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Left Inferior Frontal Cortex Is Involved in Probabilistic Serial Reaction Time Learning

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Abstract

Cerebral blood flow was estimated using positron emission tomography and H2O15 infusions in 12 volunteers while they were trained on the probabilistic serial reaction time task developed by Jimenez, Mendez, and Cleeremans (1996). Participants' reaction times to predictable and nonpredictable stimuli showed increasing sensitivity to the probabilistic constraints set by previous elements of the sequence. Analysis by statistical parametric mapping showed a significant interaction between participants' performance and time effect in the left inferior frontal cortex. Our results provide the first evidence of this cerebral area being involved in the processing of contextual information in a probabilistic sequence learning task.

Introduction

The aim of this study is to explore the cerebral structures involved in implicit learning by means of a serial reaction time (SRT) task in which the sequence of stimuli was based on a probabilistic finite-state grammar, and in which random material was interspersed with structured material. Previous studies (e.g., Jimenez, Mendez, & Cleeremans, 1996) have shown with this task an increasing sensitivity, after an extended practice, to the probabilistic constraints set by two previous elements of the sequence. In the present positron emission tomography (PET) experiment, regional cerebral blood flow (rCBF) was recorded while participants were exposed without any prior practice to the aforementioned probabilistic sequence-learning task. This procedure was designed to highlight the cerebral structures associated with the early stage of the implicit acquisition of the probabilistic constraints set by only one previous element in the sequence. Learning of these constraints is expected to occur after a limited practice and to be reflected in the interaction between behavioral performance and rCBF of the participants.

Method

Twelve right-handed volunteers (7 men and 11 women, mean age 22.1 years, range 20–28 years) were exposed to a six-choice reaction time (RT) task. The session consisted of 25 blocks of 205 successive trials. For each trial, a stimulus could appear on a computer screen at one of six horizontally laid locations. The task consisted of pressing as fast and as accurately as possible with the right hand on one of six corresponding keys. Unknown to participants, the sequential structure of the material was manipulated by generating successive stimuli based on the finite-state grammar shown in Fig. 1. To assess learning, there was a 15% chance on each trial of replacing the grammatical (G) stimulus with a nongrammatical (NG), random stimulus (identity and grammatical substitutions were discarded). This procedure thus generates material such that the predictability of each stimulus depends probabilistically on the context set by previous elements of the sequence. Assuming that response preparation is facilitated by high predictability, predictable G stimuli should thus elicit faster responses than NG stimuli, but only if the context in which stimuli may occur has been encoded by participants. Jimenez et al. (1996) showed that participants can learn about the constraints set by two previous trials at most, and that this sensitivity emerged through practice as a gradually increasing difference between the RTs elicited by G and NG stimuli occurring in specific sets of controlled context of length 1 to 3. Similarly, we computed the differences between RTs elicited by G and NG stimuli in contexts defined by either one (i.e., variable L1) or two (i.e., variable L2) previous stimuli.

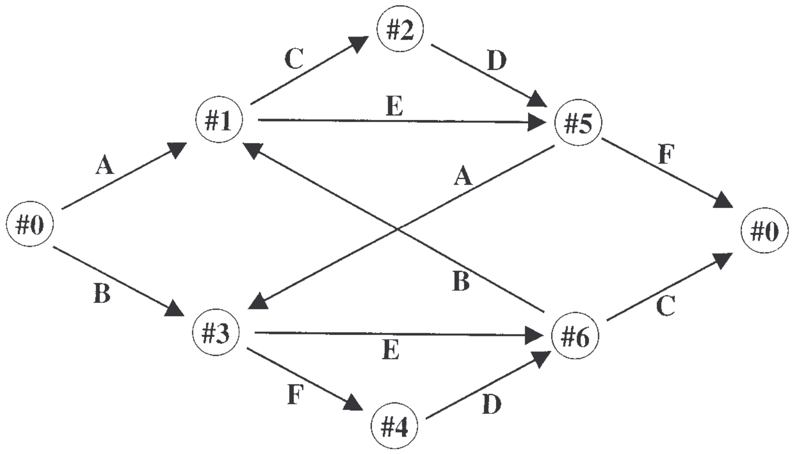

FIG. 1. The finite-state grammar used to generate the stimulus material, from Jimenez et al. (1996). Each letter corresponds to a stimulus location on the screen.

PET Acquisition

Twelve PET scans were obtained by a Siemens CTI 951 R 16/31 scanner in 3D mode. The rCBF was measured using iterative infusion of oxygen-15 labeled water (6 mCi/222 MBq in 5 cc saline). One SRT training block was given prior to the scans, and the 24 remaining experimental blocks were given during and between each scan. Data analysis was conducted using the statistical parametric mapping (SPM96) software (Wellcome Department of Cognitive Neurology, UK) and the specific rCBF response to a covariate was estimated at each and every voxel according to the general linear model, using a design matrix which included block effect and global activity as confounding covariates. The covariate of interest consisted in the interaction between L1 or L2 performance and the increasing time. The latter variables were entered as confounding covariates. The resulting foci of activation were characterized in terms of peak height over the entire volume, by reference to the theory of gaussian random fields (Friston, Worsley, Frackowiak, Maz-ziotta, & Evans, 1994).

Results

Median reaction time was computed for each of the 12 pairs of SRT blocks practiced during the 12 scans. A two-way analysis of variance revealed a significant main effect of Grammaticality for the L1 context only, $F(1, 11) = 5.63$, $MSE = 9047.8$, $p < .05$, indicating participants' sensitivity to the first order sequential constraints set by one previous trial. A significant main effect was also found for the global RT for L1, $F(1, 11) = 10.81$, $MSE = 2054.6$, $p < .0001$, and L2 context, $F(1, 11) = 8.14$, $MSE = 3404.1$, $p < .0001$, showing improvement of the global performance with practice irrespective of the grammatical status of the stimuli. A significant Grammatical-ity x Global RT interaction, $F(1, 11) = 2.38$, $MSE = 1023.8$, $p < .05$, for L1 context only indicates that performance for G stimuli improved more than for NG stimuli with practice. An SPM analysis revealed that the interaction between L1 and increasing time is significantly correlated ($Z = 4.82$, p corrected $< .01$) with the voxel rCBF at —52, 48, —4 mm in the Talairach and Tournoux (1988) space. This voxel corresponds to an area located in the left inferior frontal cortex (Broadmann area 47), as shown in Fig. 2.

Discussion

RT analysis are in accordance with previous studies (Jimenez et al., 1996), suggesting that with restricted practice participants are able to learn about the constraints set only by the preceding trial. Broadmann area 47 has been found mainly activated in naming and reading tasks (see Cabeza & Nyberg, 1997, for a review), but to our knowledge it is the first time that a relationship is highlighted between the metabolic activity of this cortical area and the processing of contextual information in a sequential learning paradigm. Further studies should make precise the role of this cerebral region in the processing of more sophisticated contextual information.

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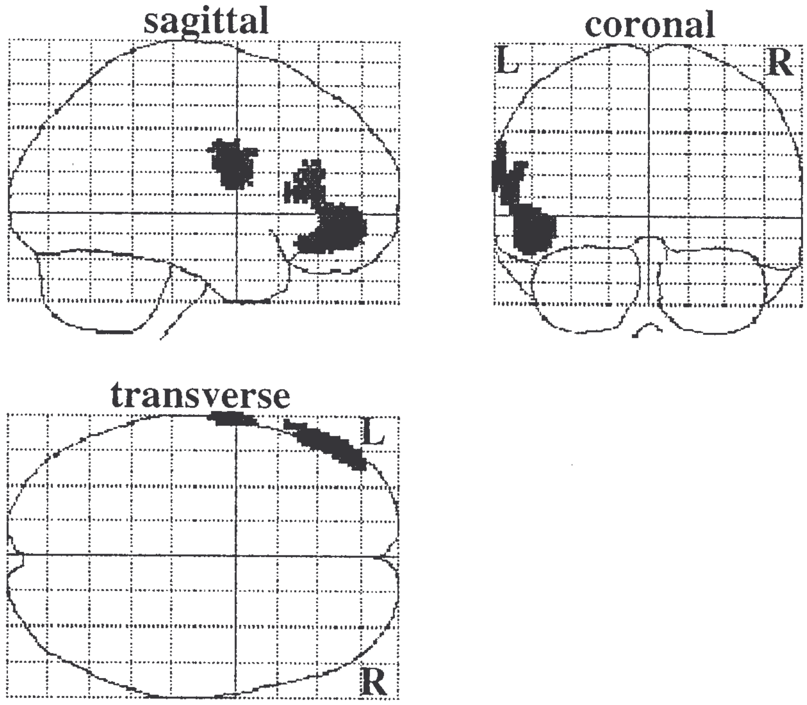

FIG.2. SPM {Z} tresholded at Z > 3.09 showing rCBF significantly correlated to the interaction between performance and time effect at voxel —52, 48, —4 mm.

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