Exploring the relationship between the neural signatures of perceptual decision-formation and metacognition

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Abstract:

Computational modelling and neurophysiological recordings suggest that perceptual decision-making involves integrating noisy sensory evidence up to an action-triggering threshold. The same process also plays a direct role in informing representations of choice confidence but the exact relationship remains unclear. Here, participants performed two versions of a random dot motion discrimination task in which kinematograms were presented at pseudo-random intervals. Analyses centered on three neural signatures of decision formation. Firstly, the Centro-Parietal Positivity exhibited a gradual build-up during coherent motion presentation and the amplitude reached at response cue presentation and at response execution both exhibited a strong positive correlation with confidence reports and choice accuracy. Second, higher choice confidence was associated with reduced preparation of the unchosen effector, while the chosen effector reached a fixed threshold at response irrespective of stimulus duration, RT or certainty. Thirdly, higher Fronto-Central Theta was observed on low confidence trials, consistent with models in which choice certainty reflects the relative activation of the chosen and unchosen response alternatives. These results suggest the neural representation of cumulative evidence and response conflict provide the necessary information for the emergence of graded representation of choice certainty and provide support for the neural mechanisms posited by these frameworks.

Keywords: perceptual-decision making; metacognition; choice certainty;

Introduction

Extensive theoretical, computational and empirical research indicates that perceptual decisions are formed by accumulating noisy sensory evidence into a decision variable that triggers action upon reaching a threshold. Recent studies suggest the same accumulation process may have a functional role beyond the decision process and might provide the input to our confidence judgments but the manner in which decision evidence is read-out for metacognition remains unclear. Recent electrophysiological research has uncovered two functionally distinct classes of decision signal. Most human and non-human recording studies have focused on effector-selective signals that combine cumulative sensory evidence with other inputs (e.g. urgency) and represent the preparation of a specific motor plan. More recently, human work has uncovered a centro-parietal postivitiy (CPP) that traces the accumulation of sensory evidence and does so independently of sensory or motor requirements (Steinemann et al., 2018; O'Connell et al., 2012). This latter signal represents an ideal input for choice confidence since it represents the cumulative evidence irrespective of any strategic adjustments that are made at the motor level when accounting for factors such as speed pressure or prior information (Steinemann et al., 2018). However, the relationship between the choice confidence and neural signatures of perceptual decision-formation has yet to be fully understood.

The current study aims to explore this relationship through adopting a novel version of the random dot motion discrimination task in which stimuli disappeared at pseudo-random intervals. Afterwards a response cue appeared, prompting participants to simultaneously indicate the dominant motion direction and their confidence in that choice. The task was administered under two separate conditions requiring either saccadic or bimanual button press responses. Analyses centred on three non-invasive electroencephalographic signatures of decision formation: Centro-Parietal Positivity (CPP), which traces the accumulation of sensory evidence for perceptual decisions irrespective of sensory or motor requirements, effector-selective premotor beta-band activity (Lateralised Beta), which reflects the translation of the decision into a specific motor plan, and Fronto-Central theta (Fcθ),

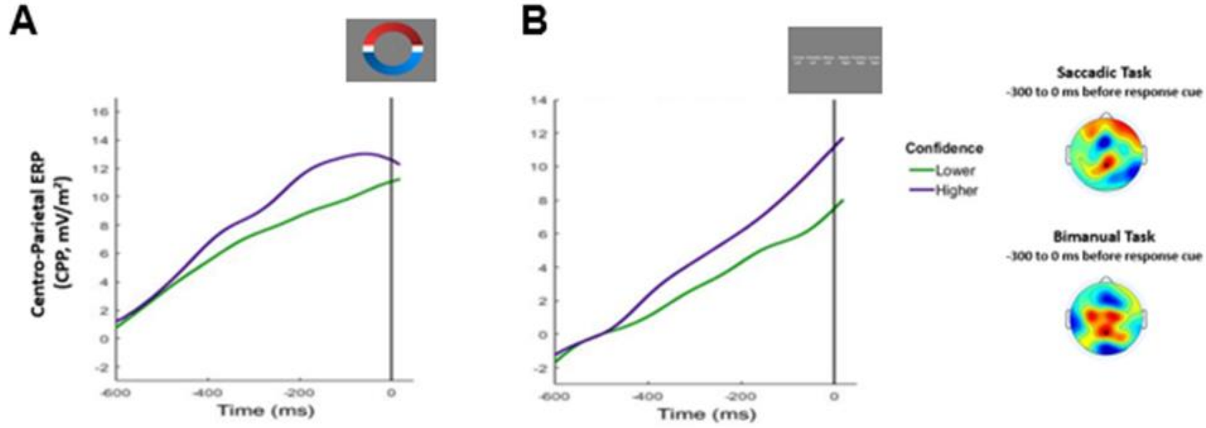

Figure 1: Time point 0 indicates the onset of the response cue in both panels. A. CPP by confidence for the saccadic dot motion task B. CPP during coherent motion presentation in the bimanual dot motion paradigm.

hypothesised to index conflict between competing action plans.

Results

Data analyzed from a total of 41 subjects, 21 and 20 participants in the saccadic and bimanual paradigm respectively, indicate the CPP reached a significantly higher amplitude when participants indicated higher confidence at the time of the response cue (figure 1.A & B). This difference in amplitude emerges gradually during the coherent motion presentation and is most prominent in the final moments before the response cue, consistent with the predictions of the sequential-sampling models, which expect a gradually emerging difference in the decision variable across the stimulus presentation.

Further analysis of the motor preparation signals showed additional support that accumulated evidence for the unchosen decision can impact confidence. Significantly stronger ipsilateral motor preparation was observed when confidence in the motion direction was low, while contralateral beta activity reached a stereotyped threshold at response execution (figure 2.A). Response conflict, indexed through Fcθ power, similarly was significantly elevated in the final moments before response execution with lower certainty (figure 2.B).

Discussion

The current study aimed to investigate the role of different neural signatures into the emergence of a graded representation of choice confidence. We found that the amplitude of the CPP during stimulus presentation predicted the level of choice confidence in the final decision. Ipsilateral motor preparation and Fcθ power showed a similar relationship in the response-aligned signals. Taken together these results suggest that the neural representation of choice confidence manifests in the neural signatures of perceptual decision-making in qualitatively different ways. Further work will be required to determine the causal role that these signals play in determining choice confidence.

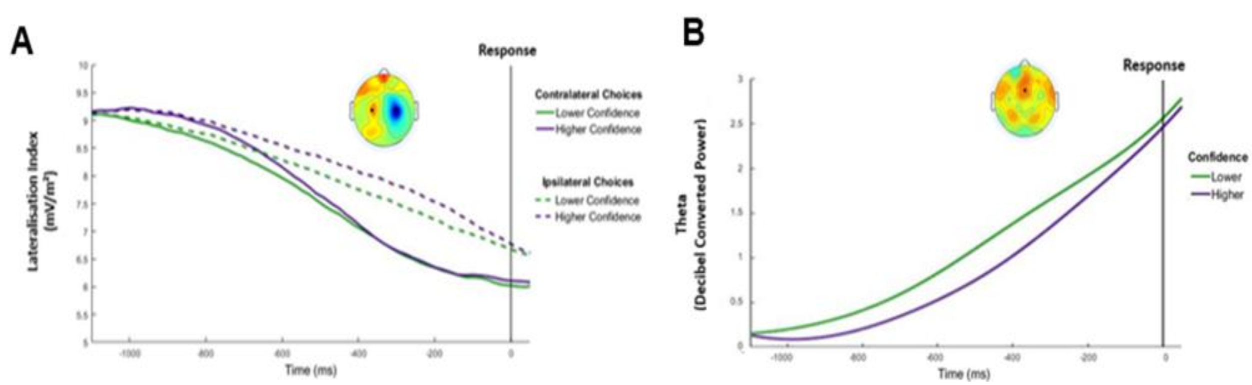

Figure 2. Time point 0 denotes response execution. A. Response-aligned lateralised beta traces separated by response side and confidence in the bimanual dot motion task. B. Decibel (Db) Converted Theta power for high and low confidence choices in the bimanual dot motion task.

Acknowledgments

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