Effective connectivity of the human motor system: differences in subcortical influences during automatic and effortful movements

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INTRODUCTION

We present for the first time evidence for differences in the activity of subcortical motor structures involved in automatic and effortful movements. Functional activation maps calculated for these two movement conditions show a dichotomy between the subcortical structures involved in automatic movements, the basal ganglia, in particular the putamen, and those involved in effortful movements, most notably, the cerebellum. However, these activation maps do not provide any information as to the extent to which both structures influence the motor cortex during the respective movement conditions. To that end, we used structural equation modeling (SEM) [1], [2] to estimate the path coefficients between the subcortical motor structures and supplementary motor area (SMA) and motor cortices to determine the influence the putamen and the cerebellum have on the primary motor structures during automatic and effortful movements.

METHODS

Data were acquired on six healthy, right-handed adults on a 1.5T scanner (Signa LX; GE Medical Systems, Milwaukee, WI). A single-shot gradient-recalled echo-planar pulse sequence (TR/TE = 1750/40 msec) with FOV = 24 cm and a 64x64 matrix was used to acquire 23 axial slices (5mm/1mm) yielding whole brain coverage. All subjects gave informed consent, and all successfully completed the study. fMRI data was collected for four different finger tapping tasks; each task consisted of alternating 20 second blocks of rest and tapping and lasted for 3 minutes and 40 seconds. The finger tapping tasks were: (1) tapping both index fingers simultaneously at a comfortable pace, (2) tapping both index fingers alternating at a comfortable pace, (3) tapping both index fingers simultaneously emphasizing the down stroke of the tap, and (4) tapping both index fingers alternating emphasizing the down stroke of the tap. Of particular interest are the bimanual tapping tasks. The final two tasks were designed to elicit effortful movement on the part of the subject.

Data for each subject were corrected for motion, normalized to the ICBM template, smoothed with an 8 mm FWHM Gaussian, and processed using SPM2 (Wellcome Department of Cognitive Neurology, London, UK). Volumes of interest (VOIs) were defined using SPM2 based on a combination of underlying anatomy and individual subject activation maps. VOIs were defined for each of the seven areas of interest shown in the anatomical model for each of the four bimanual tapping tasks. The average time series data from each VOI for a given task were used as inputs to an SEM algorithm, and the path coefficients between the brain regions shown in the path model in Figure (1) were calculated.

RESULTS

The results of SEM analysis show a trend towards the basal ganglia, in particular the putamen, exerting greater influence on the SMA during the bimanual, automatic tapping tasks and the lateral cerebellum, in the area of the dentate nuclei, exerting greater influence on the SMA during the bimanual, effortful tapping tasks. In addition, as the effortful tapping tasks require additional drive of the motor cortices, increased influence of the SMA on the motor cortices was seen during these two tasks.

In line with the functional activation maps generated for the tasks, we observe an increase in the influence of the putamen on the SMA paired with a decrease in influence of the cerebellum on the SMA for the automatic tapping tasks. Conversely, for the effortful tasks, we observe an increase in influence of the cerebellum on the SMA paired with a decrease in influence of the putamen on the SMA.

The observed differences are greater for the dominant, right hand. The data indicate that the non-dominant, left hand requires drive from both the cerebellum and the putamen during both automatic and effortful tapping tasks. The continual cerebellar influence on the SMA may be due to the role of the dentate nucleus in the timing of movements and the coordination of finger movements.

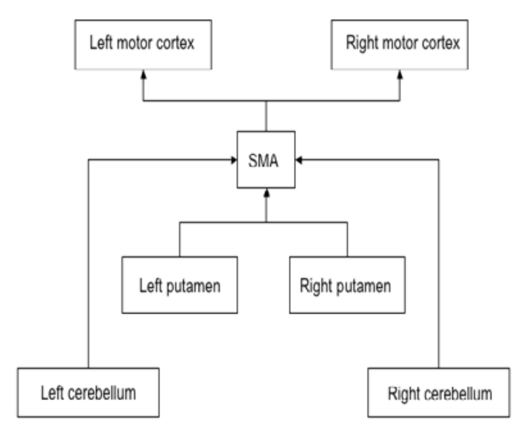

Figure 1: Path model used for SEM analysis of effective connectivity.

CONCLUSIONS

The results of the SEM analysis indicate a trend towards the putamen having a larger influence on automatic movements and the cerebellum on effortful movements. The results have the potential to address aspects of Parkinson's disease such as whether it is a disease caused solely by a loss of dopaminergic cells, or whether the connections between the subcortical and cortical motor structures also play a role.

REFERENCES

[1] McIntosh A and Gonzalez-Lima F. *Human Brain Mapping*, 1994; 2(**1-2**): 2-22.
[2] Rogers B et al. *NeuroImage*, 2004; 22: 855-859.