

The time course of brain signals reflect different cognitive processes during human decision making

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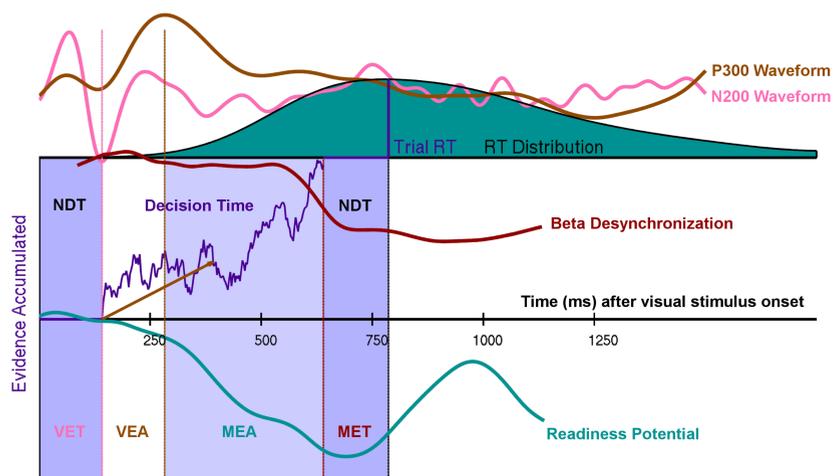
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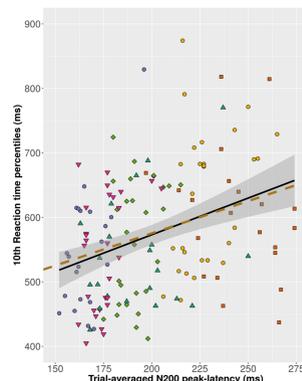
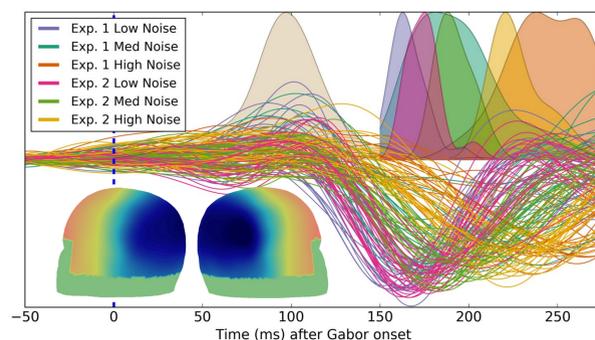
Hypothesized theory of Neural Decision Making

A theory of decision making predicts **distinct time periods** that contribute to a response time (RT): **visual encoding time** (VET; figure-ground segregation), **visual evidence accumulation** (VEA), **motor evidence accumulation** (MEA), and **motor execution time** (MET). It is our goal to accurately measure these time periods within participants using EEG and human behavior. Decision time (DT; evidence accumulation) and Non-Decision Time (NDT) can be estimated directly from accuracy and RT. EEG could further differentiate these time periods.



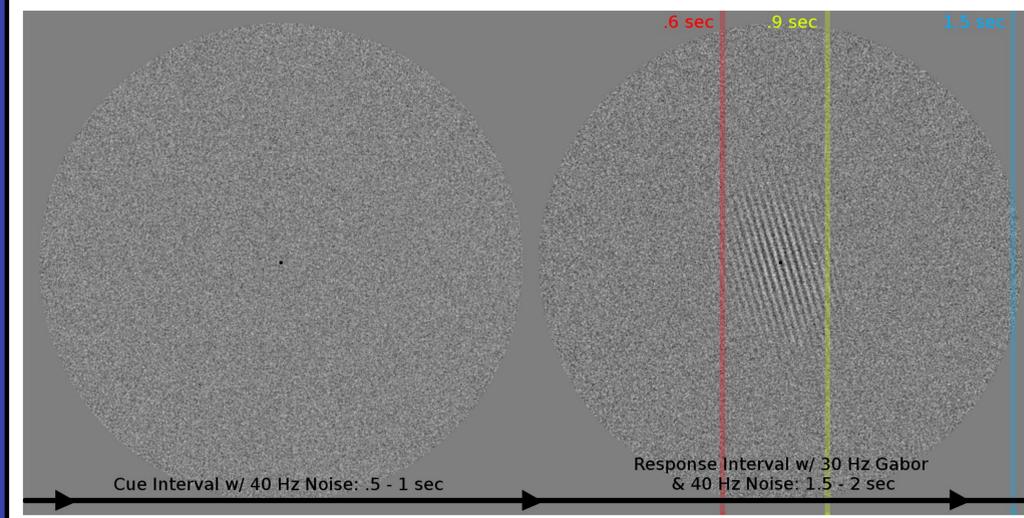
Previous evidence for this theory

- Drift-diffusion model theory (Ratcliff & McKoon, 2008) and neural evidence accumulation theory (Shadlen & Kiani, 2013)
- P300 ERP latencies (~ 300 to 1000 ms) reflect **visual evidence accumulation** (O'Connell et al., 2012; Philiastides et al., 2014)
- Readiness potentials (RP) reflect decision-time related to **motor evidence accumulation** (tinyurl.com/RP-DecisionTime)
- N200 ERP latencies (~ 150 to 275 ms) reflect **visual encoding time** (tinyurl.com/N200-Evidence)



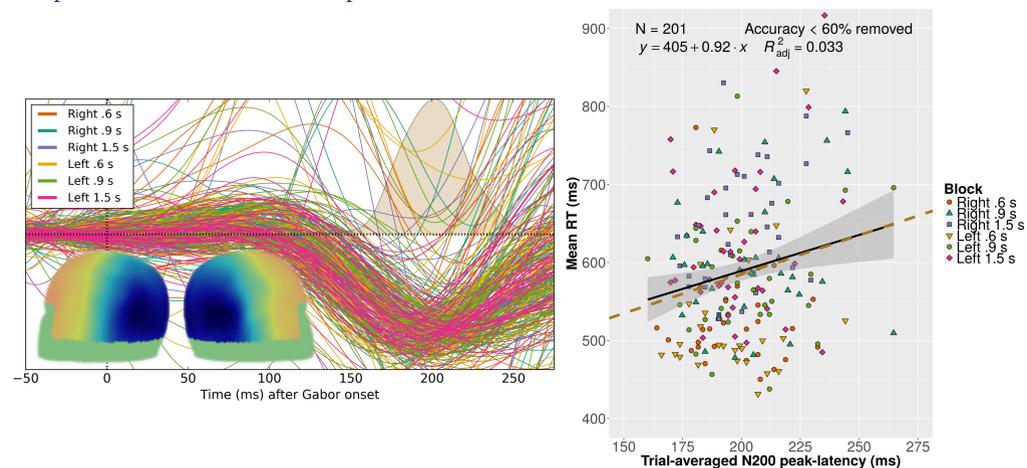
Spatial Frequency Differentiation Task (time pressured 2AFC)

On every trial, participants ($N = 32$ with 2 EEG sessions each) matched a randomly-rotated **Gabor** to previously-studied *high* or *low* spatial frequencies. Participants responded during the **response** interval by pressing one of two buttons with their right or left hands (3 blocks each). Feedback was given based on 3 different time pressure cutoffs (2 blocks each; 6 unique blocks during an EEG session). Distracting visual **noise** onset before the Gabor.



New evidence that N200 ERP latencies track VET

Visual ERPs to the target Gabor were reduced to single time series per EEG session and condition by SVD (PCA) from 128 electrodes. Latencies of early negative peaks (**N200s** with weight in occipital electrodes) were obtained from conditions in which participants were thought to be cognitively engaged in the difficult task (accuracy > 60%; $N = 201$). Some new evidence exists for a **slope-of-one** relationship between N200 latencies and **mean response times**. Mean RTs are likely to better reflect NDT in this cognitive task than early RT percentiles due to the time pressure cutoffs.

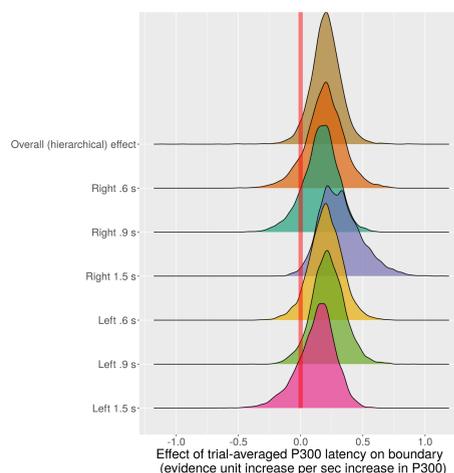


Testing via Hierarchical Bayesian (HB) Parameter Posteriors

$(RT, Acc)_{ijk} \sim (1 - \theta_{jk}) * DDM(\delta_{jk}, \alpha_{jk}, \tau_{jk}) + (\theta_{jk}) * Uniform(-max(RT)_{jk}, max(RT)_{jk})$
 Drift-diffusion model with lapse trials for trial i per EEG session j and condition k

$\delta_{jk} \sim Normal(\eta_{(\delta)k} + \gamma_{(\delta)k} * (ERP_time), \sigma^2_{(\delta)})$ Evidence accumulation rate prior

$\alpha_{jk} \sim Normal(\eta_{(\alpha)k} + \gamma_{(\alpha)k} * (ERP_time), \sigma^2_{(\alpha)})$ Evidence boundary prior

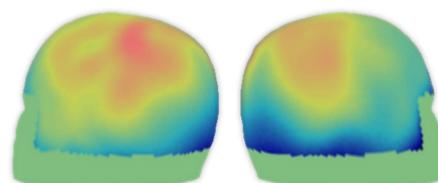


$\tau_{jk} \sim Normal(\eta_{(\tau)k} + \gamma_{(\tau)k} * (ERP_time), \sigma^2_{(\tau)})$ Non-decision time prior

$\theta_{jk} \sim Normal(\eta_{(\theta)k} + \gamma_{(\theta)k} * (ERP_time), \sigma^2_{(\theta)})$ Lapse-probability prior

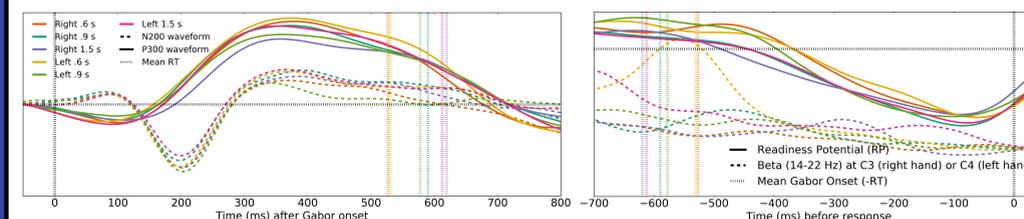
$\gamma_{(*)k} \sim Normal(\mu_{(*)}, \sigma^2_{(*)})$ Effect of ERP

$\mu_{(*)} \sim Normal(1, 3^2)$ Overall effect prior



No evidence of hypothesized condition effects on brain signals

Better estimates of P300, RP, and beta desynchronization may need to be found in order to provide evidence for or against neural reflection of evidence accumulation.



Ability to measure chronometric differences

Simple regression analysis yielded further evidence that visual event-related **N200 latencies** reflect **visual encoding times**. Some initial evidence was found that event-related **P300 latencies** reflect **visual evidence accumulation**.

Preregistration: <https://osf.io/78dgw/> Support: NSF Grant #1658303 Correspondence: mdnunez1@uci.edu

References: Ratcliff, R. & McKoon, G. (2008). The diffusion decision model: theory and data for two-choice decision tasks. ; Shadlen, M. N. & Kiani, R. (2013). Decision making as a window on cognition ; O'Connell, R. G., Dockree, P. M., Kelly, S. P. (2012). A supramodal accumulation-to-bound signal that determines perceptual decisions in humans. ; Philiastides M. G., Heekeren, H. R., Sajda, P. (2014) Human scalp potentials reflect a mixture of decision-related signals during perceptual choices.

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