Neural mechanisms of imaginary pushing an object in different spatial directions: an fMRI study

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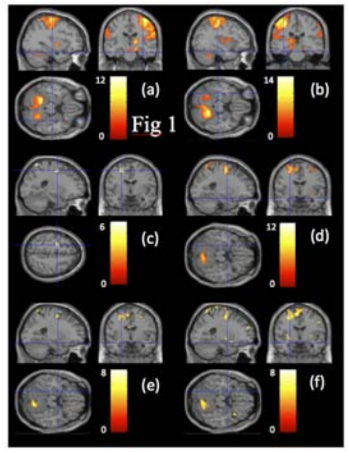
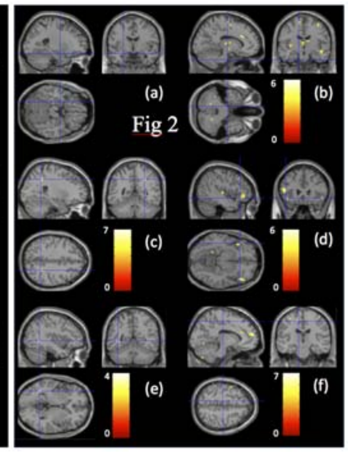
Target audience: neuroscientists, fMRI researchers, brain-computer interface researchers, clinical neurologists

Purpose: There is an increasing interest in measuring brain activities of motor imaginary, as they have potential to being used as a brain-computer interface (1). Functional MRI (fMRI) is increasingly used for brain-computer interface systems, as it provides a high-resolution map of the brain activities associated with neuronal activation. To date, most studies on motor imaginary are based on the immediate imitation of hand movements (2), grasping objects (3), or mental calculation or speech generation (4). The purpose of this study was to examine the potential of simple neural mechanisms of imaginary pushing a cross on the screen to the left, right, up or down to be used as a brain-computer interface. The goal of the study is twofold, (i) examining the neural mechanisms of imaginary pushing a cross on a screen in different directions, and (ii) assessing the potential of imaginary pushing as input for a brain-computer interface systems.

Methods: fMRI data were acquired of 15 healthy, male and right-handed volunteers (23-45 years), without a history of neurological or psychiatric deficits. Three runs were taken, each consisting of 28 trials, in which the different tasks (ie imaginary pushing a cross to the left, right, upwards or downwards or fingertapping, used as a control task) were executed in a random order (EPI sequence with TE=33ms, TR=3s, voxel size=2.2x2.2x3.5mm, acquisition time= 14min). To ensure that all tasks were performed correctly, all subjects were trained before scanning, involving a description of the task as well as the performance of the whole experiment. Finally, as eye movement could potentially affect the results, all subjects were informed not to move their eyes during imaginary pushing of the cross. All data were analysed using SPM8 software (www.fil.ion.ucl.ac.uk/spm/software/spm8). Preprocessing included motion and slice time correction, coregistration of the functional images with a T1 MPRAGE image, normalization to MNI space, and smoothing with a 8x8x8mm FWHM kernel. At the first-level analysis, contrasts of the different tasks were calculated as well as differences between left and right, upwards and downwards pushing. Second-level group analysis was then applied to display brain activation for the calculated contrasts on a group level. Voxels with uncorrected p < 0.001 were subsequently reported.





In addition to the fMRI processing, we also performed a predictive analysis to evaluate how well the fMRI signal could be used as a brain-computer interface. The three runs of the experiment were split up into two training runs and a third validation run. A Gaussian Naïve Bayes pooled variance classifier was thereby used to assess the predictive value of the results (Shinkareva et al. (2008)).

Results: In Fig 1, brain activations are shown, for the different conditions, i.e fingertapping left (a) and right (b) hand and imaginary pushing to the left (c), right (d), upwards (e), and downwards (f). An overview of the significant areas can be found in Table 1. As similar areas were activated during imaginary pushing in different spatial directions, only small differences were observed when the tasks were statistically compared (Fig 2). In Fig 2 results are displayed for pushing left>right (a), right>left (b), up>down (c), down>up (d), left+right>up+down (e), up+down>left+right (f). An overview of the significant areas can be found in Table 2.
For the predictive analyses, the best agreement with ground truth was found in discriminating fingertapping from imaginary pushing (agreement of 87.4%). Discrimination of left from right imaginary pushing resulted in an agreement of 61.2%, for upwards vs downwards 58.5%.

Table 1	Pushing right			Pushing Left			Pushing Down			Pushing Up		
Brain area	MNI	Z	N	MNI	Z	N	MNI	Z	N	MNI	Z	N
Right cerebellum	4 -70 -18	7.9	426				6 -70 -14	6.9	343	10 -68 -18	5.9	194
Left cerebellum	-22 -62 -22	4.9	20							-14 -62 -20	4.6	10
Right putamen	28 -8 -6	4.7	18				30 -2 2	5.2	35			
Left putamen	-28 -8 -2	5.3	12				-24 -6 -6	4.9	73	-28 -4 -6	5.3	7
Right insula	38 4 10	5.9	129	40 2 12	5.2	26	34 18 -14	5.4	74			
Left insula	-38 8 4	7.2	468				-40 0 10	5.23	79			
Right superior frontal	28 -2 62	5.9	106	30 -2 62	5	6	26 0 62	5.7	31			
Left superior frontal	-24 -8 56	12	622	-22 -4 54	5.8	72	-24 54 26	7.2	36	-12 -2 72	4.5	11
Right suppl motor area	2 -10 78	4.8	13				8 14 66	7.2	24			
Left suppl motor area	-10 0 56	5.6	64				-10 -8 60	7.6	891	-8 -6 56	5.8	37
Right supramarginal	62 -32 34	4.8	16				52 -20 36	5.5	74			
Left supramarginal	-64 -26 36	7.6	332							-64 -24 38	7.6	99
Right superior parietal	22 -56 64	4.4	12				18 -58 74	5.9	105	24 -56 64	5.7	86
Left superior parietal	-28 -58 70	9.5	331	-22 -60 72	6.1	57	-28 -58 70	6.5	305	-38 -52 66	8.3	243
Cingulate	2 18 28	5.4	6	-4 8 24	5	62	2 6 40	6.3	87			
Right middle frontal							46 -2 54	5.1	16	28 -4 54	4.9	14
Left middle frontal							-52 2 42	5.6	37	-28 -6 48	5.9	178
Right inferior frontal	54 2 12	4.3	8									
Left inferior frontal	-60 10 28	4.3	6				-56 12 10	8	643	-54 10 8	5.5	162
Left inferior parietal							-38 -22 42	6.3	226			

Table 2	Right > Left			Left > Right			Down > Up			Up > Down		
Brain area	MNI	Z	N	MNI	Z	N	MNI	Z	N	MNI	Z	N
Right cerebellum	26 -54 -32	4.6	22									
Left cerebellum	-38 -46 -38	4.5	6									
Left putamen	-18 8 2	4.5	7									
Right insula							34 18 -14	4.2	16			
Left insula	-34 -10 2	6.1	59				-38 -14 -4	6.3	68			
Right superior frontal	38 -12 60	5.3	30				12 40 46	6.3	5			
Left suppl motor area	-10 -4 60	5.3	36									
Left supramarginal	-66 -40 28	5	24									
Cingulate	-12 30 26	6	29				-2 40 8	5	25			
Left middle frontal	-32 46 18	4.4	7				-42 24 44	4.5	5			
Right inferior frontal							52 30 -10	6.3	70			
Left inferior frontal	-58 14 30	5.6	32				-40 24 -12	6.8	110			
Right inferior parietal										26 -50 40	7.1	28
Left inferior parietal	-40 -22 44	6.5	80				-8 -60 34	6.3	33			
Left parahippocampal							-22 -10 -30	4.7	10			
Left thalamus	4 -4 10	6.5	183				-8 -12 2	4.9	22			

Discussion: The brain regions that were activated during imaginary pushing were in agreement with literature, ie putamen, middle frontal gyrus, cerebellum, parietal cortex, supplementary motor area, etc. The motor imaginary task that was used in this study demonstrated the involvement of the neural motor network on a group level in healthy subjects. However, the involvement of different networks during imaginary pushing in different spatial directions could not be clearly demonstrated. Our results suggest the involvement of a bilateral network for imaginary pushing in all directions. The predictive analysis yields, with a prediction agreement of almost 87.4%, the best results for discriminating between imaginary movement and finger tapping. While significant, the prediction agreement of the other classifiers is insufficient for use in clinical practice. This proofs, as could be expected, that the discrimination between similar tasks, such as imaginary movement in different directions, or left and right finger tapping, is much more difficult than the discrimination between totally different tasks. Future work is needed to explore the neural mechanisms of motor imaginary further.

Conclusion: In this study, the neural mechanisms of imaginary pushing a cross on a screen were examined. We found that similar, bilateral brain regions were activated, during pushing a cross in different spatial directions, which were also found during other imaginary motor tasks (5). Differences between actual fingertapping and imaginary pushing could be reliably predicted, but the predictive value of pushing in different spatial directions was low.

References : (1) Wolpaw et al. IEEE Trans Neural Syst Rehabil Eng.2003;11(2):204-7; (2) Krams et al. Exp Brain Res.1998;120(3):386-98; (3) Matsumura et al. Neuroreport.1996 29;7(3):749-52; (4) Yoo et al. IEEE Trans Biomed Eng.2004;51(5):838-46; (5) Jeannerod et al. Neuroimage.2001;14(1 Pt 2):S103-9