

Long term representation of motor sequences in the putamen

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Introduction. Previous studies have demonstrated that learned motor procedures can be effector-dependent. For example, when monkeys were asked to switch to the hand that has not been used during long-term practice of a given sequence, their performance became very poor (1). The performance using the opposite hand was worse than that using the trained hand, but was still better than the one with new sequences. This indicates that memory for the sequential procedure is only partially accessible to the hand that is not used during practice. In this study, we hypothesized that this partial transfer is possible because regions supporting the new memory for sequential movements can be recruited when performing the trained sequence using the untrained hand. Among candidates for this long term storage, the sensorimotor putamen and the SMA were specifically examined (2,3). On the other hand, activation of regions associated with new learning is probably also necessary because the transfer is only partial. In this study, we examined whether the sensorimotor putamen and/or the SMA were more activated during performance of the trained sequence using both hands, and whether areas activated during the early learning stage were recruited for movements using the untrained hand.

Material and methods. 14 right-handed volunteers were studied with EPI BOLD contrast at 3T. Subjects had to practice 15 min daily a sequence of 8-moves using fingers 2-5 of the left hand. Maximal speed and accuracy were assessed weekly using a keyboard. A MRI session was performed after 4 weeks of training. Single shot oblique slices were obtained (TR/TE/angle: 4.5s/40ms/90°, voxel size: 1.5x1.5x2.5 mm³, no gap, 123 acquisitions, 43 slices). The same subject performed sequences of identical length, but different pattern for the unpracticed control state. Subjects performed the trained (T) and untrained (U) sequences with the trained (LH) and untrained (RH) hands. The order in which subjects performed the T and U sequences was random. Movements were audio-paced at 2 Hz and alternated with rest. Random effect analysis was performed using SPM99 (p<0.0001, not corrected).

Results. After 4 weeks of training, subject's maximal speed was 60% (LH) and 31% (RH) faster during the T than the U sequence (ANOVA, F=41.5, p<0.001). During fMRI sessions, there were less errors during the T than the U sequences for both hands (Percentage errors \pm SD, T: LH=0.85 \pm 0.23, RH=1.10 \pm 0.28, U: LH=2.31 \pm 0.64, RH=2.11 \pm 0.41, ANOVA, F=6.3, p=0.027). Reaction times were shorter for the T sequence with the LH only and similar in the other conditions (reactions times \pm SD in msec, T: LH=374 \pm 27, RH=386 \pm 26, U: LH=391 \pm 22, RH=390 \pm 28 ANOVA, F=25.1, p<0.001).

The contralateral sensorimotor cortex, sensorimotor putamen and globus pallidus (GP), ventral posterolateral thalamus, and dentate nucleus (DN), the ipsilateral associative putamen and GP, anterior thalamus, and bilateral SMA and cerebellum were activated for all tasks and hands compared with rest. The contralateral premotor cortex (PM), associative putamen, anterior thalamus, subthalamic nucleus (STN), red nuclei (RN) and bilateral substantia nigra (SN) were recruited during performance of the T sequence with the RH. Bilateral preSMA, anterior cingulum, parietal areas (BA 40 and precuneus), the pons and the ipsilateral PM, STN, RN, DN were further recruited during performance of the U tasks with both hands.

In the sensorimotor compartment of both putamen, ANOVA for percentage signal increase for both hands showed a significant effect of the tasks (T > U, F=4.9, p=0.047) and an interaction between hemisphere and task (contralateral > ipsilateral, F=14.6, p=0.002, Fig. 1 right). The same comparisons did not reach significance in the SMA.

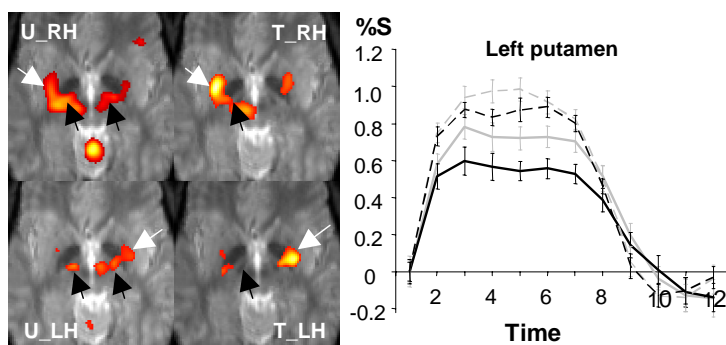


Figure 1. Left: Activation maps obtained in the putamen and STN area superimposed on an axial EPI image. Activation in the ventral part of the contralateral putamen body was higher for the T than the U sequences (white arrows). Activation was observed bilaterally in the STN during the U sequences, contralaterally during the T sequence with the RH, and no activation was found during the T sequence using the LH (black arrows). Left is left. Right: BOLD responses \pm SEM in the left sensorimotor putamen during the T (light grey) and U sequences (dark lines) using the LH (solid lines) and the RH (dashed lines). Time is in TR (action=6TR, rest= 6TR).

Conclusion. After 4 weeks of training, the long term representation of the sequence was accessible to the untrained hand (similar number of errors for both hands), whereas the speed of execution was not. This representation may be stored in the sensorimotor compartment of the putamen as this compartment was more activated for the trained than the untrained sequence for both hands. In contrast, activation in the associative compartments of the striato-pallidal complex, anterior thalamus, STN, SN, RN and cerebellum appear to play a more important role for acquiring greater speed on the sequential task.

References. (1) Rand et al. Exp Brain Res 1998, (2) Tanji et al. Trends Neurosci 1999, (3) Doyon et al. Proc Natl Acad Sci 2002.

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