

Research report

Bilateral cortical representation of tactile roughness

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ABSTRACT

Roughness is the most important feature for texture discrimination. Here we investigate how the bilateral cortical representation of touch is modulated by tactile roughness by analyzing the neural responses elicited by stimuli with various coarseness levels ranging from fine to medium.

A prolonged stimulation was delivered to 10 healthy subjects by passively sliding tactile stimuli under the fingertip while recording the EEG to study the modulation of Somatosensory Evoked Potentials (SEPs) as well as activity in the theta and alpha bands. Elicited long-latency SEPs, namely bilateral P100–N140 and frontal P240 were consistent across stimuli. On the contrary, the temporal lag N140 – P240 was non-linearly modulated both in contralateral and ipsilateral sides, in agreement with literature.

Using a time-frequency analysis approach, we identified a theta band power increase in the [0 0.5]s interval and a partially overlapped power decrease in the alpha band which lasted throughout the stimulation. The estimated time these two phenomena were overlapped was comparable across stimuli, whereas a linear decrease in alpha band amplitude was reported when increasing the stimulus roughness in both contralateral and ipsilateral sides.

This study showed that the selected tactile stimuli generated physiological bilateral responses that were modulated in a diversified way according to the stimulus roughness and side. Specifically, we identified sensory processing features (i.e., theta and alpha time overlap) invariant to the stimulus roughness (i.e., associated to a basic cortical mechanism of touch) and roughness-dependent cortical outputs comparable in the contralateral and ipsilateral sides that confirm a bilateral processing of tactile information.

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1. Introduction

Touch enables us to manipulate objects (Johansson and Flanagan, 2009) and recognize their properties such as shape and symmetry (Ballesteros and Reales, 2004; Klatzky et al., 1985).

In the haptic perception of materials, roughness is the most important feature for discrimination of textured surfaces and thus salient to the sense of touch (Bergmann Tiest and Kappers, 2007; Taylor and Lederman, 1975; Weber et al., 2013).

Recently, psychophysical protocols have been combined with neurophysiological studies to provide a better understanding of the afferent peripheral neural mechanisms that produce the spatial and temporal codes mediating tactile perception (Connor et al., 1990; Oddo et al., 2016; Weber et al., 2013; Yoshioka et al., 2001).

Several studies showed that the cortical processing of roughness discrimination is organized hierarchically and follows two

principal schemes (Kitada et al., 2005): i) the cognitive-based processing (i.e., roughness estimation task) (Burton et al., 1997) that generates activation in prefrontal area (i.e., active discrimination of surfaces) (Bodegård et al., 2000; Harada et al., 2004; Stoeckel et al., 2003); ii) the sensory processing (i.e., roughness no-estimation task) that involves mostly the somatosensory area (Coghill et al., 1994; Francis et al., 2000; Roland and O'Sullivan, 1998).

A number of studies have examined the global somatosensory response using fMRI (functional Magnetic Resonance Imaging) (Arthurs et al., 2000; Backes et al., 2000; Nelson et al., 2004) and MEG (Magnetoencephalography) (Iguchi et al., 2002; Torquati et al., 2002). In general, they indicate the existence of a relation between the stimulus intensity and the intensity of the evoked signal as well as the activated volume of cortex.

Electroencephalography (EEG) can provide additional information not only on the amplitude and topography of the brain responses but also on the latency of the evoked potentials (Munoz et al., 2014). Furthermore, the EEG allows monitoring Somatosensory-Evoked Potentials (SEPs), which represent the

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direct cortical response of the Central Nervous System to sensory stimuli (Allison et al., 1992; Salenius et al., 1997). SEP characterization is also fundamental to identify which components are involved in the roughness discrimination task and which ones reproduce the same features across stimuli (Ballesteros et al., 2009; Munoz et al., 2014).

Given the concurrent activation of several processes, it is currently unclear how to determine what amounts to be a separation between processing related simply to touch from that related to fine-grained texture discrimination. The hypothesis behind the study is that, by carefully tuning a specific parameter of tactile stimulation (roughness) in carefully controlled conditions, it is possible to disentangle the role these processes have in the tactile discrimination of surfaces. Understanding these roles has important implications in neuroprosthetics, e.g. to assess the cognitive workload required for the control of prostheses (Deeny et al., 2014). The identification of the hallmarks of texture discrimination may also provide objective evidence of a successful restoration of homologous tactile feedback via somatotopic intraneural stimulation (Kaczmarek et al., 1991; Oddo et al., 2016).

In our previous study (Genna et al., 2017), we proposed a tactile stimulation consisting in a passive dynamic stimulation that replicates a controlled sliding action of the human fingertip during the recording of EEG activity. This stimulation has two main advantages: i) record the bilateral brain responses generated by the activation of the full range of mechanoreceptors; ii) monitor the dynamics of the brain responses to a prolonged stimulation.

Here we delivered tactile stimuli with different levels of roughness and we studied the whole brain activation elicited by the different stimuli, both in the time and time-frequency domains. The goal of this study was to evaluate the cortical mechanisms underlying fine-grating tactile stimulation and disentangle them from the processes related to the sensory processing of touch. We followed a similar EEG analysis scheme to that in (Genna et al., 2017), and used approaches both in time and frequency domains as follows. In the time domain, the passive sliding of a finger over a surface generated long-latency SEPs consisting in a bilateral P100 – N140 sequence located in the somatosensory area, a pre-frontal P240 and a central peak at 200 ms after the end of the stimulation (Genna et al., 2017).

For the time-frequency analysis we computed the somatosensory Event-related Synchronization (ERS) and Desynchronization (ERD) (Pfurtscheller and Lopes da Silva, 1999). In (Genna et al., 2017) we identified two consecutive cortical phenomena modulating two different bands: i) increase of power in the theta band only in the initial stimulation phase (i.e., below 500 ms); ii) bilateral decrease of alpha-band power throughout the stimulation.

We compared the activation of the contralateral and ipsilateral hemispheres to observe whether tactile roughness modulated SEP amplitude/latency and the related somatosensory ERS/ERD across stimuli.

2. Results

2.1. SEP characterization

Each stimulus generated long-latency SEPs comparable to our previous study (Genna et al., 2017) (see Fig. 1).

The contralateral ROI (see CLH-ROI in Fig. 1A) clearly identified the temporal sequence P100–N140 across stimuli in the following time intervals: [60 120]ms for the P100 and [120 220]ms for N140. The identified SEPs reported slight differences across stimuli in the amplitude of the scalp topographies. Furthermore, for all four stimuli, the scalp topographies confirmed that P100 and

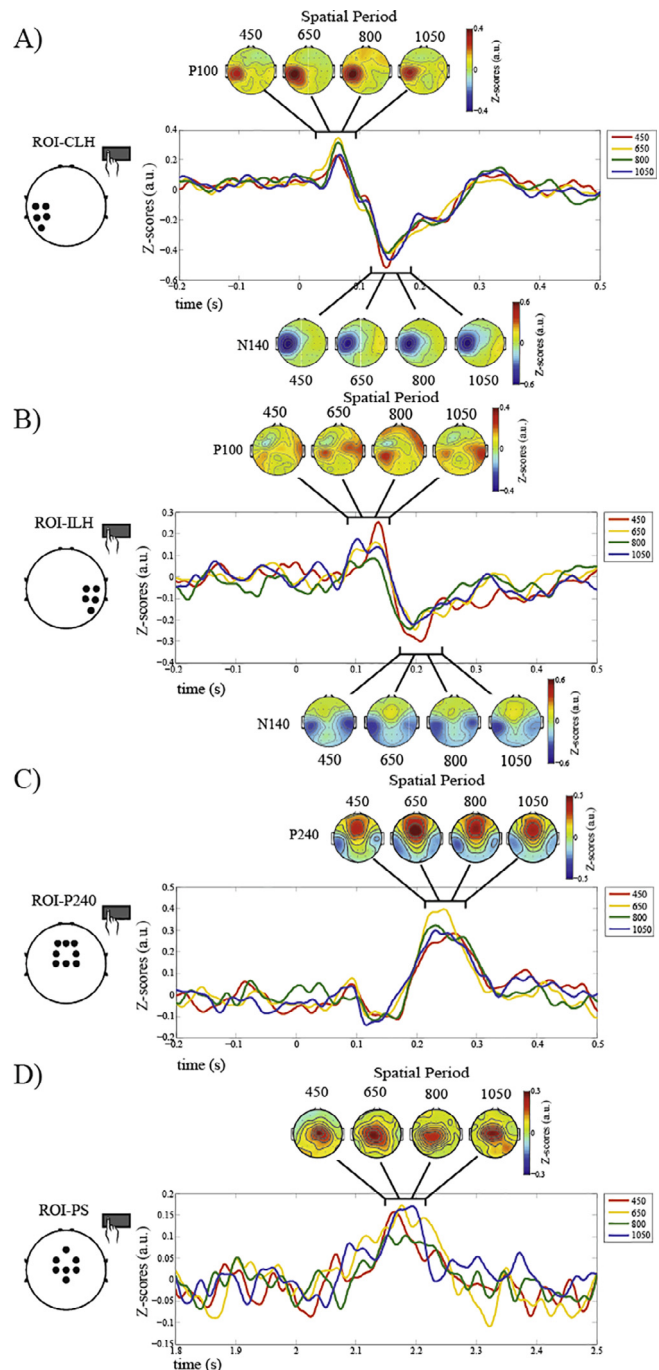


Fig. 1. Stimulus-dependent characterization of SEPs. A) Significant electrodes of the contralateral cluster (ROI-CLH) and temporal evolution of SEPs (i.e., average of the channels in ROI-CLH) for each stimulus. The reported scalp distributions represent the max in [0.05 0.1]s for the P100 and min in [0.08 0.15]s for N140 across stimuli. Both P100 and N140 are generated systematically across stimuli reporting some variability in amplitude and latency. B) Significant electrodes of the ipsilateral cluster (ROI-ILH) and temporal evolution of ipsilateral SEPs, computed as average of the channels of ROI-ILH. The scalp distributions were evaluated as max in [0.1 0.17] s for P100 and as min in [0.18 0.24]s for N140. The topography of P100 shows variability, whereas the ipsilateral N140 is elicited systematically across stimuli. C) Significant electrodes of the frontal cluster (ROI – P240) and temporal evolution, computed as average of the electrodes of ROI-P240. The P240 scalp topography was evaluated as max in [0.19 0.28]s and it shows similar site of activation across stimuli. D) Significant electrodes of the central cluster (ROI-PS) and temporal evolution, computed as average of the electrodes of ROI-PS. The PS peak was identified as max in [2.14 2.26]s and it is comparable across stimuli.

N140 SEPs were generated in the contralateral somatosensory cortex (see scalp topographies in Fig. 1A).

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