# An investigation into the sensory properties of materials

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**Abstract**
An initial matrix of material representation was established for studying human perception and response to different materials. A conceptual discrimination was clarified between texture and texture perception. Analysis of the preliminary results from the psychological tests have enabled four character dimensions of texture description to be proposed: geometrical dimension; physical-chemical dimension; emotional dimension; and associative dimension. Lexicons within these dimensions were found to be slightly different in responsive sensitiveness under different conditions (material surface finish, sensory conditions, subject groups etc.). A comparison was made between visual touch and blindfold touch. With the proposed dimension-lexicon system, people could subjectively describe the material texture in a common way.

*keywords* materials, sensory perception, tactual texture, product design

## 1. Introduction

Our physiological, psychological and cultural responses and expectation are key elements of the way we perceive the products we see and use, and should be considered much more in the design strategy for new manufactured products[1]. When consumers are faced with a product for the first time, they will formulate a perception of the product partly based on the materials' sensory properties (colour, texture, sound, smell, taste…). Selecting materials with particular sensory properties will enhance the product's total image and the market's perception of its value. Although industrial product designers are very aware of the importance of material as the medium through which products are interpreted, they do not have an in-depth body of research information to use, about the sensory properties of materials. This investigation is concerned with our perception of the inherent and perceived properties of materials within a holistic environment. This will be referred to as **'material representation'**. It is defined as: **the perceived images, properties, meanings, and values of a material in the human-product interface under a specific set of environmental conditions.** The term emphasises: 1. a human-material dialogue; 2.sensory perception; 3. the environmental context. Information regarding this material representation would be a very important aid in material selection for today's product designer.

This research programme aims to investigate material representation within a framework or matrix (such as the one outlined in Fig.1 below), identify all the elements or variables in the whole matrix, and then carry out an in-depth systematic investigation into the relationships between these elements or variables under controlled experimental conditions (materials as samples) and contextual conditions (materials applied in manufactured products), respectively. The theoretical analysis and the experimental findings will contribute to the development of a new database integrating the research with other evolving new knowledge about the subjective-objective dialogue. This innovative database is expected to make it possible for designers, artists, and engineers (through innovative treatment and application of existing and emerging materials) to be able to create artefacts more effectively, matching human perceptual, sensory and emotional expectation.

This paper reports the first-stage results from this research program. Research was focused on tactual texture of materials, being carried out through theoretical, empirical, and controlled experimental methods.

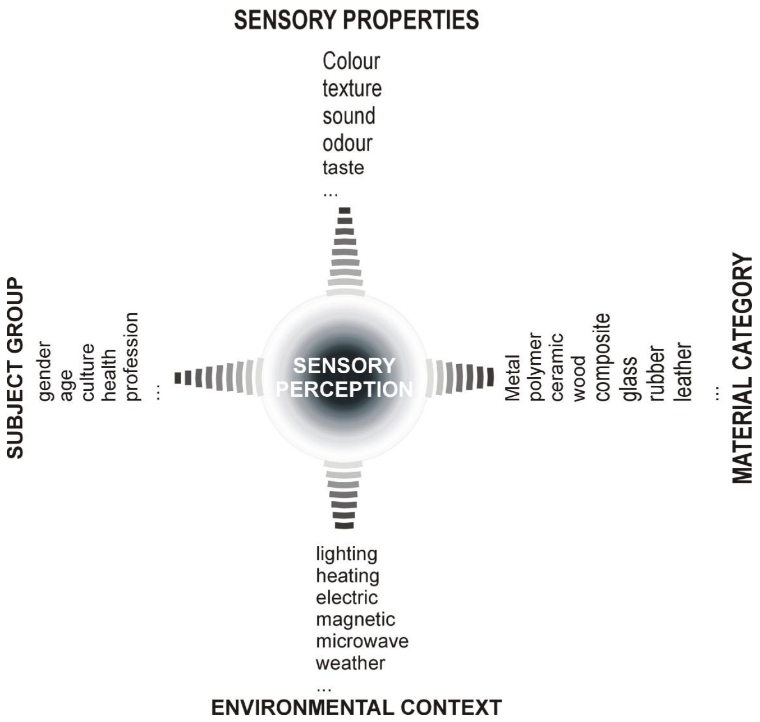



Fig.1 Diagram of materials representation

## 2 Theoretical research on texture

### *2.1 Texture and texture perception*

Originally, the word 'texture' was a textile term, a quality of fabrics appraised and appreciated through the sense of touch. Then gradually the concept was expanded to a wider range from a philosophical and cognitive angle of view, and also was transplanted to a more specific meaning in the materials science and engineering fields.

In the field of materials science and engineering, texture, as a specific term, means **a particular orientation distribution in microstructure**. When a piece of metal is deformed by some directional process such as wire-drawing or rolling, the constituent crystal grains acquire a preferred orientation. This orientation is called texture[2]. The orientation can result in changes of material properties, but because of its micro-scale magnitude (the crystallitic grain size is usually from 1μm to 100μm or even smaller from 1nm to 100nm(nano-materials)), the texture is difficult for a human to perceive directly by sensation. This texture can only be tested and analysed by means of specialist equipment such as an X-ray diffraction device etc. So, essentially, this could be called **micro-texture**.

On the other hand, cognitive scientists have recognised texture as a visual[1] cue[3] that plays a significant role in a variety of cognitive tasks. A common use is in describing and differentiating between different kinds of objects, for example, wallpaper, furniture, carpets, sand, and grass. A working definition of texture in this context is **the surface markings on an object or the 2-D appearance of a surface**[3]. Obviously, here the texture is not micro- but macro- as it can be perceived by sensation.

However, surface markings include something more geometrical like isotropy, roughness etc. and partly physical, e.g. colour. This definition seems suitable for visual texture but not for tactual texture. Tactual texture should go beyond merely surface markings, and should concern other characteristics such as the moisture retention level, thermal conduction, temperature etc.

By integrating the content of tactual texture into visual texture, we propose a definition of texture: **the geometrical configuration and physical-chemical attributes of the surface or the bulk of materials/**

[1] in fact, not only visual but also tactual.

**objects).** In this definition, the content of texture includes two aspects: geometrical configuration – the spatial constructive elements and their shape, size, orientation and distribution which will be perceived as, e.g., *fine, granular, linear, regular* etc.; and physical-chemical attributes – the dynamic characters which need energy exchange (such as mechanical, thermal, optical, etc.) with environment and is time-related, and usually perceived as *warm, cold, hard, soft, shining, moist, sticky*, etc.
We emphasise that it is necessary to discriminate between two concepts. One is **texture**, the other is **perceived texture** or **texture perception**. The former is objective, the latter is subjective. As a comparison, we also propose a definition of perceived texture: **a synthesis of physiological and psychological response and impression to the geometrical configuration and physical-chemical attributes of the surface or the bulk of materials/objects.** In this definition, the 'synthesis' means it is not simply 'A plus B' but 'A fusing with B', therefore the subjective responses to A (geometrical configuration) and B (physical-chemical attributes) would interact. Although under certain conditions (e.g. by vision), the response to geometrical characteristics may be dominant over physical-chemical attributes of texture, or the inverse, under other conditions (e.g., by blindfold touch). What's more, the subjective response will possibly go beyond these two aspects as can be found in the experimental research (section 3).

It is the very understanding of the correlation between the objective texture parameters and the subjective texture perception which will provide the framework for creating suitable, aesthetic material textures.

### *2.2 Subjective description of texture*

In parallel to identifying the geometrical, physical-chemical properties for texture from the objective side, it is also necessary to understand how people subjectively perceive texture.

Researchers have investigated material texture description although the reports have proved to be very limited. Ohno R[4] in his study of visual perception of texture of building materials, used six pairs of adjectives to describe the visual texture of different materials: 1). *rich-poor*; 2). *rough-smooth*; 3). *bright-dark*; 4). *hard-soft*; 5). *heavy-light*; 6). *warm-cold*. Ozawa et al.[5] extracted three dimensions for the identification of visual texture of wood surface under normal lighting conditions (incandescent light 60 lux, fluorescent light 60 lux, and natural light): 1). *comfortable*; 2). *tense/nervous*; 3). *tasty/tastefulness*, while under the condition of strong intensity of lighting (300 lux, 700 lux), the impression of visual texture was dominated mainly by the two dimensions: *comfortable* and *tasty/tastefulness*. Therefore it seems that the dimensions of texture identification tend to be influenced by the environmental context. Tanaka Minami [6], in an experiment of texture evaluation of handmade straw paper, obtained other dimensions for describing the texture of paper. They are: 1). *calm-lively*; 2). *comfortable-uncomfortable;* 3). *warm-cold*. Terauchi Fumio et al[7] in a study of evaluation of a gathered leather seat, extracted five dimensions for constructing the texture evaluation of leather materials. The five dimensions are: 1). *boldness*; 2*). regularity*; 3). *softness*; 4). *elegance*; 5). *tension.*

Aoki H[8] in his early research on material sensory properties, used four dimensions for tactual texture evaluation of several different materials such as aluminium, iron, glass, plastic. The four dimensions are: 1). *warm-cold* (thermal character); 2). *wet-dry* (moist character); 3). *rough-smooth* (surface contour); 4). *loose-dense* (denseness). A fifth dimension, *preference*, was added as a general impression evaluation especially related to materials selection. These dimensions were analysed both for visual tactual and blindfold tactual conditions in Aoki's experiment, but whether there was difference in dimensions under these two conditions was not indicated. In another study [9], Aoki used 25 dimensions for the subjective evaluation of leather texture by vision and by touch. The 25 dimensions are: 1). *isotropic – anisotropic*; 2). *warm – cold*; 3*). with wet absorption – without wet absorption*; 4). *with wet transmission – without wet transmission*; 5). *smooth – rough*; 6). *dense – loose*; 7). *with air transmission – without air transmission*; 8). *glossy – non glossy*; 9). *regular – irregular*; 10). *light – weighty*; 11). *flexible – unflexible;* 12). *elastic – non-elastic*; 13). *good – bad*; 14). *attracting – disgusting*; 15). *applicable – non-applicable*; 16). *good tone – bad tone;* 17). *low lightness – high lightness*; 18). *cold colour – warm colour*; 19). *low colourful – high colourful*; 20). *low compress-resistance – high compress-resistance*; 21). *low compress-recovery – high compress-recovery*; 22). *low bend-resistance – high bend-resistance*; 23). *low bend-recovery – high bend-recovery*; 24). *low extend-resistance – high extend-resistance*; 25). *low extend-recovery – high extend-recovery*.

Generally, it seems that all the above character dimensions (words or word pairs) of texture description are different between researchers and show a lack of a systematic classification. For this purpose, we carried out a preliminary study to identify suitable character dimensions.

## 3 Experimental research

### *3.1 Experiment method*

The controlled experiments were conducted to assess a person's response to different material surfaces. Information was obtained through both visual touch and blindfold touch on the surface of various material samples.

In the experiment, 21 pieces of material in a specific size from four categories (aluminium, plastic, ceramic, rubber) were adopted as samples which were coded as – aluminium: AL1(rolled), AL2, AL3, AL4(sandblasted with different grain size), AL5(mirror-polished), AL8, AL9, AL10(PVD with different-sized patterns); plastic: ABS1~ABS10(moulded with different patterns); ceramic: C1(polished with pattern), C2(natural); rubber: R1, R2, R3(different patterns). 37 Psychology students (average age 24 years) and 24 Design students (average age 21 years) served as participants in the tests. Both the Design and Psychology participants were divided into two groups: one group for visual touch tests, the other for blindfold touch tests. The environmental condition was set as: temperature 20°C; humidity 50%; and under fluorescent light. The material samples were presented to the participants in a random order. Participants were then asked to select words from a vocabulary list or go beyond the list by using more words chosen by themselves to describe the material surface they touched. The vocabulary list (see Table 1) was set up by the authors through unifying all the most common words of texture description used in existing reports of other researchers. Photographs of test participants are shown in Fig.2 and Fig.3.

Table 1 the texture vocabulary list presented to the participants in the test

| |
|---|
| *coarse, fine, smooth, rough, bold, bumpy, plain, isotropic, anisotropic, repetitive, nonrepetitive, linear, radial, regular, irregular, dot-scattered, line-scattered, granular, arbitrary, simple, complex, moist, clammy, dry, arid, warm, cold, dense, loose, hard, soft, light, heavy, clear, vague, dim, bright, dark, shining, glossy, unshining, gloomy, sticky, unsticky, viscoid, non-viscoid, viscoelastic, non-viscoelastic, comfortable, uncomfortable, flabby, tense, nervous, modern, traditional, calm, lively, showy, depressing, dull, cheerful, safe, relaxed, tedious, elegant, ugly, tasteful, tasteless.* |

Fig.2 blindfold touch test

Fig.3 visual touch test

### *3.2 Results and discussion*

#### *3.2.1 Dimensions of texture perception*

By grouping the high-frequency words and combining them into pairs which have bipolar meanings, e.g. *warm – cold*, (except the associative description words), we classified these word pairs, which here we called **lexicons**, into four **dimensions**: geometrical dimension, physical-chemical dimension, emotional dimension, and associative dimension.

§ **Geometrical dimension:** this dimension describes the subjective response to the geometrical configuration of a material surface. High-frequency lexicons used in this dimension include such as: *smooth – rough, fine – coarse, plain – bumpy, regular – irregular, linear – nonlinear,* etc.

§ **Physical-chemical dimension:** this dimension describes the subjective response to the physical and/or chemical attributes of a material surface. High-frequency lexicons used in this dimension include such as: *warm – cold, hard – soft, moist – dry, shining – unshining, sticky – unsticky,* etc.

§ **Emotional dimension:** this dimension describes the hedonic, valuable, affective feelings which are evoked by touching the material surface. High-frequency lexicons in this dimension include such as: *comfortable – uncomfortable, lively/cheerful – dull, elegant – ugly, modern – traditional,* etc.

§ **Associative dimension:** this dimension describes the subjective association from the material, that is: to what existing things in the perceiver's experience can the texture be compared? This description is beyond the description of geometrical and physical-chemical characteristics, and is much more individual-dependent. Therefore the lexicons in this dimension are random, and have low frequency, but they are rich, such as *plastic-like* (the material in fact may not be plastic), *matt-like, rubber-like, treebark-like, animalskin-like, honeycomb-like, dimples-like, ice-like,* …etc.

We obtained a minimum collection of lexicons by looking at where the lexicons intersected in terms of different material categories, different surface finish, different sensory conditions, different subject groups. This minimum lexicon collection – $\{\text{Dimensions-Lexicons}\}_{min}$ – which we called the 'primary' texture lexicons collection was shown in Fig.4. Similarly, by unifying all the lexicons in terms of the above different conditions, a maximum collection of lexicons – $\{\text{Dimensions-Lexicons}\}_{max}$ – which we called 'secondary' texture lexicons collection was obtained and shown in Fig.5.

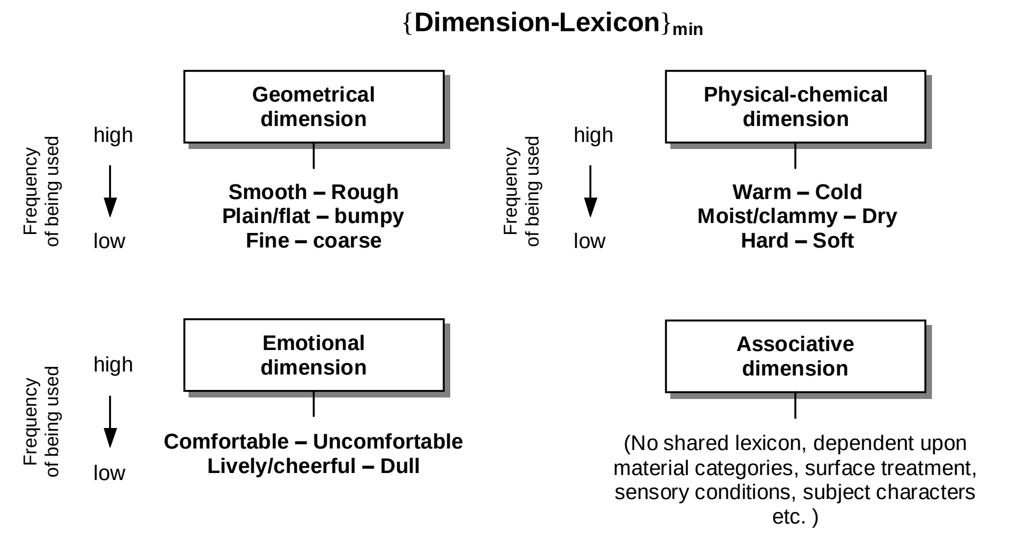



Fig.4 $\{\textbf{Dimension-Lexicon}\}_{\textbf{min}}$ – the primary lexicons collection of material tactual texture

With this Dimension-Lexicon system, the subjective perception of material texture would hopefully be described consistently. Only the detailed lexicons within each dimension tend to be slightly different in the number of lexicons and responsive sensitiveness by subjects under different conditions. We have compared the details between visual touch and blindfold touch.

### *3.2.2 Texture lexicons in terms of sensory conditions*

The lexicons within each dimension in terms of visual touch and blindfold touch was compared in Fig.6
From Fig.6, it can be seen that between visual touch and blindfold touch, the description lexicons within the four dimensions have different coincidence (that is the rate of shared lexicons).

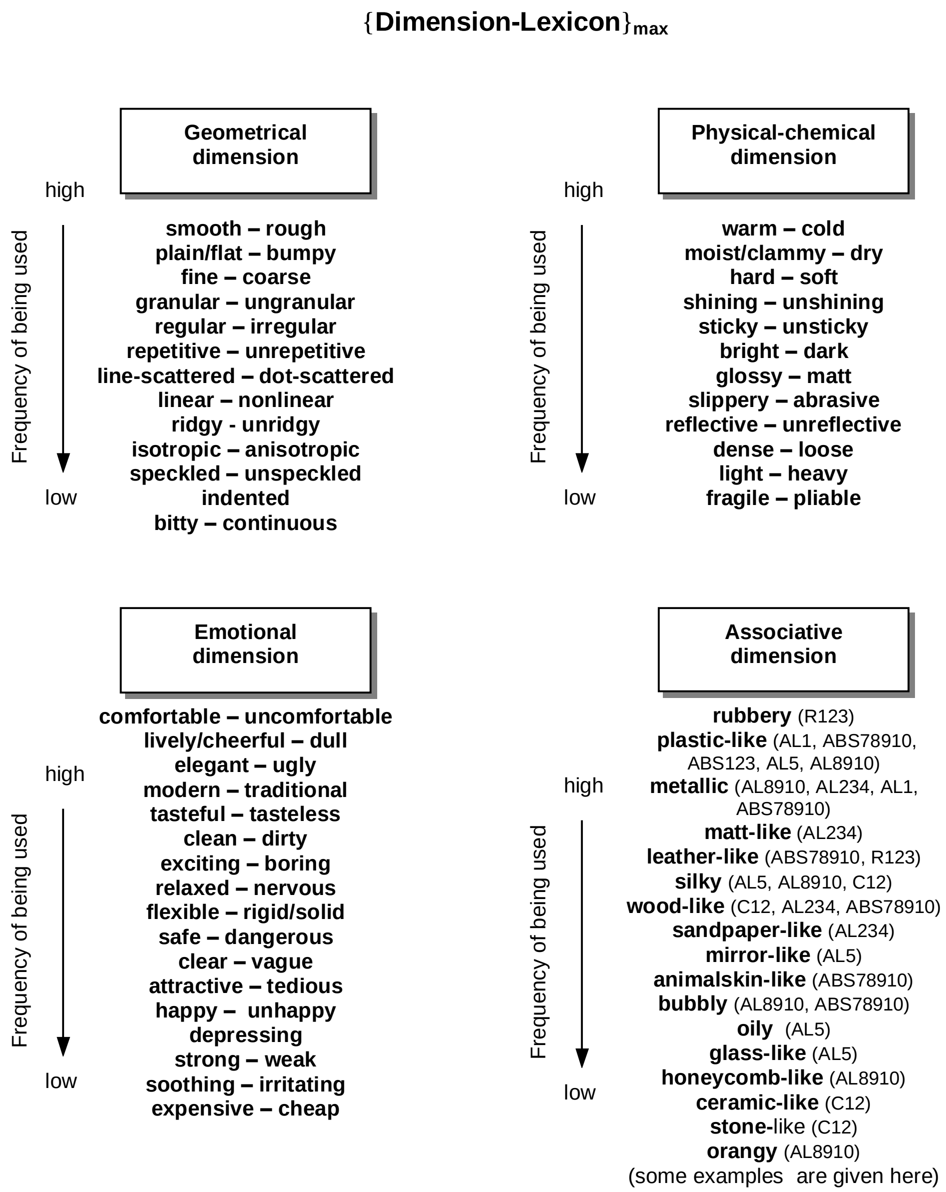
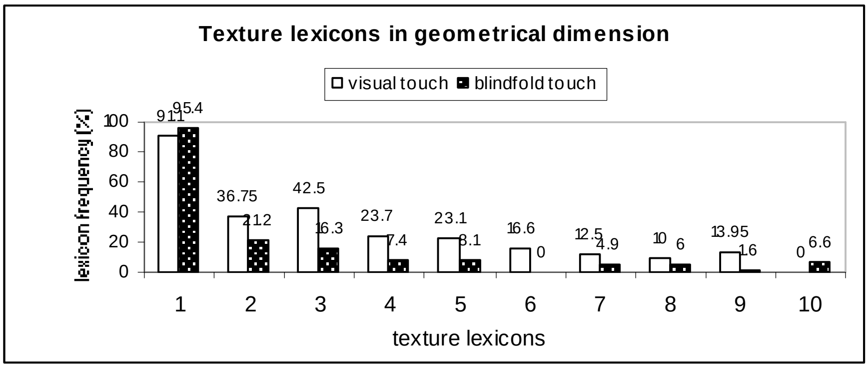



Fig.5 {**Dimension-Lexicon**}$_{max}$ – the secondary lexicons collection of material tactual texture

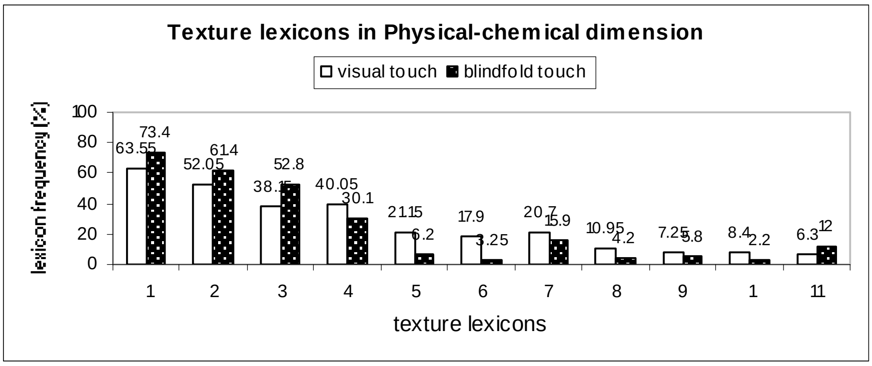
The frequency of the lexicons in the geometrical dimension is generally higher for visual touch than for blindfold touch. This means the responsive sensitiveness to geometrical configuration for visual touch is greater than that for blindfold touch. In other words, the combination of vision and touch can strengthen the subjective perception to geometrical configuration of a material surface. But interestingly, the response to *smooth* – *rough*, seems to be approximately the same level for both conditions, or even a bit more sensitive for blindfold touch. The reason for this is to be further explored. (Fig.6 a))

Within the physical-chemical dimension, the subjective response to the three highest-frequency lexicons *warm* – *cold, moist* – *dry, hard* – *soft*, and *slippery* – *abrasive,* is stronger for blindfold touch than that for visual touch. On the other hand, the response to other characters such as *shining* – *unshining, bright* – *dark, glossy* – *matt,* etc. is more sensitive for visual touch than that for blindfold touch. This is not difficult to understand because these a)



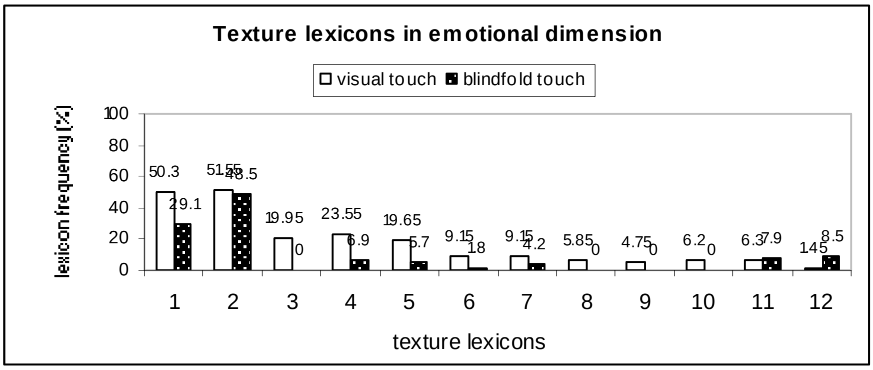

1.smooth – rough
2.fine – coarse
3.plain – bumpy
4.regular – irregular
5.granular – ungranular
6.simple – complex
7.repetitive – unrepetitive
8.linescattered – dotscattered
9.isotropic – anisotropic
10.ridgy – unridgy

b)



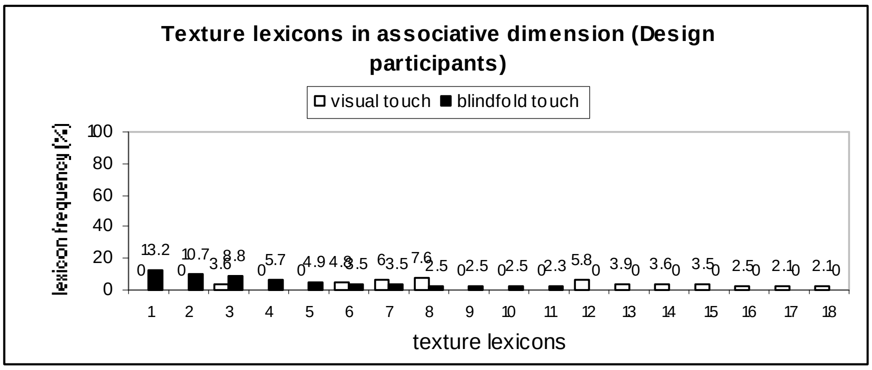

1.warm – cold
2.moist – dry
3.hard – soft
4.shining – unshining
5.bright – dark
6.glossy – matt
7.sticky – unsticky
8.reflective – unreflective
9.dense – loose
10.light – heavy
11.slippery - abrasive

c)




1.Lively/cheerful – dull
2.comfortable – uncomfortable
3.tasteful – tasteless
4.elegant – ugly
5.modern – traditional
6.relaxed – nervous
7.exciting – boring
8.attractive – tedious
9.depressing
10.clear – vague
11.clean – dirty
12.flexible – rigid/solid

d)




1.plastic-like
2.metallic
3.rubbery
4.bubbly
5.wood-like
6.leather-like
7.silky
8.matt-like
9.ceramic-like
10.stone-like
11.orangy
12.animalskin-like
13.honeycom-like
14.sandpaper-like
15.oily
16.ripples-like
17.mirror-like
18.clay-like

Fig.6 Comparison of the lexicons of subjective texture description between visual touch and blindfold touch: a) geometrical dimension; b) physical-chemical dimension; c) emotional dimension; d) associative dimension.

characteristics are directly related to vision. But it is interesting that these usually vision-related characteristics can still be perceived when subjects are blindfolded. (Fig.6 b))

The number of lexicons in the emotional dimension is larger for visual touch than for blindfold touch. Except for the feeling of *comfortable* – *uncomfortable*, other emotional feelings for visual touch seem stronger than those for blindfold touch. (Fig.6 c))

The lexicons in the associative dimension tend to be at the same level both for visual touch and blindfold touch, but the situation might not be so simple because these descriptions are much more dependent upon material surface finish, material categories, and subject individuals. This issue will be addressed separately. (Fig.6 d))

The number of lexicons, lexicons coincidence and response sensitiveness are slightly different for texture perception for visual touch and for blindfold touch. It is concluded that when subjects touch the surface of materials, vision can increase the response to geometrical configuration. Emotional feelings can also be enriched and strengthened. Interestingly, blindfold touch can increase the responsive sensitiveness to some physical-chemical characteristics, particularly *warm* – *cold*, *moist* – *dry*, and *hard* – *soft*.

The results of texture perception lexicons in terms of materials surface finish, subject groups (disciplines, gender, etc.) will be reported in further papers.

## 4 Conclusion

1) Human perception to materials should be investigated systematically in a holistic environment, which would be an important aid for materials selection in product design.
2) Texture and texture perception or perceived texture are two different concepts, the former is objective, the latter is subjective. For investigating the correlation between them, the dimensions both for objective texture identification and for subjective texture description need to be explored in parallel.
3) Subjective texture description of materials are to be classified into four dimensions: geometrical dimension, physical-chemical dimension, emotional dimension, and associative dimension.
4) Under different conditions, texture lexicons within four dimensions are slightly different in the number of lexicons, and responsive sensitiveness.
5) In the material texture perception by touch, vision can increase the response to geometrical configuration, and enrich, strengthen the emotional feelings. Blindfold can increase the responsive sensitiveness to some physical-chemical characteristics, particularly *warm* – *cold*, *moist* – *dry*, and *hard* – *soft*.

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