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Activation of cerebellar nuclei comparing finger, foot and tongue movements as revealed by fMRI

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Abstract

The aim of the present study was to compare possible activation of the interposed and dentate cerebellar nuclei during finger, foot and tongue movements using functional magnetic resonance imaging (fMRI). Nineteen healthy control subjects performed sequential finger and repetitive tongue and foot movement tasks. Thin slices (2.5 mm) were acquired of the cerebellar region containing the cerebellar nuclei with high spatial resolution (matrix size 128 × 128 × 10) using a Siemens 1.5 T Sonata system. Use of an eight channel head coil provided better signal-to-noise-ratio compared to standard head coils. Only data of those 12 subjects were included in final statistical analysis, who showed significant activation of the cerebellar nuclei at least in one task. Cortical activations of the superior cerebellum were found in accordance to the known somatotopy of the human cerebellar cortex. Nuclear activations were most significant in the sequential finger movement task. Both interposed nuclei and ipsilateral dentate nucleus were activated. Dentate activation was present in the more caudal parts of both the dorsal and ventral nucleus. Activation overlapped with motor and non-motor domains of the dentate nucleus described by Dum and Strick [R.P. Dum, P.L. Strick, An unfolded map of the cerebellar dentate nucleus and its projections to the cerebral cortex, J. Neurophysiol. 89 (2003) 634–639] based on anatomical data in monkey. Tongue movement related activations were less extensive and overlapped with activations of caudal parts of the dentate nucleus in the finger movement task. No nuclear activation was seen following foot movements.

The present findings show that both interposed and dentate nuclei are involved in sequential finger movements in humans. Interposed nucleus likely contributes to movement performance. Although no direct conclusions could be drawn based on the present data, different parts of the dentate nucleus may contribute to movement performance, planning and possible non-motor parts of the task.

Keywords: Cerebellar nuclei; Human; Somatotopy; Interposed nucleus; Dentate nucleus

1. Introduction

Early animal studies have shown a gross somatotopy within the cerebellar cortex [2,28,41]. Two inverted somatotopic maps have been found. The leg is represented anteriorly within the anterior lobe, with the arm and face represented successively more posteriorly. In the posterior lobe the arrangement is the reverse with the face represented anteriorly. Later animal studies have described a fractured somatotopy, that is the receptive fields of adjacent cerebellar cortical patches do not present adjacent skin areas, and multiple patches exist for the same skin area [5,39]. Earlier PET studies and more recent fMRI studies have confirmed a gross somatotopy within the cerebellar cortex in humans [21,31,33].

Animal data suggest a somatotopically representation also within the cerebellar nuclei. According to Thach and others each of the cerebellar nuclei – fastigial, interposed and dentate – contains a complete map of the body parts with the leg located anteriorly, the arm at intermediate sites, and the head located posteriorly [3,44]. Distal parts are located medial (that is limbs) and proximal parts (that is trunk) are lateral. More recent studies of Strick and Dum [10] support that rostral-leg to caudal-face

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somatotopy within the dorsal dentate nucleus. According to their findings, the dorsal parts of the dentate nuclei project to motor areas whereas the ventral parts project to non-motor areas of the cerebral cortex. Recent recording studies in rats, on the other hand, found that the receptive fields of all responsive neurons in the dentate nucleus were large. The receptive fields of most neurons covered the ipsi- and contralateral face as well as forepaws [36].

None of the fMRI studies in humans examining somatotopic representation within the cerebellum report activation of the cerebellar nuclei. Activations were shown in the cerebellar cortex only. The aim of the present fMRI study was to examine possible activation of the interposed and dentate nuclei during finger movements compared to foot and tongue movements. Movements in particular of the fingers were expected to be followed by activation of both the interposed and the dentate nucleus, primarily on the ipsilateral side. Movements were examined with eyes closed and arms and legs fully supported. Because of no oculomotor and no or little postural requirements, activation of the fastigial nuclei was not expected [6,26, 32,38].

2. Material and methods

2.1. Subjects

A total of 19 healthy subjects (11 males/8 females, mean age of 27.5 ± 5.8 years) participated. Only data of individual subjects were included in final analysis, which showed significant activation of the cerebellar nuclei in at least one of the three tasks (see below). Data of 12 of the subjects (11 right handed, 7 males/5 females, mean age of 29.3 ± 5.6 years) were included in group statistical analysis. An informed consent was obtained from all the participants. The study was approved by the local Ethics Committee.

2.2. Experimental tasks

The subjects had to perform four block design (7×30 s rest, 6×30 s task) fMRI sessions (135 scans each). The four sessions were performed on the same day with the entire fMRI experiment lasting 26 min. The *first* session was used as control condition: auditory clicks (50 ms duration, 750 Hz) were presented via headphones with a frequency of 3 Hz and the subjects had only to listen to the clicks. In the *second* session sequential finger tapping was performed. Subjects used their right index finger and pressed one out of four buttons in the following order: 1-2-3-4-4-3-2-1-1-2-3-4. The same clicks as in the first session were presented and the subjects had to tap synchronized with the clicks (one tap per click). Tapping movements were recorded with an optical response keypad (LUMItouch, Photon Control Inc., USA). To avoid possible additional movements of the upper arm and forearm the right arm of the subjects was strapped to the subjects' body. In the *third* session rapid right foot movements paced with the clicks were performed. The leg was fixed. The foot was passively held in 90° dorsalflexion. Mediolateral foot movements were performed with two movements per click. Foot movements were recorded with a custom-made optical response system. In the *fourth* session tongue movement was performed by repeating the syllables "da-da" auditory paced to the clicks (one syllable per click). To avoid possible head movement artifacts subjects were instructed to perform this task "silent" that is moving only their tongue but without moving their lips. Subjects layed in a dark scanner room with their eyes closed during the whole measurement.

2.3. fMRI scanning

A Siemens 1.5T Sonata system (Siemens, Erlangen, Germany) was used to acquire blood oxygenation level dependent (BOLD) contrast-weighted echo-planar images (EPIs) for functional scans. Thin slices were acquired of the cerebellar region containing the nuclei using high spatial resolution. All fMRI images were acquired with an eight channel head coil using standard imaging. Eight channel head coils provide better signal-to-noise-ratio (SNR) and image quality compared to standard circular polarized (CP) head coils [20].

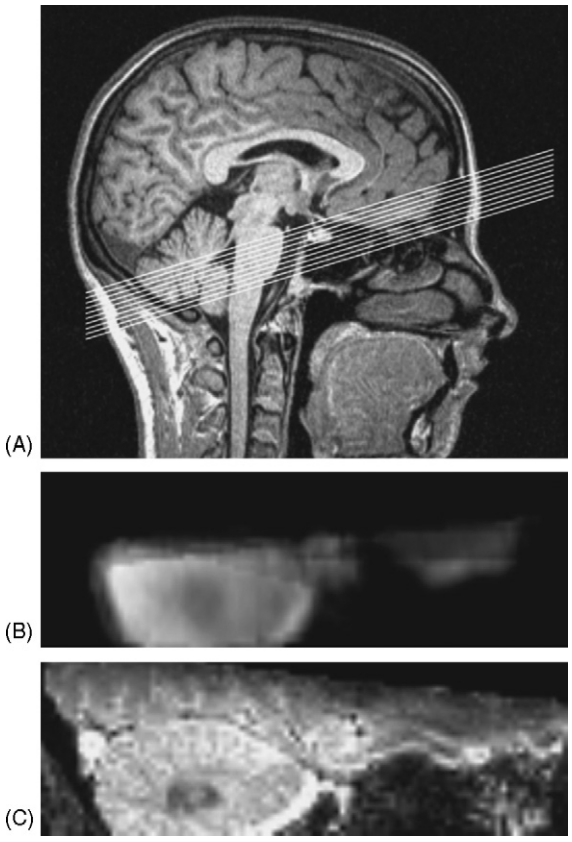

Fig. 1. Illustration of the cerebellar region, which was scanned during the experiment. Ten axial slices parallel to AC–PC line were acquired covering the region posterior to the roof of the fourth ventricle. (A) Localiser scan. (B) Group average of the normalised volumes of the 12 subjects included in final statistical analysis. (C) For comparison similar sagittal section ($x = 16$ mm) taken from the MRI atlas of the human cerebellar nuclei published by Dimitrova et al. [8]. Hypointense (dark) areas in the centre of the cerebellar sections correspond to the dentate nucleus.

For each subject the roof of the fourth ventricle was identified on the localizer scan and 10 continuous 2.5 mm thick axial slices parallel to AC–PC line were set up covering the region posterior to the roof of the fourth ventricle (Fig. 1). Each EPI session consisted of 135 mosaic scans with matrix size = $128 \times 128 \times 10$, TR = 3000 ms, TE = 55 ms, FoV = 230 mm, flip angle = 90° and voxel size = 1.8 mm × 1.8 mm × 2.5 mm. Because of magnetization relaxation effects the first five volumes in each session were discarded from further analysis.

2.4. Image analysis

Preprocessing and statistical analysis of the imaging data was performed with statistical parametric mapping software (Wellcome Department of Cognitive Neurology, London, UK, http://www.fil.ion.ucl.ac.uk/spm2.html), version SPM2, implemented in MATLAB (Mathworks, Sherborn, MA). All images were first realigned then spatially normalised into the reference system of Talairach and Tournoux [43], using a representative standard EPI template from the Montreal Neurological Institute (MNI) [12,14]. During normalisation the functional images were subsampled to a voxel size of 2 mm × 2 mm × 2 mm and then smoothed using an isotropic Gaussian kernel (6 mm full width at half-maximum).