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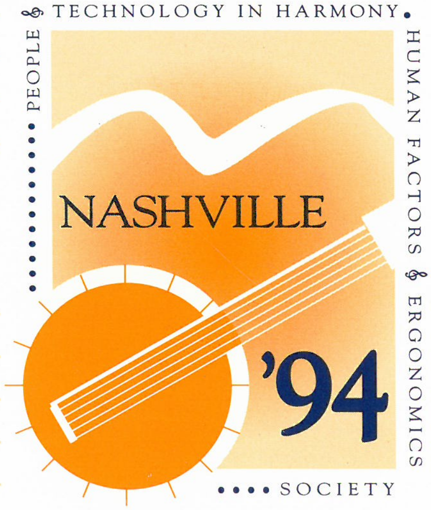

People & Technology in Harmony

CONTACT AREA EFFECTS ON DISCOMFORT

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Most "ergonomic" products attempt to adopt a uniform force distribution strategy to improve comfort. The rationale being that force distribution over a large area reduces pressure and thereby enhances user comfort. However, sensory literature alludes to the concept of spatial summation, i.e. greater sensation by stimulating a larger surface area. Hence spatial summation would tend to suggest a greater discomfort when forces are applied over large surface areas. This study reports the effect of surface area on maximum discomfort causing pressure or maximum pressure tolerance (MPT). Two circular probes of different cross sectional area were used to stimulate the skin surface. The mean MPT with a probe of 5mm diameter was 3.3 times higher than the MPT with a probe of 13mm diameter. These findings suggest the following:

- Perceived discomfort and contact area seem to have a "U-relationship" above a critical force value. Traditional thinking of distributing forces is successful only in the first half of the U-curve or with forces below the critical value. The section with the monotonically increasing relationship between discomfort and contact area (i.e., second half of U) may not be seen at very low forces or forces below the critical value.
- "High" pressures in concentrated areas may cause less discomfort than "moderate" pressures over a larger area.
- The critical or threshold pressure to induce discomfort is force and contact area dependent.

INTRODUCTION

Researchers have been limited by the lack of a viable operational definition of comfort and designers have difficulty to design products right the first time for improved user comfort (Gross et al. 1992). Comfort encompasses different characteristics based on the operating environment of the human. As a result, comfort is not easily quantifiable, and many resort to the notion of discomfort to understand comfort. The forces generated when objects contact the human body are in many cases one source of discomfort. In such cases, the most logical approach is to distribute the forces over as large an area as possible. For example, in the seating industry two possible design solutions exist:

a) Distribute the forces generated thereby achieving "uniform" pressure (Sprigle et al., 1990), or
b) Minimize the pressure in the soft tissue regions and let high pressures develop under the ischial tuberosities (i.e. localized high pressure regions).

Most human-"machine" interactions are designed today with compliance or pressure distribution in mind. Hence the common approach is to adopt choice a), thereby *attempting* to design for improved compliance or improved force distribution. Sprigle et al. (1990) and others have shown that custom-contoured cushions result in a pressure reduction and better comfort. Air-filled cushions are examples of this type where an attempt is made to reduce the pressure under the ischial tuberosities by evenly distributing the pressure across the whole body area at the cushion interface. The motivation for such cushions comes from the application of Pascal's law which states that the pressure exerted at any point upon a confined liquid is transmitted undiminished in all directions. In a related study of pressure distribution and comfort, Krouskop (1985) found that mattresses with a uniform pressure distribution makes people restless thus somewhat doubting improved comfort with condition a) indicated above.

Researchers have attempted to quantify comfort and design products that are comfortable to use. One such effort is described by Gross et al, (1992) where over 1100 seat-subject evaluations were conducted and a comparison performed on subjective comfort ratings and load distributions. The primary weakness of such extensive studies have been that they lack scientific evidence of why and how some interface pressure profiles render optimum comfort. A better understanding of "machine"-human interface pressure and the comfort perception may allow more universal design criteria to be established. In this regard one may draw important theories applicable to everyday things from the sensory literature. One such theory states that simultaneous stimulation of many sensory receptors is required to arouse a stimulation; a property referred to as ***Spatial Summation*** (Hardy and Oppel, 1937). Alternatively, one may state that a greater sensory response is experienced with a larger stimulated area. In the limit, when sensations tend toward discomfort, it may be said that a force distributed over a large area may increase the likelihood of discomfort as opposed to the same force over a small area.

Hence one may ask the question: "Does force distribution over a large area really increase comfort, or does it increase discomfort?" With the above rationale, an attempt was made to investigate the effect of surface area on maximum discomfort-inducing pressure or maximum pressure tolerance (MPT).

METHOD

Subjects

Eight volunteers, four females and four males were tested for their MPT on the dorsum side of the foot.

Apparatus

A digital force gauge (Chatillon Model DFI 100) was mounted on a height and orientation adjustable platform having an area larger than a human foot. A similar platform with no accessories was used for the other foot. A threaded steel rod with a silicone-tipped probe provided manual application of force at an approximate rate of 0.05 kg/s.

Procedure

The goal of the experiment was to assess the MPT at two locations on the top (dorsum) of the foot over two trials with a minimum of a four hour hiatus between trials with two different probes. The probes had a diameter of 5 mm and 13 mm. The two locations tested were the metatarsophalangeal joint 5 and point midway between metatarsophalangeal joints 1 and 2 on the dorsum side of the foot of each subject. The presentation order was balanced over the two probes, locations, and trials to control for any order effects. Each subject was subjected to an increasing force stimulus normal to the foot surface with the two probes. All testing was performed under "unmotivated" conditions (Sternbach and Tursky, 1965). In "unmotivated" conditions, the subjects are asked to inform the experimenter when they do not want to go any higher. The dependent variable was maximum tolerable pressure (MPT) where

MPT = maximum applied force/probe area.

RESULTS

Subject data are shown in Table 1. The ANOVA indicated a significant ($p < 0.05$) probe effect ($F(1,6)=138$, $p=0.0001$), significant trial effect ($F(1,6)=9.98$, $p=0.02$) and a significant (probe x trial) interaction effect ($F(1,6)=9.33$, $p=0.02$). MPT means are shown in Figures 1, 2, and 3. The mean MPT using the smaller probe size was 831 kPa and the MPT using the larger probe size was 249 kPa. A post-hoc analysis of the simple effects showed that the smaller probe was the cause of the significant interaction. No significant location effects or gender effects were present.

Table 1. Subject Data

	Gender	Mean	Std. Dev.
Age	Female	28	4
	Male	31	3
Stature (m)	Female	1.7	0.1
	Male	1.8	0.1
Mass (kg)	Female	54.41	4.12
	Male	75.34	7.70
Foot Length (cm)	Female	23.6	1.4
	Male	27.1	0.8

DISCUSSION

The maximum pressure tolerance (MPT) seems to be strongly related to the probe size or the contact area of the stimulus. The mean MPT using the smaller probe was 3.3 times the MPT using the larger probe size (Figure 1), i.e., a smaller probe allows a higher pressure to be applied before a subject experiences the same level of discomfort as a larger probe with lower pressure. The difference may be attributed to a decreased discomfort threshold caused by the higher number of nerve receptors stimulated by the larger probe (or larger surface area), thus supporting the spatial summation theory.

CONCLUSIONS

Since the MPT is dependent on the contact area it may be concluded that, at high forces, a larger area may cause a higher level of discomfort than a smaller area when stimulated with the same magnitude of pressure. The research suggests that localized high pressure regions may in fact prove to be less discomforting when compared to "distributed-moderate" pressures. However, we do know that with low forces, the distribution of force over a larger area may increase comfort. The results from the above experiment and intuition suggest a turning point or a threshold pressure depending on the applied force and the contact area for maximum comfort. Hence one may conclude that perceived discomfort and contact area seem to have a "U-relationship" above a critical force value. Traditional thinking of distributing forces is successful only in the first half of the U-curve or with forces below the critical value. The section with the monotonically increasing relationship between discomfort and contact area (i.e., second half of U) may not be seen at very low forces or forces below the critical value. Hence the decision to distribute or concentrate forces is really dependent on the magnitude of the pressure exceeding a critical or threshold pressure for a given surface area.

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Figure 1. Probe effect on MPT.

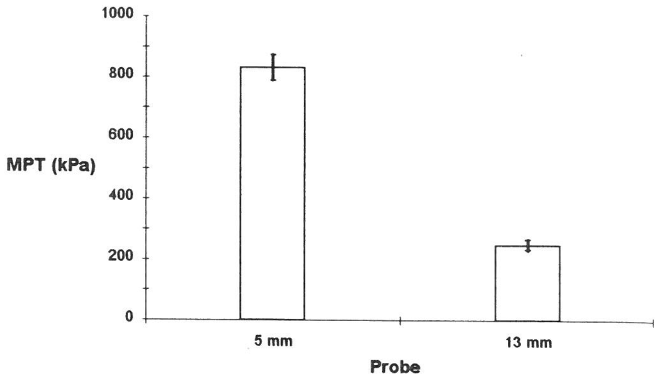
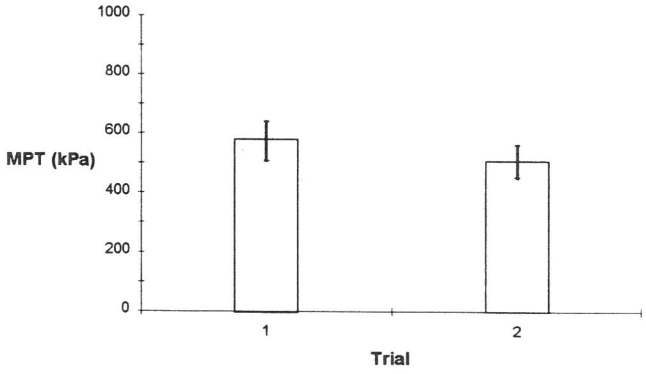
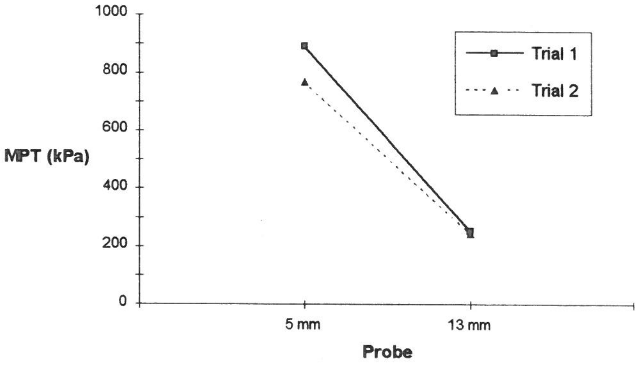


Figure 2. Trial effect on MPT.



Note: Bars indicate the standard error of the mean

Figure 3. Probe x Trial interaction effect on MPT



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