Neural correlates of fast and slow ocular sequence learning

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Background

In this study, we investigated the neural correlates of the fast and slow components of procedural learning using the SORT (Serial Ocular Reaction Task), an ocular adaptation of the serial reaction time task. We already showed, using SORT (Ruby, Albouy, Peigneux, Maquet et al., *in preparation*), that performance rapidly improves during training (fast component), further followed by a sleep-dependent off-line improvement (slow component).

Methods

Eleven volunteers (age=18-23 years) were trained to the SORT. They were instructed to press a key at each colour change of a dot moving across four possible locations. Unbeknownst to the subjects, the dot moved according to a fixed 8-elements, second order sequence. The training session included, 18 blocks (5 sequences per block) with sequence 1 (S1, "learned") and 1 block with sequence 2 (S2, "new"). Twenty-four hours after training, subjects were tested using 9 blocks of S1 and 9 blocks of S2.
Subjects were scanned during training and retest sessions using a 3T *Allegra MR scan* (Siemens, Erlangen, 32 slices, voxel size:3.4x3.4x3, TR: 2130 ms, TE: 40 ms, FA: 90°). Ocular movements were measured online using eyetracking (LRO5000, ASL, Bedford, MA). Ocular reaction times (RTs) were estimated as the delay between the display of the dot and the initiation of the saccade.
BOLD data from both sessions were analysed using SPM2 (http://www.fil.ion.ucl.ac.uk) at the individual level in a general linear model including the following factors as covariates of interest : responses to S1 and S2 and their modulation by RTs, motor responses to the dot color changes. Linear contrasts tested the main learning effect (S1-S2) and its modulation by RTs ($S1_{RT}$-$S2_{RT}$). A final contrast tested the session (trainingVSretest) by learning (S1vsS2) interaction. Individual summary statistic images were used in a random effects analysis. Statistical inferences were made at $p<0.05$, after small volume correction.

Results

Main learning effect in training session

During training, all the subjects improved their performance specifically on S1.

This learning effect was observed in putamen [Z=3.61, coordinates:-24,2,-12mm]. When modulated by RTs, this effect was associate with bilateral FEF, bilateral IPS, visual cortex and putamen activations (figure 1).

Main learning effect in retest session

In retest session, performance on S1 improved significantly (vs the end of training, p=0.0015). Learning effect was observed in the caudate nucleus [Z=3.28; -20,16,12 mm], and bilateral hippocampus [(Z=5.23; -34,-26,-22 mm);(Z=4.85; 38,-32,24 mm)], but no effect of RTs modulation.

Interaction

Performance was significantly improved on S1, and more so in the retest than in the training session. It was related to a significant activation of bilateral parahippocampal gyri [(Z=3.33; -32,-30,-22mm);(Z=4.20; 36,-30,-28mm)] (figure 2).

Conclusions

Our data are in line with the hypothesis that procedural learning takes place across two successive, within- and post-training, components. Presumably, performance-dependent changes in brain response during the learning session reflect the fast, within session, component of learning, whereas the interaction effect between sequence [S1vsS2] and session [training vs test] in parahippocampal regions reflects the trace of the slow, offline, learning component that reprocesses the learned oculor-motor sequence after training has ended.

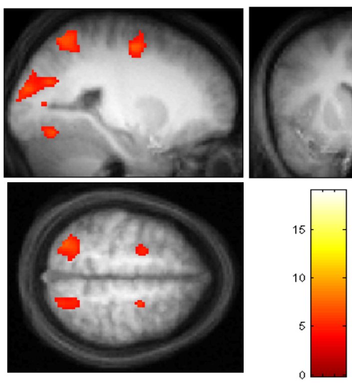

Figure 1: Learning effect modulated by RTs in training session .
training session.

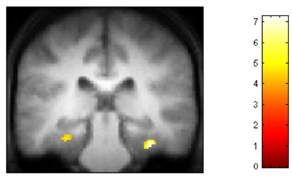

Figure 2: Interaction.