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Do we know enough to design comfortable products?

Ravindra S. Goonetilleke
Human Performance Laboratory
Department of Industrial Engineering and Engineering Management
Hong Kong University of Science and Technology
Clear Water Bay
Kowloon, Hong Kong

Abstract

Comfort plays an important role when people buy products. However, the "fit" of a product is assessed only after it has been tried in a physical setting. In an E-economy, it is necessary to be able to "predict" and convince a customer of the comfort properties. Some manufacturers have been successful in creating this mental model among users. However, the scientific principles governing the interface designs are not very clear. This paper is an attempt to understand the nature of touch and pain so that manufacturers may be able to design comfortable products knowing the physical constraints.

Keywords: Designing-in comfort, sensation, discomfort

1. INTRODUCTION

Consumer products that are used extensively are generally bought after trying them in a retail store or elsewhere. Examples include footwear, garments, mobile phones, tools, equipment and so on. When such products are to enter the E-economy, consumers seem to take a step back as they cannot experience the touch and feel and thereby the comfort of the product as there has been very little research to "predict" comfort.

With product variety growing exponentially, people are becoming more selective on their purchases looking for more usable and comfortable products while being lured into buying "comfort" products and accessories. For example, insoles made of relatively expensive polymers such as silicone [1] appear to replace the cheaper insoles in footwear. These silicone insoles claim to evenly distribute the loads thereby reducing pain, foot fatigue and stress. Some distinct advantages of silicone material are related to its long-term softness properties while retaining original shape without permanent deformation and its shock absorption characteristics. Are such products that distribute pressure really effective and if so, what is the mechanism that makes such products effective? This paper is an attempt to explore these issues.

2. WHAT IS COMFORT?

Pressure at the human interface has received considerable attention over the years since it can cause injury, pain, discomfort, and/or possibly improve comfort. When we wear clothes, shoes, neckties, sleep on a bed, sit on a chair, use a headset, use hand tools during manual work, or use arm rests or elbow supports to reduce muscle fatigue, the forces from these external implements exerted on the body are quite varied, but in all cases act on limited areas.

Many designers and engineers consider comfort as very subjective and evaluate the comfort level based on empirical observations. The literature also appears to be somewhat split between comfort and discomfort or pain. Comfort has been defined as a lack of discomfort [2]. More recent publications [3] have challenged the above definition with the notion that comfort is associated with feelings of relaxation and well-being. In creating the second definition, however, Zhang et al. [3] pointed out that poor biomechanics may turn comfort to discomfort even though good biomechanics is not a necessary and sufficient condition for comfort. The hierarchical structure of discomfort proposed by Krist [4] seems to supports this notion. According to the Krist model, the higher level of comfort can only be achieved when the physiological needs (possibly biomechanical) have been satisfied. In other words, comfort and discomfort may not be complementary, but, are established in a sequence so that achieving the lower level objectives are necessary, in order to experience the higher level of comfort. The words of William Penn in "no cross, no crown", saying, "No pain, no palm; no thorns, no throne; no gall, no glory; no cross, no crown" ([5], p. 302) attests to this approach.

The Bennett College, Sheffield dictionary gives Comfort as "relief, to relieve from pain or distress, ease, freedom from annoyance". The word, comfort is a derivation from the Latin word, "confortare". Interestingly, the German word, "Komfort" implies "ease, convenience, cosy furnishing, luxurious equipment" (German Foreign Word, Duden, 1990, p 411). In all such definitions, comfort is implied to mean a positive experience or the lack of a negative one. Through a series of interviews, Metzger [6] found the comfort is a term that people use to describe the quality of specific objects or situations such as a comfortable chair, comfortable shoe and so on. Slater ([7], p. 4) proposed a similar definition for comfort as "a pleasant state of physiological, psychological, and physical harmony between a human being and the environment".

2.1 Is comfort a composite function?

It is worthwhile exploring the sensation literature as a means to solving the dilemma in relation to the definition of comfort. In terms of hearing, sound pressure level has been used to understand human hearing. Generally, the threshold of hearing, discomfort threshold, pain threshold of hearing and their variations with frequency tend to be plotted on the same curve. Except for touch, similar curves are available and well known for other senses too. Thus in terms of a product or equipment, if we separate the sensory qualities of the product in relation to touch or feel (pressure, texture), looks (aesthetics), smell, taste, and hearing, we may be able to derive a composite "function" that may describe or explain comfort. This paper will address the touch or feel aspects of products in relation to their interaction with people through an understanding of the psychophysics and physiology.

3. PAIN

Pain is a means to warn us of potentially damaging situations to help us avoid cuts, burns, broken bones and so on. Intense pressure, high temperatures stimulate the receptors in the skin called nociceptors. The National Science Foundation Research Briefing on Pain and Pain Management stated "Pain has attributes of a sensation, yet its usual capacity to make us uncomfortable or to suffer distinguishes it from other sensations" [8]. Pain has been defined as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage, or described in terms of such damage" [9]. Pain in general is accepted to be a specific sensation, the intensity of which is proportional to the extent of potential tissue damage [10]. However, pain need not always be linked to tissue damage as it may persist even after tissues have healed. The gate control theory proposed by Melzack and Wall [11, 12] has been used to explain how non-painful tactile stimuli can result in a decrease in the perception of pain. We hope that our day-to-day consumer products do not induce any tissue damage and even if they did, non-painful tactile stimuli may help to reduce the intensity of pain.

4. THE PSYCHOPHYSICS AND PHYSIOLOGY OF TOUCH

Similar to hearing, the sensation of touch spans from a threshold of feeling to pain. There has been little research exploring the transformation of touch to discomfort or pain. Interestingly, touch is generally always never explored in conjunction with pain possibly as a result of the different mechanisms by which this sensation operates in humans. The mechanoreceptors that respond to mechanical stimulation of pressure, stretching and vibration lie on the external layer (epidermis) and the layer below (dermis) it. Four types of mechanoreceptors are responsible for tactile perception:

1. The Merkel receptor (for light touch) is located near the border between the epidermis and the dermis.
2. The Meissner corpuscle (for light touch) is in the dermis
3. The Ruffini cylinder (for sensing heat) located in the dermis and
4. The Pacinian corpuscle (for deep pressure) located deep in the skin

Von Frey's (1890) ideas that the Meissner corpuscles, Krause end bulbs, Ruffini cylinders and free nerve endings respond to touch, cold, warmth, and pain respectively have existed for a long time but recent research with cat skin has shown that there may be many more receptor types that may respond to steady indentation of skin, rapid indentation of skin, steady displacement of hair, rapid indentation of hair and so on.

Bolanowski [13, 14] has shown that the four mechanoreceptors mentioned above respond to stimuli frequencies ranging from 0.3 Hz (slowly pushing and releasing the skin once every 3 seconds) to 500 Hz (rapid vibration such as from equipment) as shown in Table 1.

Receptors	Receptor Field Size	Frequency Range	Perception
Merkel	Small	0.3-3 Hz (slow pushing)	Pressure
Meissner	Small	3-40 Hz	Flutter (light tapping)
Ruffini	Large	15-400 Hz	Stretching
Pacinian	Large	10-500 Hz (very rapid vibration at the upper range)	Vibration

Table 1. Mechanoreceptor Properties (Bolanowski, 1994)

The mechanoreceptors differ in the way they respond to stimulation. For example the Merkel discs and the Ruffini cylinders respond when a stimulus is present without much decrease in its firing rates and are called *slowly adapting* (SA) fibers (Figure 1). The fibers associated with Meissner corpuscles and Pacinian corpuscles respond with a sudden burst at the onset of a stimulus and are thus called *rapidly adapting* (RA) fibers (Figure 2).

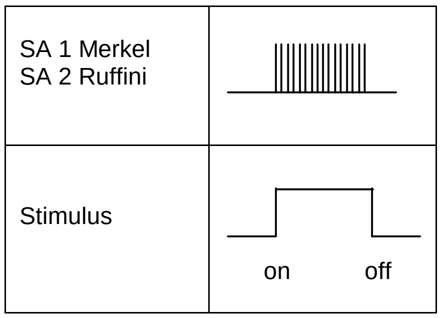

Figure 1: Slow Adapting (SA) mechanoreceptor response to a stimulus. They continue to fire without much change in rate during a sustained stimulus

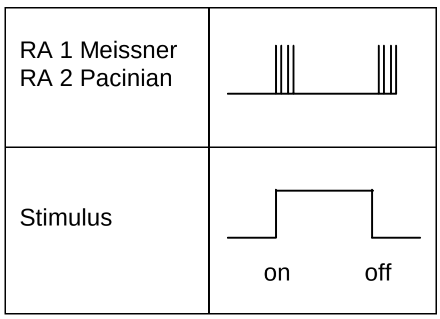

Figure 2: Rapidly Adapting (RA) mechanoreceptor response to a stimulus. They fire only at the onset and then the offset of a sustained stimulus.

An important property of these mechanoreceptors is the receptive field, which is the area of skin when stimulated directly affects the firing rate of neurons. The Merkel

(SA1) and Meissner (RA1) receptors have small receptive fields, while the Ruffini endings (SA2) and the Pacinian corpuscles (RA2) have larger receptive fields. Figure 3 shows the low threshold effects over a small area for the SA1 (and RA1) fibers [15]. This implies that the SA 1 (and RA1) fibers respond well only within this area, as the cell has a small receptive field.

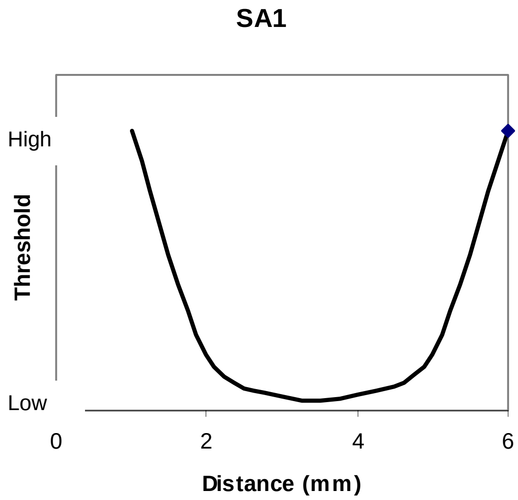

Figure 3: The SA1 and RA1 fibers have a low threshold over about 1 mm of skin (Adapted from [16]).

The SA2 and RA2 fibers, however, respond over a larger area and thus have a larger receptive field. It is interesting to note that the receptors with the small receptive areas are located close to the surface of the skin whereas the fibers with the larger receptive areas (SA2 and RA2) are located deeper in the skin.

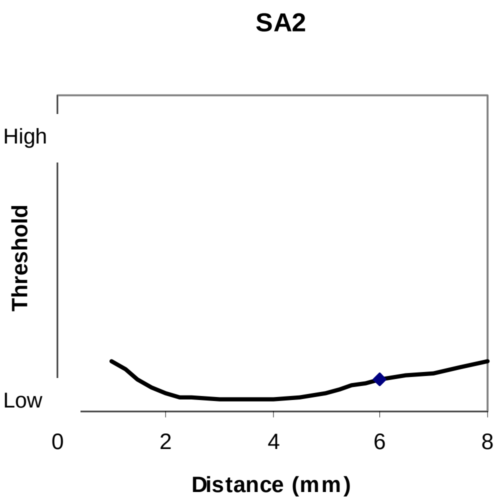

Figure 4: The low threshold area for the SA2 and RA2 fibers extend for more than 8 mm (Adapted from [16]).

As each mechanoreceptor has its specialized response, any given stimulation on the skin will generally activate many of these types, some stronger than others, depending on the stimulus. For example, if someone happens to grasp a cup, the SA1 (Merkel) fibers will fire to feel small details and the texture of the surface, while the SA 2 (Ruffini) fibers will fire as the hand stretches around the cup. The Meissner fibers also may fire depending on the texture. The overall perception will this be determined by all the fibers [17].

5. THE DISCOMFORT EXPERIENCE

Interface pressures have governed the development of many devices in the form of fluidised beds, seat cushions, shoe insoles with claims of reduced pressure sores and in some cases, claims of improved comfort. In general, it appears that injury can be minimized through pressure distribution and lowering pressure magnitude over human tissue. It is also claimed that injury is generally preceded by discomfort. If this statement is true, then logical reasoning implies that distributing force, thereby distributing pressure or reducing pressure at a particular location should result in a reduced level of discomfort or alternatively an improved level of comfort.

But, Krouskop and co-workers [18] found that mattresses with a uniform pressure distribution make people restless thus causing concern about the distributed theory of force. In addition, products such as a bed of nails or a bed of springs, "health sandals", shoe insoles, or steering wheel covers with semi-spherical protrusions, beaded car seat covers popular in the eastern cultures, massage mats made of wooden slats or "massage" rollers are popular. All such devices induce localized force rather than "distributed" force, supposedly creating desired sensations rather than discomfort. Hence it appears that concentrated force also has certain advantages and possibly a sensation of comfort or relaxation and well-being as defined by Zhang et al. [3].

Sacks and co-workers [19] have shown that force or load is unimportant in relation to ischemia and claimed that the skin blood flow changes are influenced by only three factors: the ratios of bone depth, the ratios of indentor diameter to bone diameter, and percentage compression of the tissue overlying the bone. "Indentor" or loading area is a factor neglected by many and its effect on discomfort can be quite significant.

Goonetilleke and Eng [20] under "unmotivated" conditions, found that the maximum pressure tolerance (MPT = applied force/probe area) is strongly related to the probe or indentor size or the contact area of the stimulus. The mean MPT with a probe of 5 mm diameter (831 kPa) was 3.3 times that when using a probe of 13 mm diameter (249 kPa). Two locations on the dorsum (top) side of the foot were tested. The measurement procedure is presented in [20]. There were no significant ($p < 0.05$) differences between locations or between genders. The results show that

$$MPT_{5\text{ mm diameter}} = 3.3 * MPT_{13\text{ mm diameter}}$$

It is logical for a layman to look at the maximum *force* (or maximum force tolerance, MFT = MPT* Area) that can be supported rather than at the pressure. The force relation between the two probe sizes would thus be as follows:

$$MFT_{5\text{ mm diameter}} = 3.3 * (5/13)^2 * MFT_{13\text{ mm diameter}}$$

or

$$MFT_{5\text{ mm diameter}} = 0.5 * MFT_{13\text{ mm diameter}}$$

In other words, at the maximum tolerable value, the force that a 5 mm diameter probe can exert is half of what a 13 mm diameter probe can exert. This suggests that even though the MPT is lower with a 13 mm diameter probe, the force that the 13 mm probe can support at the tolerable threshold is twice that of the 5 mm probe. This result is surprising when compared to a "dead" material. For any material other than human tissue, there is generally no difference in MPT at the breaking point. The MPT value corresponding to breaking strength for a material is indicated using stress (force/area), which is independent of area (Note that the breaking strength of "dead" material is independent of area since it is a constant).

If the maximum force is such that even though only half of the force can be supported with a 5 mm probe, it has 3.3 times tolerance thereby implying a counter-intuitive suggestion for loading on the human body. Consider the force supported at the tolerance level of the 13 mm probe. The maximum force corresponding to the MPT with the 13 mm probe (249 kPa) is 33 Newtons and the corresponding area of support is 132.7 mm^2. The area of the 5 mm probe is 19.6 mm^2 (that is 6.8 times smaller). If 6 (for convenience, rather than 6.8) load bearing areas of 5 mm diameter are chosen to carry the load corresponding to the tolerance level of the 13 mm probe, the load on each 5 mm probe will be 5.5 Newtons or a pressure value of 281 kPa (will be 249 kPa if 6.8 was used instead of 6) which is far below the MPT with a 5 mm probe. In other words, the load which may have caused someone to indicate that it is the maximum amount of force that could be tolerated over an area of 132.7 mm^2, could now be shared among a number of smaller areas (localized) without experiencing any such maximum tolerable value. The advantage of smaller areas to support loads is clear when the loads are high. In the above discussion, it should be noted that there is a minimum distance in order to distinguish the localized forces as separate forces (rather than a distributed force over the complete area). This distance may be variable depending on the body characteristics (such as size, sex, fat/muscle distribution, clothing, etc.) as well as the location on the body at which the pressure is exerted (e.g., arm, leg, foot back, etc.).

6. CONCLUSIONS

Even though aesthetics may play a role in comfort, products such as silicone insoles are used to change discomfort and pain to a comfort experience.

It is clear from the physiology that the touch sensing mechanisms are quite different depending on the characteristics of the stimulus. The receptors that fire vary depending on the stimulus. For slow movement and light pressure, it is clear that the distribution of force over a large area can result in a higher and comfortable sensation whereas higher forces or deep pressure may be better supported on the human skin when concentrated due to the larger, low threshold areas of the deep pressure sensing mechanoreceptors. The magnitude of the force and the available area of support, thus determine the ultimate balance of force between distribution and concentration for a comfort experience.

7. ACKNOWLEDGMENTS

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