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Auditory stimuli from a sensor glove model modulate cortical audiotactile integration

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HIGHLIGHTS

- The sensor glove generates auditory feedback.
- We examined how the sensor glove influences the cortical audiotactile integration.
- The BOLD signal in the somatosensory area is changed by auditory stimuli.
- Training with sensor glove favors the cortical audiotactile integration mechanisms.

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ABSTRACT

The purpose of this study was to shed light on cortical audiotactile integration and sensory substitution mechanisms, thought to serve as a basis for the use of a sensor glove in the preservation of the cortical map of the hand after peripheral nerve injuries. Fourteen subjects were selected and randomly assigned either to a training group, trained to replace touch for hearing with the use of a sensor glove, or to a control group, untrained. Training group volunteers had to identify textures just by the sound. In an fMRI experiment, all subjects received three types of stimuli: tactile only, combined audiotactile stimulation, and auditory only. Results indicate that, for trained subjects, a coupling between auditory and somatosensory cortical areas is established through associative areas. Differences in signal correlation between groups point to a pairing mechanism, which, at first, connects functionally the primary auditory and sensory areas (trained subjects). Later, this connection seems to be mediated by associative areas. The training with the sensor glove influences cortical audiotactile integration mechanisms, determining BOLD signal changes in the somatosensory area during auditory stimulation.

1. Introduction

Changes in sensitivity of the hand occurs mainly due to traumatic lesion of peripheral nerves [21] and can seriously affect its function, impairing the performance in the execution of daily life activities and reducing the quality of life of an individual [13,16]. The recovery of sensory function of the hand is found to be unsatisfactory in clinical practice in most cases and still represents a challenge to reconstructive surgery [13,17].

Strategies of sensory reeducation of the hand have been introduced after nerve repair in order to help the patient to reinterpret the altered sensory stimuli originating in the injured hand [5–7,19]. Currently, interventions such as the Sensor Glove System [16], involving the principles of cross-modal plasticity and cortical audiotactile interaction have become important tools in the attempts to preserve as much as possible the cortical map of the hand during the immediate post-injury period.

The glove has microphones on the back of the fingertips. An amplifier is responsible for sending the sound to earphones. Thus, when it stimulates the fingertip, the individual is able to hear the sound generated by the touch of that finger on a specific texture

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Fig. 1. Sensor glove components: earphones, amplifier, microphones, glove.

[13–16]. The sensor glove allows the individual "to hear what the hand should feel" and this process seems to be bridged by the common vibrational sense shared by tactile gnosis and auditory perception [13]. Other studies have pointed out positive results of its application when started early after nerve repair [15].

The objective of this randomized controlled study was to determine whether training with auditory stimulus from a sensor glove would be effective in modulating cortical audiotactile integration in healthy subjects. Differences in the time course of BOLD (Blood Oxygenation Level Dependent Effect) activations between trained and untrained groups may shed light on sensory substitution mechanisms, thus paving the road for greater use of the sensor glove as a tool for the rehabilitation after peripheral nerve injuries in the upper limbs.

2. Methods

The study was approved by the Research Ethics Committee of the institution and all subjects gave written informed consent.

2.1. Subjects

Fourteen subjects (13 women and 1 man) with a mean age of 26.8 ± 1.4 years were invited and the inclusion criteria were normal hearing assessed by pure tone threshold audiometry; preserved sensitivity, strength and amplitude of movement of the upper limbs; hear the sound of velcro texture during fMRI exam. After randomization (random number table), the subjects were allocated to the training group (TG) and to the control group (CG).

Before the fMRI exam, TG subjects were trained to use the sensor glove model, whereas CG subjects were not trained and had no contact with the subjects of the TG or the sensor glove before the exam. Investigators with experience in hand therapy collected all data and trained the TG subjects.

2.2. Training

A sensor glove model developed by the authors [20] and similar to that described by Lundborg et al. [16] was used for training (Fig. 1).

The objective of training was to habilitate the volunteers to replace touch for hearing as much as possible during the identification of textures using the sensor glove. It was based on the traditional programs of sensory reeducation of the hand and was performed for seven consecutive days before the fMRI exam. The volunteers were trained by the investigator, in a silent environment, only once a day in an individual session lasting 15 min.

During training, the subjects wore the glove with a single mini-microphone coupled to the second finger of the right hand and earphones, with the amplifier volume being adjusted to the most comfortable level for each subject. Five different textured materials were then presented to the subjects: rough velcro, velvet, jute, felt, and textured vinyl. Initially, the volunteers observed and heard the sound of passive touch of the texture on their right index finger and, then with eyes closed, just heard the sound of touch. At the end, they had to identify the textures based only on sound and at this time, they received feedback (correct or not). Each session (eyes open, eyes closed, identification) lasted 5 min, totalling 15 min.

The sound produced by touching the velcro texture was the one that most salient during the scanner noise and so was chosen to be used during the fMRI exam. Thus, the velcro texture touch was emphasized and standardized throughout the training. Subjects had no access to this information. To this end, the touch with each texture has always been intercalated with the velcro texture. In this way, during training, the texture with which the subjects had greater contact was velcro.

2.3. Stimulation procedures during fMRI

All subjects were submitted to the fMRI exam using a Philips Achieva 3T (Best, the Netherlands) magnetic resonance apparatus in four blocks of 30 s for the task and of four blocks of 30 s of rest. A complete run lasted for four and a half minutes.

During the functional exam, the subjects were submitted to three consecutive runs and received three different types of stimuli in the same order: tactile stimulus alone (task 1), tactile and auditory stimuli combined (task 2), and auditory stimulus alone (task 3).

The volunteer was positioned in the scanner and wore air duct earphones, an inbuilt device in the Achieva 3T scanner, that received the sound sent by the glove amplifier and partially blocked the noise of the scanner. An auxiliary investigator applied the tactile stimulus by passing the velcro texture on the tip of the volunteer's right hand second finger. The auditory stimulus was applied by another investigator, who was in the command room and wore a glove with a single microphone placed on the second finger of his left hand.

The audio-feedback intensity was adjusted at maximum level allowed by the amplifier and scanner sound control. Thus, the interference of the scanner characteristic noise was minimized by both earphones and audio-feedback setting on the highest possible intensity. Then, during auditory stimulation, the researcher applied the stimulus in his own finger over the microphone, and the sound captured was sent to the volunteer earphones.

For the simultaneous application of tactile and auditory stimuli, researchers worked as synchronously as possible by direct visual contact, and the researcher who was in the command room gestured to another the moment that stimulation should begin. The time of application of the stimuli was controlled by the researcher in the command room. Even though there was no millisecond precision in the timing of stimulation, this procedure was not deleterious, once the time resolution in both stimulation and image acquisition were in the range of thousands of milliseconds. Thus, asynchronies between both auditory and tactile stimulations can be considered as normally distributed, given the expertise of the researchers involved, the timing in communication and the sampling rate of the neurophysiological tool used here.

2.4. Acquisition and processing of images

Structural T1-weighted images were obtained using a standard gradient-echo sequence (TR = 7.2 ms, TE = 3.3 ms and 8° spinning angle, 240×240, 180 slices). Three sets of functional echo-planar images were acquired (TR/TE = 2000/40 ms, matrix dimension 128×128 in-plane matrix, 30 slices, 135 volumes).

Functional images were processed using the software Brain Voyager™ QX 2.3 (Brain Innovation, the Netherlands). Pre-processing consisted of 3D movement correction, a 5-mm FWHM Gaussian spatial filter, and a temporal high-pass filter. Data were analyzed statistically by the General Linear Model [8] with the evolution of each voxel being compared to a modeled reference function. Statistical maps were