Neural bases of the temporal prediction of affective signals

Over the past decade the principle of predictive coding -- the idea that a core function of the brain is to construct, and constantly update, a model of what's likely to happen in the future -- has emerged as a powerful model for understanding brain function at many levels of analysis. One example is the recent study of Samaha, Bauer, Cimaroli, and Postle (2015), in which subjects made a forced choice about whether briefly flashed luminance gratings were tilted to the left or right of vertical, followed by a confidence rating. Both objective and subjective performance was superior on the half of trials on which the pre-stimulus cue indicated (with 100% validity) the interval that would elapse prior to target onset. The other half were cued with "uninformative" cues that could be followed by any of four equiprobable cue-target intervals. Intriguingly, concurrent recording of the EEG indicated that a neural correlate of this temporal prediction effect was the strategic control of posterior alpha-band dynamics. On predictively cued trials, each subject altered the rate of the alpha-band oscillation such that it would be closer to his/her optimal phase angle for stimulus perception; subjects with a relatively fast resting alpha-band oscillation tended to "slow down" during predictive trials, and subjects with relatively slow resting alpha-band oscillations tended to "speed up".

We find these results to be promising, primarily because they suggest a strategy that might be effective for addressing more fundamental questions about the neural bases of core human behaviors. At one level is the domain of cognition. If predictive coding has been selected because it confers a survival advantage, it's unlikely that this is attributable to improved discrimination of oriented luminance gratings. Rather, *an intriguing possibility raised by the Samaha et al. (2015) results is that a similar mechanism may underlie the perception of information with clear implications for survival, such as facial affect.* A second key question is that of mechanism. Because the scalp EEG offers only a heavily filtered transform of neural activity, the actual mechanism(s) that underlie the "strategic control of posterior alpha-band dynamics" described in Samaha et al. (2015) remain unclear. However, with ECoG recordings collected at both putative sources (medial and inferior frontal regions; hippocampus) and sites (amygdala and ventromedial temporal neocortex) of the control of emotion processing, and with sophisticated analytic tools being developed in the Voytek and Lin labs, we are in a unique position to address fundamental questions about the processing of emotional stimuli.

The experimental design that we propose is modified from Samaha et al. (2015) in two critical ways. First, oriented luminance gratings are replaced by faces expressing fearful or neutral expressions. Second, so as to minimize the number of trials required per subject, there will only be one cue-trial interval following predictive cues (650 msec), and the cue-trial interval following *less-predictive* cues will be drawn from a Weibull probability distribution ranging from 650 msec to 1350 msec. This distribution has the desirable properties of generating 40% of trials at the critical 650 msec cue-target interval, yet also having a uniform hazard rate, meaning that no particular time point (including 650 msec) is more or less anticipated. Thus, administering trials from these two conditions in a ratio of $2_{\text{predictive}}:5_{\text{less predictive}}$ will yield an equal number of 650 msec cue-target interval trials from both conditions. The design is summarized in the *Figure 1*.

Hypotheses

The design can be construed as a simple 2 x 2 factorial, with the factors of Predictability (predictive, less-predictive) and Valence (fearful, neutral). Importantly, the influences that these two factors can have on the neural data are separated in time, because Predictability is known with the onset of the cue, but Valence can't be known until the onset of the face. This feature will allow for straightforward discrimination of neural effects that are associated with the control of the processing of facial affect vs. the real-time processing itself, as is made concrete in *Table 1* and *Table 2*.

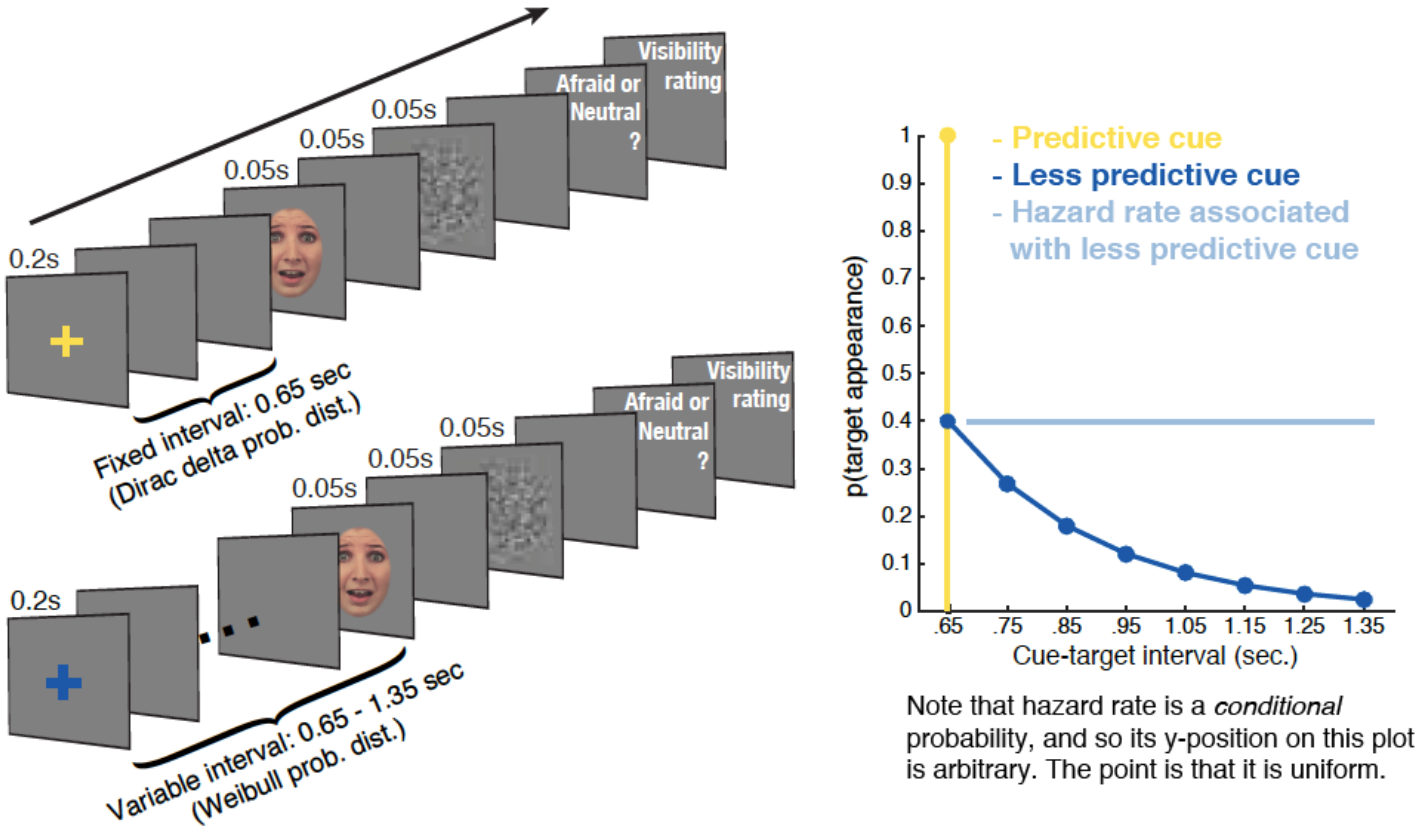

Figure 1. Diagram of predictive (yellow cue) and less-predictive (blue cue) trial types, on left, and of the associated probability structures and, for the less-predictive condition, the associated hazard rate.

Table 1. Hypotheses about **cue-related effects** (all effects are for Predictive condition, in relation to Less predictive, unless otherwise noted.)

		Temporal Predictability	
		Predictive	Less Predictive
Valence	Fearful	• Increased PFC-MTL and hippocampus-amygdala coupling during CTI, in theta band in PFC and hippocampus, and in either theta or high beta/low gamma in amygdala. • Frequency modulation of theta-band oscillations in amygdala and ventromedial temporal neocortex, to optimize instantaneous phase angle in conjunction with face onset.	
	Neutral	• Increased PFC-MTL and hippocampus-amygdala coupling during CTI, in theta band in PFC and hippocampus, and either theta or high beta/low gamma in amygdala. • Frequency modulation of theta-band oscillations in amygdala and ventromedial temporal neocortex, to optimize instantaneous phase angle in conjunction with face onset.	

CTI= cue-target interval
HFA = high-frequency activity (a.k.a. “high gamma”)

Table 2. Hypotheses about **face-related effects**

		Temporal Predictability	
		Predictive	Less Predictive
Valence	Fearful	• Fastest behavioral RT relative to other three cells of design • Highest HFA in amygdala and ventromedial temporal neocortex, relative to other three cells of design	• Faster behavioral RT relative to Less predictive/Neutral condition • Higher HFA in amygdala and ventromedial temporal neocortex
	Neutral	• Faster HFA in amygdala relative to Neutral/less predictive	

CTI= cue-target interval
HFA = high-frequency activity (a.k.a. “high gamma”)

Predictions from Table1 and 2 are cartooned in Figures 2 and 3.

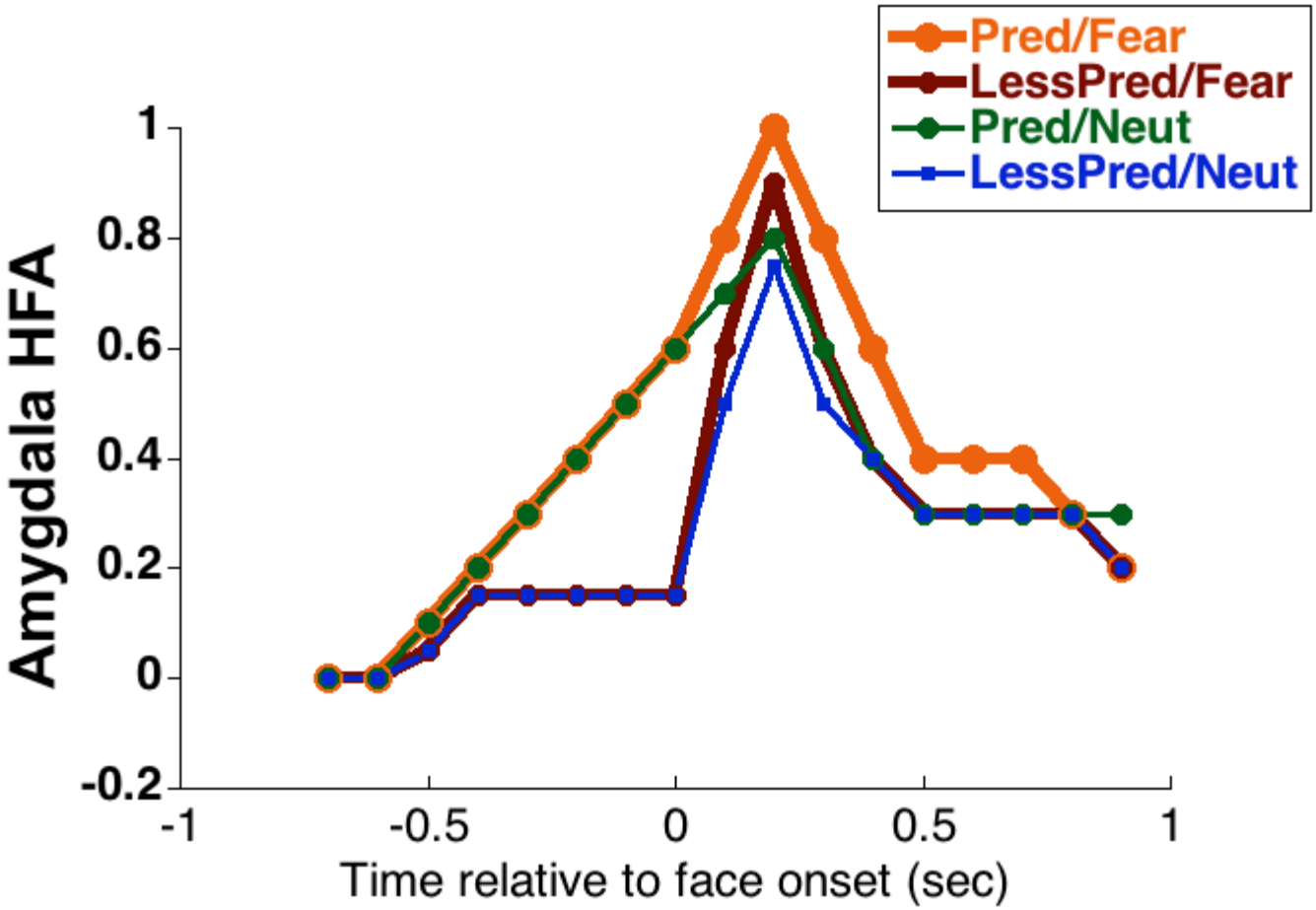

Figure 2. Hypothesized dynamics of Amygdala HFA in the four conditions the experiment. (Note that colors correspond to those from the tables. In the two predictive cue conditions, amygdala HFA is seen to rise beginning shortly after the onset of the cue, at time -650 msec. These trials diverge at time 0, however, because the onset of a fearful face evokes more vigorous activity in the amygdala than does the neutral face. For the two less-predictive cue conditions, after an initial cue-locked rise of HFA, the level of HFA flattens out, because subjects can not predict when the face will appear. (Note that only 650 msec CTI trials area shown for less-predictive trials.)

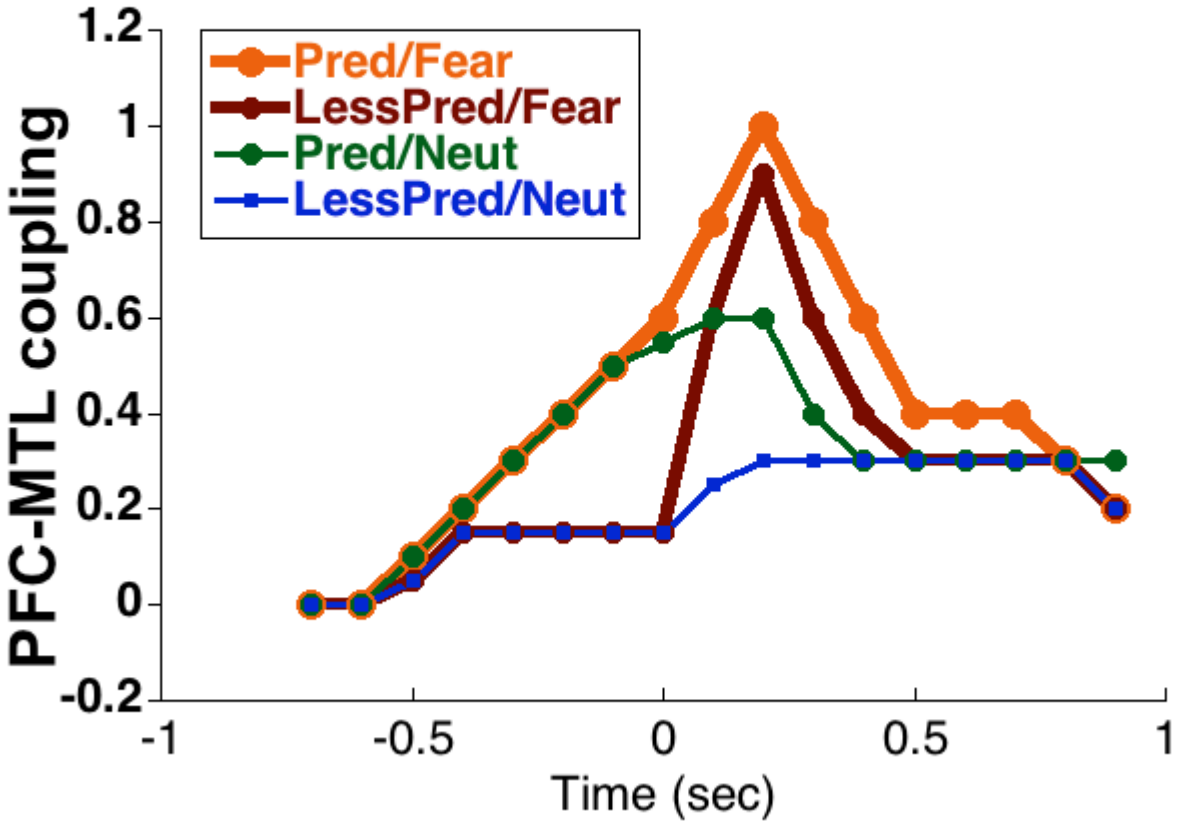

Figure 3. Hypothesized dynamics of PFC-MTL coupling in the four conditions the experiment. Whereas top-down control is highest during CTI for the two predictive conditions, these patterns diverge dramatically once the amygdala has decoded emotional valence, shortly after face onset at time 0 sec. This reflects greater recurrent communication between MTL and PFC needed to carry out the emotion regulation required by the fearful face. A similar divergence is seen for the two less predictive conditions, although the benefit conferred by the predictive cue is seen in the overall stronger PFC-MTL coupling observed in the Predictive/Fearful condition relative to the Less predictive/Fearful condition.

Samaha, J., P. Bauer, S. Cimaroli and B. R. Postle (2015). "Top-down control of the phase of alpha-band oscillations as a mechanism for temporal prediction." Proceedings of the National Academy of Science (USA) **112**: 8439–8444. PMCID: 4500260