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Developing Labeled Affective Magnitude Scale and Fuzzy Linguistic Scale for Tactile Feeling

Diyar Akay *
Department of Industrial Engineering, Faculty of Engineering, Gazi University
06570, Ankara, Turkey. E-mail: diyar@gazi.edu.tr

Burcu Uzgur Duran
Department of Industrial Engineering, Faculty of Engineering, Gazi University
06570, Ankara, Turkey. E-mail: uzgurburcu@gmail.com

Engin Duran
Department of Industrial Engineering, Faculty of Engineering, Gazi University
06570, Ankara, Turkey. E-mail: enginduran89@gmail.com.

Brian Henson
School of Mechanical Engineering, University of Leeds
Leeds LS29JT, United Kingdom. E-mail: b.henson@leeds.ac.uk.

Fatih Emre Boran
Department of Energy Systems Engineering, Faculty of Technology
Gazi University, 06500, Ankara, Turkey. E-mail: emreboran@gazi.edu.tr.

* Corresponding author.
Tel. : +90 312 582 38 44; Fax : +90 312 230 84 34

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Abstract

Affective design is the inclusion or representation of human emotions and subjective impressions in product design processes. In affective design, a number of different scales are commonly used to reveal and measure subjective emotions related to design features of products. Osgood's Semantic Differential Scale (SDS) is one of the scales that has often been used for this purpose. However, there are some drawbacks in the SDS due to the ordinal nature of the scale that lead to losses or distortions of a significant amount of information and this makes it difficult to justify parametric statistical analysis. In this study, two scales, namely a Labeled Affective Magnitude (LAM) scale and a fuzzy linguistic scale, are developed. The LAM scale is an alternative scale based on magnitude estimation and has ratio properties. The fuzzy linguistic scale is an interval scale for which responses are linguistic descriptors that are identified with fuzzy numbers or intervals. The scales were developed for tactile feelings because they are an important factor in product evaluation. Statistical analysis was conducted to compare the scales. There was no significant difference between the new constructed fuzzy scale and eleven point SDS, whereas there was asignificant difference between the new constructed LAM scale and eleven point SDS.

Keywords: Affective design; Fuzzy linguistic scale; Labeled Affective Magnitude scale; Tactile feelings

1. INTRODUCTION

Affective design is about measuring people's emotional responses to products, identifying the characteristics of products by taking into account people's feedback, and designing better products using the information (Chen, Shao, Barnes, Childs, & Henson, 2009). This concept is considered to be a westernized approach to kansei engineering which was developed by Nagamachi to incorporate customer emotions and perceptions into the product design process (Nagamachi, 1996). Affective design has been applied in many fields for product design, such as automotive, electric home appliance, house construction, office machine and costume industries, in the early period of its application (Nagamachi, 2002). Most recently, as affective design has become a world-wide recognized concept, it has been used in numerous innovative areas, e.g. computer games (de Byl, 2015; Gizvcka & Nalepa, 2018), websites (Taharim, Zainal, & Lim, 2018), software (GhasemAghaei, Arya, & Biddle, 2016; Pieroni, Scarpato, & Scorza, 2018) and mobile security authentication (D. Park, Lee, Lee, & Song, 2018).

Affective design converts the information obtained from humans' sensorial feelings regarding to product features into a consumer-oriented design by applying mathematical models (Jiao et al., 2007). All the sensory information people receive when they interact with products – independently of whether the designer created it intentionally or accidentally, and independent of whether the user perceived it consciously or unconsciously – can have an effect on product perception, cognition, experience and behavior. Besides affecting functional aspects of the product, sensory information can also contribute to the various components of the product experience. First of all, a product can evoke pleasure (an aesthetic response), because it has a beautiful appearance, makes a pleasant sound, feels good to touch, or smells nice. Second, the senses provide input for forming all kinds of expressive, semantic, or other connotative meanings. Finally, interacting with a product leads to various emotional responses, such as anger, fear, satisfaction, happiness or admiration (Desmet & Hekkert, 2007). It is argued that the sensory side of design is more decisive than the practical elements in the success of a product. Sensorial feelings help to understand a person's perceptions of a product and to include these feelings in the product design process (Norman, 2004).

It is remarkable to enlighten the tie between affective design and Human Factors and Ergonomics (HFE). As an evolving research area in HFE, affective design implies a gradual shift in research paradigm from human performance (time and error) and physical or psychological pain to the study of emotion, pleasure and affect (Helander, 2001; Vergara, Mondragón, Sancho-Bru, Company, & Agost, 2011). For HFE, it is new aspect about how the user evaluates rather that how to evaluate the user. In other words, HFE attempts to identify the value of preventing events that eventually do not happen while affective design tries to identify the advantages of value of events that do (Hancock et al., 2005). From this standpoint, they are two sides of the same coin directed toward the same objective of optimized human-technology interaction, which is prominent goal of design. In recent years, there are many studies in HFE taking this perspective into account (Guo, Liu, Cao, Liu & Li, 2016; Li & Wei, 2017; Ou, 2020).

The affective design process is represented in Figure 1 (Schütte & Eklund, 2005). As shown in Figure 1, a product within a specific domain is defined by two different aspects, namely semantic and physical spaces. At the synthesis stage, the interaction between these two spaces is examined using the sensory scales and the semantic effect of the physical properties is determined. Then a validity test is performed and a model that explains how the semantic space and properties space are associated can be established if the test results are acceptable.

[Insert Figure 1 about here]

It is a difficult task to reveal and measure the feelings of individuals during interaction with any object or event in affective design. Many researchers have worked on the detection and measurement of feelings and have proposed various approaches that can be used for this purpose.

The approaches for measuring emotions are categorized under two groups as physiological and psychological measures (Nagasawa, 2002). Physiological measurement is a method aimed at measuring emotions triggered by external stimuli using autonomic nerve reflections and brain waves. Since physiological measures are concerned with the reactions of the human body to a stimulant, no definite judgment can be made as to whether these responses are caused only by the stimuli taken into account. For this reason, results obtained by physiological measurements may not accurately reflect the user's emotions about the product (Schütte, 2005). Nevertheless, there are studies aiming to measure the customer's feelings about the product using physiological measures (Jenkins, Brown, & Rutterford, 2009; Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007; Tomico et al., 2008; Zhang, LEI, Harada, & Yamanaka, 2006).

Psychological measures aim to reveal subjective feelings about products using self-reporting instruments (Khalid & Helander, 2004). When interacting with a product, users generally describe and evaluate their feelings with words (linguistic expressions) in their minds (Krippendorff & Butter, 1984). It is first necessary to transform a subjective feeling into a verbal description or number to compare these feeling to those felt by others (Hayes, Allen, & Bennett, 2013). A number of different scales are used to assess the intensity of feeling related to product attributes and the degree of liking or disliking for products (Cardello, Lawless, & Schutz, 2008). The Semantic Differential Scale (SDS), was first developed by Osgood, Suci, and Tannenbaum (1957), and is the most widely used rating scale used for measuring the affective and emotional value of products (Kong & Yang, 2009). Participants are asked to rate a stimulus on usually five, seven, or nine points scales between bipolar adjectives, with the positive word on the right and its negative counterpart (antonym) on the left, in a semantic differential questionnaire (Osgood, 1964). On this evaluation scale, a score of seven points means that the subject has a very strong positive impression of the sample, while one point means a very strong negative impression (Figure 2).

[Insert Figure 2 about here]

Many applications are found in the literature that apply SDS for evaluating products, e.g. the design of street furniture (Maurer, Overbeeke, & Smets, 1992), car interior (Jindo & Hirasago, 1997; Nagamachi, 1994), doors (Matsubara & Nagamachi, 1997), microelectronics (Chuang & Ma, 2001), mobile phones (Chuang, Chang, & Hsu, 2001), office chairs (Hsiao & Huang, 2002; Jindo, Hirasago, & Nagamachi, 1995), printers (Chang & Van, 2003), glasses (Petiot & Yannou, 2004), footwear (Alcántara, Artacho, González, & Garcia, 2005), rock switch (Schütte & Eklund, 2005), cloth fabric (Huang, Chen, Han, & Chen, 2013), ketchup sauce bottle (Mamaghani, Rahimian, & Mortezaei, 2014), kitchen products (Bevan, Liu, Barnes, Hassenzahl, & Wei, 2016), anthropomorphic package shapes (De Bondt, Van Kerckhove, & Geuens, 2018) and others.

Though simple and easy to use which make SDS, as an example of a categorical scale, popular in sensory evaluation, there are controversies about the use of the scale. One of the criticisms is that intervals defined by the semantic labels do not reflect equal differences in perception although the numerical values attributed to the categories have equal intervals (De La Rosa De Sáa, Gil, González-Rodríguez, López, & Lubiano, 2015; Stevens & Galanter, 1957). This fact reduces the measurement level of the data from interval to ordinal level and so retrieved data from the scale fail to satisfy assumptions required by parametric statistical analysis (Schutz & Cardello, 2001). Second, the limited number of response categories in the scale may restrict subjects when expressing their sensory perceptions. Third, subjects generally avoid using end categories considering the possibility of confronting a stimulus perceived more (less) than the one assigned to upper (lower) end category (Stevens & Galanter, 1957). This avoidance narrows the scale and thus limits its ability to identify the extreme stimuli.

In order to overcome problems arising from the ordinal nature of the SDS, alternative scaling methods have been designed by researchers. The Labeled Affective Magnitude (LAM) scale was developed by Schutz and Cardello (2001) for assessing food liking and is a widely used scale among these alternative scaling methods. Since the dataset obtained using the LAM scale has ratio characteristics, one can assert a statement that “stimulus X is twice as warm as stimulus Y for subject A”. Moreover, many parametric statistical analyzes can be conducted with retrieved data from this scale

(Jaeger & Cardello, 2009). Another alternative and more powerful approach that can eliminate the problems of ordinal scales is fuzzy set theory (Brouwer, 2006). Fuzzy sets is a concept that extends the notation of a classical set by assigning to each element of a set a value representing its degree of membership in [0,1] (Zadeh, 1965). Fuzzy numbers grasp the vagueness inherent in human evaluation much better and more accurately and meaningfully than crisp numbers. Thus the fuzzy linguistic approach is a very appropriate concept to model and cope with the information associated with human evaluation, feeling and perception (De La Rosa De Sáa et al., 2015).

Tactile feeling is a sensation that a product arouses in a person when it is touched or rubbed. It has become increasingly important in customer-oriented product design and has great potential (Zuo, Hope, & Jones, 2014). Ordinal rating scales, such as SDS, Likert scale, etc., have been generally employed to measure tactile feelings in prior studies (Elkharraz, Thumfart, Akay, Eitzinger, & Henson, 2014; Koskinen, Kaaresoja, & Laitinen, 2008). Because of the drawbacks of ordinal scales, new scaling methods are needed to prevent the information loss problem. In the context of this study, two new scales, LAM and fuzzy linguistic scales, are constructed to measure tactile feelings of humans regarding to a product, and the measurements obtained are compared to those from the use of SDS.

The construction of LAM scale is based on magnitude estimation in which the locations of the semantic labels are determined by direct estimation of their perceptual and psychological magnitude. The fuzzy linguistic scale is based on fuzzy logic approaches that handle both personal and inter-personal uncertainty and enable researchers to more strongly and accurately measure the perception of touch and extract meaningful semantic information (Li, 2013; Lim, Wood, & Green, 2009).

The rest of this paper is structured as follows. Section 2 provides an overview of alternative approaches (LAM and fuzzy linguistic approach) to scaling sensory attributes. Section 3 contains two experiments to construct LAM and fuzzy scales for touch feelings. Section 4 presents the comparison results for the scales. Finally, the closing remarks are discussed in Section 5.

2. ALTERNATIVE APPROACHES TO SCALING SENSORY ATTRIBUTES

2.1. Labeled Affective Magnitude Scales

To avoid problems arising from ordinal scales, magnitude estimation scaling was developed in which subjects assign numbers to represent the magnitude of their sensation in a ratio manner (Moskowitz, 1977). It provides an unbounded upper limit for ratings and ratio data allowing parametric statistics to be applied. In addition, it offers useful information when making comparison between stimuli (e.g., stimulus X is twice as warm as than stimulus Y for subject A). However, it can be difficult to use by consumers. Labeled Magnitude Scale (LMS) were developed to eliminate the limitations of magnitude estimation. The LMS (aka category-ratio scale) consists of a vertical line upon which semantic labels for intensity levels have been added at locations experimentally determined using magnitude estimation. Once a LMS is constructed, subjects put a mark on the line to indicate their sensations to stimuli.

The first LMS was the Borg perceived exertion scale (Borg, 1982). Later on, LMSs of taste and smell sensation were developed (Green et al., 1996; Green, Shaffer, & Gilmore, 1993). The key features of both scales are unequal, quasi-logarithmic spacing of its verbal labels and the existence of ‘‘maximal”, ‘‘strongest imaginable” or ‘‘strongest possible” used as a fixed end point of sensation to put judgments of different subjects on a common sensory ruler (Green et al., 1996; Jaeger & Cardello, 2009). Using the same concept of LMS, Schutz and Cardello (2001) developed a LAM scale for assessing food liking. The scale was constructed by asking subjects to give modulus free magnitude estimates of word phrases that express the feelings of like and dislike existing in the nine point hedonic scale plus the phrases “greatest imaginable liking” and “greatest imaginable disliking”. The algorithm applied to construct the LAM scale is shown in Figure 3 (Guest, Essick, Patel, Prajapati, & McGlone, 2007).

[Insert Figure 3 about here]

The LAM scale has been used as an efficient method for evaluation of food likes and dislikes. Many published studies are found in the literature, e.g. consumer liking for orange juice (Forde & Delahunty, 2004) and tea (Chung & Vickers, 2007), emotional responses to twelve comfort foods (Cardello et al., 2012), sweet taste perception (Keskitalo et al., 2007; Tuorila, Keskitalo-Vuokko, Perola, Spector, & Kaprio, 2017), preference for salt in a food (Bobowski, Rendahl, & Vickers, 2015) and people’s liking for chocolate pudding (Laureati et al., 2018).

2.2. Fuzzy Linguistic Approach

People prefer words in natural language instead of numerical values when qualifying things related to human perceptions. For example, linguistic terms such as very good, poor or very poor are used when evaluating the comfort level of a product. Here, comfort is a linguistic variable whose values are not numbers but linguistic terms in natural language. A fuzzy set (FS) is commonly used to characterize the values of a linguistic variable (Herrera & Herrera-Viedma, 2000). FS is a concept that extends the notation of a classical set by assigning to each element of a set a value representing its degree of membership in [0,1] (Zadeh, 1965). For example, assume that age is described as a linguistic variable, and middle aged is one of its values. Figure 4 shows both a classical (crisp) set and a fuzzy set for middle aged. The vertical axis, called membership degree (belongingness), defines to what extent an age value is considered as middle aged. In a classical set, membership degree can only take values of 0 (nonmembership) or 1 (membership), and so a person belongs to the middle aged set only if s/he is between 40 and 50. This approach, however, might not reflect the reality because a person with an age of 53 can also be regarded as middle aged to some extent.

[Insert Figure 4 about here]

A FS is achieved if the strict constraint on membership degree in a classical set is replaced with partial membership degree in a unit interval [0,1]. In FS, an age of 53 now belongs to the middle aged set with a degree of 0.75. In this way, FS provides a flexible way to mathematically define the vagueness in the meaning of linguistic concepts. Formally, A FS is described by a membership function (MF) mapping the elements of a universe X to the unit interval $[0, 1]$: $A: X \rightarrow [0,1]$. It can also be viewed as a set of ordered pairs of the form $A = \{(x, \mu_A(x)) \mid \forall \in X, \mu_A(x) \in [0,1]\}$, where x is an element of X and $\mu_A(x)$ denotes its corresponding degree of membership in [0,1] (Pedrycz & Gomide, 2007).

FSs prevent the problems that occur when the linguistic terms are defined on a typical ordinal scale in which linguistic terms are directly assigned to the numeric values that are equally spaced (Brouwer, 2006). In an ordinal scale (Figure 5), the real difference between the linguistic terms is not known, although we assume that they are equally spaced to satisfy some assumptions required by statistical methods. Furthermore, as mentioned before, an object may be characterized by more than one linguistic terms but different degrees. This is possible with the FS approach but not with an ordinal scale approach. Actually, an ordinal scale is a type of simple FS, named as a singleton FS, that has nonzero membership value for only one element of the set (Figure 5). As a result, a FS is a more powerful approach than an ordinal scale to model linguistic terms.

[Insert Figure 5 about here]

The process of representing a linguistic variable as a set of FSs is called fuzzy quantification. There are two important stages in this process. First is the identification of cardinality of fuzzy sets (i.e. linguistic terms) used to express a linguistic variable. Psychological findings reported by Miller (1956) demonstrate that human beings can reasonably manage to bear in mind 7 ± 2 items due to the limited capacity of short-term memory. This implies that the number of fuzzy sets for a linguistic variable should be restricted to the same level. Second is the construction (elicitation) of a MF which must adequately capture the meaning of the linguistic term. Linguistic terms are not only vague, but their meanings are also context dependent, and therefore require some calibration or refinement (Klir & Yuan, 1995). For example, the concepts of young and old change when applied to different animal species. There are six methods for the experimental construction of MFs: polling; direct rating (point estimation); reverse rating; interval estimation; membership function exemplification; and pair wise comparison (Bilgiç & Türkşen, 2008; Türkşen, 2006). In the polling method, the answers are polled and an average is taken to acquire membership degree after which a yes/no question “Do you agree that the age of 53 is considered as middle aged?” is asked to different persons. The fuzziness here arises from inter-uncertainty which is the uncertainty that a group of people have about a linguistic term. In direct rating, a person is required to give a membership grade $\mu_{\text{middle aged}}(53)$ to age of 53 repeatedly at different times, according to his or her opinion. The fuzziness here arises from intra-uncertainty which is the uncertainty a person has about a linguistic term. In the reverse rating, the person defines an object for the given membership degree. This method is used to confirm the membership degree defined previously. In the interval estimation method, individuals define a value in the form of intervals for the given linguistic term. The degree of membership of an object is determined by the proportion of the intervals that contain the value of the given object to the number of intervals. In this method, similar to the polling method, interpersonal uncertainty is handled. In the membership function exemplification, different objects are ordered from small to large and each object is marked with an ordinal number. People are asked to write numbers for the words "small", "large", and "very large". Membership degrees are determined by the proportion of how many intervals contain the value of the given object to the number of intervals. In the pair wise comparison, the degree of belonging of two different objects (e.g., eagle and penguin) to a set (e.g., bird set) is compared. The question of which one is a better example of bird is asked and the membership degree is determined accordingly. When the literature is reviewed, it is seen that explained methods are mostly used to construct membership function.

Ordinary FSs (hereafter called type-1 fuzzy set (T1FS)) constructed by these ways however do not handle both inter-uncertainty and intra-uncertainty. It is argued that "words mean different things to different people" and a better way to handle both uncertainties is the usage of Type-2 Fuzzy Sets (T2FS) (Mendel, 2001). This discussion was also underlined by Klir and Yuan (1995), Türkşen (2006) and Pedrycz (2008). A T2FS in X is $\tilde{A}$, and the membership degree of $x \in X$ in $\tilde{A}$ is $\mu_{\tilde{A}}(x)$ which is a T1FS in $[0, 1]$ (Zadeh, 1975). The elements of domain of $\mu_{\tilde{A}}(x)$ are called primary memberships of x in $\tilde{A}$ and the memberships of the primary memberships in $\mu_{\tilde{A}}(x)$ are called secondary memberships of x in $\tilde{A}$. Unlike an T1FS whose MF is a crisp number in [0,1], a T2FS has grades of MF that are themselves fuzzy (Dubois & Prade, 1980; Mendel, 2007a). T2FSs are useful in circumstances where it is difficult to specify a MF with precision, as when modeling words with a T1FS. A T2FS, $\tilde{A}$, is characterized by a type-2 MF, $\mu_{\tilde{A}}(x,u)$. $\tilde{A} = \left\{ \left((x,u), \mu_{\tilde{A}}(x,u) \right) \mid \forall\, x \in X, \forall\, u \in J_x \subseteq [0,\ 1] \right\}$ where $0 \le \mu_{\tilde{A}}(x,u) \le 1$. $\tilde{A}$ can also be expressed as $\tilde{A} = \int_{x\in X} \int_{u \in J_x \subseteq [0,1]} \mu_{\tilde{A}}(x,u)/(x,u) = \int_{x \in X} \left[\int_{u \in J_x \subseteq [0,1]} f_x(u)/u \right] / x$ where the double integral denotes over all admissible x and u. The primary variable is x with domain X; J_x is denoted as the primary membership of x; u the secondary variable with domain J_x at each $x \in X$; $\int_{u \in J_x \subseteq [0,1]} f_x(u)/u$ is the secondary MF at x, and $f_x(u)$ is the amplitude of the secondary MF called secondary grade. Figure 6b shows a type-2 fuzzy MF that is derived by blurring the type-1 MF illustrated in Figure 6a by shifting the points on the triangle either to the left or to the right, but not necessarily by equal amounts as in Figure 6b.

[Insert Figure 6 about here]

Interval Type-2 Fuzzy Set (IT2FS), a particular case of T2FS, is obtained when all secondary grades, i.e., $f_x(u)$, are one. Figure 7 shows an IT2FS. As, $f_x(u) = 1 \quad \forall x \in X$, an IT2FS can again be shown in two dimensions. Uncertainty about IT2FS is conveyed by the union of all the primary memberships (i.e., shaded region in Figure 7) which is called the footprint of uncertainty (FOU). It is bounded by an upper MF (UMF) denoted $\bar{\mu}_{\tilde{A}}(x)$ and a lower MF (LMF) denoted $\underline{\mu}_{\tilde{A}}(x)$ both of which are T1FSs; consequently, the membership grade of each element of an IT2FS is an interval $[\underline{\mu}_{\tilde{A}}(x), \bar{\mu}_{\tilde{A}}(x)]$. An IT2FS can therefore be represented as $\tilde{A} = 1/FOU(\tilde{A})$.

[Insert Figure 7 about here]

To characterize the linguistic terms as IT2FS, Liu and Mendel (2008) proposed the interval approach to capture the strong points of the earlier two approaches, i.e., the person MF and the interval end-points (Mendel, 2007b). In the interval approach, data intervals about a vocabulary of words are obtained from a group of persons by asking them to locate the end-points of an interval on a scale of 0-10 that they associate with the word. Then, each subject's data interval is mapped into a T1FS, after which the union of all of these T1FS is taken to obtain FOUs which completely describe a IT2FS (see Liu and Mendel (2008) for more information about computation). The centroid of an IT2FS is an interval set computed by Karnik-Mendel iterative algorithms (Karnik & Mendel, 2001). A crisp output can also be calculated by taking the average of endpoints of the interval.

Many researchers have developed scales based on fuzzy sets theory and these scales have been implemented in various fields, e.g., service industry (C.-C. Chou, Liu, Huang, Yih, & Han, 2011; Hu, Lee, & Yen, 2010), medical science (Li, 2013; Navarro, Wagner, Aickelin, Green, & Ashford, 2016), investment decisions (Massanet, Riera, Torrens, & Herrera-Viedma, 2014), education system (Gil, Lubiano, de la Rosa de Sáa, & Sinova, 2015; Guajardo, Lopez, & Ruiz, 2015; Lubiano, de Saa, Montenegro, Sinova, & Gil, 2016; Lubiano, Salas, De Sáa, Montenegro, & Gil, 2017), and public administration (Marasini, Quatto, & Ripamonti, 2016). Fuzzy sets theory also has been used effectively in a great variety of field for modeling humans' feeling of words for product design (De La Rosa De Sáa et al., 2015; Shimizu & Jindo, 1995). Examples of products for which studies have measured customer preferences using fuzzy logic-based methods include cars and pizzas (Türkşen & Willson, 1994), weapon systems (C.-H. Cheng & Mon, 1994; C. H. Cheng & Lin, 2002), office chairs (J. Park & Han, 2004), mobile phones (Lin, Lai, & Yeh, 2007), USB flash drives (J. R. Chou, 2016), packaging design of gin bottles (Quirós, Alonso, & Pancho, 2016), and snack foods (Solanke, Jaybhaye, & Jadhav, 2018).

3. EXPERIMENTS

In this section, two different sensory scales are developed for four tactile feelings and these scales are compared statistically. The measurements obtained are compared to those using SDS. For this purpose, two different experiments were carried out to develop fuzzy linguistic and LAM scales. The general procedures for the experiments are detailed in this section.

Thirty eight participants who were balanced in terms of age and gender and responded to posters and e-mails inviting volunteers, participated in the experiment. The participants consisted of university students and they were aged between 18 to 30. Ten pounds was paid to each participant to compansate them for their involvement. In each experiment, assessments are made by 38 people for 11 adjective pairs and thus 418 trial numbers are obtained. Since this number remains above 400, which is specified as the reasonable trial number by Kingdom and Prins (2016), sufficient number of trials is reached to conduct the experiments.

Thirty-seven materials with different textures were used as stimuli (Figure 8). The stimuli can be grouped into three categories: 1) Stimuli 1–22 were cardboards; 2) 23–31 were papers and foils; and 3) stimuli 32–37 were laminate boards. The cardboards, papers, and foils were packaging materials used for confectionery items. The laminate boards were samples of materials typically used for making office furniture and were included to increase the variety of textures. As a result, the thirty seven stimuli covered a variety of textures with different physical properties, such as roughness, hardness, and thermal conductivity. The stimuli were cut into 10 cm × 8 cm rectangles and were numbered for identification.

[Insert Figure 8 about here]

The tactile properties of the stimuli were rated by participants against four pairs of adjectives. The adjective pairs were "sticky–slippery", "soft–hard", "smooth–rough," and "warm–cold". These adjectives were used because they are often used in affective engineering experiments concerning touch in a variety of contexts.

Before starting the experiment, the purpose and procedures of the experiment were explained to the participants and they were informed of the definition of each adjective pair. In each adjective word pair, it is assumed that the first adjective expresses a positive feeling and second adjective a negative feeling. Participants were trained and instructed to evaluate each feeling separately because participants should evaluate one feeling at a time. In this context, before starting assessment, for each tactile feeling, several stimuli which have different physical characteristics were provided to help participants become familiar with the concepts (smooth–rough, warm–cold, sticky–slippery, soft–hard) and to reduce the halo effect.

In the experiments, eleven semantic phrases were used to describe different levels of each of the tactile senses. The semantic phrases for smooth–rough were: *"smoothest imaginable, extremely smooth, very smooth, moderately smooth, slightly smooth, neither smooth nor rough (or neutral), slightly rough, moderately rough, very rough, extremely rough, roughest imaginable"*. Similar phrases were used for warm–cold, sticky–slippery and soft–hard.

The stimuli were presented to the participants in boxes so that they could not be seen. One side of each box was kept open and was covered with a small white curtain to prevent sight of the stimuli while still allowing participants to touch them. Each participant was asked to place his or her hands into the box under the white curtain and touch one texture at a time. The stimuli were presented in a random order. Participants were allowed to use active dynamic touch to explore the surface of each texture. No restrictions were given as to which hand or parts of the hand could be used or for how long the stimuli could be inspected.

Participants are randomly divided into two groups, and two sessions are organized. The experiment process is detailed in Table 1.

[Insert Table 1 about here]

3.1. Experiment 1

The purpose of the first experiment was to construct fuzzy linguistic scales for four tactile feelings. The methodology used to construct the scales is IT2FS. In the experiment, the semantic phrases for tactile senses were placed in a circle in a random order and presented to the participants for assessment. These semantic phrases are intended to measure subjective feeling (e.g., smooth-rough) to tactile textures when touching them. Participants were asked to look at the semantic phrases carefully and to define each phrase as an interval or range that falls somewhere between 0 to 100. That is, it was desired to tell where the interval for each semantic phrase would start and where it would stop with a scale of 0-100. For example, very smooth [65 - 84] or slightly rough [40 - 46]. In the scale, 0 means something which is rough while 100 means that it is smooth. It is important to note that not all the ranges for the semantic phrases are the same size. Also, ranges are allowed to overlap. There is no right or wrong answer; participants were asked to give only their personal thoughts. Because the aim of the experiment was to measure the immediate response of the participants against the semantic phrase, participants were asked to evaluate each semantic phrase separately and not to look back at their previous answers.

Eleven phrases were presented one at a time in random order during the experiment and participants were asked to fill the space for the written phrase (e.g., *extremely smooth* [,]). All phrases were presented on separate pages along with space for written interval ranges, and presented randomly to reduce presentation order and carry over effect. The order of ratings for the four tactile feelings was also random.

After collecting a set of intervals from the experiment, IT2FS are estimated using the interval approach that takes into account the collective uncertainty of participants. This type of uncertainty is considered as inter-personal disagreement. In order to create fuzzy sets from the data, the interval approach was implemented in two steps, the data part and the fuzzy set part. The data part consisted of the steps of surveying, data preprocessing and computation of statistics. In the fuzzy set part, embedded T1FS were created, and then IT2FS were formed by aggregating T1FS with the union operation. Each of the phrase's FOUs was obtained independently of the others. The FOUs that were calculated for the semantic phrases can be seen in Figure 9.

[Insert Figure 9 about here]

After the FOUs of the phrases were formed, the type reduction process was performed using the center of sets method, and then the type reduced sets were defuzzified to get a crisp output from the IT2FS. The computed centroids reflect the position of the phrases on the fuzzy linguistic scale. The constructed fuzzy linguistic scales are shown in Figure 10. A code in MATLAB was used to construct IT2FS using interval approach of Liu and Mendel (2008).

[Insert Figure 10 about here]

3.2. Experiment 2

The aim of the second experiment was to construct LAM scales for four tactile feelings. The methodology used to construct the scales was modulus free magnitude estimation. Making practice trials on using magnitude estimation is important if the participant does not have any experience about magnitude estimation procedure. Only participants who can respond in a reasonable manner during the practice trials are allowed to continue to the test. A written instruction about the procedure was presented. The details of the procedure were also explained by investigators to each participant and all participants were allowed to ask questions before starting the experiment.

This experiment aimed to obtain participants' opinion about the meaning of different phrases that are commonly used to describe one's feelings for tactile textures. In order to obtain participants' opinions about these phrases, a method that allows participants to indicate the magnitude of feeling associated with each phrase by assigning numbers to them was used. The participant was asked to write a number (greater than zero, including non-integers) for the first phrase. Participants were advised not to use a very small number for the first phrase. The reason for this is that the subsequent phrase may reflect much lower levels of feeling. Aside from this restriction, the participants were able to use any number they wanted.

The important point in this experiment is that participants' numerical judgment should be made proportionally (in a ratio manner) to the first phrase for each subsequent phrase. That is, if a participant assigned the number 800 to index the strength of feeling denoted by the first phrase and the strength of feeling denoted by the second phrase is twice as great, the participant would assign it the number 1600. If it were three times as great, the participant would assign it the number 2400. Similarly, if the second phrase denoted only 1/10 the magnitude of feeling as the first, the participant would assign it the number 80, and so forth. There is no need to spend a lot of thought on making precise ratings.

The important matter is that each evaluation should be made in comparison with the initial phrase. Upon completion of this procedure, the participants were allowed to check on the ratings they had made to the phrases, and then adjust the ratings that they felt were not optimal. Similar to Experiment 1, all phrases were presented on separate pages along with space for numbers that reflect the magnitude of feeling associated with the phrase, and were presented randomly to reduce presentation order and carry over effect.

After collecting a set of magnitude estimates from the experiment, the geometric means that were used to construct LAM scales were computed for positive and negative semantic phrases separately and then both positive and negative phrases are combined to locate them in a vertical line scale. A code in MATLAB was developed to construct the LAM scales. The constructed LAM scales are shown in Figure 11.

[Insert Figure 11 about here]

4. RESULTS AND DISCUSSION

In this section, the scales developed are compared with the SDS, which is frequently used for evaluating products as mentioned in Section 2. The Wilcoxon Signed Rank Test was applied for the comparison of the scales. SPSS software was used to conduct statistical analysis. In Figure 12, the eleven point SDS scale is positioned to be best fit (diagonal dashed line) and deviations of the constructed fuzzy linguistic scales from SDS are shown. Inspection of the figure suggests that the rank order of the semantic phrases, based on the ratings, happen as expected given their generally accepted meanings. Also, it is observed that locations of semantic phrases of the fuzzy linguistic scales for the four adjective pairs have very similar positioning to the eleven point SDS. Wilcoxon Signed Rank Test statistics are evidence of this appearance. The results show that there is no significant difference between the scales in terms of locations of semantic labels ($p=.722$ for soft-hard, $p=.824$ for smooth-rough, $p=.919$ for sticky-slippery and $p=.168$ for warm-cold) at the 0.05 significance level (Table 2).

[Insert Figure 12 about here]

[Insert Table 2 about here]

This result implies that the linguistic label corresponding to the emotional feeling of a person about a product does not change sharply between the scales. Although the location of the sematic phrases is similar, these new fuzzy linguistic scales have provided interval data and overcome the lost information problem arising from the ordinal nature of the SDS. In addition, calculating the centroids of each fuzzy set related to semantic phrases and then locating them in a vertical line provides convenience to the user. With all these advantages, the constructed fuzzy linguistic scales can be used as a scale that produces interval data for product evaluation.

In Figure 13, eleven point SDS and constructed LAM scales are compared. Differences are observed between the scales, especially in positive phrases. This is due to the respondents evaluating the positive phrases at lower degrees when assigning them magnitude estimates. In fact, the scale's power to reflect human feelings comes from these differences. In addition, the Wilcoxon Signed Rank Test statistics provides a holistic view to compare scales. The results indicate that there is significant difference ($p=.012$ for soft-hard, $p=.012$ for smooth-rough, $p=.017$ for sticky-slippery and $p=.012$ for warm-cold) between the scales (Table 3). According to test results new constructed LAM scales are valid alternatives to SDS for measuring to tactile feelings by means of yield ratio data. Consequently, the use of parametric statistics can be justified on these data, and enable researchers flexibility to interpret ratings. The conceptual benefits of LAM and fuzzy linguistic scales might, however, require researchers to have specialist expertise in affective computing, whereas use of SDS only requires knowledge of basic statistics.

[Insert Figure 13 about here]

[Insert Table 3 about here]

The scales developed for the present work are particular to touch perception and provide a measurement tool to reveal the relationships between affective responses and a surface's topographical and material properties (Chen, Barnes, Childs, Henson & Shao, 2009). There is also great possibility to design new tactile products with controlled material properties satisfying certain affective needs (Elkharraz,Thumfart, Akay, Eitzinger, & Henson, 2014) that will ultimately improve product ergonomics.

While the findings of this work are significant, there were some noted limitations: First, although the scales are reliable in terms of number of subjects, the same may not be correct for the stimuli selected. Experiments can be repeated on a wider range of stimuli since the existing ones have been selected only from packaging materials. Second, the scales are not general and should be developed specifically for related affective needs other than touch perception that will lead to additional time and cost.

5. CONCLUSION

Product design researchers commonly use a number of scales to measure subjective feelings about products. The scales used in affective design yield different data characteristics. When analyzing these data, it is necessary to apply appropriate statistical procedures in accordance with the characteristics of the data. Parametric analysis is carried out by the researchers with the data obtained from the scales providing ordinal data. However, this approach is not considered as convenient because ordinal scales, such as SDS, suffer from problems related to unequal scale intervals in perception and frequently fail to satisfy assumptions required by parametric statistical analysis. For this reason, scales are required that produce ratio or at least interval data to overcome the lost information problem arising from ordinal scales.

In this paper, we have developed a fuzzy linguistic scale and LAM scale for four tactile feelings. For this purpose, two experiments were conducted and participants touched the various stimuli unseen and rated them against the adjective pairs “sticky–slippery”, “soft–hard”, “smooth–rough” and “warm–cold” by using semantic phrases that describe different levels of each of the tactile senses. After collecting a set of intervals and magnitude estimates from the experiments, respectively, a fuzzy linguistic scale was constructed based on the interval approach and a LAM scale was constructed based on modulus free magnitude estimation by locating semantic phrases along a visual analogue scale in compliance with their determined semantic meaning. The constructed scales were pairwisely compared with the SDS by applying the Wilcoxon Signed Rank Test. The test results showed that there is no significant difference between the new constructed fuzzy scale and eleven point SDS, whereas there is significant difference between the new constructed LAM scale and eleven point SDS. Although the SDS and fuzzy linguistic scale for four adjective pairs have similar appearance, a major presumed advantage of constructed scale is the ability to produce interval data for product designers. On the other hand, differences are observed between the location of the sematic phrases on SDS and LAM scale, and the test results prove this appearance. Moreover, the LAM scale produces data with ratio characteristics that enables the use of parametric analysis.

There are many studies that apply fuzzy linguistic approach and LAM scales to measure sensory perceptions about a product. However, few of these studies have been concentrated on touch perception which is a critical concept for affective engineering. The major contribution of this study lies in a successful exploration in bridging the fuzzy sets theory and magnitude estimation with measurement of touch perception.

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Figure Legend

Figure 1 Affective design process.

Figure 2 The semantic differential scale for hard-soft bipolar adjectives.

Figure 3 LAM scale construction algorithm.

Figure 4 Middle aged defined as a classical set (left) and a fuzzy set (right).

Figure 5 Representation of linguistic terms: ordinal scale (left), singleton fuzzy sets (upper right) and fuzzy sets (lower right).

Figure 6 (a) Type-1 membership function; (b) type-2 membership function

Figure 7 FOU (shaded area), UMF (solid line) and LMF (dashed line) for IT2FS.

Figure 8 Stimuli.

Figure 9 FOUs of all 11 semantic phrases for 4 adjective pairs.

Figure 10 Fuzzy linguistic scales of semantic phrases for touch feelings.

Figure 11 LAM scales of semantic phrases for touch feelings

Figure 12 Comparison of fuzzy linguistic scale and 11 point SDS.

Figure 13 Comparison of LAM scale and 11 point SDS.

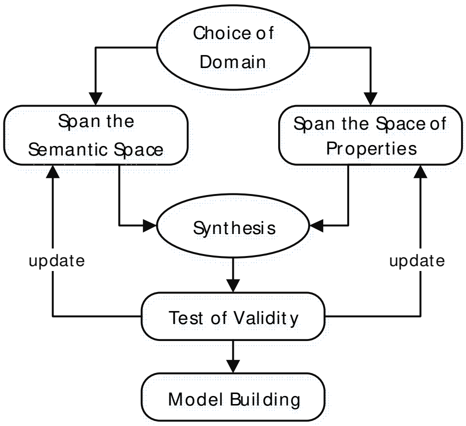


Figure 1 Affective design process.

hard _____ : _____ : _____ : _____ : _____ : _____ : _____ soft

Figure 2 The semantic differential scale for hard-soft bipolar adjectives.

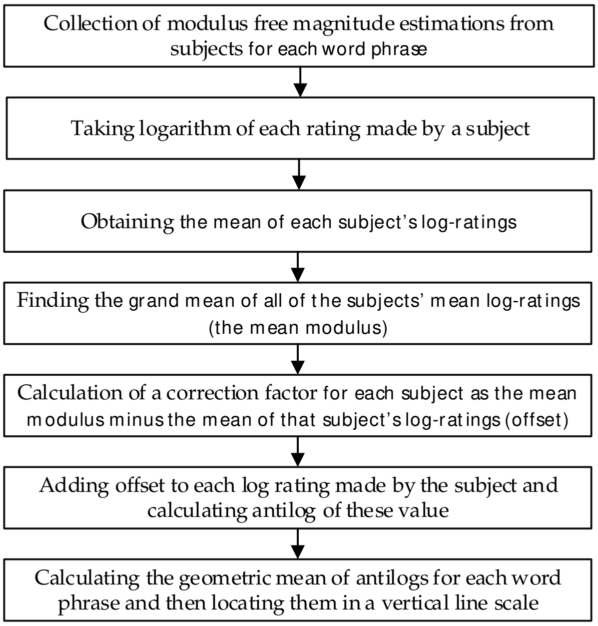


Figure 3 LAM scale construction algorithm.

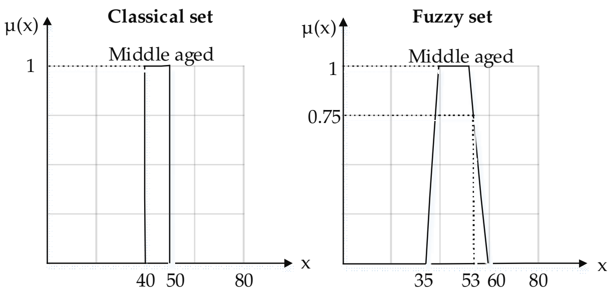


Figure 4 Middle aged defined as a classical set (left) and a fuzzy set (right).

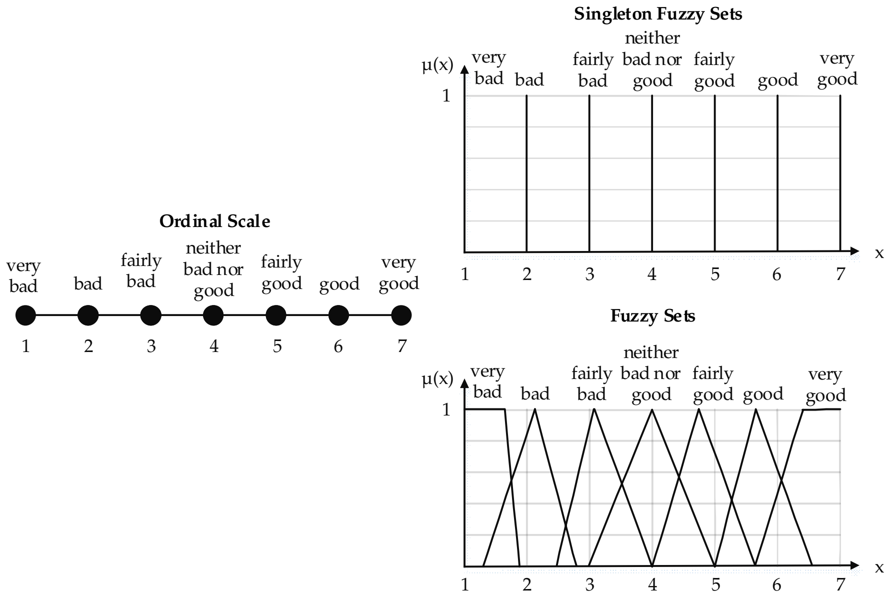


Figure 5 Representation of linguistic terms: ordinal scale (left), singleton fuzzy sets (upper right) and fuzzy sets (lower right).

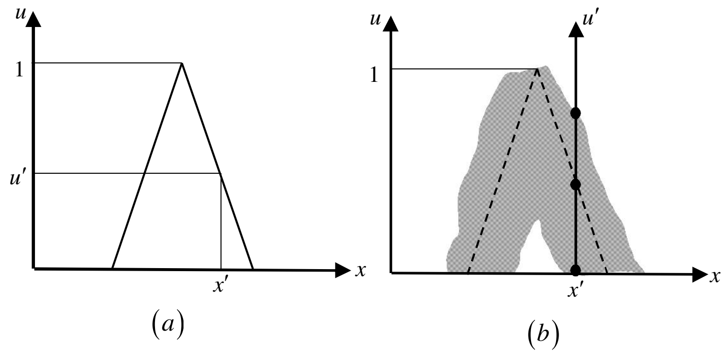


Figure 6 (a) Type-1 membership function; (b) type-2 membership function.

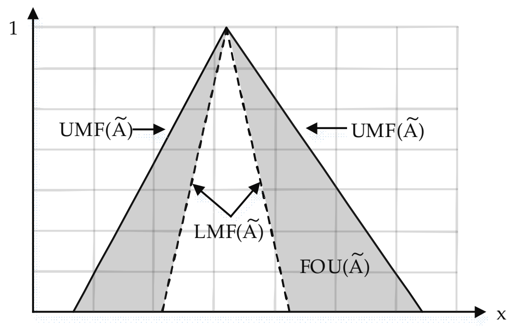


Figure 7 FOU (shaded area), UMF (solid line) and LMF (dashed line) for IT2FS.

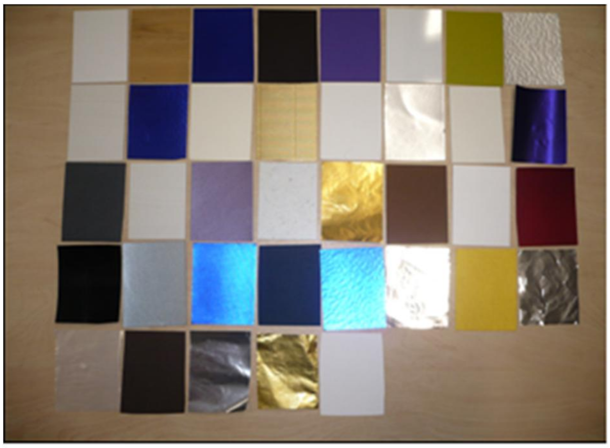
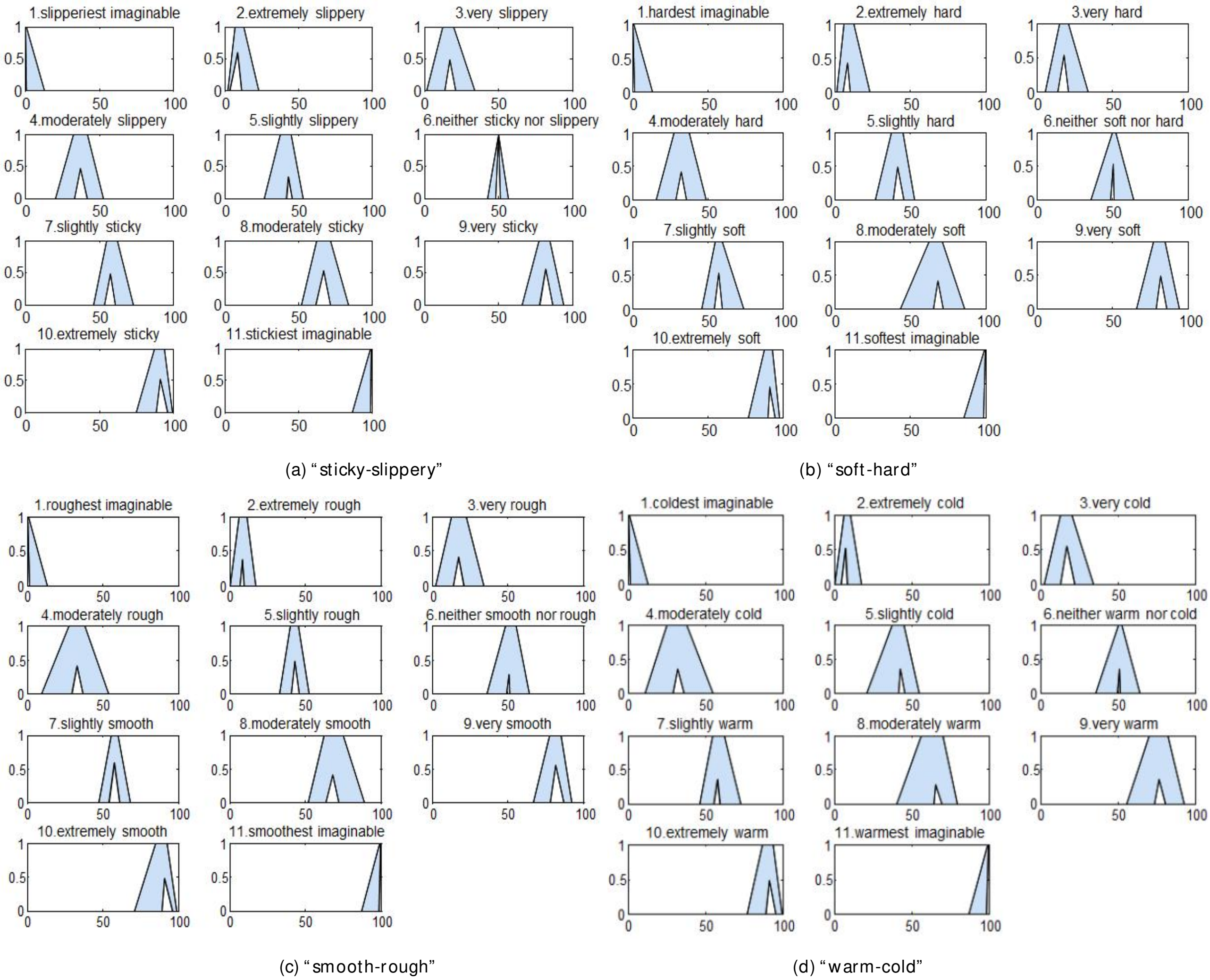


Figure 8 Stimuli.



(a) “sticky-slippery” (b) “soft-hard”

(c) “smooth-rough” (d) “warm-cold”

Figure 9 FOUs of all 11 semantic phrases for 4 adjective pairs.

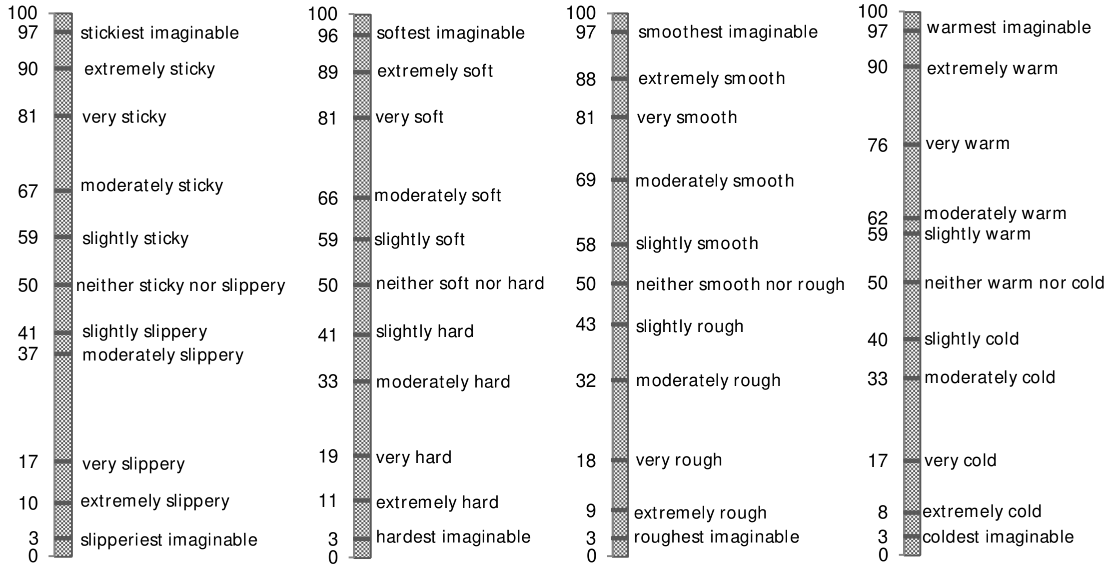


Figure 10 Fuzzy linguistic scales of semantic phrases for touch feelings.

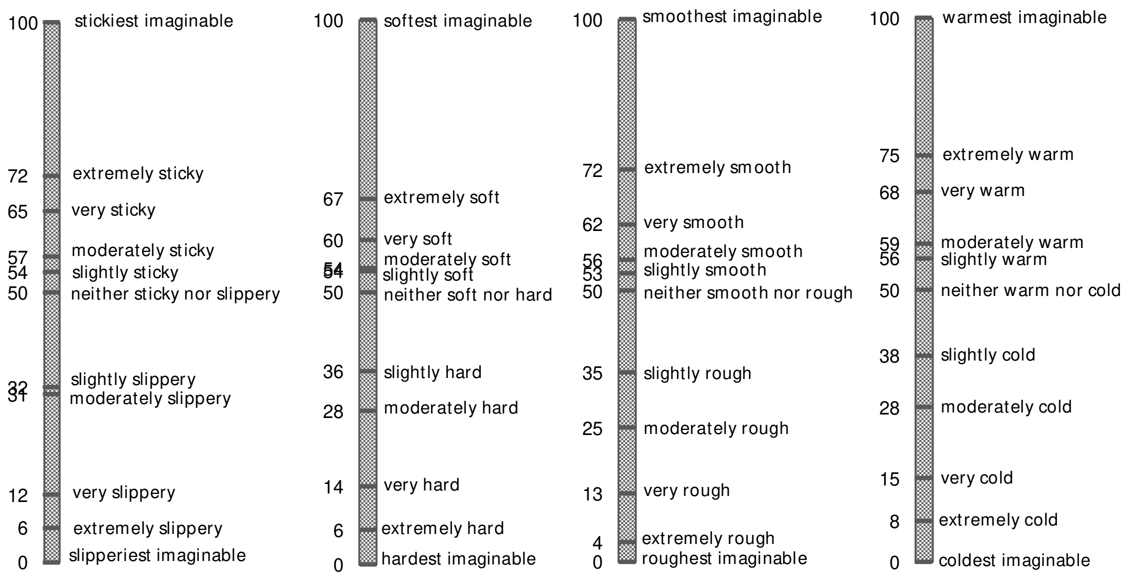


Figure 11 LAM scales of semantic phrases for touch feelings.

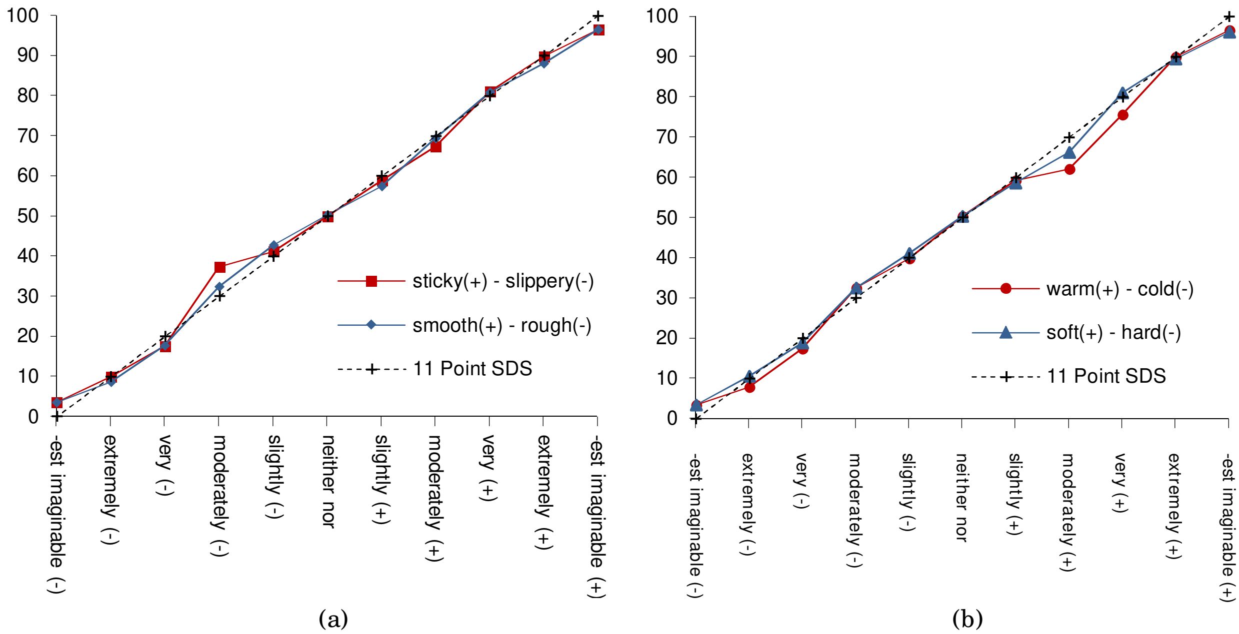


Figure 12 Comparison of fuzzy linguistic scale and 11 point SDS.

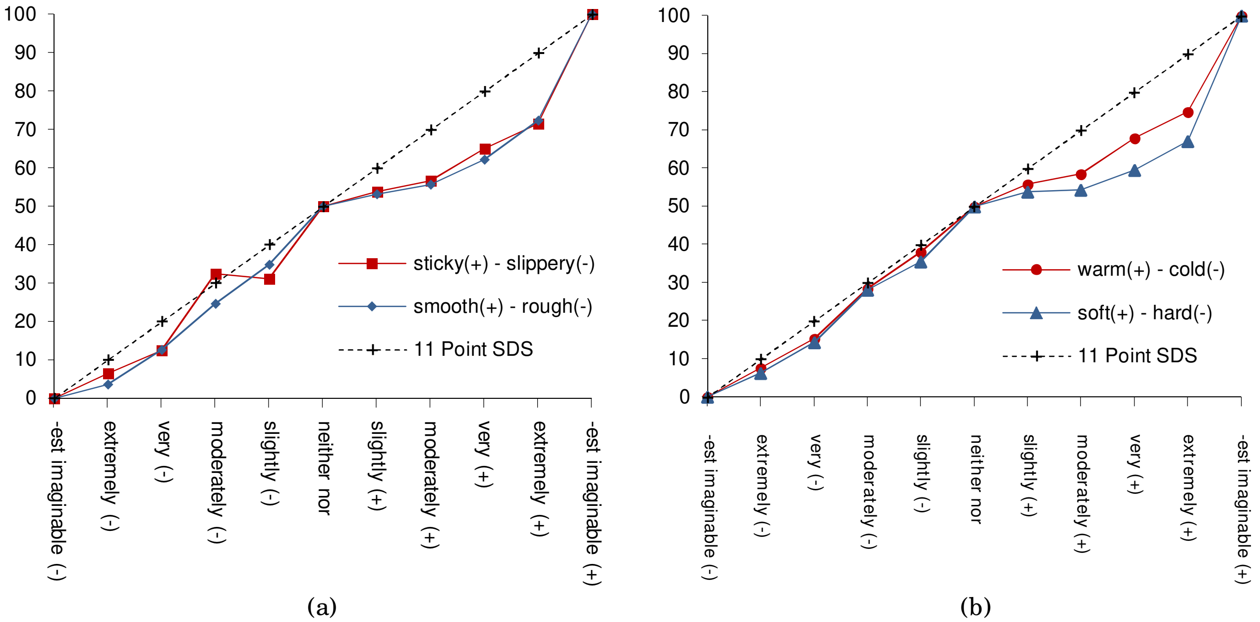


Figure 13 Comparison of LAM scale and 11 point SDS.

TABLE 1. Experiment Process

	Session 1	Session 2
1st Group	Experiment 1	Experiment 2
2nd Group	Experiment 2	Experiment 1

TABLE 2

The Results of Wilcoxon Signed Rank Test to Compare Fuzzy Linguistic Scale and 11 Point SDS

	Soft Hard	Smooth Rough	Sticky Slippery	Warm Cold
Z	-.356[a]	-.222[a]	-.102[a]	-1.379[a]
Asymp. Sig. (2-tailed)	.722	.824	.919	.168

[a] *Based on positive ranks*

TABLE 3

The Results of Wilcoxon Signed Rank Test to Compare LAM Scale and 11 Point SDS

	Soft Hard	Smooth Rough	Stick Slippery	Warm Cold
Z	-2.521[a]	-2.521[a]	-2.380[a]	-2.521[a]
Asymp. Sig. (2-tailed)	.012	.012	.017	.012

[a] *Based on positive ranks*