sensory as well as the motor capabilities within the skin, joints, muscles and tendons	Grunwald (2008), Kern (2009)
Kinesthesis	The ability to sense the movement of the body and limbs perceived by muscles and joints.	Goldstein (2009), Grunwald (2008), Kern (2009)
Kinesthetic information	Kinesthetic information refers to the sensation of positions, velocities, forces and constraints that arises from the muscle spindles and tendons. Force feedback haptic interfaces appeal to the kinesthetic senses by presenting computer controlled resistive forces to create the illusion of contact with a rigid surface.	Wall, Brewster (2006), Jones (2000)
Mechano-receptors	Receptors that respond to mechanical stimulation such as pressure, stretching, and vibration, compression, bending, stretching of cells, pressure, proprioception, and balance	Goldstein (2009)
Muscle spindle	Mechanoreceptors embedded between muscle fibers in skeletal muscle monitoring muscle length.	Grunwald (2008)
Passive touch	Refers to a non-moving observer that obtains tactile information passively from cutaneous sources only	Grunwald (2008), Goldstein (2009)

Proprio-ception	The ability to sense the position of the body and limbs	Goldstein (2009)
Roughness	A measurement of small-scale variations in the height of a physical surface. Usually, spacing, size and density of raised elements are crucial factors that determine texture perception	Grunwald (2008)
Somato-sensory system	A term referring to body senses which includes the cutaneous senses, proprioception, and kinesthesis related to the sense of temperature, pain, proprioception, mechanoreception and itch.	Goldstein (2009), Grunwald (2008)
Stiffness	Stiffness of a contact describes the rigidity of a contact in terms of a relation between the penetration depth and the reflecting force.	
Tactile	The mechanical interaction with the skin	Kern (2009)
Tactile feedback	Tactile feedback deals with the devices that interact with the nerve endings in the skin which indicate heat, pressure, and texture.	Grunwald (2008), Smith (1997)
Texture	The contribution of static characteristics of skin deformation, such as depth of penetration, volume of skin deformed, skin tension and skin stretch are the defining factors in perception of roughness.	Katz (1970), Lederman & Taylor (1972), Lederman, Loomis, Williams (1982)
The sense of force or tension	The process by which we perceive forces generated through the muscles	Taylor (2009)
The sense of joint movement	The process by which we perceive movements of parts of the body relative to one another. It includes detection of movements and perception of their direction, velocity, distance, and timing.	Taylor (2009)
The sense of joint position	The process by which we perceive the current positions of parts of the body relative to one another.	Taylor (2009)

국문초록

사람-로봇 상호작용, 가상 현실 등에서 멀티모달, 실감 인터페이스에 대한 관심이 많아지면서 촉각에 대한 연구가 다양한 분야에서 이루어지고 있다. 하지만 아직까지 멀티모달 인터랙션 구현을 위해 필요한 기술 자체에 대한 연구와 개발된 기술을 적용하여 어떻게 활용할 것인가에 대한 연구는 부족한 실정이다. 햅틱기술 적용을 위해서는 햅틱 자극의 특성을 정확하게 이해하고 사용자 측면에서 어떻게 인지하는지에 대한 체계적인 연구가 필요하다. 본 연구의 목적은 1) 운동감각과 관련된 햅틱 피드백의 특성을 도출하고 각 특성들이 사용자가 인지하는 감성에 미치는 영향에 대한 연구, 2)mode of haptic 가 운동감각 인지에 미치는 영향에 대한 분석, 두 가지이다. 본 연구에서는 width, magnitude, detent type, detent width 로 정의된 사인파 형태로 표현되는 총 33 개의 햅틱 피드백을 시뮬레이터를 이용하여 제공하였다. 25 명의 피험자가 6 가지 감성어휘(명확함, 부드러움, 조작력, 탄력감, 경쾌함, 만족도)에 대한 평가를 수행하였다. 실험은 조그 다이얼을 대상으로 햅틱 피드백이 제공되는 상황을 사용자가 조그 다이얼을 직접 조작하면서 자극이 제공되는 active haptic 와 사용자는 가만히 있고 조그 다이얼이 움직이면서 자극이 제공되는 passive haptic 로 나누어 진행하였다. 감성요소와 만족도 사이의 관계를 회귀분석으로, 감성요소와 설계변수 사이의 관계를 수량화 1 류 분석으로 수행하고 감성 모델을 도출하였다. 요인분석을 통하여 감성요소들은 힘과 관련된 감성요소, 움직임과 관련된 감성요소로 나누어 볼 수 있었고 만족도를 감성요소를 통하여 설명할 수 있었다(R^2=0.6). 그리고 각 세부 감성요소들을 설계 변수들을 통하여 설명할 수 있었다(R^2=0.2~0.5). 상황에 따라 사용자가 인지하는 차이를 분석하기 위하여 ANOVA 를 통하여 각 상황의 평균을 비교하고 force profile 요소에 따른 감성의 변화 경향을 조사하였다. 분석 결과 명확함과 조작력은 active haptic 일 때, 부드러움은 passive haptic 일 때를 통계적으로 유의하게 더 크게 평가하였다. force profile 요소에 따른 변화 경향을 살펴보면 active haptic 일 때는 force profile 요소와 선형적인 관계를 보인 반면 passive haptic 일 때는 그렇지 않은 것으로 나타났다. 실험결과를 통하여 힘의 차이와 관련된 요소를 passive haptic 일 때보다 active haptic 일 때 더 크게 평가하는 것과 passive haptic 일 때는 자극의 차이에 대한 일관적인 평가가 이루어지지 않는 것을 알 수 있었다. 사용자들이 인지하는 운동감각과 관련된 감성을 파악하기 위한 감성 차원 및 피드백 요소의 특성에 대한 기초 연구를 수행함으로써 보다 복잡한 운동감각에 대한 감성인지를 분석하고 사용자가 원하는 햅틱 피드백을 제공할 수 있는 토대를 마련할 수 있을 것으로 기대된다. 또한 실감 재현과 관련하여 사용자가 수동적으로 제공받는 피드백에 대한 인지 특성을 분석함으로써 능동적으로 사물을 조작하면서 느끼는 피드백과 다른 점을 고려해 볼 수 있었다.

주요어 : Haptic perception, Kinesthetic feedback, Force profile, Affective engineering, Mode of haptic
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