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# Beta coherence within human ventromedial prefrontal cortex precedes affective value choices

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ABSTRACT

Ventromedial prefrontal cortex (vmPFC) forms a core region of larger brain circuits that assign value to sensory inputs and interfaces motivational and cognitive dominated brain processes. This network function of the vmPFC could be realized by synchronizing local activity at time scales that are shared by connected brain areas, but it is unknown whether vmPFC circuitry engages in functionally specific synchronization. Here, we recorded in human subcallosal vmPFC while subjects engaged in an emotion tracking task that required the assignment of positive or negative affective value to ambiguous (happy–sad) facial expressions. We found that vmPFC engages in low beta-band (15–20 Hz) coherent activation just before subjects subjectively judged ambiguous facial expressions as conveying negative valence ('sad') information, but not before positive valence ('happy') judgments. The predictive beta coherence emerged particularly for conflicting rather than pure emotional facial cues and dissipated slowly after the choice was made. These results suggest that 15–20 Hz coherent activity within vmPFC marks a functional signature of a valuation process that informs categorical affective choices. We hypothesize that coherent beta band activation signifies functional interactions to anatomical vmPFC projection targets, raising the possibility that dysfunctional biases in affective valuation and an enhanced decision conflict in clinical depression could be indexed by alterations of beta coherent network activation.



## Introduction

The human ventromedial prefrontal cortex vmPFC contributes to value-based choice behavior in addition to its role in regulating affective states and interpreting emotional events (Lindquist et al., 2012; Price and Drevets, 2012; Roy et al., 2012; Rushworth et al., 2012). These functions of the vmPFC have been suggested to derive from its functional connectivity to 'limbic' and the 'default' mode functional brain networks (Choi et al., 2012; Lindquist and Barrett, 2012; Yeo et al., 2011) that interconnect the vmPFC with prominent subcortical circuits for reward and memory (Euston et al., 2012; Haber and Knutson, 2010). Consistent with these functional connectivity patterns, fMRI studies have shown that the subcallosal part of the vmPFC encodes the specific affective content of sensory inputs independent of modality (Peelen et al., 2010), represents subjective value preferences (Plassmann et al., 2010), and conveys emotional evaluations even in the absence of active task demands (Lebreton et al., 2009). Beyond these affective evaluation signals, overlapping subcallosal vmPFC brain regions consistently activate in decision making fMRI studies, providing a value difference signal about choice options that is believed to either inform top-down control circuits in prefrontal and parietal cortices during the implementation of a decision, or to reflect the decision mechanism itself (Kable and Glimcher, 2009; Kahnt et al., 2010; Kaping et al., 2011; Kolling et al., 2012; Rushworth et al., 2011).

These diverse functional signatures of vmPFC activation suggest that its particular role in emotional and choice related evaluation processes depends on the particular task probing larger functional brain circuit (Lindquist and Barrett, 2012). Tasks may emphasize either the integration with subcortically dominated reward related processes, or the coupling to cognitive control processes that predominantly engage neocortical fronto-parietal networks. For either type of process, it has been difficult to determine how the vmPFC realizes its network function at the fast time scales that are beyond the temporal resolution of fMRI. For these faster time scales, recent studies suggest that decision relevant information is processed by coherent oscillatory activity among those brain areas participating in the functional network (Siegel et al., 2012; Womelsdorf et al., 2010). In the prefrontal and

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parietal cortices, decision variables are encoded by coherent activity in frequency ranges spanning the theta to high beta bands (Buschman and Miller, 2007; Gould et al., 2012; Pesaran et al., 2008; Salazar et al., 2012; Siegel et al., 2012). Within subcortical brain circuitry including amygdala, striatum and medial temporal cortex choice related information is conveyed by coherence at theta to low beta frequencies (Fell and Axmacher, 2011; Rutishauser et al., 2010; Womelsdorf et al., 2010). It remains however unknown whether rhythmic activity indexes choice processes in the human medial frontal cortex (Hunt et al., 2012).

Here, we utilized a rare opportunity to test for local synchrony modulation in human subcallosal vmPFC by recording activity from electrodes implanted in subjects with clinical depression (Hamani et al., 2010; Lozano et al., 2012). Subjects engaged in an attentive tracking task of emotional cues in a facial morph sequence and judged

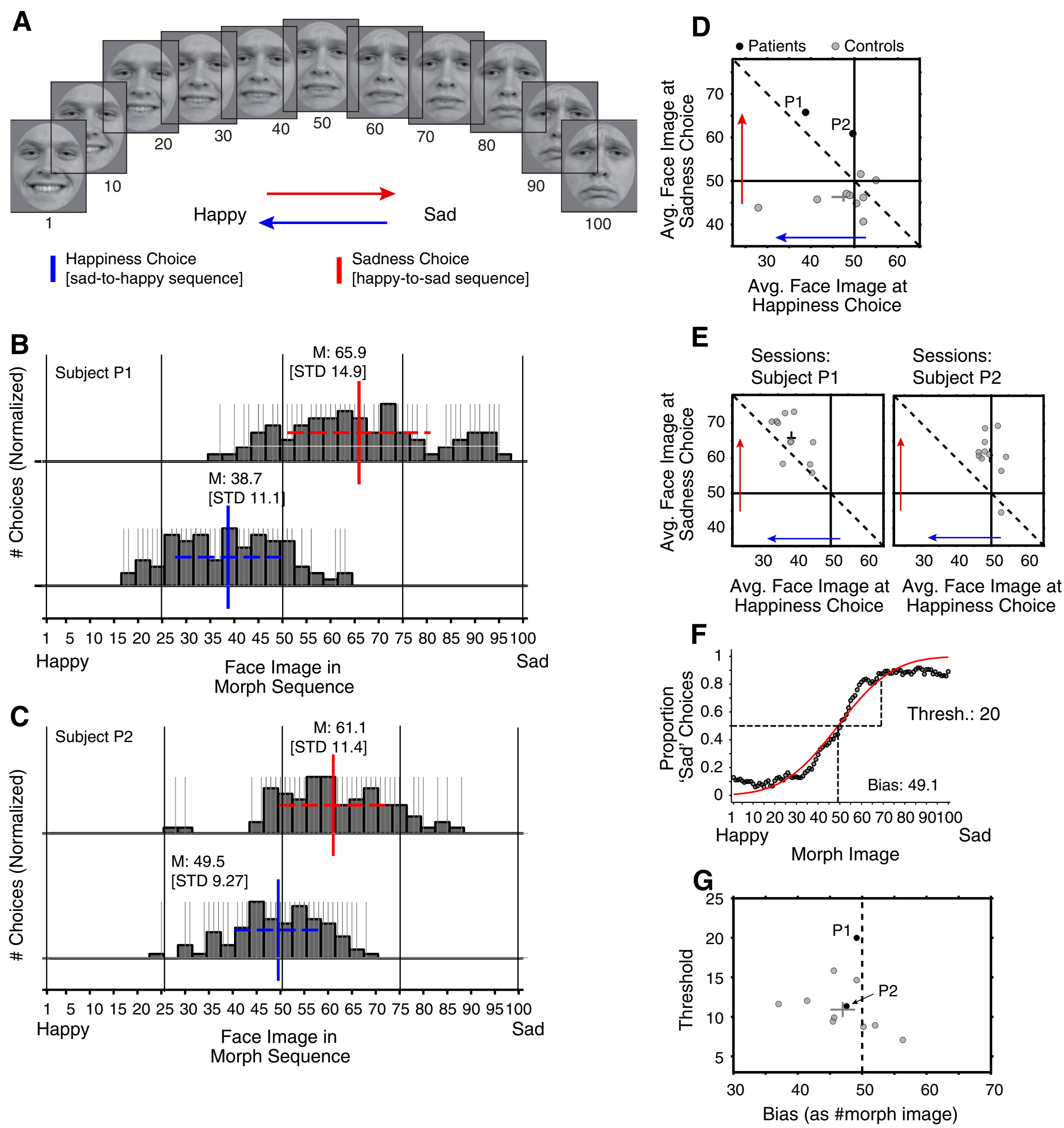


**Fig. 1.** Behavioral performance. (A) Illustration of the morph sequence of facial expressions ranging from happy towards sad expression with a linearly spaced morphing of both standards in between. (B, C) Normalized histograms of choices (*y-axis*) that a happy expression changed to a sad expression (*upper histogram*), or that a sad expression changed to a happy expression (*bottom histogram*) for subject P1 (B) and subject P2 (C). Gray lines show the chosen image (*x-axis*) of individual trials. Vertical red (blue) lines indicate the average morph level that triggered a change 'to sadness' ('to happiness') decision. Dashed horizontal lines denote the 95% confidence range around the mean. (D) Average morph levels that triggered a negative valence choice (*y-axis*), or positive valence choice (*x-axis*) for each control subject (gray dots) and subject P1 and P2 (black dots). The gray cross denotes the mean ± SE across sessions of the control subjects. The diagonal dashed line shows the unity line. (E) Average morph levels that triggered a negative/sad (y-axis), or positive/happy (x-axis) decision for each behavioral session of subject P1 (*left panel*) and subject P2 (*right panel*). The black cross denotes the mean ± SE across sessions. The diagonal dashed line shows the unity line. (F) Psychometric function of sad vs. happy decisions (*y-axis*: proportion of sad choices) plotted against the morph level of the facial expression (*x-axis*) from six staircase experiments of subject P1 that required a forced choice decision to static facial expressions. The red line shows the best sigmoidal fit, with the bias (morph level that corresponds to p = 0.5 sad/happy choices) and the 84% threshold indicated by dashed lines. (G) Average thresholds (*y-axis*) and biases (*x-axis*) for control subjects (gray dots) and the mean across control subjects (gray cross). Black dot denotes the means for subjects P1 and P2.