Temporal Dynamics of Selective Attention During Dichotic Listening

Bernhard Ross
Rotman Research Institute, Baycrest Centre, Toronto, ON, Canada, M6A 2E1, bross@rotman-baycrest.on.ca
Department of Medical Biophysics, University of Toronto, Toronto, ON, Canada

1. INTRODUCTION

In a multi speaker environment we can direct our attention to one conversation and ignore the voices of other simultaneous speakers. Nevertheless, our attention can still be captured if somebody outside of the focus of attention mentions our name. How is the brain able to work through these complex and often conflicting tasks?

A long standing debate is whether selective attention facilitates the sensitivity in the attended sensory channel and suppresses non-attended input [1,2] or alternatively all environmental information is pre-processed and stimulus selection takes place later at a higher order stage [3].

Advanced techniques of source analysis of magnetoencephalographic data provide spatial information about which brain area is modulated by attentional control. Moreover, MEG provides high resolution time courses of activity. We reconstructed the time courses of cortical source activity to study the neural processes underlying stimulus selection during dichotic listening.

2. METHOD

Twelve healthy normal hearing young university students participated in the study and listened to streams of dichotic sounds during whole head magnetoencephalographic (MEG) recordings.

The stimuli were amplitude modulated (AM) tones of 600 ms duration presented in random order to the left and right ear with stimulus onset asynchrony of 900-1100 ms. The modulation frequency of 40 Hz was infrequently changed to 20 Hz in both ears and listeners attended for the duration of a recording block of 7 min either to the left or right ear stimuli and responded to the targets in the attended ear with a right hand button press. A non-modulated 'filler' tone was presented opposite to the AM sound to reduce bottom-up effects of attention switching between ears. Thus, the participants to simultaneous streams of sound in both ears. Different carrier frequencies of 400 and 700 Hz for both ears supported maintaining attention to one ear.

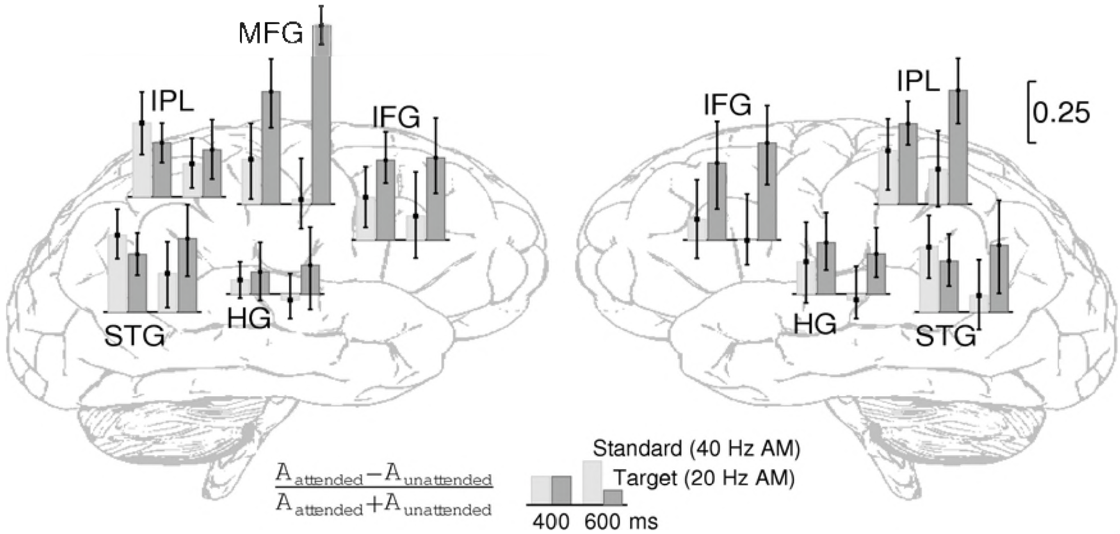
MEG was recorded with a 275 channel whole head system. Auditory evoked magnetic fields were transformed into volumetric maps of source activity using the MEG beamformer approach. This resulted in time courses of % activity change for each volme element separately for standard and target stimuli and attention focused to the left and right ear. Repeated measures ANOVAs were performed for each voluime element to identify the effects of attention and stimulus type on the evoked brain activity as well as interactions between attention and stimulus type. Structural magnetic resonance images were recorded for the overlay of maps of MEG source activity on the individual anatomical image. The same spatial transforamtion of individual MRI onto an atlas brain was applied to the MEG data for group analysis in standardized Talairach coordinates.

3. RESULTS

Listeners were able to focus their attention on the tones in the required ear and accurately detected the targets. However, false positive responses were made to 3.6% of targets in the unattended ear, 0.2% of attended standards, and 0.06% of unattended standard stimuli. Thus, false positive responses were predominantly a result of interference by the contralateral deviant stimulus. The detectability for left ear sounds of $d'=3.15$ was in group mean higher than for the right ear ($d'=2.96$, $t(11)=3.23$, $p=0.008$). The median reaction time was 663 ms with respect to the stimulus and slightly faster for left than right ear stimuli ($t(11)=2.4$, $p=0.035$) consistently with the observed left ear advantage.

The auditory evoked responses showed predominantly a P1 wave and a sustained response, lasting for the duration of the stimulus, whereas the N1-P2 complex was only small because of the fast stimulation rate. The sustained response showed strong modulation with attention. In general responses were larger for target than standard stimuli and responses to both stimuli were larger when presented in the attended ear. Cortical sources were identified as spatially distinct areas with strongest contrast between responses to attended versus non-attended stimuli: bilateral Heschl's gyri, (HG) the location of primary auditory cortex, bilateral posterior superior temporal gyri (STG) and inferior parietal lobules (IPL), as well as bilateral inferior frontal gyri (IFG) and the central part of the medial frontal gyrus, location of the supplementary motor area (SMA).

Larger responses to stimuli presented in the attended ear regardless of stimulus type were observed as early as 150 ms after stimulus onset in bilateral HG and simultaneously in bilateral IFG. A similar effect of attention became significant at around 300 ms in bilateral STG and IPL however, the response increase under attention was much stronger expressed in the posterior sources than in HG. The over time developing evoked activity was in general larger for target than standard stimuli. This effect of the stimulus type became significant at around 300 ms latency in HG and IFG and shortly later at around 400 ms in STG and IPL. The



$$\frac{A_{attended} - A_{unattended}}{A_{attended} + A_{unattended}}$$

Figure.1. Effect of attention, expressed as relative amplitude increase for stimuli in the attended ear, on responses to standard and target stimuli at various brain regions at 400 and 600 ms latency. The effect of attention increases over time for the targets and decreases for the standard stimuli, indicating the stimulus selection process predominantly in posterior brain regions.

effect of larger responses to targets increased over time and reached a maximum at around 600 ms just before the subjects responded. Interactions between attention and stimulus type, expressed as larger effects of attention on target than standard stimuli were significant in posterior sources at around 400 ms latency. The interaction was strongest at 600 ms in SMA, where attended target stimuli only resulted in strong activity increase.

We expressed the effect of directed attention as the normalized amplitude difference between responses to stimuli in the attended and unattended ear and compared this measure between the stimulus types at latencies of 400 and 600 ms. The hypothesis was that the stimulus selection process would be expressed as initially large effect of attention for both stimuli but the effect would diminish over time for standards and increase for targets. Indeed, the attention effect increased significantly for the targets and decreased for the standards. This interaction is demonstrated in the bar graphs shown in Fig. 1. The effect off 'time' was significant for all sources, whereas the interaction between 'stimulus type' and 'time' was significant for the posterior sources in IPL and STG indicating that the posterior sources were strongly involved in the process of stimulus selection.

In similar way we analyzed the response increase for targets, which may reflect a bottom-up capture of attention by the infrequent targets. No significant interaction between 'attention' and 'time' was found, indicating that the salience of targets increased over time for stimuli in both attended and unattended ears. This temporal dynamic was most pronounced in the posterior sources. Whereas the contrast between attended target and standard responses increased over time through suppression of responses to standard sounds, the responses to unattended targets even increased.

4. Discussion

Using advanced MEG data analysis approaches we identified spatial maps of cortical source activity underlying attention control during dichotic listening. More importantly, we obtained time courses of activation with high temporal resolution. Directing attention to one ear enhanced the sensitivity in the sensory channel and was associated with increased activation in HG and IFG at latencies 150-500 ms. A later effect of attention was different on target and standard stimuli and identified IPL and STG as the location of stimulus discrimination during the 400-600 ms latency interval. The responses to targets presented to the unattended ear showed an increase of activity during the time interval of stimulus discrimination indicating that despite the higher sensitivity in the selected channel discrimination still proceeded in the ignored channels. Time courses of early activation in IFG as well as early onset of effects of attention and effects of stimulus type suggest a role of IFG in monitoring auditory input, maintaining attention to the selected sensory channel, and controlling stimulus discrimination.

5. REFERENCES

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