An fMRI Study of Temporal Sequencing of Motor Regulation Driven by an Auditory Cue - A Comparison with Visual Guidance

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Introduction

External cues are utilized to temporally regulate movements. The network of the supplementary motor area (SMA), pre-motor area (PMA), superior parietal lobule (SPL) and cerebellum is responsible for integrating an external visual cue and internal initiation to generate temporally complex and precise movements [1]. The SPL seems to be the conjunction of the visual pathway and the higher motor areas. In this study, the role of these areas under an external auditory guidance and the areas responsible for processing the auditory information to generate temporal movement sequence were investigated using fMRI. The activation was compared with that under visual guidance.

Material and Methods

Measurements were performed in 8 normal subjects (3 females, all right handed), who gave written informed consent. The finger tapping task was designed in a block manner (4 task and 5 rest blocks, 30 sec each). Five conditions were compared. In three conditions, an auditory cue (frequency 440Hz, duration 200 ms) was given at 1Hz, and opposing movements of right thumb and index finger were performed at 0.5, 1 or 2Hz. In the other two conditions, two taps per second and a rest for 1 second were alternatively repeated in the task blocks according to the 1Hz auditory cue (A-INT) or 1Hz visual cue (V-INT). The visual cue was prompting of a black dot at the center of the visual field. The volunteers maintained fixation during the task and rest blocks in the auditory cued conditions and the rest blocks in the visually cued condition.

Functional data were obtained using a T2* weighted gradient recalled echo spiral sequence (TR = 3000 ms, TE = 30 ms, 30 axial slices, 4 mm thick, FOV = 22 cm) on a 3T MRI scanner (GE Signa VH/i3.0T). Ninety images per slice were acquired in 270 seconds. T1 and T2 weighted images were obtained at the identical slice locations to the functional images for anatomical references. Statistical tests were performed using statistical parametric mapping (SPM2). The data were realigned and normalized to an MNI template for a group study ($p < 0.001$).

Results

General activation: Activation was observed in the left primary motor area (M1), bilateral SMA, PMA (dorsal and ventral), SPL, supra marginal gyrus (SMG; rt > lt), superior temporal gyrus (STG; rt > lt), thalamus, globus pallidus and right cerebellum.

Differential activation: Among the four conditions with the auditory cue, activation in the bilateral SMA, dorsal PMA and SPL was most augmented in A-INT and least in 1Hz, whereas the activation in M1 correlated with the amount of finger movement. This response agreed with the report using a visual cue [1]. The differential activation in the SMA, PMA and SPL between V-INT and 0.5, 1 (Fig.1A; V-INT – 1Hz) or 2Hz (Fig.1B; V-INT – 2Hz) had more cluster size than that between A-INT and 0.5, 1 or 2Hz. Activation in the rt SMG, bilateral V3 and V5 was also significantly augmented in V-INT in this comparison. In the comparison of A-INT and V-INT, activation in the middle portion of the rt STG increased in A-INT (Fig.2A; A-INT – V-INT), and that in the rt SMG, bilateral SPL, V3 and V5 increased in V-INT (Fig.2B; V-INT – A-INT).

Discussion

With the auditory cue, the activation in the rt STG and SMG extended over their whole areas and the cluster size was larger than that on the left side. This observation was in contrast to the activation limited to the anterior part of the STG under visual guidance [1]. It was reported that rt STG is involved in movement sequence generation based on auditory rehearsal [2]. Since the activation in the rt STG was more augmented by A-INT than V-INT (Fig.2A), and that in the SMG by V-INT than A-INT (Fig.2B), the rt STG may be more responsible for the conversion of an external auditory cue into a movement sequence, and the rt SMG may play a more general role in temporal sequencing.

Since the activity in the SMA-PMA-SPL-cerebellum network reproduced the same response as that induced by the visual cue [1], this functional unit seems to have a common role to integrate the input impulses and generate a temporal sequence. More demand for this network by V-INT than A-INT suggested that the visual cue required more processing to be converted into a temporal sequence than the auditory cue did.

References

[1] Nakai T et al. Brain Res, 968, 238-247, 2003

[2] Rao et al. J Neurosci, 17, 5528-5535, 1997

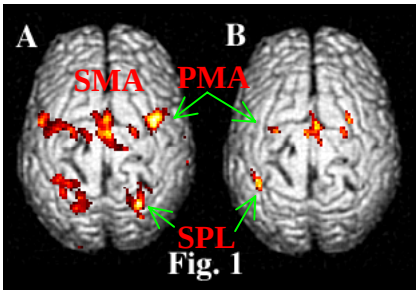

Fig.1 More contrast was detected in V-INT - 1Hz (A) than in V-INT - 2Hz (B). The extent of the differential activation in the network of SMA-PMA-SPL-cerebellum depended on the demand to integrate the input impulses.

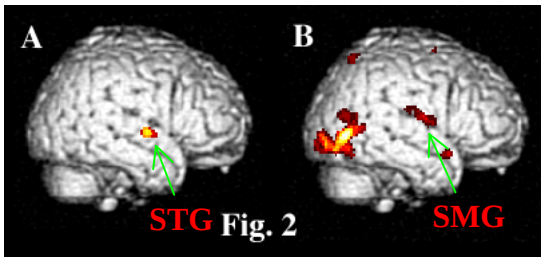

Fig.2 Integration of the external auditory cue and internal initiation induced higher activation in the rt STG than that by the external visual cue and internal initiation did (A). The latter condition augmented the activation in the rt SMG as well as that in the V3 and V5 (B).