Origins of Response Time Variability in a Rapid Serial Visual Presentation Task

Lucas Parra
Department of Biomedical Engineering
City College of New York

Adam Gerson, Paul Sajda
Department of Biomedical Engineering
Columbia University, New York

1 Background

Several researchers have used electroencephalography (EEG) and a rapid serial visual presentation (RSVP) paradigm to demonstrate that object recognition in human's requires as little as 150ms of processing time [1,2]. The earliest motor response however is not observed until 350 ms after stimulus presentation and may be as late as 800 ms. An open question is what is the cortical origin of this large response time (RT) variability.

2 Methods

Data was collected for 8 right handed subjects ages ranging from 23 to 37. Images of natural scenes were presented using a "barrage" style RSVP paradigm (Blocks consisting of 50 images presented at 10Hz starting with a fixation cross). For each block there was a 50% chance the sequence contained a target image of a person or man-made structure (see Figure 1). Subjects were instructed to respond rapidly, with a button release, to the appearance of a target image.

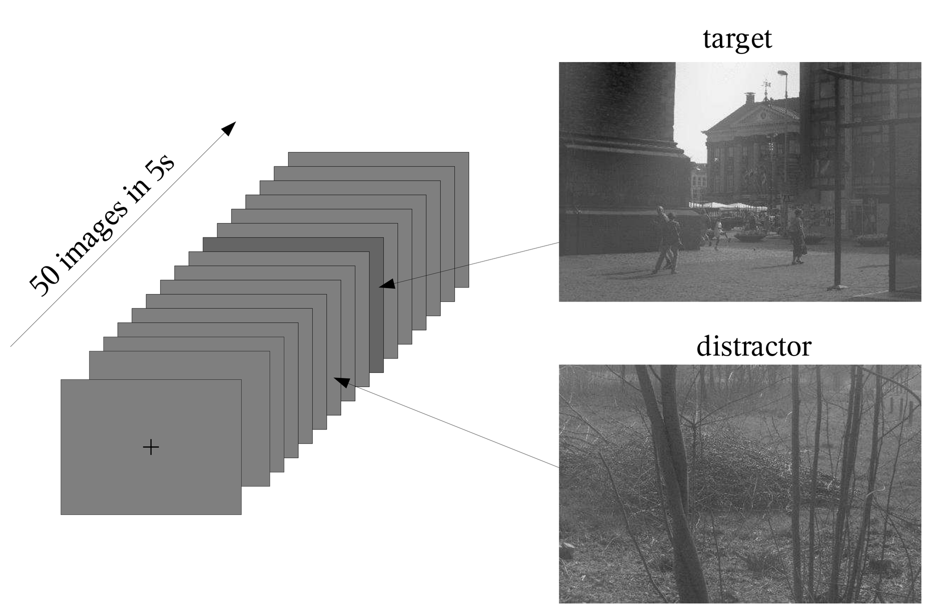

Figure 1: RSVP stimuli

EEG was recorded at 60 scalp locations and spatially filtered to reduce activity due to eye-movement and eye blinks. A zero-phase high pass filter was used to remove DC drifts. The activity in the multiple sensors was combined via a spatially weighted integration to optimally discriminate between target and non-target presentations [3]. Briefly, a single component, $y(t) = \mathbf{v}^T\mathbf{x}(t)$, is generated from the 60 EEG sensor readings $\mathbf{x}(t)$. The spatial weighting vector $\mathbf{v}$ is optimized to give maximum difference between distractor and target trials during a predefined time window (time between white lines in figure 2. The significance of the activity can be assessed by measuring the discrimination performance between the two conditions. Here we use A_z, the area under the Receiver-Operator-Characteristic (ROC) curve as our metric for discrimination performance (e.g. $Az = 0.75$ corresponds roughly to 75% correct classification of trials).

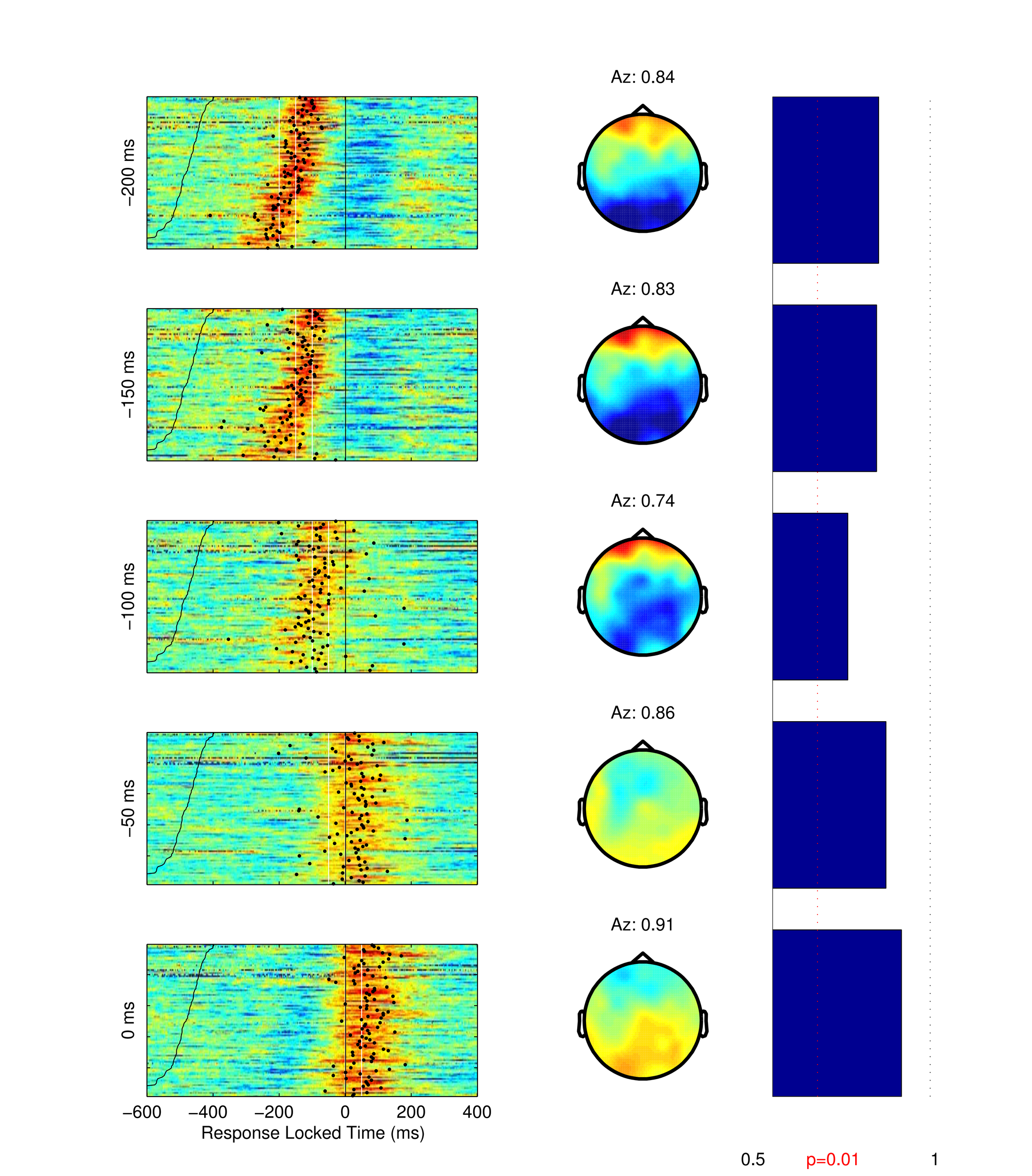

Figure 2: Discriminant activity shows the difference between target and non target trials. Each panel on the left shows the extracted single-trial activity. The activity is color coded (positive activity is red, negative activity is blue). Horizontal axis represents time from 600ms prior to button release to 400ms after. Trials are aligned vertically so that button release time is at 0ms (vertical black line). Stimulus onset is indicated by a black curve. Since trials are sorted by response time this curve is "S"-shaped. Each row shows the activity extracted for a window of 50 ms duration. The window, relative to the button release time, is displayed as two white parallel vertical lines in the left panels. By moving the window, discriminant activity for various latencies can be extracted. A representation of the topology of the extracted activity is shown to the right (dorsal view). The color code indicates (red) positive correlation of the sensor readings with the extracted activity and (blue) negative correlation. These scalp plots can be thought of as a coupling of the discriminating activity with the sensors, therefore reflecting the proximity and orientation of the discriminating activity. The A_z value shown as a bar graph on the third column indicates the significance of the difference activity (red doted line corresponds to $p = 0.01$).

3 Results

The first reliable indication of a difference between target and non-target images arises between 200-250ms after stimulus onset (see Figure 2). The corresponding activity is stimulus locked (see Figure 2 and 3). It has a bilateral frontal distribution which is consistent with activation of lateral prefrontal cortex (LPFC) (see Figure 4). The activity remains frontal for about 100 ms. A posterior activity over parietal areas (e.g. posterior parietal cortex, PPC) arises 50-100 ms prior to button release. Its onset time is delayed as compared to stimulus onset. Single trial analysis of the delay and duration of activity, shown in Figure 3, indicates a gradual transition from stimulus locked to response locked activity. Delay is introduced as the activity moves from frontal to parietal areas.

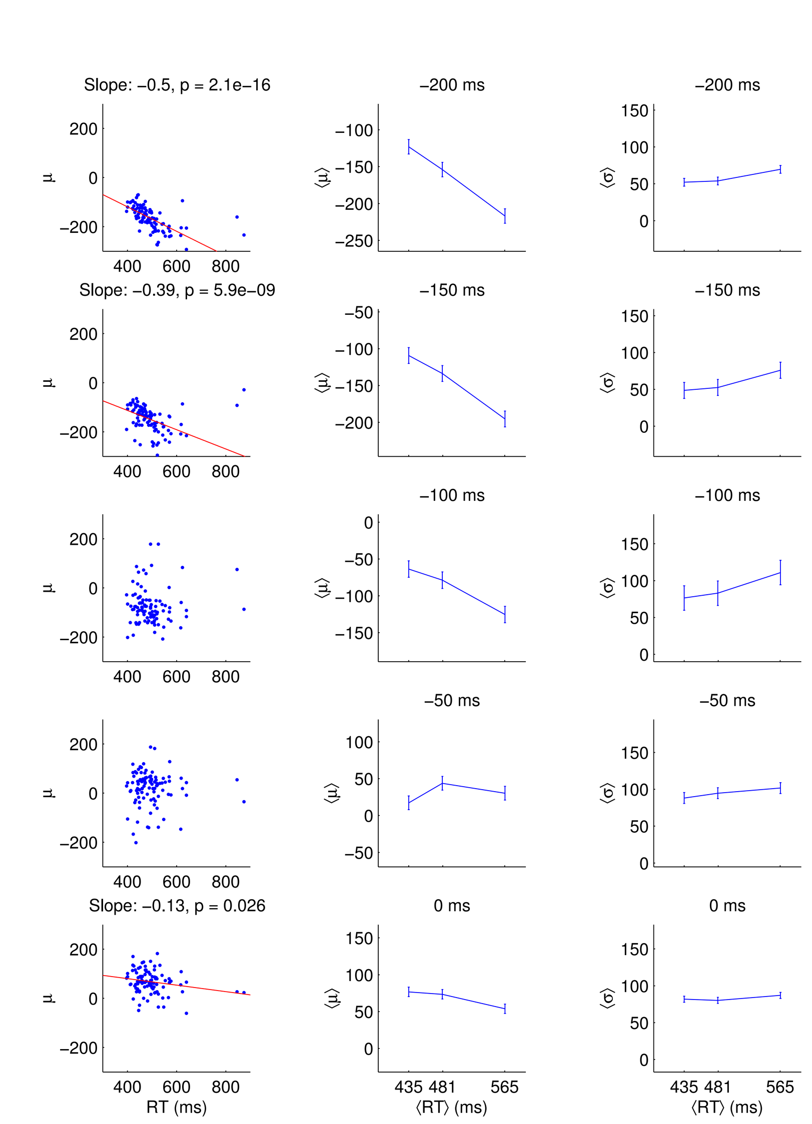

Figure 3: Detailed temporal analysis of discriminant activity. Activity was fit to a Gaussian profile to determine delay (μ) and duration (σ). Left column shows delay determined for each trial vs. corresponding RT (black dots in Figure 2). Center and right columns show result of fitting a Gaussian to the average of fast, medium, and slow RTs. Decreasing slope in $< \mu >$ indicates transition from stimulus locked to response locked activity. $< \sigma >$ increasing with RT indicates that this activity introduces delay. Each row corresponds to activity in rows of Figure 2.

4 Discussion

The "barrage" RSVP task requires high vigilance and likely involves no explicit memory retrieval. Presumably processing time is largely required for decision making and formation and execution of the motor response. This task appears to successively engage two cortical areas: LPFC presumably involved in executive control followed by PPC often implicated in visual-motor integration and intention/attention. We do not find a single cortical source of RT variability, rather half of the variability can be attributed to the processing from frontal activity, beginning stimulus locked, transitioning to parietal activity. The remaining variability/delay appears to be introduced after the activity has arrived in parietal and motor areas.

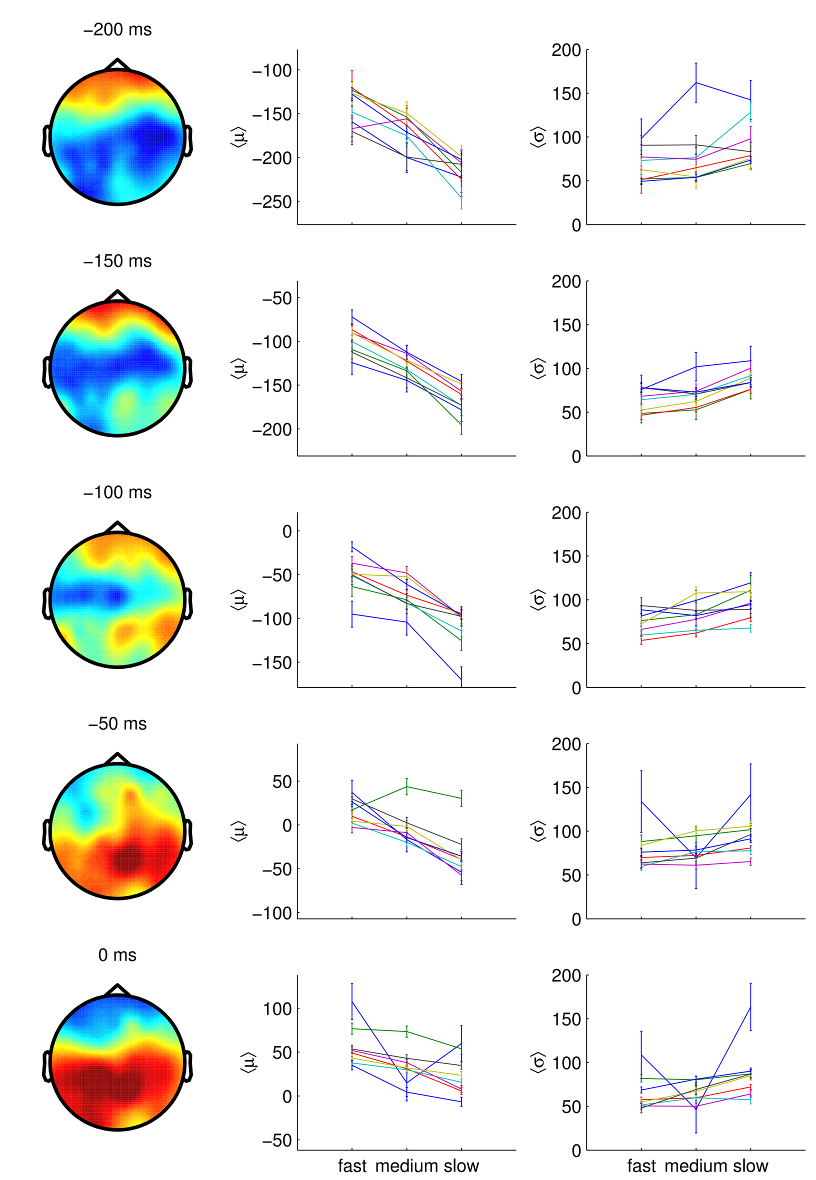

Figure 4: Summary over all 8 subjects. Left column shows scalp distribution of discriminant activity averaged over all subjects. Center column shows the timing of the activity (relative to button response) for slow, medium, and fast response times. For all subjects the first discriminant activity is frontal and stimulus locked (timing of activity relative to response is correlated to RT). By the time it arrives in parietal areas a delay has been introduced (correlation with RT is reduced).

5 References

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