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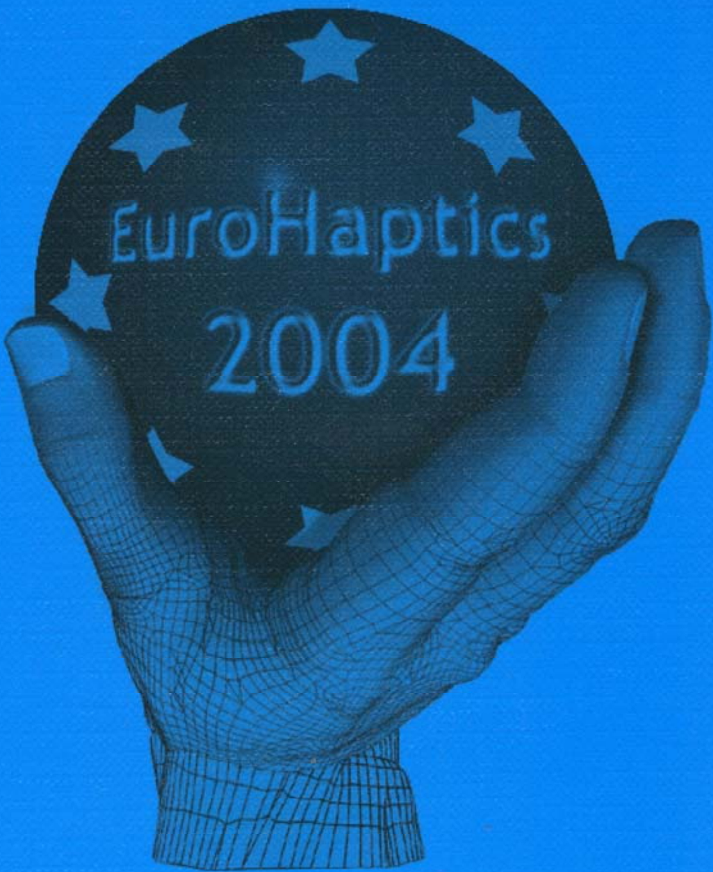

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Improving human haptic sensing in normal and impaired human populations through activation-based learning

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Abstract. Human haptic sensing is not fixed, but subject to major alterations through perceptual learning processes. We describe a new stimulation protocol that allows to improve haptic sensing in humans in a highly systemic way. The so-called coactivation protocol is based upon temporal constraints of Hebbian learning where simultaneity plays a key role for the induction of plastic changes. We summarize recent experiments showing that coactivation alters haptic sensing in parallel to major cortical reorganization in somatosensory cortex. We describe first results where coactivation has been utilized for therapeutical purposes in impaired human populations, and we sketch the next steps to be able to apply the concept of coactivation on a regular and reliable basis as a therapeutical tool to selectively interfere with impaired haptic sensing.

1 Introduction

It is common wisdom that perceptual skills improve with training [1]. Consequently, haptic sensing, and thus haptic performance is subject to considerable modification through training, or to enhanced or reduced use [2,3]. Recent studies in "perceptual learning" have revealed that skill acquisition in the haptic domain is associated with selective plastic reorganizational changes in the cortical representations of the respective body part. For example, Recanzone and coworkers showed that tactile frequency discrimination training over several months leads to a significant reduction of frequency discrimination threshold and to an expansion of the cortical maps in somatosensory cortex that represent the used finger [4]. On the other hand, imaging studies performed over the last years provided overwhelming evidence that extensive use and practice result in substantial changes of associated cortical representations in blind Braille readers [5] or string players [6]. According to these finding, both long-term training and long-term differential use is able to modify haptic sensing.

2 Activation-based learning

We have recently introduced an alternative approach to control and to improve haptic sensing in humans through so-called activation based learning protocols on a very short time scale of only a few hours.

Given the knowledge about brain plasticity accumulated over the last years [7], we suggested that specific stimulation protocols can be designed through which it becomes feasible to change purposefully brain organization and thus perception and behavior. Based on this concept, we have developed a so-called coactivation protocol, through which we can enforce localized activation pattern [8-12]. Coactivation is a task-free, passive stimulation that allows to study systematically the impact of altered input statistics on plastic capacities of cortical networks. The protocol induces perceptual learning in parallel to cortical reorganization without invoking task training, or cognitive factors such as attention or reinforcement [8-12].

Coactivation follows closely the idea of Hebbian learning [13]: Synchronous neural activity, which is regarded instrumental to drive plastic changes, is generated by the simultaneous tactile "co-stimulation". Conceivably, coactivation modifies synaptic efficacy between and within the cortical neuron pool representing the stimulated skin sites thereby altering cortical maps and associated perceptual performance.

2.1 Coactivation

To apply coactivation, a small device consisting of a solenoid with a diameter of 8 mm was taped to the tip of the right index finger (IF) (Fig. 1). The device allows stimulation of the skin portions underneath thereby coactivating the receptive fields within this area. Coactivation-stimuli were drawn from a Poisson process at interstimulus-intervals between 100 to 3000 ms; average stimulation frequency is 1 Hz and the duration of each pulse is 10 ms. The pulse trains required to drive the solenoid were recorded on tape and are played back via portable tape recorders allowing unrestrained mobility of the subjects during coactivation. Subjects are instructed not to attend the stimulation. In fact, all subjects resumed their normal day's work. Coactivation stimuli are applied at supra-threshold intensities. Duration of coactivation is 3 hours, see [8-12] for more details.

2.2 Experimental schedule and design

A typical experiment consists of two different components: First, the measurement of haptic performance as a marker of the efficacy of perceptual learning induced by the coactivation protocol. As a parameter, we mostly used spatial 2-point discrimination thresholds on the tip of the left and right index finger (IF), see chapter 5. for other haptic parameters. Second, the coactivation on the tip of the right IF for a period of 3 hours as a tool to induce perceptual learning. For details of the testing procedure see [8-12]. In brief, to obtain a stable base-line of performance, we tested the subjects on 5 consecutive sessions over several days on the right IF. In the 5th session, the threshold of the left IF was additionally measured. Previous studies showed that the effect of task familiarization was transferred to the IF of the left hand [8-12]. As a rule, the IF of the right hand was used for coactivation. In contrast to the initial task familiarization, the coactivation effect imposed on the right IF did not generalize to the IF of the left hand [8-12]. Because of this locality, we used the IF of the left hand as a control and for the assessment of possible unspecific side-effects of coactivation.

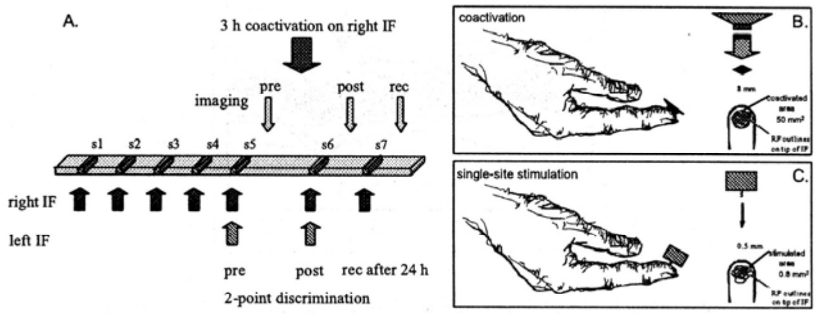

Fig. 1. (*A*) Experimental design: Sessions 1 to 5 (s1-s5) served to create a stable discrimination performance for the right IF. The left IF serving as control is only tested at session s5 (pre coactivation) and after coactivation (session s6, post). After s5, pre-imaging is performed, then coactivation of the right IF is applied for 3 hrs. After the termination of coactivation and after the completion of session 6, post-imaging is repeated. The 7th session (determination of 2-point discrimination thresholds and imaging) was performed to assess the recovery of the coactivation induced effect. (*B*) Application of coactivation: A small solenoid with a diameter of 8 mm was mounted on the tip of the right IF to coactivate the receptive fields representing the skin portion under the solenoid (50 mm^2). (*C*) Control protocol. Application of a so-called single-site stimulation: A small device consisting of only one tiny stimulator (tip diameter 0.5 mm) was mounted on the tip of the right IF to stimulate a single "point" (0.8 mm^2) on the skin. Duration of stimulation was also 3 hrs. The schedule was the same as described in (*A*) for coactivation, however, no recovery sessions were performed. Also, frequency and duration of pulses were as described above for coactivation (see [12] for statistics). Reprinted with permission from Neuron [12]

3 Basic effects of coactivation on tactile acuity and associated cortical maps

The fundamental effects of coactivation are illustrated in Fig. 2. Shown are 2-point discrimination thresholds for 35 subjects plotted versus successive sessions [8]. Except for the first session, all subjects show a remarkable stable and reliable baseline of performance with very little scatter. After several hours of coactivation, all subjects without exception improve their acuity as indicated by a lowering of thresholds (pre 1.37 mm +/- 0.21 (mean +/- s.d.), post 1.12 mm +/- 0.22, n=35, p=0.000064, 2-tailed t-test). Retesting after 24 hours revealed restoration of initial performance.