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# Electrocutaneous Stimulation of Skin Mechanoreceptors for Tactile Studies with Functional Magnetic Resonance Imaging

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## INTRODUCTION

In many simulation and exploration tasks such as exploring the real and virtual environment, tactile information is necessary to get surface information of objects. Moreover, in rehabilitation and sensory prostheses training, this kind of sensory information is indispensable (Yarimaga, Lee, Lee, & Ryu, 2005).

Since the 1980s, electrotactile stimulation has been considered a possible way to reproduce the glabours skin tactile sensations, first by using intracutaneous electrodes inserted into the nerves and then by using transcutaneous electrodes placed in contact with the skin.

Electrotactile stimulation is a potentially useful method for sensory augmentation or substitution and permits accurately controlling the perceived stimulus intensity that is fundamental in any tactile communication system. In several virtual reality applications, the electrostimulation could be a viable solution in substituting for tactile displays, increasing the augmented reality performance.

If it could be possible to elicit selectively each kind of skin afferent fibers using analogously to mechanical stimulus, any sensation could be evocated by combining specific inputs.

To evoke specific sensations related to specific types of *mechanoreceptors,* we consider here the possibility of using electrotactile stimulation, varying the amplitude and the frequency of the stimulating electric signal, but maintaining the same waveform. According to a different specificity of the mechanoreceptors at different mechanical stimulus (Kaczmarek, Webster, Bach-y-Rita, & Tompkins, 1991), there might exist receptor specificity for different amplitude and frequency of electrical stimulus. In this case it could be possible to stimulate specifically several types of mechanoreceptors maintaining the same waveform and varying only its amplitude or frequency, with the possibility of creating a different sensation for tactile studies and augmented reality applications.

## BACKGROUND

The *microstimulation* technique of tactile receptors by using electric current has been largely used to study the specific role of several types of mechanoreceptors and characterize their functional properties (Vallbo, Olsson, Westberg, & Clark, 1984). Passing small electric currents through microneurography electrodes placed directly on the nerve ending of the receptors, it is possible to evoke several localized sensations such as flutter or pressure.

Many authors have proposed several techniques to record this sensation in awake human: Trulsson Francis, Kelly, Westling, Bowtell, and McGlone (2001) demonstrated that intraneuronal microstimulation of single afferents produces robust hemodynamic responses in somatosensory cortex that can be measured using the *functional Magnetic Resonance Imaging* (fMRI) technique.

Another technique of electrical stimulation of skin receptors is known as "electrocutaneous stimulation": with the term electrocutaneous (or electrotactile) is intended the evocation of a tactile sensation using an electric current flowing through the skin, via electrodes placed on the skin surface. A device that stimulates nerve afferents within the skin by electric current is known as "electrocutaneous display" and can be constituted by several surface electrodes.

Because their small size, longer durability, energy efficient, and ease of use, electrocutaneous displays are superior to mechanical tactile displays.

Several papers report the use of this technique in sensory substitution system for blind or deaf persons (Bak, Girvin, Hambrecht, Kufta, Loeb, & Schmidt, 1991; Eisenberg, Maltan, Portillo, Mobley, & House, 1987) and in training for prostheses use. Electrocutaneous stimulation has been also used in augmented reality and telepresence in order to provide the user with tactile information (Nojima, Sekiguchi, Inami, & Tachin, 2002).

The mechanism of tactile stimulation was first described in literature approximately in 1960 and the first tactile display was proposed in 1970 (Strong & Troxel, 1970). It was based on the principle that an electric current pulse from surface electrodes generates an electric field inside the skin, which induces nerve activity.

Approximately 44% of mechanoreceptors lying into the human hand are found to be slowly adapting (SA) (i.e., they also respond with a sustained discharge to static tissue deformation), while the remaining are fast adapting (FA), only responding to the rate of skin indentation and its higher derivatives. Depending on the extension of their receptive fields, SA and FA tactile units can be subdivided into two categories: type I have restricted and sharply defined receptive fields and type II have larger fields and less precise contours. The correspondence between SAI and *Merkel's complexes*, FAI and *Meissner's corpuscles,* SAII and *Ruffini's endings*, and FAII and *Pacinian corpuscles* is widely accepted (Johnson, 2001).

Each class of mechanoreceptors responds to skin deformation and motion in a different way (Kaczmarek et al., 1991). If it could be possible to find the electric current which is able to elicit selectively each kind of afferent fibers analogously to mechanical stimulus, any sensation could be evocated by combining specific inputs.

Kajimoto, Hawakami, Maeda, and Tachi (2002) have already shown that electrical selective stimulation is possible using anodic or cathodic current: they called the specific stimuli "tactile primary colours" in analogy to the visual system and its primary colours (red, green, and blue). In their paper the authors show that Meissner corpuscles can be selectively stimulated in

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