Cerebellar processing in a mental rotation task

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Abstract

We recorded 306-channel MEG data during a mental rotation task. Nine subjects viewed 48 pairs of 3D perspective drawings of 10 cubes arranged in chiral patterns in a variety of orientations. These were displayed on a screen for 6 seconds at interstimulus intervals of 600 ms; each pair was presented 5 times. Participants were asked to judge whether the paired images represented the same object viewed from different angles or different objects, and to indicate their response with their dominant hand using a response pad. L1 minimum-norm estimates were calculated for trials with correct responses. The minimum response latency was 830 ms and the mean initial response time was 1250 ms. Consistent with previous studies [1], activation was observed during the first 350 ms after stimulus presentation in occipital, posterior parietal and superior postcentral cortex and the parieto-occipital region. Prominent cerebellar activation was seen at mean latencies of 126 and 212 ms. This finding complements previous MEG studies showing cerebellar activation during somatosensory tasks [2]. Cerebellum has been viewed as a motor organ. The observation of short-latency cerebellar evoked responses to visual input support a role for cerebellum in the processing of purely sensory input.

1 Introduction

Although a majority of the neurons in the human brain are contained in the cerebellum, the role of the cerebellum was long believed to be limited to motor performance. This view changed rapidly toward the end of the 20th century; one recent review of cerebellar research discussed a plethora of topics, including sensation, cognition, mood, schizophrenia, autism, and dementia [3]. Cerebellum has also been implicated as an adaptive predictor of somatosensory input, acting in anticipation of sensory stimuli [2].

Of particular interest here is the role of cerebellum in sensory processing. Given the phylogenetic age of the cerebellum, it should not be surprising that this structure would play a part in processing sensory input. Cerebellar involvement has been demonstrated in tactile acquisition and discrimination [4], the development and satiation of thirst [5], and response reassignment [6].

In addition to psychophysiological data, neurophysiology also suggests a role for cerebellum in sensory processing. Data from nonhuman primates indicates rich, topographically distinct cerebellar projections to sensory areas via the dentate nucleus [7]. Moreover, evidence from human populations reveals alterations in primary somatosensory cortex following cerebellar lesion, suggesting a role for cerebellum in early sensory processing [8].

The mental rotation of 3-dimensional objects has been used in psychological research for over 30 years [9]. The demands of the task make it well-suited for research into sensory processing, attention, working memory, and individual differences. To investigate these and other issues, we used magnetoencephalography (MEG) to study the neural basis of the task. MEG was chosen in order to capitalize on its unique combination of unsurpassed temporal precision and more than adequate spatial localization.

2 Methods

Nine normal adult volunteers (7 males) were presented with a computerized version of the Mental Rotations Test A. The task consisted of 48 pairs of 3D perspective drawings of 10 cubes arranged in chiral patterns and viewed from a variety of rotation angles (Fig. 1); each pair was presented 5 times. A randomly ordered series of these image pairs was projected on a screen. The stimuli were visible for 6 seconds with a constant inter-stimulus interval of 600 ms. Participants were asked to judge whether the paired images represented the same object viewed from different angles or different objects, and to indicate their response with their dominant hand using a fiber optic response pad. Data were sampled at 600 Hz using a 306-channel MEG array. MEG data was co-localized to the anatomical MRI of each subject using a Polhemus head position device. Waveforms were averaged over trials and band-pass filtered (0.5–45 Hz, width 0.1 and 10 Hz respectively). Blink and heart artifacts were removed using signal-space projection [10]. L1 minimum-norm estimates were calculated using MCE [14] for trials with correct responses.

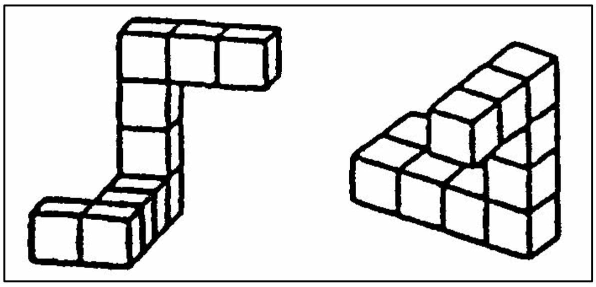

Figure 1 : *Sample image pair*

3 Results

The minimum response latency observed was 830 ms and the mean initial response time was 1250 ms. The first 350 ms after stimulus presentation were evaluated to best characterize stimulus-processing phenomena. Consistent with previous studies [2, 3], activation was observed in occipital, posterior parietal and superior postcentral cortex and the parieto-occipital region. Prominent cerebellar activation was seen at a mean latency of 126 ms, with a later response at 212 ms. A typical current distribution and waveform for the early response is illustrated in Figure 2; the later response is shown in Figure 3.

4 Discussion

The current distributions observed in cerebral cortex were, reassuringly, highly consistent with studies of mental rotation using EEG [12] and fMRI [1, 13]. Somewhat more intriguing was the pattern of cerebellar activation. Cerebellar involvement has previously been observed in a PET study of mental rotation tasks [11], although the limited temporal resolution of this methodology did not permit a detailed characterization of the dynamics of the cerebellar activation. We have used the excellent temporal resolution of MEG to observe cerebellar involvement in early visual sensory processing during the performance of a mental rotation task. The first observed visual evoked responses in cerebellum occurred at a mean latency of 126 ms following

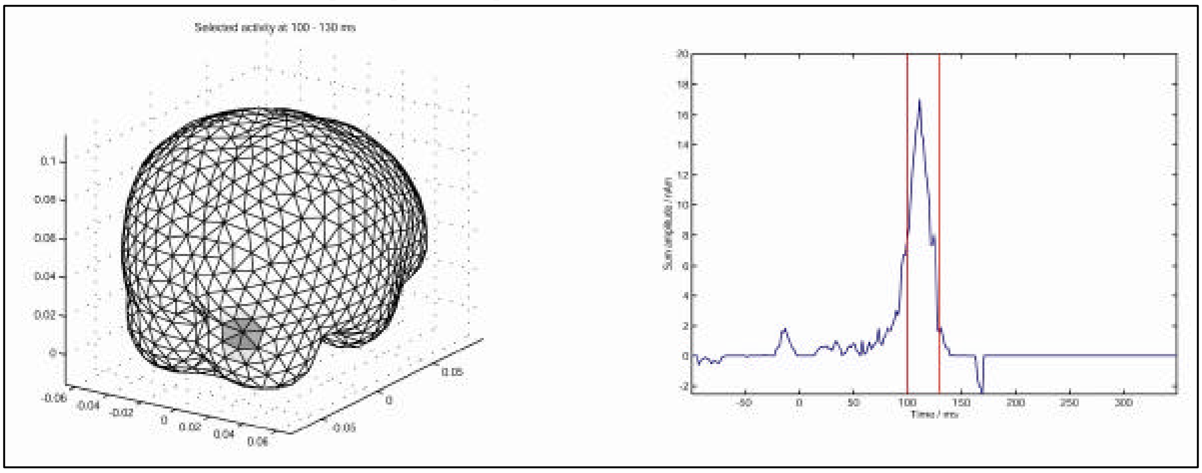

Figure 2: *Early cerebellar response*

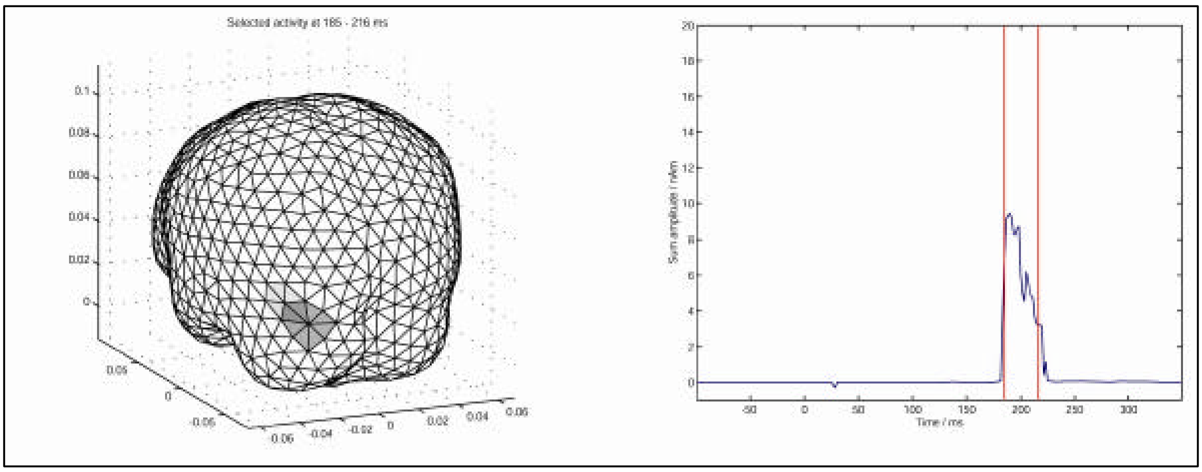

Figure 3: *Later cerebellar response*

stimulus presentation. These responses occurred at latencies similar to those observed in occipital cortex, and preceded any saccades performed by the subjects. The observed short-latency cerebellar activity was associated with early visual stimulus processing rather than preparation for or generation of the motor response. Although subjects were requested to make a motor response, the minimum response latency was 830 ms following stimulus presentation. The crisp evoked response peaks time-locked to stimulus presentation and broad distribution of response latencies speak against the interpretation of the cerebellar activation as preparation for movement.

One role for cerebellum may be as an adaptive predictor of somatosensory input [2]. In this view, cerebellar activation may be observed prior to anticipated stimulus presentation, and may be modulated by the temporal dynamics of the presented stimuli. Anticipatory cerebellar activation has been observed in a MEG study of intermittent median nerve stimulation [4]. Cerebellar responses to the somatosensory stimulation in that study were observed prior to stimulus onset following an unanticipated interruption of an established temporal pattern of stimulus presentation. In contrast, the timing of stimulus presentation in the present study was consistent throughout the block of trials. Moreover, anticipatory cerebellar activation was not observed in the 100 ms prior to stimulus onset. The lack of anticipatory activity supports the interpretation of the cerebellar evoked response peaks at 126 and 212 ms as contributors to the processing of visual input per se, rather than involvement in processing of a temporal pattern established by sensory input.

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