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Magnetoencephalography responses to unpredictable and predictable rare somatosensory stimuli in healthy adult humans

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Highlight and Discussion:

In the present study, we introduced a new oddball stimulus protocol for investigating brain responses to unpredictable and predictable rare somatosensory events. Use of this stimulus protocol allowed us to control for the rarity (probability) of the unpredictable and predictable stimuli. We found two main components, M55 and M150, for each stimulus type: the frequent stimulus (FRE), unpredictable rare stimulus (UR), and predictable rare stimulus (PR). The sources of both components were located on the contralateral somatosensory cortices. The sensor level and the source level results showed a similar pattern: both components elicited a larger activity for the UR and PR than for the FRE. A larger response was observed for the UR than for the PR only for M55, whereas no difference was found in response amplitudes between the UR and PR for M150. This pattern of results suggests that M55, but not M150, possibly signals the prediction error. The results also highlight the need for controlling the stimulus rareness or for disentangling stimulus rareness and predictability in future studies.

Introduction:

According to the predictive coding theory (Friston, 2005), neural networks constantly learn the statistical regularities of the surrounding stimulus environment and make predictions of future events. In experimental research, the oddball paradigm, wherein a standard stimulus is rarely and randomly replaced by a deviant stimulus, is a feasible tool for studying predictive coding. The event-related potential, called mismatch negativity (MMN) (Näätänen et al., 1978) is elicited by the deviant stimulus and is suggested to reflect prediction error (Friston, 2005; Carbajal and Malmierca, 2018). Compared to its counterparts in auditory and visual modality, the somatosensory mismatch response (sMMR) is less studied and it is more difficult to design a control condition with different feature levels to somatosensory modality. Therefore, we introduced a new passive stimulus paradigm that can investigate somatosensory responses to unpredictable and equally rare predictable events. In principle, increased activity related to the unpredictable in comparison to predictable rare and frequent stimulus could be associated to prediction error.

Methods:

We used magnetoencephalography (MEG) to record 15 healthy participants' (12 females, 3 males, aged 21-43 years old) brain responses. Stimuli were electrical pulses of 200 µs in duration, delivered via flexible, non-magnetic metal ring electrodes to the left forefinger and little finger. The stimulus procedure was a modified oddball paradigm. A frequently presented stimulus was occasionally replaced by two different rare stimuli: the first one, which was unpredictable, was always followed by another one that was predictable. The experiment had two main stimulus conditions (condition A and condition B, Figure 1), which had counterbalanced stimulus features for the FRE and the PR. In condition A, the FRE was stimulation to the little finger and the PR was stimulation to the forefinger. In condition B, the stimulus assignment was reversed for the FRE and PR. The unpredictable rare stimulus (UR) was a double stimulation (forefinger and little finger, simultaneously). Each condition consisted of 1,000 trials presented in two runs for each participant. The probabilities for FRE, UR and PR were 80%, 10%, and 10%, respectively. Participants were instructed to ignore the somatosensory stimuli and focus on a silent movie. Based on these prior findings and verified in our grand-averaged source maps of the UR and PR (Figure 2), we defined two regions of interest (ROIs) on the contralateral sensory cortices of the stimulus, namely cSII (contralateral primary somatosensory cortex) and cSII (contralateral secondary somatosensory cortex).

Results:

The response waveforms are characterized by two main components: one at approximately 30-100 ms latency (M55) and the other at approximately 130-230 ms latency (M150). The corresponding topography and source activation for each component are presented in Figure 2 and Figure 3. The grand-averaged source activations for different stimuli from the right-side view are illustrated in Figure 4. The source level results showed a similar pattern for both cSI and cSII areas: both components elicited a larger activity for the UR and PR than for the FRE. A larger response was observed for the UR than for the PR only for M55, whereas no difference was found in response amplitudes between the UR and PR for M150 (Figure 3). This pattern of results suggests that M55, but not M150, possibly signals the prediction error.

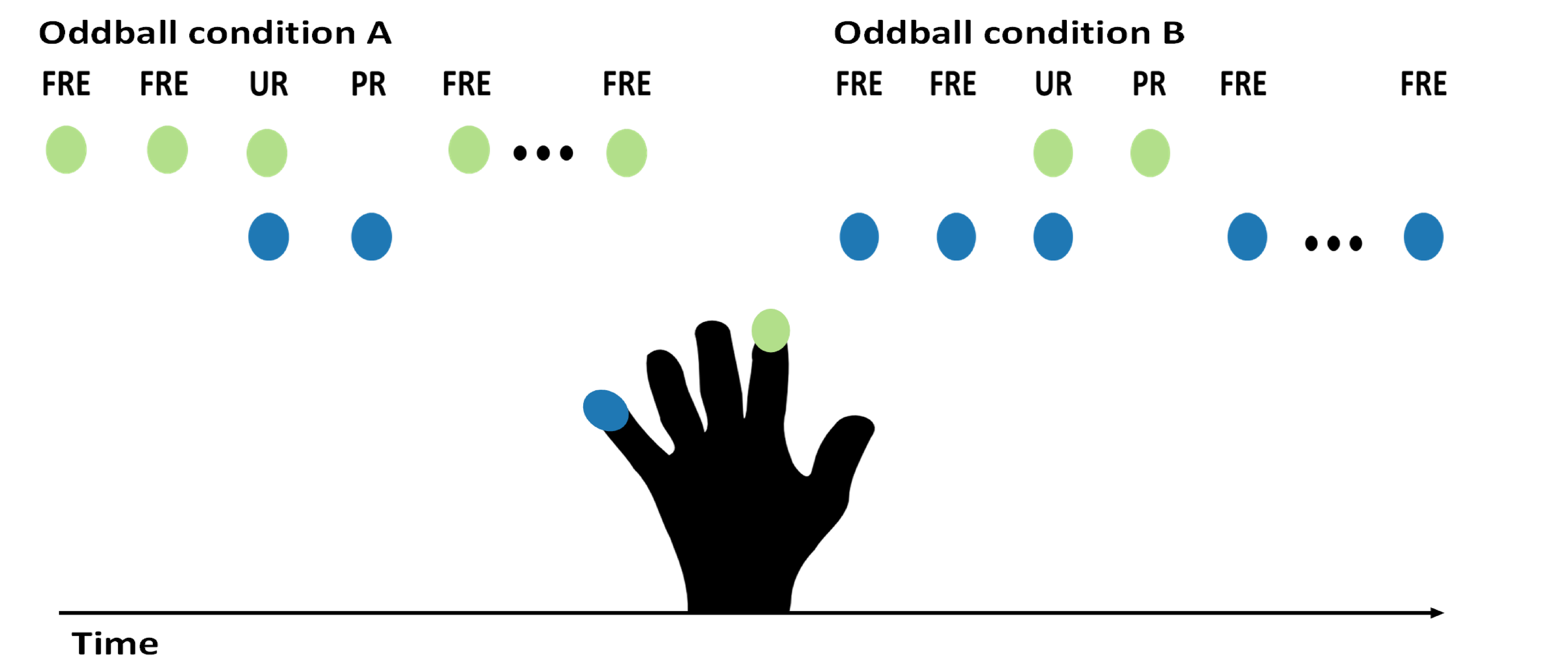

Figure 1. Illustration of the stimulus presentation for condition A and B. Under condition A, stimulation to the little finger (blue ball symbol) served as the FRE, stimulation to the forefinger (green ball symbol) as the PR, and simultaneous pulses to the forefinger and the little finger as the UR. Under condition B, the opposite assignment between the FRE and the PR was applied. In the analysis, conditions A and B were averaged; therefore, the physical features of the FRE and the PR are controlled. FRE = frequent stimulus, UR = unpredictable rare stimulus, PR = predictable rare stimulus.

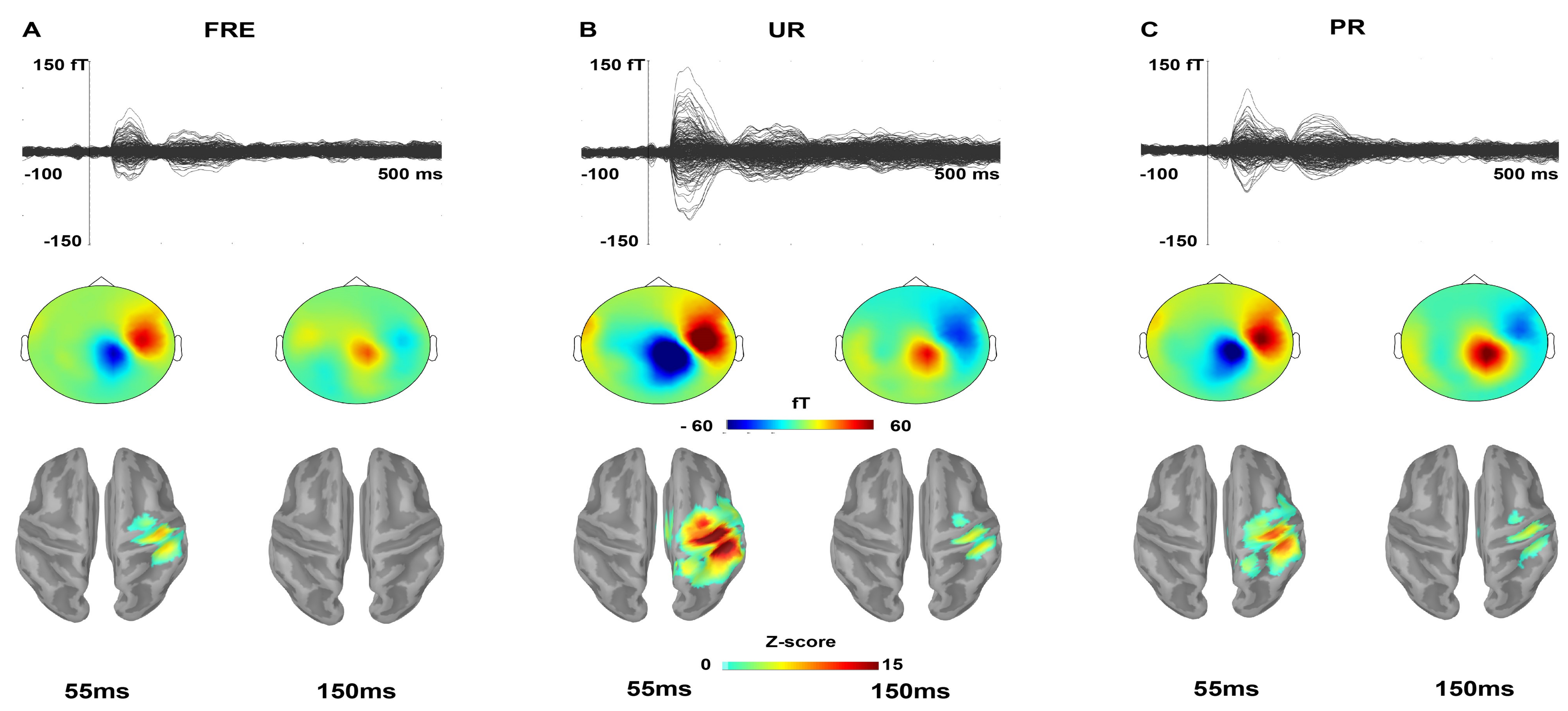

Figure 2. The grand-average responses for (A) FRE, (B) UR, and (C) PR. The upper panel shows a butterfly view of the grand average response for each stimulus type from all 306 sensors. For visualization purposes, gradiometer values are multiplied by 0.04 due to the differing units for magnetometers (T) and gradiometers (T/m). The middle and lower panel show the topographies of the sensor level activity based on magnetometers and source activation, respectively, at a time point of 55 ms and 150 ms for each stimulus type. In the lower panel, only the sources that have a value > 40% of the color bar maximum are displayed. FRE = frequent stimulus, UR = unpredictable rare stimulus, PR = predictable rare stimulus.

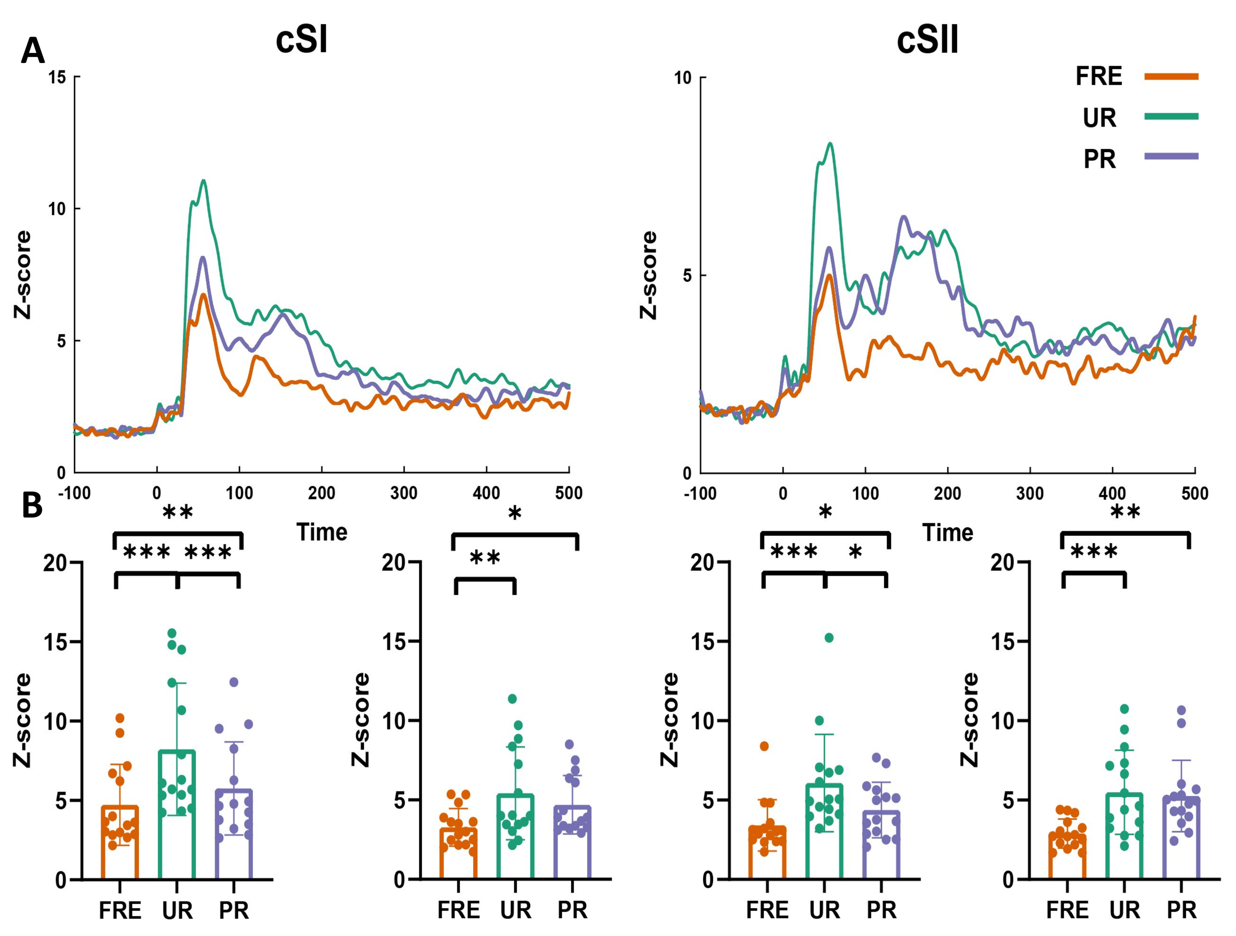

Figure 3. The summary of the results from the source level analysis. (A) The cortical time series for all three conditions (UR, PR, FRE) in the cSI (left panel), and cSII (right panel). (B) The bar graph of the source strength comparison of the FRE, UR, and PR in the cSI (left panel) and cSI (right panel). Error bars represent the standard error of the mean and the dots represent the values of the individual participants.

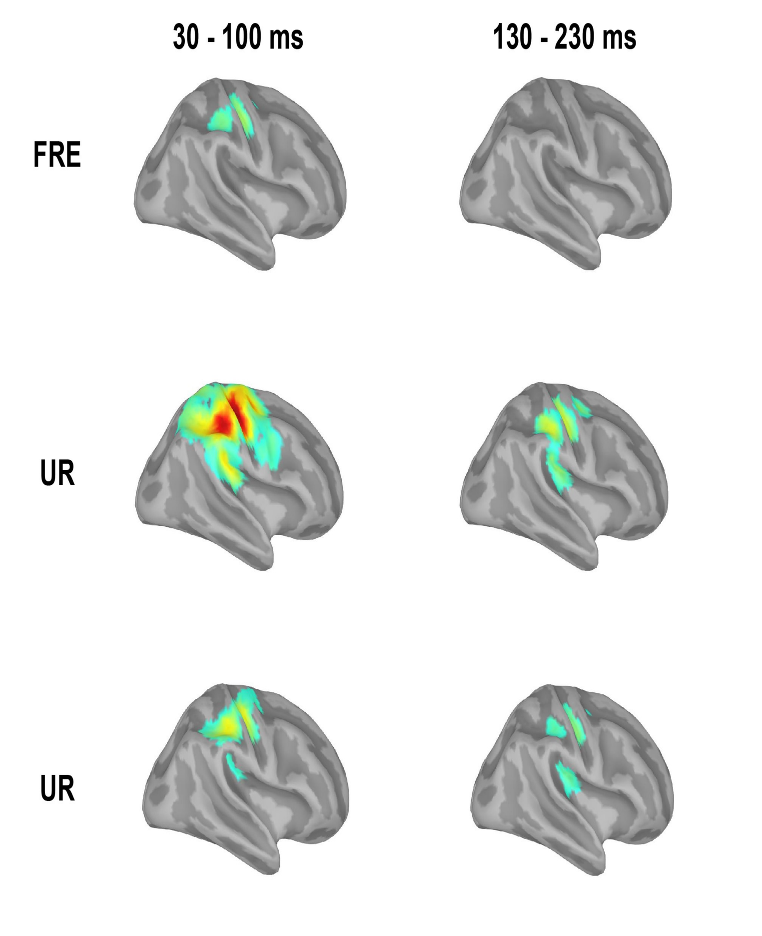

Figure 4. Grand-averaged source activation for the time window of 30–100 ms (M55) and 130–230 ms (M150) after stimulus onset for each stimulus type from the right-side view (mean values of the time windows presented). For visualization purpose, only the sources with a value > 40% of the color bar maximum are displayed here. FRE = frequent stimulus, UR = unpredictable rare stimulus, PR = predictable rare stimulus.

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