100 Hz Localized vibration increases ipsilateral cerebellar areas activity during a motor task in healthy subjects: Three Cases Report

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Abstract. Background and Purpose. The exact mechanism thought which Localized vibration (LV) acts on the motor system at the suprasegmental level is still poorly understood. In this paper we have reported three cases of healthy men exposed to 100 Hz localized vibration during a motor task.

Case Description. This case report describes 3 healthy men (age 23 years).

Outcomes. During fMRI participants were engaged in a right-hand self-paced finger tapping (FT) task, with and without a 100 Hz LV of the right hand. After standard images preprocessing and normalization, a fix-effect GLM analysis was used to test the effect of vibratory stimulation on motor network.

A bilateral activation, greater in the left hemisphere than in the right one, in the frontal premotor and supplementary motor areas (SMA), central gyrus (M1), postcentral gyrus, was found without any statistical significance between conditions. Activation in the left lenticular nucleus and thalamus was also found without differences between conditions. When using the FT activation map as a mask, the analysis showed that only the right cerebellum correlate positively with the vibratory stimulation.

Discussion. Using fMR a localized vibratory stimulus was found to significantly increase the activity in homo-lateral motor cerebellar areas during a motor task. This finding aims to trigger new studies on how a LV can influence motor recovery in neurorehabilitation and to (re) consider the role of cerebellum in the rehabilitation strategy.

Key words: localized vibration, 100 Hz, sMNR, cerebellum, rehabilitation.

Introduction

Detection of mechanical forces is essential for living organisms to interact with external environments and to maintain stable biological systems (1,2). Moreover mechanotransduction in response to mechanical forces of different intensity and frequencies locally applied, such as touch, pressure and vibration is the first step toward corticalization.

Vibration in medicine has a double-faced aspect. On one side mechanical vibration has been shown to induce a work related pathology (3,4) leading to several attempts to reduce risks and increase surveillance (5,6).

However on the other side vibratory stimulations locally applied (LV) (3) on the skin overlaying muscles and tendons have been used for many years in clinical neurophysiology to study spinal cord reflex activity (4). LV has been also used as a non-invasive physical modality for the management of several conditions such as pain (5-12) and spasticity (13-16).

LV has been also proposed as a non-invasive methodology to improve motor functions in normal subjects as well as in hemiplegic subject (17). Although the exact mechanisms thought which LV acts on the sensory motor integration system is still a matter of deepening. It has been postulated that LV can act at several neural level both at spinal cord (18-20) as well as at supra segmental level both in normal and in patients (17,12,21).

With technical improvements in the last decades, investigations pertaining to human brain functions by non-invasive methods have become possible. Likewise, because of its improved spatial resolution and whole brain coverage, fMRI can demonstrate differences between brain images at rest or during various conditions. Accordingly, assessment of sensory-motor activity by the use of functional imaging with positron emission tomography and fMRI have been reported in the recent literature during a wide range of physiological settings such as controlled movements (22). Only very few data are present in fMRI literature on the central effects of LV (23, 24).

No data are present on the possible effect of LV associated with a motor task on the central motor activity. A great interest for the use of vibration as a therapy would be to understand if and where these areas are activated and to what extent.

References

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The purpose of this case report is to describe central effect of a localized vibration during a motor task in healthy men.

Subjects History and Review of Systems

The subjects were 3 healthy men (all aged 23 years). All 3 subjects not exhibited substantial skeletal, muscular, neural, and neuromuscular impairments. Written informed consent was obtained from the subjects.

Clinical impression

The 3 young men included in this case series were all healthy university students of the Pavia Medical School. Subjects were assigned at different sequences of interventions during fMRI acquisitions: movement task alone and movement task with vibratory stimulus. All subjects completed the case series designed study.

Examination

Movement task

Participants were engaged in a right-hand self-paced finger tapping task (FT) (25). During the fMRI acquisition, all study participants were instructed to alternatively rest for 1 minute and tap using their index, middle and annular fingers for 2 minutes for a total duration of 18 min and 15 sec. All subjects undergo the same procedure two times, for each subject, the images were realigned to the first image in the time series to correct for head motion. Different slice acquisition times and linear trends and non-linear drifts were also removed by temporal filtering. These preprocessed images were then co-registered to T1 images acquired for each subject and normalized into a standard stereotactic space (Talairach stereotactic system) (27,28). All the analysis were conducted using BrainVoyger QX 2.8 (Brain Innovation, Maastricht, The Netherlands) (29).

Outcome

We first run a GLM-FFX analysis to identify the area significantly active in the FT condition. We used motion correction predictors as covariate of no interests because during preprocessing the 3D motion correction was major than 1 mm. Statistical map was then created using a False Discovery Rate threshold correction (q<0.01), considering positive all clusters bigger than 9 voxels (30).

In the FT>REST condition (Figure 1) we found a significant bilateral activation, greater in the left hemisphere than in the right one, in the frontal premotor area, SMA, central gyrus (M1), postcentral gyrus, cerebellum. Only in the left hemisphere we found activation in the lenticular nucleus and in the thalamus.

We also found a bilateral activation of the visual area due to the stimulus signal.

We run a second analysis using the FT activation map as a mask, excluding the negative signals, to verify the hypothesis that the vibratory stimulation associated with Finger Tapping movement could amplify the activity of the motor network. This analysis showed that only the right cerebellum correlate positively with the vibratory stimulation (Figure 2).

Discussion

As far as we know this is the first observation using fMRI in which a vibratory stimulus was found able to ac-
tivate, as expected, not only different sensory areas (both homo- and contralateral) but also to significantly increase the activity in ipsilateral motor cerebellar areas when applied during a motor task.

Vibratory stimulation is transduced through the activation of mechanoreceptor located at the distal end of sensory neurons and innervated by Aβ afferents that transmit tactile sensory signals to the central nervous system. Their activation elicit a somatosensory, tactile, perception: from a sensation of light touch to flutter and vibratory sensation (31-35). These afferents are not intermingled as they transmit the tactile sensory signals to the cortex in a segregated way. This segregation is at the basis of different responses according to the types of vibration. Imaging studies in animals have demonstrated a specific spatial patterns in the primary sensory cortical area (S1) activity in response to the sustained pressure (1 Hz), flutter (30/50 Hz) and vibration (200 Hz). A frequency inducing flutter sensation increased cortical activity in contralateral S1 and S2, whereas a frequency inducing vibration increased activity in contralateral sensory cortical area S2 respectively (36-40).

Since the 60s LV has been demonstrated to induce different neurophysiological effects such as an initial inhibition of spinal monosynaptic reflex (41), a tonic prolonged contraction of the vibrated muscle (Tonic Vibratory Reflex-TVR) (42), and a post vibratory potentiation (43). Indeed all these effects are mainly related to the impact of LV on the spinal cord network and were found short lasting.

The exact mechanism thought which LV acts on the motor system at the suprasegmental level is still poorly understood. In a previous work, we observed that LV, acts at a central system level generating a long lasting modification in the motor unit recruitment pattern reducing the recruitment of fast fatigable motor unit. The conditioning was able to maintain the same mechanical output requested, reducing the myoelectric manifestations of fatigue, thus increasing the neuromuscular efficiency of the system (17).

The brain maintains the capacity of reorganizing its neural network architecture following environmental changes (17,44,45). The fMRI findings of an increase motor activity in the cerebellar cortex could be related to this ability of the nervous system to modify its activity depending on the continuous inflow of relevant inputs (46).

The cerebellum is placed at the crossroads of sensory-motor integration. Purkinjé cells are its landmark. While Purkinjé cells are the only output neurons of the cerebellar cortex, they receive two distinct afferent pathways convey...
information from the periphery. Mossy and climbing fibres inputs from cutaneous mechanoreceptors reach Purkinje cells and can be accounted for the anatomical pathway through which mechanical stimulations can reach the cerebellum (47). Moreover the cerebellar distribution of these mechanoreceptive inputs are highly somatotopical and mainly ipsilateral to the side of the mechanostimulation (48). These data are congruous with our results of an ipsilateral activation of the cerebellum. Indeed in animal experiments most of the short latency responses via mossy fibers resulted from activation of the receptors of the ipsilateral side and that also climbing fibre discharges from the ipsilateral side were more frequently evoked than from the contralateral side (47).

These data pin point a possible new role of cerebellar activation in the rehabilitation as well as in training setting of the healthy person. A congruous LV stimulation seems able to induce plastic rearrangement in the sensory motor coupling involving the cerebellar structure. This could be the basis for a better coordination in health subject, as well as a novel approach to patients with the activation of a non-lesioned pathway in case of central nervous lesions such as in hemiplegia.

The importance of high frequency vibration versus lower frequency vibration is forwarded by laboratory acquisition showing that only when muscle stretch receptors are driven maximally by a high frequency vibration, neurons in the motor cortex and in area 3a in monkeys are effectively activated (49). This could indicate a supremacy in cortical activation of high frequencies versus lower frequencies.

This report is aiming to trigger new studies on how a LV can influence motor recovery in neurorehabilitation and to (re) consider the role of cerebellum in the rehabilitation strategy.

It is thus possible if not mandatory to speculate further experimental protocols aimed to better assess other conditioning effects of a vibratory stimulus on the central nervous system and in particular on the cerebellum and the role played by different stimulus parameters.

References


