

Mapping the human brain during a specific Vojta's tactile input: the ipsilateral putamen's role

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Abstract

A century of research in human brain parcellation has demonstrated that different brain areas are associated with functional tasks. New neuroscientist perspectives to achieve the parcellation of the human brain have been developed to know the brain areas activation and its relationship with different stimuli. This descriptive study aimed to compare brain regions activation by specific tactile input (STI) stimuli according to the Vojta protocol (STI-group) to a non-STI stimulation (non-STI-group). An exploratory functional magnetic resonance imaging (fMRI) study was performed. The 2 groups of participants were passively stimulated by an expert physical therapist using the same paradigm structure, although differing in the place of stimulation. The stimulation was presented to participants using a block design in all cases. A sample of 16 healthy participants, 5 men and 11 women, with mean age 31.31 ± 8.13 years was recruited. Indeed, 12 participants were allocated in the STI-group and 4 participants in the non-STI-group. fMRI was used to map the human brain in vivo while these tactile stimuli were being applied. Data were analyzed using a general linear model in SPM12 implemented in MATLAB. Differences between groups showed a greater activation in the right cortical areas (temporal and frontal lobes), subcortical regions (thalamus, brainstem, and basal nuclei), and in the cerebellum (anterior lobe). STI-group had specific difference brain activation areas, such as the ipsilateral putamen. Future studies should study clinical implications in neurorehabilitation patients.

Abbreviations: fMRI = functional magnetic resonance imaging, STI = specific tactile input.

Keywords: basal ganglia, brain, magnetic resonance imaging, neurology, palpation, physical therapy

1. Introduction

A century of research in human brain parcellation has demonstrated that different brain areas are associated with functional tasks.^[1] New neuroscientist perspectives to achieve the parcellation of the human brain have been proposed.^[2] Several neurological approaches have been developed to know the brain areas activation and its relationship with different stimuli.^[3]

Indeed, recent studies showed that a 20 minutes length touch input promotes contralateral putamen stimulation.^[4] These studies prompted us to develop an evidenced-based model to understand the interactions between specific tactile stimulus and brain areas activation. Since the 20th century, Vojta therapy proposed tactile stimulation in body areas which were determined to activate innate motor programs in humans. According to this therapy, different body areas were proposed for specific tactile stimulation such as the chest, iliac spine, calcaneus, or femoral epicondyle. During this stimulation, involuntary contractions and movements may be observed. After this activation, motor behavior changes may be produced.^[5-8] We aimed to exploit this knowledge to improve specific tactile stimulation protocols for clinical approaches and brain areas patterns recognition. This clinical framework may guide the design of neurological therapy strategies to enable robust modulation of gait and posture.^[3] Thus, this stimulus seems to be widely applied in clinical practice, nevertheless research studies about the effect of a specific tactile stimulation need to be stated in a specific body area according to Vojta therapy and a nonspecific area.^[5-8]

The long-lasting touch input is transmitted by a sensory system of low threshold mechanoreceptive tactile C-afferents. These afferents innervate the human skin and show the major firing frequency by this maintained skin stimulation.^[4,9,10] In addition, C-fibers project to the posterior insula.^[11] The tactile input may modulate various brain areas functionality via the insular cortex. The insular cortex and related brain network could be relevant to the changes in brain functions promoted by tactile stimuli.^[12]

According to our research, the human putamen's role could be influenced by a short-term specific touch stimulus at a located chest point.^[5] Therefore, the putamen and the caudate nucleus, together, form the dorsal striatum, where the cortical and

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subcortical inputs are processed into the basal ganglia. Despite of the putamen is commonly activated during pain; its role has often been related to motor processing.^[13] Nowadays, new insights of ex vivo microdissection and in vivo diffusion tractography demonstrated a previously unappreciated 3-dimensional architecture in mediating the interhemispheric connectivity with the contralateral putamen and caudate nucleus.^[14]

Up to now, the human putamen's role correlated to touch is rarely reported. We anticipate our intervention to be a starting point for more sophisticated in vivo models during specific tactile stimulation to improve brain knowledge. Our results could show that a specific directional tactile input located between the 7th and 8th ribs of the thoracic region during at least 5 minutes length may functionally activate a main part of the basal ganglia, the ipsilateral putamen.

2. Experimental procedures

No statistical methods were performed to predetermine sample size. The participants were randomized by the Epidat 3.1 software and the random numbers according to an equal probability were obtained. The researchers were not blinded to allocation during experiments. Nevertheless, outcome assessment was a blinded process. An exploratory functional magnetic resonance imaging (fMRI) study was carried out following The Strengthening the Reporting of Observational Studies in Epidemiology statement and checklist.^[15]

2.1. Participants

The ethic committee of the Ruber International hospital approved this study (registry number: 0761). All subjects signed the consent inform before the data collection. Therefore, this informed consent was obtained for the experiments involving human participants. All methods were performed in accordance with the relevant guidelines and regulations. A sample of 16 asymptomatic participants, 5 men and 11 women, with mean \pm standard deviation, age 31.31 ± 8.13 years, height 1.67 ± 8.83 m, and weight 63.68 ± 10.62 kg were included. Indeed, 12 participants received a specific tactile input (STI-group) and 4 participants received a non-STI-group.

2.2. Tactile stimuli location

The main difference between both stimuli (STI-group and non-STI-group) was the skin place of stimulation. STI-group was stimulated in a specific area (intercostal space, at the mammillary line between the 7th and 8th ribs) according to the Vojta therapy,^[5-8] while the non-STI-group was stimulated in a nonspecific area (quadriceps distal 3rd and 8cm cranial to the superior angle of the patellar bone). This may result so relevant in order to know differences about the stimulated area.

2.3. fMRI stimuli

The 2 groups of participants (STI-group and non-STI-group) were passively stimulated by an expert physical therapist using the same paradigm structure, although differing in the place of stimulation as explained below. The stimulation was presented to participants using a block design in all cases. The block design consisted of blocks of stimulation of 5 minutes duration per side. The block started with 30 seconds of rest and then 30 seconds of stimulation, this protocol was repeated 5 times by half body. All runs started with a rest block.

All participants were placed in supine decubitus with a relaxed anatomical position. The head was rotated 30° at the same side of stimulation. Nevertheless, all of them were stimulated by an ipsilateral input. First, the STI-group was stimulated over the skin on the intercostal space, at the mammillary line between the 7th and 8th ribs. This stimulus was applied by the right thumb of the physical therapist. A slight pressure between 1.4 and 1.8 kg/cm² \pm 200g was performed with a dorsal, cranial, and medial directional specific tactile stimulus, toward the contralateral shoulder, during 5 minutes, according to Vojta.^[5-8] Second, the non-STI-group was stimulated over the skin on the quadriceps distal 3rd and 8cm cranial to the superior angle of the patellar bone. Furthermore, the same direction, duration, and pressure were performed in both groups for both sides (1° right side; 2° left side). For both groups, 2 series of fMRI data were acquired, for left and right sides of the body. Previous training with the task was applied to all participants outside of the scanner in a previous session.

2.4. fMRI acquisition

The fMRI data were acquired on a 3.0T Magnetom Prisma scanner (Siemens, Erlangen, Germany) using a 64 channel head coil. Head motion was minimized with a vacuum pack system molded to fit each participant. Functional images were obtained with a gradient echoplanar sequence using blood oxygenation level-dependent contrast, each comprising a full volume of 50 contiguous axial slices (2mm thickness, 0.5mm spacing) covering the whole brain. Volumes were acquired continuously with a repetition time (TR) of 3 seconds (TE = 3 milliseconds, flip angle = 90, field of view [FOV] = 220 mm). A total of 100 scans were acquired for each participant in a single session (5 minutes run). High-resolution T1-weighted magnetization prepared rapid gradient-echo (MPRAGE) anatomical images were also obtained for each participant (144 1.1-mm-thick sagittal images, TR = 2300, TE = 2.98, FOV = 220 mm, 248 \times 256 matrix).

2.5. fMRI data analysis

The data were analyzed using a general linear model in SPM12 (Wellcome Department of Imaging Neuroscience, London, UK, www.fil.ion.ucl.ac.uk/spm/) implemented in MATLAB R2010a (Mathworks, Inc, Sherborn, MA). Individual scans were; spatially realigned and unwarped to compensate for head-movement; corrected for differences in slice acquisition time (slice timing correction); spatially normalized; and spatially smoothed to reduce noise and to compensate for anatomical intersubject variability (Gaussian filter of 8 mm FWHM), using standard SPM methods. Population inference was made through a 2-stage procedure. First, a subject-specific analysis was carried out where the blood oxygenation level-dependent response for each voxel and experimental condition was modeled by a boxcar waveform convolved with a canonical hemodynamic response function plus temporal and dispersion derivatives. Rest condition served as baseline.

Statistical parametric maps of the t statistic (SPM{t}) were generated for each participant, and the contrast images were stored. For each individual, we determined the effect of the condition of interest: stimulation > rest and rest > stimulation.

In a 2nd level random-effects analysis, a 2 \times 2 (lateral by group) ANOVA model was used. We constructed an F contrast to test for the main effect of group, which indicates the extent

Table 1**Descriptive data between both groups.**

Descriptive data	Group		P	Statistics (df)
	STI-group (n=12)	Non-STI-group (n=4)		
Sex (male/female)	3/9	2/2	.547 [*]	$\chi^2=0.873$ (1)
Age, y	29.50 ± 15.25	37.00 ± 15.75	.298 [†]	$U=15.500$
Weight, kg	62.75 ± 9.35	66.50 ± 15.15	.559 [‡]	$t=-0.598$ (14)
Height, cm	166.08 ± 7.77	170.25 ± 12.28	.433 [‡]	$t=-0.808$ (14)
BMI, kg/m ²	22.68 ± 2.29	22.68 ± 2.48	.997 [‡]	$t=-0.004$ (14)

BMI=body mass index, df=degrees of freedom, IR=interquartile range, SD=standard deviation, STI=specific tactile input.

^{*} Frequency and Fisher exact test were applied.

[†] Median ± IR and Mann–Whitney *U* test were used.

[‡] Mean ± SD and Student *t* test for independent samples were utilized.

to which the STI-group differs from that applied in the non-STI-group (a $P < .001$ at the voxel level was applied in all cases). Then, 2 2-sample *t* test were used in order to compare the effects of STI-group versus non-STI-group in the left and right hemi-body. The surviving activated voxels were superimposed on high-resolution structural magnetic resonance (MR) scans of a standard brain (Montreal Neurological Institute [MNI]). Anatomical identification was performed with reference to the Talairach Daemon Software (<http://www.talairach.org/>) and also via XjView8 (<http://www.alivelearn.net/xjview8/>).

2.6. Descriptive data statistical analysis

SPSS 22.0 software (IBM SPSS Statistics for Windows; NY: IBM Corp) was used for the descriptive analysis data. An α error of 0.05 (95% confidence interval) and a desired power of 80% (β error of 0.2) were utilized. First, the Shapiro–Wilk test was applied to assess normality. Second, a comparative analysis between both groups was performed. For the qualitative variable, frequency and Fisher exact test were analyzed. For the parametric data, mean ± standard deviation and Student *t* test for independent samples were used. For the nonparametric data, the median ± interquartile range and Mann–Whitney *U* test were applied.

3. Results

3.1. Descriptive data

Regarding the Table 1, there were not statistically significant differences between the STI-group and non-STI-group for sex ($P = .547$; $\chi^2 = 0.873$), age ($P = .298$; $U = 15.500$), weight

($P = .559$; $t = -0.598$), height ($P = .433$; $t = -0.808$), and body mass index ($P = .997$; $t = -0.004$).

3.2. fMRI results

Functional images were analyzed by SPM12 using a general linear model applied at each voxel across the whole brain. We localized those brain areas that modulated their activity during the stimulation condition. We focused on voxels for which the difference between the responses to the stimulation blocks and resting condition was statistically significant. Results showed a main effect of group (Table 2 and Fig. 1), showing a greater activation in the right cortical areas (BA 46), subcortical regions (basal ganglia), and in the cerebellum (culmen).

In order to separate effects of stimulation on the left or right side of the body, 2 two-sample *t* tests were applied. Results for the left side of the body stimulation are shown in Table 3 and Fig. 2, showing a greater activation in the right parahippocampal gyrus, and in different subcortical areas (putamen, medial globus pallidum, and subthalamic nucleus).

On the other hand, results for the right side stimulation are shown in Table 4 and Fig. 3, showing a greater activation in the right frontal lobe (BA 6), right subcortical regions (putamen, subthalamic nucleus and thalamus), and in the left cerebellum (tonsil).

When we directly compared the statistically significant differences between the STI-group and the non-STI-group, we found cortical activation in the frontal and temporal areas, a great bilateral activation in putamen and thalamus, besides the activation of the insula and anterior cerebellum (Table 5; Figs. 4–7).

Table 2

Locations and *t*-values of the main clusters when comparing the main effect of group. In columns: lobe and region, Brodmann area, hemisphere (H), cluster size, MNI coordinates, *t*-value, and Z.

Region	Lobe	Brodmann area	H	Cluster	x,y,z, mm	F-value	Z
Cortical	Temporal lobe	Middle temporal gyrus (BA 21)	R	13	56 -24 -6	18.03	3.45
	Frontal lobe	Middle frontal gyrus (BA 46)	R	10	42 30 16	17.63	3.42
Subcortical	Thalamus		L	26	-2 -18 0	16.61	3.33
	Brainstem	Mammillary body	L		-4 -12 -6	17.32	3.39
	Brainstem	Subthalamic nucleus	R	1	8 -12 -2	14.68	3.15
	Basal nuclei	Lentiform nucleus (putamen)	L	105	-26 -6 8	31.13	4.27
Cerebellum	Anterior lobe	Culmen	R	30	8 -28 -12	21.24	3.69
	Anterior lobe	Culmen	R	1	16 -34 -18	14.34	3.12

H=hemisphere, L=left, MNI=Montreal Neurological Institute, R=right.

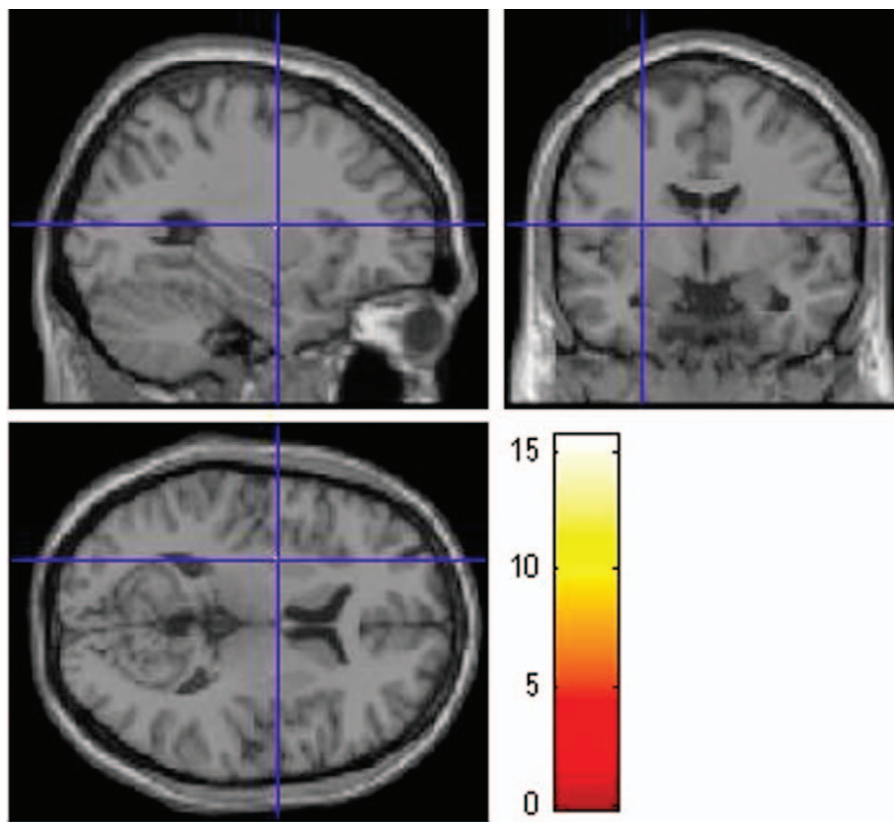


Figure 1. Group activation map showing the main effect of group. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

4. Discussion

The primary objective in the present study was to analyze the differences at the central nervous system between the STI-group and a non-STI-group procedure in healthy participants. Our results revealed statistical differences among groups showing a greater activation in cortical areas, subcortical regions (putamen), and in the cerebellum in the STI-group. These structures play a very important role in the involvement of the ganglia in motor acts.^[16] It is also part of a circuit that is affected by numerous neurological alterations such as in Parkinson disease.^[17]

Other authors such as Pastor et al^[18] also observed their activation during tactile stimulation and where they emphasize the importance of the putamen in the automatic processing of the perceptive characteristics before a stimulus. The stimulus used

during STI-group triggers the activation not only of the basal ganglia, but also of the structures that accompany it in the cerebral circuits for the control (among other actions) of the motor function. More authors such as Malouin et al perform a study of motor imagination in which they obtain an activation of the basal ganglia before the imagination of different everyday situations. They conclude in their study that basal ganglia play an important role in locomotor movements of an automatic nature.^[19] Also, other investigators found a relationship between the supplementary motor area, the putamen, and the anterior cerebellum. They concluded that when actions become automatic, these zones increase their brain activity.^[20–22] Our study differs in the design of the task proposed by the previous authors, but it coincides in the activation of this areas, which could be due because of the automatic nature proposed with this stimulation.^[8]

Table 3

Locations and *t*-values of the main clusters when comparing the STI-group > non-STI-group stimulation in the left side of the body, in columns: lobe and region, Brodmann area, hemisphere, cluster size, MNI coordinates, *t*-value, and Z.

Region	Lobe	Brodman area	H	Cluster	x,y,z, mm	<i>t</i> -value	Z
Cortical	Limbic lobe	Parahippocampal gyrus (BA 28)	R	19	18 -12 -12	5.73	3.90
Subcortical	Sublobar	Lentiform nucleus (putamen)	L	84	-28 -6 10	7.69	4.54
	Sublobar	Claustrum	L		-32 0 -2	5.10	3.65
	Sublobar	Lentiform nucleus (medial globus pallidus)	L	13	-12 -8 -6	4.80	3.52
	Brainstem	Subthalamic nucleus	R	5	8 -10 -4	4.37	3.32
	Brainstem	Mammillary body	R	1	4 -8 -12	4.04	3.15

H=hemisphere, L=left, MNI=Montreal Neurological Institute, R=right, STI=specific tactile input.

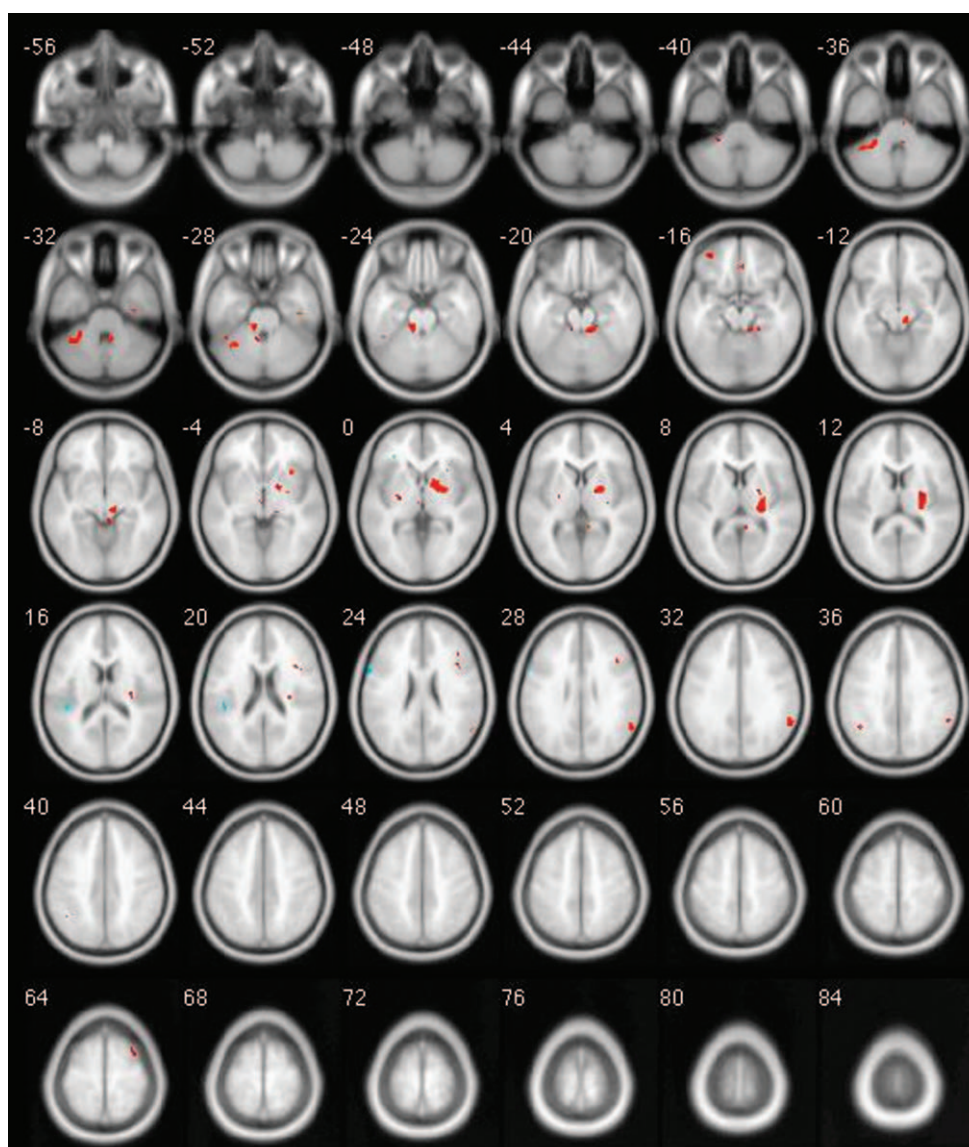


Figure 2. Map showing the differences between the specific tactile input (STI)-group > non-STI-group stimulation in the left side of the body. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

Moreover, the results of this intervention show a relationship with the only similar study found to date.^[23] This survey found an increase of the cerebral activity in the contralateral pontomedullar reticular formation, in the posterior bilateral

hemisphere and vermis. Contrary to this study, we used the pectoral area to perform the stimulation, obtaining a different activation in a greater number and specificity of cortical areas (Brodmann 46, 20, 21, 22, hippocampal gyrus, and inferior

Table 4
Locations and t-values of the main clusters when comparing the STI-group > non-STI-group stimulation in the right side of the body, in columns: region, hemisphere, cluster size, MNI coordinates, t-value, and Z.

Region	Lobe	Brodmann area	H	Cluster	x,y,z, mm	t-value	Z
Cortical	Frontal lobe	Middle frontal gyrus (BA 6)	R	1	36 4 64	3.93	3.09
Subcortical	Basal nuclei	Lentiform nucleus (putamen)	R	1	24 -4 2	4.18	3.22
	Basal nuclei	Lentiform nucleus (putamen)	R	1	28 -14 12	4.07	3.16
	Basal nuclei	Lentiform nucleus (lateral globus pallidus)	R	1	20 -4 2	4.08	3.17
	Brainstem	Red nucleus	R	2	8 -26 -8	4.07	3.17
Cerebellum	Posterior lobe	Cerebellar tonsil	L	10	-26 -42 -34	4.60	3.43

H=hemisphere, L=left, MNI=Montreal Neurological Institute, R=right, STI=specific tactile input.

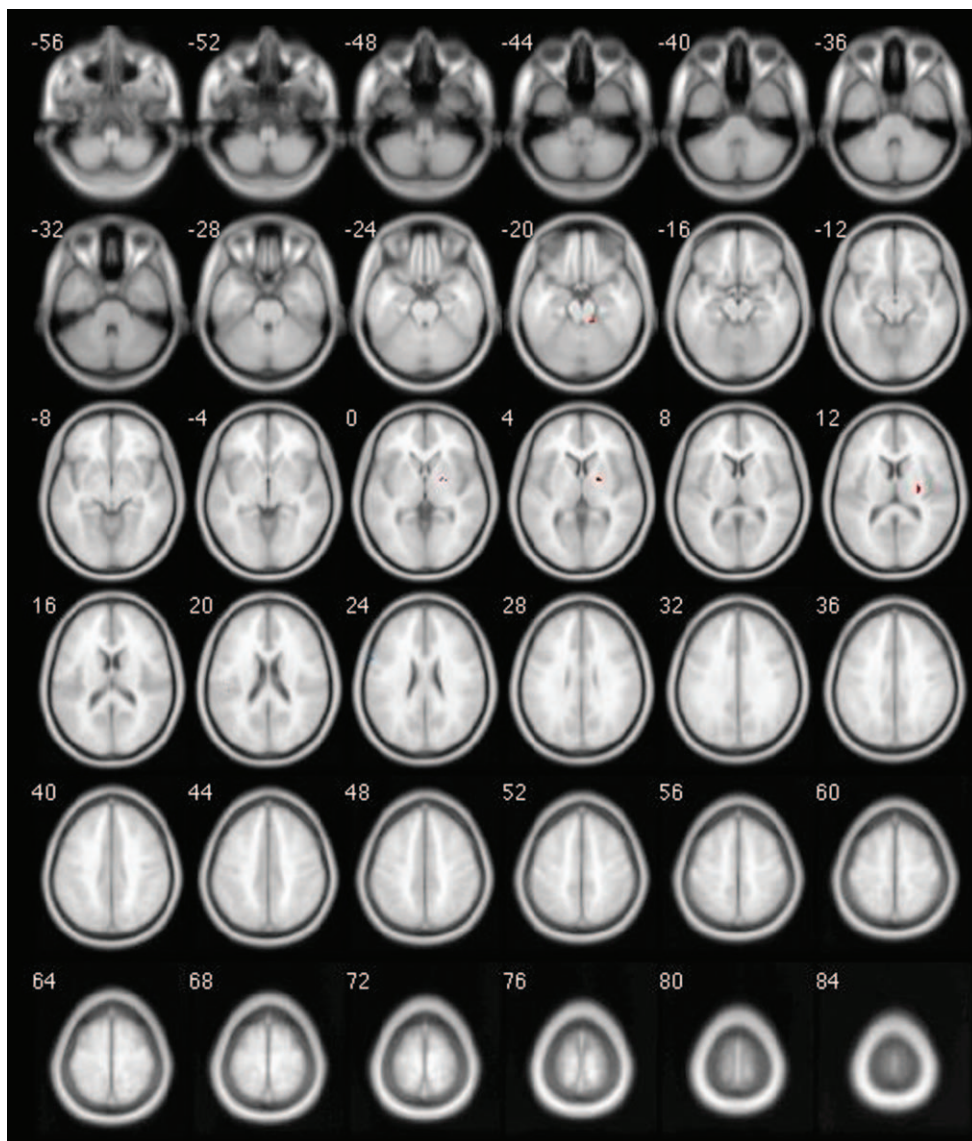


Figure 3. Map showing the differences between the specific tactile input (STI)-group > non-STI-group stimulation in the right side of the body. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

Table 5

Locations and t -values of the main clusters when comparing the STI-group > non-STI-group stimulation, in columns: region, hemisphere, cluster size, MNI coordinates, t -value, and Z .

Region	Lobe	Brodman area	H	Cluster	x,y,z, mm	t -value	Z
Cortical	Temporal lobe	Middle temporal gyrus	R	28	56 -24 -6	4.25	3.63
	Frontal lobe	Frontal lower gyrus	R	22	42 30 16	4.20	3.60
	Frontal lobe	Subfrontal gyrus	R	9	42 16 26	3.58	3.17
Subcortical	Basal nuclei	Lentiform nucleus (putamen)	L	142	-26 -6 8	5.58	4.42
	Basal nuclei	Lentiform nucleus (putamen)	R	8	24 14 -2	3.74	3.28
	Basal nuclei	Caudate nucleus	R	8	14 10 8	3.69	3.25
	Thalamus	Thalamus	R	14	8 -12 -2	3.83	3.35
	Thalamus	Thalamus	L	1	-2 -18 0	4.08	3.52
Cerebellum	Insula	Insula	R	10	32 18 -4	3.72	3.27
	Anterior lobe	culmen	L	8	16 -34 -18	3.79	3.32

H=hemisphere, L=left, MNI=Montreal Neurological Institute, R=right, STI=specific tactile input.

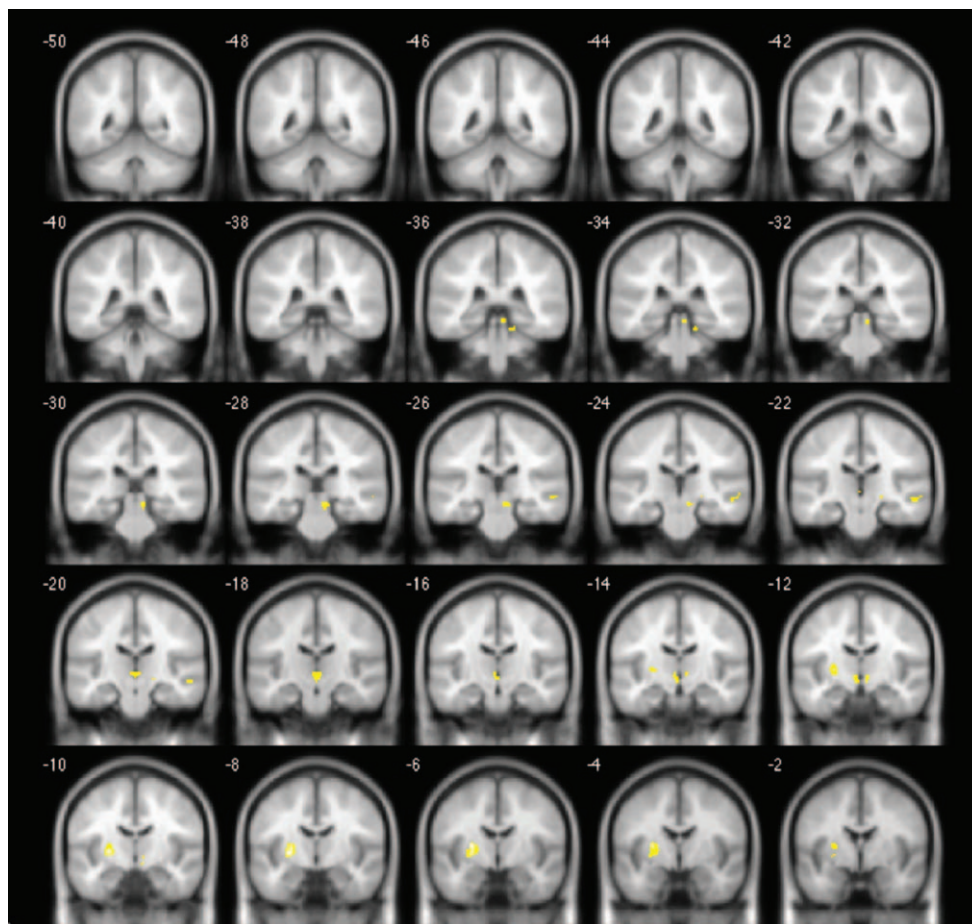


Figure 4. Map showing the differences between the specific tactile input (STI)-group > non-STI-group stimulation. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

frontal gyrus), and a greater specificity in the results on active subcortical structures (putamen, globus pallidus, subthalamic nucleus of luy, C, mammillary bodies, and red nucleus).

On the other hand, when we examined the data obtained comparing the left and right side of the body we found a greater activation at the subcortical area like the putamen when ipsilateral stimulation was performed. The data are in line with previous surveys studying the motor sequencing and learning.^[24] and with Preusser et al^[25] in which they relate the basal ganglia

with the perception of the tactile stimuli, concretely the putamen. Additional research such as Chang et al recorded the brain activity before the application of sensory and proprioceptive stimuli in humans, reporting a greater ipsilateral influence to the stimulated zone.^[3] Finally, another study performed acupuncture stimulation and found an activation of the ipsilateral putamen to the stimulated zone.^[16] In contrast, other investigators compared the motor task with tactile stimulation and reported lower ipsilateral hemisphere activity during the execution of a motor

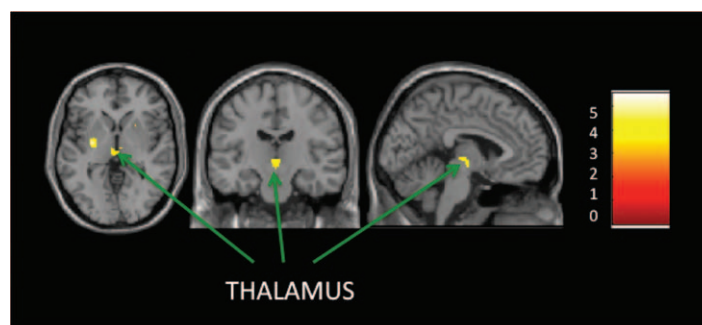


Figure 5. The image shows the activation of the thalamus area during the activation of the specific tactile input (STI)-group > non-STI-group. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

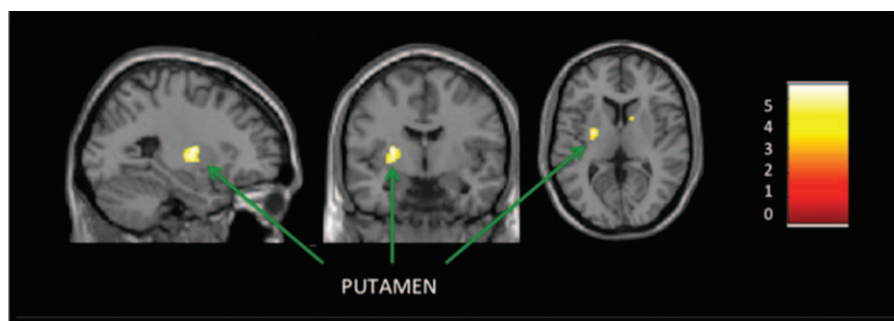


Figure 6. The image shows the activation of the putamen area during the activation of the specific tactile input (STI)-group > non-STI-group. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

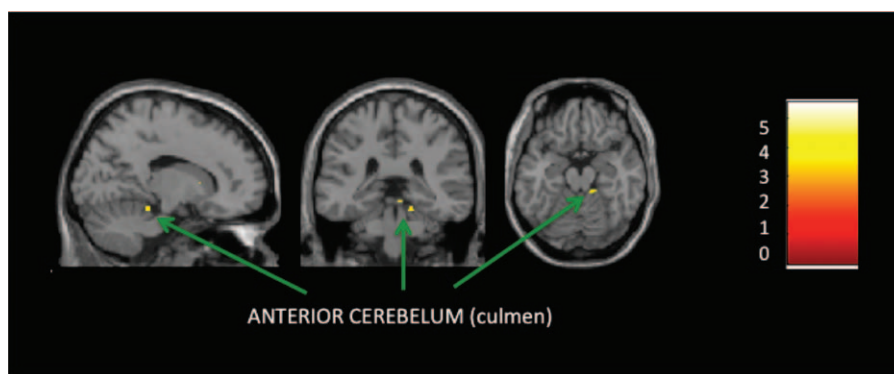


Figure 7. The image shows the activation of the anterior part of the cerebellum during the activation of the specific tactile input (STI)-group > non-STI-group. Images thresholded at $P < .001$. Neurological convention is followed (left side of the brain is shown on the left side of the figure). Results are visualized using xjView toolbox (<http://www.alivelearn.net/xjview>).

task.^[26] Future studies should improve current knowledge to better understand the functional specialization of the cerebral hemispheres and the recording of tactile, proprioceptive, and motor action information which could help the tactile stimulation treatments develop on patients.

According to Hok et al,^[23] the brainstem modulation role after peripheral pressure stimulation and the after-effects of reflex locomotion physiotherapy involve a modulation of the pontomedullary reticular formation. This may be a strong hypothesis in order to justify the Vojta therapy mechanisms.^[5–8] As future research in order to understand deeply these mechanisms, we propose the tractography analysis in conjunction with fMRI in patients with cerebral palsy during Vojta stimulation.^[27]

Banazek et al^[28] promoted the main hypothesis about the Vojta effect and how the central nervous system with a Vojta stimulation allows to, using neuronal plasticity, recreate an access to the human's postural development program and gradually replace pathological motor patterns by those more regular.

Along with these results in asymptomatic participants, future studies should be carried out with STI-group intervention in neural rehabilitation treatment for patients who need Vojta therapy.

5. Conclusion

In conclusion, our results illustrate that the specific Vojta tactile input generates important changes at the cortical and subcortical levels, especially the ipsilateral putamen. Future studies should study clinical implications in neurorehabilitation patients.

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