Functional bold MRI: advantages of the 3 T vs. the 1.5 T

Reyes García-Eulate[a],*, David García-García[b,c], Pablo D. Dominguez[a], Jose J. Noguera[a], Esther De Luis[a], María C. Rodriguez-Oroz[b,c], Jose L. Zubieta[a]

[a] Department of Neuroradiology, Clínica Universidad de Navarra and Medical School, University of Navarra, Pamplona, Spain
[b] Neuroscience Division, Department of Neurology and Neurosurgery, Clínica Universidad de Navarra and Medical School, CIMA, University of Navarra, Pamplona, Spain
[c] Centro Investigación Biomédica en Red Enfermedades Neurodegenerativas (CIBERNED; Spanish Government), Madrid, Spain

* Corresponding author. Clínica Universidad de Navarra, Avenida Pio XII 36, Pamplona 31008, Spain. Tel.: +34 948255400; fax: +34 948 296500. E-mail address: mgeulate@unav.es (R. García-Eulate).

ABSTRACT

We quantitatively evaluate the benefits of a higher field strength for functional brain MRI (fMRI) based on the blood oxygenation level-dependent contrast. The 3-T fMRI shows a higher sensitivity for the motor and somatosensory stimulation and more specific localization in the grey substance. The 3-T fMRI detects additional areas of activation with the motor paradigm.

KEYWORDS

Functional MRI; Motor task; Somatosensory stimulation; Field strength

1. INTRODUCTION

Functional MRI (fMRI) based on the blood oxygenation level-dependent (BOLD) contrast is one of the most frequently used functional neuroimaging techniques. It is becoming an indispensable technique for the study of cortical function organization, both in healthy subjects and in patients with neurological diseases, both for clinical and research goals. Because of the widespread availability of the 1.5-T equipment, these magnetic fields are usually the ones most frequently used for fMRI explorations.

However, several biophysical models analyzing the MRI signal, sensitive to oxygenation changes induced by neuronal activity, propose that the variation of the water proton relaxation ratio located inside or near large vessels (veins) is linearly proportional to the static magnetic field strength (B_0), while the water proton relaxation ratio near small vessels and capillaries (tissue) is proportional to the square of the static magnetic field strength (B_0^2) [1–7].

Therefore, the use of higher strength fields will probably bring a significant improvement in the sensitivity results related to the BOLD changes in the "capillary bed" as a response to neuronal activity.

With increasing field strength and increasing susceptibility effects, a larger extent of brain tissue reveals signal changes due to activity. Then, the number of voxels labelled as activity increases and the *t* value of activated voxels may serve as a measure of functional sensitivity [8–15].

The aim of this study was to evaluate the potential benefits of higher field strength for the fMRI based on the BOLD contrast using motor and somatosensory tasks.

2. MATERIALS AND METHODS

2.1. Subjects and tasks

Ten healthy volunteers, four women and six men, participated in the study. The age range was 26–49 years and the mean age was 39. All of them were right handed. None of them had any history of neurological, psychiatric disease, or head trauma. All the participants provided written informed consent after an explanation of the experimental study. The study protocol was approved by the local ethics committee.

Each session consisted of performing the motor task followed by the somatosensory stimulation. Each subject performed two sessions on the same day, one at 1.5 T and another at 3 T. Half of the volunteers, randomly chosen, began the study on the 1.5-T machine and the others on the 3 T to exclude training bias.

2.2. Paradigms

The motor paradigm consisted of touching sequentially the right-hand fingers with the thumb (finger–thumb opposition movement). For the somatosensory paradigm, the left-hand palm was brushed by the same investigator for all the subjects.

For the two paradigms, we used a block design: each task was performed followed by rest in four cycles. This resulted in four right-hand tapping conditions and four baseline conditions per run for the motor task and four left-hand palm brushed conditions and four baseline conditions per run for the somatosensory stimulation. Each block lasted for 30 s (acquisition of 10 volumes).

2.3. Image technique

The fMR images were performed on a 1.5-T machine (Siemens Symphony Quantum magnet, Siemens AG, Erlangen, Germany) and on a 3-T machine (Siemens Trio magnet, Siemens AG) using an eight-channel head coil in both cases. The study consisted of high spatial resolution anatomic images, for coregistering the functional images (T1 3D MPRAGE sequence, 160 slices, 1 mm thickness, TR 2600 ms, TE 2.98 ms) and high time-resolution images in order to detect the signal changes (T2 EPI MOCO sequence, 36 slices, 3 mm thickness, TR 3000 ms, flip angle 90°, TE 50 ms at 1.5 T and 30 ms at 3 T, 80 volumes). The axial images were acquired parallel to the anterior and posterior commissure plane, covering the entire brain.

2.4. Data analysis

2.4.1. Preprocessing

We used SPM2 (Welcome Department of Cognitive Neurology, London; http://www.fil.ion.ucl.ac.uk) for the image preprocessing and the statistical analysis to create activation maps.

Functional volumes were realigned to the central volume (Image 40 of the temporal serial). For each image, we obtained six movement parameters (translation and rotation in each axis X, Y, Z) [16,17]. Subjects with a head movement of more than 2 mm in translation and/or 2° in rotation were excluded from the analysis.

Next, each realigned volume was spatially normalized to stereotactic space MNI (Montreal Neurologic Institute), using a bilinear interpolation (voxel size 3×3×3 mm) [18]. To increase signal-to-noise ratio, functional images were smoothed with a Gaussian isotropic filter (8 mm) [19].

2.4.2. Functional MRI data analysis

For each paradigm, BOLD response was modelled by the convolution of the neuronal functions with the canonical hemodynamic response to form the covariates in a general lineal model. The six parameters obtained in the realigned process of each subject were included as covariates in the matrix design to remove movement variance.

2.4.3. Individual analysis

In the individual analysis, we used *t*-contrast, obtaining the differences in activity between the condition in which the subject did the task and the rest condition. The activation maps for each subject were obtained with a threshold of $P<.05$ family-wise

error (FWE) corrected in the motor task. For the sensitive task, we used a threshold of P<.001 uncorrected, because of the low significance of the cortical activation obtained with this paradigm.

Sensitivity in the activity detection on each machine was quantified with the comparison of the number of activated voxels in each task. For the two tasks, the overall mean of the number of activated voxels in a specific area was calculated and compared between the 1.5- and 3-T fMRI examinations. This comparison can serve as a measure of sensitivity. As an additional measure of sensitivity, the mean *t* value in a specific area at 1.5 and 3 T was compared. The statistical analysis was performed with SPSS 15 for Windows (SPSS, Inc., Chicago, IL, USA). Both sensitivity measures were calculated for each of the paradigms (motor and sensitive). To contrast sensitivity, we first examined the distribution of each parameter and subsequently chose the most appropriate type of statistical analysis.

Based on previously published studies [10–15], we selected the left precentral area, left postcentral area, and left supplementary motor area (SMA) to calculate the sensibility for the study of the motor paradigm. In the somatosensory task, we used the right precentral area and the right postcentral area. All these areas belong to the primary sensorimotor cortex. The regions were obtained through the AAL tool (Neuroscience Research and Cerebral Image Center CYCERON, Caen, France).

For the motor task, the number of voxels and the mean *t* value in the left precentral area and in the left postcentral area, for 1.5 and 3 T, have the same distribution, so we used a paired t test to compare them. In the SMA area, the Shaphiro–Wilk test showed non-normal distribution in both machines and in both parameters of sensitivity, so we used the Wilcoxon test to calculate the significance of the increase.

For the somatosensory paradigm, the number of activated voxels and the mean t value in both the studied areas (right precentral and right postcentral) have a normal distribution in 3 T and in 1.5 T. We used paired *t* test to analyze them.

2.4.4. Group analysis

In both paradigms, we calculated the group activation map for the 1.5 and the 3 T separately (threshold P<.05 FWE corrected and minimum cluster size of 20). In this manner, we compared the activation areas obtained in each magnetic field. The activated cortical voxels surviving this procedure were superimposed on a stereotaxically normalized high-resolution MR anatomic scan, to identify the matching anatomic regions.

The coordinates of the activated clusters were projected to the standard stereotactic space of Talairach and Tournoux [20] and processed using the Talairach Daemon Client (The Researcher Imaging Center—UTHSCSA; http://ric.uthscsa. edu). To obtain brain atlas/Talairach coordinates, the nonlinear transform of MNI to Talairach brain as described by M. Brett (http://www.mrc-cbu.cam.ac.uk/Imaging/mni space.html) was applied. In this way, we determined which anatomical areas corresponded to activated voxels.

3. RESULTS

The head movement of one of the study subjects while he was performing the sensitive task overran the inclusion criteria. Therefore both somatosensory tasks of this subject were excluded from the analysis.

3.1. Individual results

3.1.1. Motor task

The overall increase in the mean number of activated voxels in 3 T compared to 1.5 T was 46% (P=.009) in the left precentral area, 60% (P=.024) in the left postcentral area, and 85% (P=.012) in the left SMA (Fig. 1A).

The overall increase in mean t value was higher at 3 T than at 1.5 T in the left precentral area (19%, P=.012), in the left postcentral area (16%, P=.015), and in the left SMA (79%, P=.008) (Fig. 1B).

This quantitative analysis revealed an overall mean increase of 57% (P=.013) on activated voxels and a mean increase of 17% (P=.004) on *t* values for the 3 T compared with the 1.5 T in the motor paradigm.

3.1.2. Somatosensory task

The overall number of activated voxels was 57% (P=.014) higher in the right precentral area and 55% (P=.028) higher in the right postcentral area at 3 T than at 1.5 T (Fig. 2A). The overall increase in mean *t* value in 3 T compared to 1.5 T was 18% (P=.008) in the right precentral area and 12% (P=.028) in the right postcentral area (Fig. 2B).

The analysis of results in the somatosensory task showed an overall mean increase of 51% (P=.028) on activated voxels and an overall mean increase of 15% (P=.028) on *t* values for the 3 T compared with the 1.5 T.

In summary, both tasks showed a similar trend towards a higher sensitivity of the 3-T field.

3.2. Group results

The statistically significant coordinates of the activated points within each of the group analyses (MNI) are projected into the standard stereotaxic space of Talairach and Tournoux [19].

The activation areas of the motor task were located in the right cerebellar lobe and in the left hemispheric precentral, postcentral, and supplementary motor regions. However, the most activated points in the 3-T machine were located more specifically in the grey matter. Furthermore, new activation areas showed up on the left deep grey matter (putamen and ventral posterior medial nucleus of the left thalamus) (Fig. 3A and Table 1).

Regarding the somatosensory stimulation, the coordinates were located in the left cerebellar lobe and in the precentral and postcentral regions of the right hemisphere. The 3-T machine showed a relatively higher activation in the grey matter, although new activation areas were not detected (Fig. 3B and Table 2).

4. DISCUSSION

This study evaluates the potential benefit of a 3-T magnetic field vs. a 1.5-T one for the assessment of brain fMRI (BOLD imaging) utilizing somatosensory and motor paradigms. We compared brain activity data elicited by motor and somatosensory stimulation at intra-individual and group levels.

We used two parameters to measure the sensitivity for each field: activity volume and mean t value of the activated areas. Both showed the benefit of a higher magnetic field objectively. Our study showed a higher sensitivity of the 3-T MR system vs. the 1.5-T one on the activated area of the somatomotor cortex. The overall mean volume increase was 57% for the motor task and 58% for the somatosensory stimulation. The overall mean *t*-value increase was 17% for the motor task and 15% for the somatosensory task. The results were statistically significant, with a higher statistical power for the motor paradigm using sequential movement of the fingers (hand-typing task). These findings support the results published in previous studies [7–14].

The difference between the statistical significance of the results obtained in the motor task and somatosensory stimulation highlights the importance of the paradigm used. Both the size and intensity of the cortical activation areas are related to the ability of the task to trigger brainwork. The cortical activation, in terms of both size and intensity, is directly related to the individual participation in the task. We often find poor patient collaboration in clinical practice due to a deteriorated physical or psychological condition. In these cases, it is important to have an alternative study strategy. Therefore this somatosensory paradigm may be useful in clinical practice.

There were concordant activation areas (identified in both 1.5- and 3-T fields), but there were also activated areas that were only detected by the 3 T. Furthermore, the concordant areas showed a higher grey- vs. white matter activation rate in the 3 T as compared to the 1.5 T.

The increment of the 3-T BOLD effect brings about several advantages for the brain fMRI. It reduces the exploration time for a given resolution, which is very helpful for the study of less collaborative or disabled patients. It also provides higher resolution for a given time or a combination of both. This benefit can be used for the design of shorter and less complicated paradigms.

The most important limitations arise because no gold standard can be offered. This is especially of concern with regard to the additional activated areas detected with 3.0 T. It is also well known that susceptibility artefacts scale exponentially with increasing field strength, causing geometric distortions, particularly in areas close to the skull base or near the air-field sinuses. Susceptibility artefacts were less problematic in our study, which mainly focused on areas were signal dropout is not a major concern. Also, a

limited number of subjects were examined; therefore, the results cannot be generalised to a larger population without reservation.

In conclusion, we demonstrate a significant increment of the 3 T vs. 1.5 T sensitivity for both the motor and somatosensory tasks in the brain fMRI. This higher sensitivity is shown by a larger activation volume size and higher mean t values. We also obtained additional activation areas and a relatively higher activation of the grey matter with the 3 T.

ACKNOWLEDGMENTS

We thank Lesley Brain for editing the English grammar during the preparation of the manuscript.

REFERENCES

1) Ogawa S, Lee TM, Kay AR, Tank DW. Brain magnetic resonance imaging with contrast dependent on blood oxygenation. Proc Natl Acad Sci U S A 1990;87:9868–72.
2) Ogawa S, Tank DW, Menon RS, et al. Intrinsic signal changes accompanying sensory stimulation: functional brain mapping with magnetic resonance imaging. Proc Natl Acad Sci U S A 1992;89: 5951–5.
3) Sunaert S. Presurgical planning for tumor resectioning. J Magn Reson Imaging 2006;23:887–905.
4) Frayne R, Goodyear BG, Dickhoff P, et al. Magnetic resonance imaging at 3.0 Tesla challenges and advantages in clinical neurological imaging. Invest Radiol 2003;38:385–402.
5) Voss HU, Zevin JD, McCadlliss BD, Functional MR. Imaging at 3.0 Tesla versus 1.5 T: a practical review. Neuroimaging Clin N Am 2006; 16:285–97.
6) Fisel CR, Ackerman JL, Garrido L, et al. MR contrast due to microscopically heterogeneous magnetic susceptibility: numerical simulations and applications to cerebral physiology. Magn Reson Med 1991;17:336–47.
7) Gati JS, Menon RS, Ugurbil K, Rutt BK. Experimental determination of the BOLD field strength dependence in vessels and tissue. Magn Reson Med 1997;38:296–302.
8) Meindl T, Born C, Britsch S, Reiser M, Schoenberg S. Functional BOLD MRI: comparison of different field strengths in a motor task. Eur Radiol 2008;18:1102–13.
9) Turner R, Jezzard P, Wen H, et al. Functional mapping of the human visual cortex at 4.0 and 1.5 tesla using deoxygenation contrast EPI. Magn Reson Med 1993;29:277–9.
10) Yang Y, Wen H, Mattay VS, Balaban RS, Frank JA, Duyn JH. Comparison of 3D BOLD functional MRI with spiral acquisition at 1.5 and 4.0 T. Neuroimage 1999;9:446–51.
11) Tieleman A, Vandemaele P, Seurnick R, Deblaere K, Achten E. Comparison between functional magnetic resonance imaging at 1.5 and 3 Tesla: effect of increased field strength on 4 paradigms used during presurgical work-up. Invest Radiol 2007; 42:130–8.

12) Hoenig K, Kuhl CK, Scheef L. Functional 3.0-T MR assessment of higher cognitive function: are there advantages over 1.5-T imaging? Radiology 2005;234:860–8.
13) Fera F, Yongbi MN, van Gelderen P, Frank JA, Mattay VS, Duyn JH. EPI-BOLD fMRI of human motor cortex at 1.5 T and 3.0 T: sensitivity dependence on echo time and acquisition bandwidth. J Magn Reson Imaging 2004;19:19–26.
14) Krasnow B, Tamm L, Greicius MD, et al. Comparison of fMRI activation at 3 and 1.5 T during perceptual, cognitive, and affective processing. NeuroImage 2003;18:813–26.
15) Krüger G, Kastrup A, Glover GH. Neuroimaging at 1.5 T and 3.0 T: comparison of oxygenation-sensitive magnetic resonance imaging. Magn Reson Med 2001;45:595–604.
16) Henson R, Büchel C, Josephs O, Friston K. The slice-timing problem in event-related fMRI (abstr). NeuroImage 1999;6:S125.
17) Josephs O, Henson R. Event-related functional magnetic resonance imaging: modelling, inference and optimization. Philos Trans R Soc Lond B Biol Sci 1999;354:1215–28.
18) Friston KJ, Ashburner J, Frith CD, Poline JB, Heather JD, Frackowiak RS. Spatial registration and normalization of images. Hum Brain Mapp 1995;3:165–89.
19) Friston KJ, Holmes AP, Worsley KJ, Poline JP, Frith CD, Frackowiak RS. Statistical parametric maps in functional imaging: a general linear approach. Hum Brain Mapp 1995;2:189–210.
20) Talairach J, Tournoux P. Coplanar stereotaxic atlas of the human brain. New York (NY): Thieme, 1988.

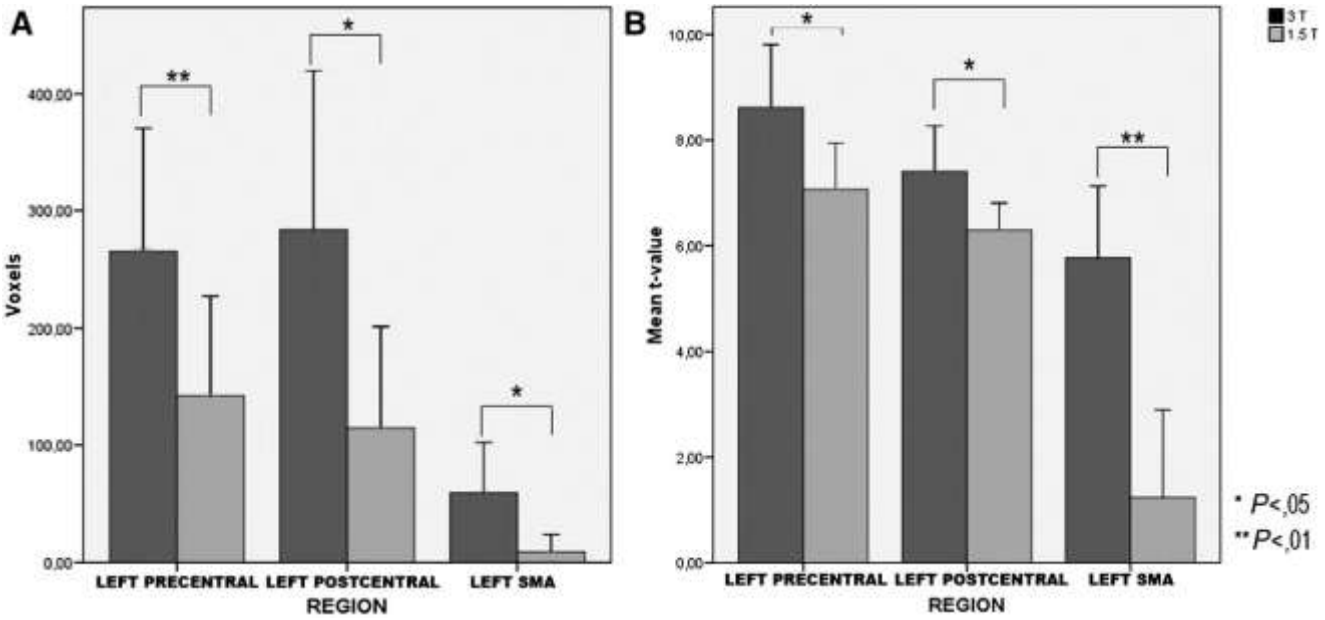

Figure 1. Motor-task sensibility. **(A)** Bar graph depicts overall mean cluster sizes (in number of voxels) of significant activation for the 3 T and 1.5 T results (P<.05 FWE corrected) in each of the selected areas. **(B)** Bar graph depicts the overall mean *t* value±standard error of the activated voxels for 3 T and 1.5 T results (P<.05 FWE corrected) in each of the selected areas (SMA: supplementary motor area).

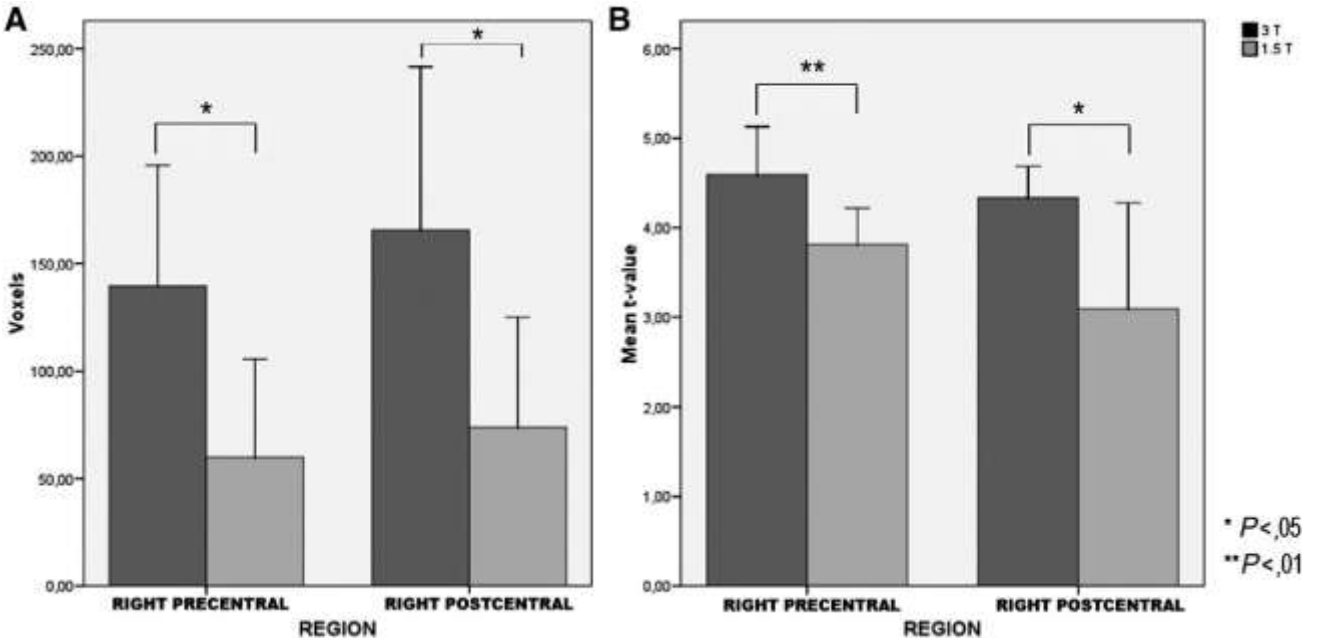

Figure 2. Sensitive-task sensibility. **(A)** Bar graph depicts overall mean cluster sizes (in number of voxels) of significant activation for the 3 T and 1.5 T results (P<.001 uncorrected) in each of the selected areas. **(B)** Bar graph depicts the overall mean *t* value±standard error of the activated voxels for 3 T and 1.5 T results (P<.001 uncorrected) in each of the selected areas.

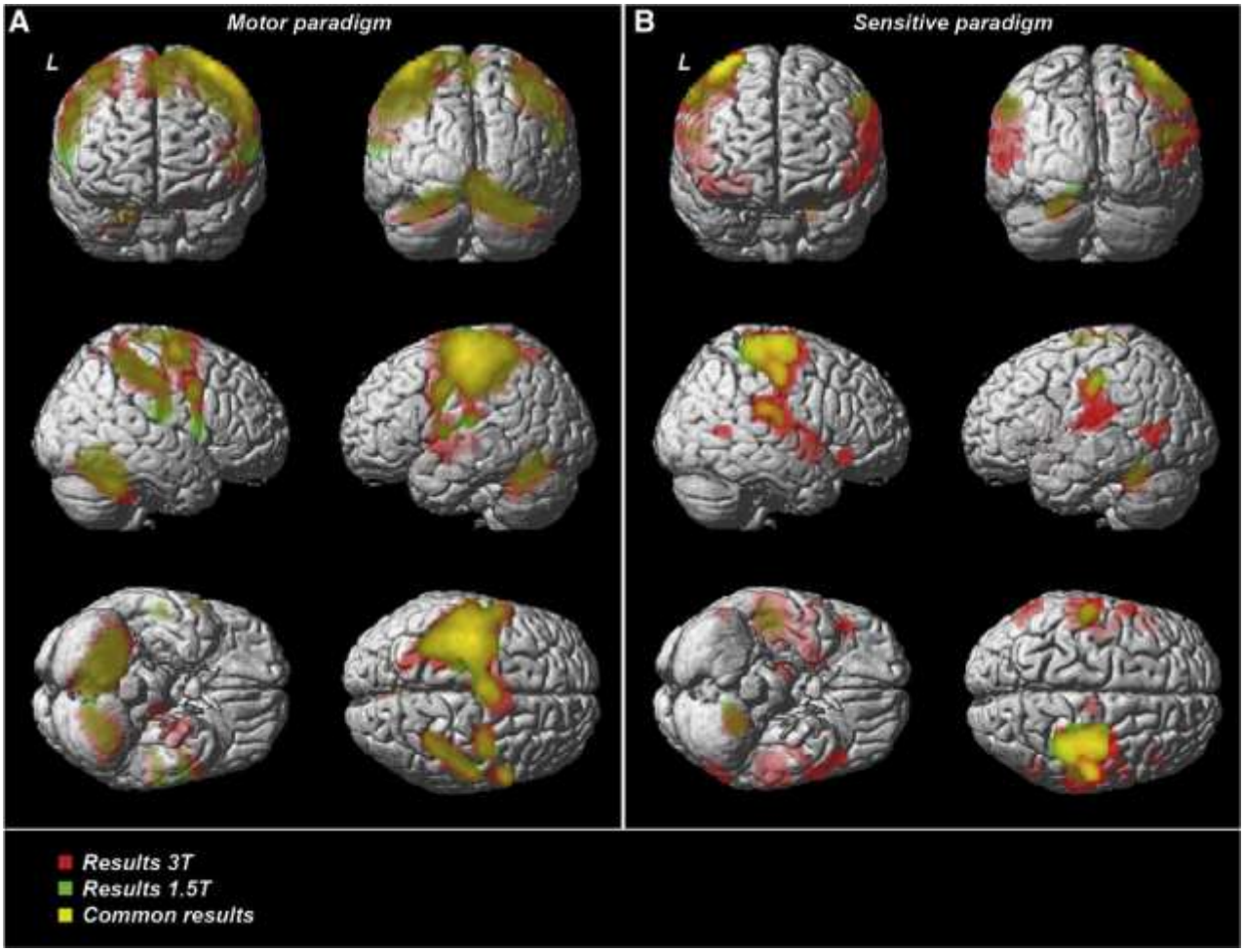

Figure 3. Functional group activation (P<.05 FWE corrected). Areas of significant activation are shown on a 3D rendering. Coordinates are listed in Tables 1 and 2. **(A)** Motor task. **(B)** Sensitive task.

Table 1. Brain areas and their local maxima stereotactic coordinates in clusters activated in the motor task in the 1.5-T and 3-T group analyses (P<.05 FWE corrected)

Region					**Cluster size**	***t* values**	**x**	**y**	**z**
1.5 T									
Left cerebrum	Frontal lobe	Precentral gyrus	White matter		1642	24.92	−36	−14	62
Left cerebrum	Parietal lobe	Postcentral gyrus	White matter			12.89	−48	−21	40
Left cerebrum	Frontal lobe	Medial frontal gyrus	Gray matter	Brodmann area 6		9.95	−3	−3	53
Left cerebrum	Frontal lobe	Precentral gyrus	Gray matter	Brodmann area 44	28	6.17	−48	0	6
Left cerebrum	Frontal lobe	Precentral gyrus	Gray matter	Brodmann area 6		5.65	−59	0	8
Right cerebellum	Anterior lobe	Culmen			765	18.13	21	−50	−18
Right cerebellum	Anterior lobe	Culmen				10.51	6	−62	−7
Right cerebellum	Posterior lobe	Declive				7.92	24	−62	−15
3 T									
Left cerebrum	Frontal lobe	Precentral gyrus	Gray matter	Brodmann area 6	2573	37.01	−39	−15	59
Left cerebrum	Parietal lobe	Postcentral gyrus	Gray matter	Brodmann area 3		18.27	−50	−18	42
Left cerebrum	Frontal lobe	Medial frontal gyrus	Gray matter	Brodmann area 6		15.52	−3	−3	53
Right cerebellum	Anterior lobe	Culmen			867	28.54	21	−50	−18
Right cerebellum	Anterior lobe	Culmen				12.16	6	−62	−10
Left cerebrum	Sub-lobar	Thalamus	Gray matter	Ventral posterior medial nucleus	50	8.52	−15	−20	1
Left cerebrum	Sub-lobar	Lentiform nucleus	Gray matter	Putamen	136	7.56	−27	−6	−5
Left cerebrum	Sub-lobar	Lentiform nucleus	Gray matter	Putamen		5.90	−27	−5	9

Table 2. Brain areas and their local maxima stereotactic coordinates in clusters activated in the sensitive task in the 1.5-T and 3-T group analyses (P<.05 FWE corrected)

Region					**Cluster size**	***t* values**	**x**	**y**	**z**
1.5 T									
Right cerebrum	Frontal lobe	Precentral gyrus	White matter		473	10.92	30	−14	67
Right cerebrum	Frontal lobe	Precentral gyrus	White matter			10.74	36	−14	62
Right cerebrum	Parietal lobe	Postcentral gyrus	White matter			10.11	42	−32	62
Left cerebellum	Anterior lobe	Culmen			59	7.88	−21	−50	−18
Left cerebellum	Anterior lobe	Culmen				5.93	−9	−53	−10
Right cerebrum	Sub-lobar	Insula	White matter		86	7.28	45	−19	20
Right cerebrum	Parietal lobe	Inferior parietal lobule	Gray matter	Brodmann area 40		7.25	50	−28	24
3 T									
Right cerebrum	Frontal lobe	Precentral gyrus			1309	13.47	36	−17	64
Right cerebrum	Parietal lobe	Postcentral gyrus	Gray matter	Brodmann area 3		12.35	53	−15	48
Right cerebrum	Frontal lobe	Precentral gyrus				11.80	39	−6	58
Left cerebellum	Anterior lobe	Culmen			116	9.91	−24	−48	−20
Right cerebrum	Sub-lobar	Extra-nuclear	White matter		73	6.41	36	−3	−5
Right cerebrum	Sub-lobar	Extra-nuclear	White matter			5.64	27	8	−8
Right cerebrum	Sub-lobar	Thalamus	Gray matter	Ventral posterior lateral nucleus	23	6.06	15	−17	4
Right cerebrum	Temporal lobe	Middle temporal gyrus	Gray matter	Brodmann area 37	21	6.01	53	−58	11