

A Discrete Motor-Independent Signature of Urgency During Human Perceptual Decision Making

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Abstract

When faced with a strict deadline, how does the brain adjust its decision processes to account for the passage of time? Computational modelling and electrophysiological investigations have pointed to dynamic ‘urgency’ processes that serve to progressively reduce the quantity of evidence required to reach choice commitment as time elapses. To date, such urgency dynamics have been observed exclusively in neural signals that accumulate evidence for a specific motor plan. Across three complementary experiments, we show that the Contingent Negative Variation (CNV) represents a discrete, motor-independent signature of urgency, aligning closely with model predicted bound adjustments and exhibiting additional properties not observed in previously identified urgency signatures. Firstly, it provides a discrete representation of urgency as it grows only as a function of time and not evidence strength. Secondly, when choice reports must be withheld until a response cue, the CNV peaks and decays long before response execution, instead mirroring the time course of a motor-independent evidence accumulation signal (Centro-Parietal Positivity (CPP)). Our data demonstrate that urgency processes can be monitored in a model-independent manner via non-invasive brain signals, and that these signals can be used to inform computational models, leading to improved fits to behaviour.

Keywords: decision-making; urgency; drift-diffusion modelling; EEG

Introduction

As the motorist fast approaching a fork in the road can appreciate, making a quick decision can be just as important as making an accurate one. According to evidence accumulation models, decision makers can adapt to speed pressure by lowering their decision bounds, reducing the amount of evidence required to reach choice commitment. This can be achieved by fixing the decision bound at a lower level prior to deliberation, and/or by implementing a dynamic, time-dependent bound collapse. Although the existence of such dynamic adjustments is a subject of long-standing debate in the behavioural modelling literature (e.g. Hawkins et al 2015; Trueblood et al 2021), neurophysiological investigations have consistently indicated that both static and dynamic bound adjustments are implemented in certain contexts. Under increased speed pressure with strict deadlines, choice-selective motor planning signals exhibit elevated starting levels of activity and evidence-independent, time-dependent ‘urgency’ build-up components during deliberation (Churchland et al., 2008; Hanks et al., 2014; Murphy et al., 2016; Steinemann et al., 2018; Kelly et al., 2021).

Thus far, these urgency components have been exclusively observed within neural populations that plan specific decision-reporting actions, such as monkey lateral intraparietal area (LIP) and human limb-selective mu/beta (8-30 Hz) activity. This apparent effector-dependence raises the question of whether urgency signals operate

exclusively within motor planning circuits or play a more general, movement-independent role in expediting choice commitment.

In the present study, we sought to test whether the Contingent Negative Variation (CNV), a human EEG signature that has long been associated with timing and anticipation (Boehm et al., 2014; Kononowicz & Penney, 2016), traces urgency during choice deliberation. Using a set of complementary experiments, we show that the CNV represents a discrete movement-independent index of urgency that is not influenced by sensory evidence strength or tied to a specific effector.

Methods

Experiment 1: Twenty-five participants (14 females, mean age: 23.10 years, age range: 18-34 years) performed a two-alternative contrast discrimination task under conditions of relative Speed or Accuracy emphasis, reporting their choice using left and right mouse clicks with their left and right thumbs. In the Accuracy Regime, points were awarded/deducted solely as a function of choice accuracy whereas in the Speed condition, points awarded/deducted scaled with response time.

Experiment 2: Thirty participants (16 females, mean age: 22.3 years, age range: 18-27 years) performed a two-alternative random dot motion task in which they had to discriminate the direction (left or right) of a cloud of moving dots. Participants performed the task in blocks with varying deadlines: 1200ms, 1800ms and Delayed Response (report choice after response cue at 1800ms).

Experiment 3: Twenty-three participants (14 females, mean age: 22.5 years, age range: 18-29 years) performed a two-alternative ‘continuous monitoring’ random dot motion task containing relatively long and unpredictable inter-target-intervals (3.6s, 6.6s or 8.4s), in alternating Speed and Accuracy Regime blocks. In the Accuracy Regime, participants had the full duration of target presentation (2s) to earn rewards for correct responses. In the Speed Regime, participants had just under half the time (0.9s) to earn points for correct responses.

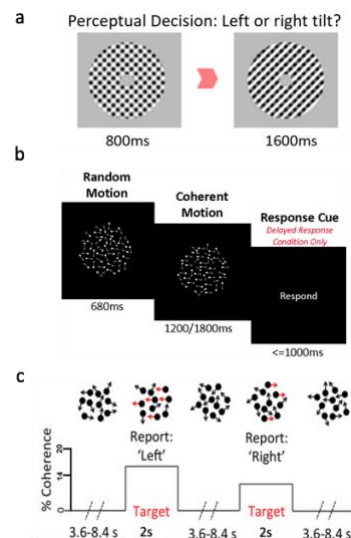


Figure 1: Task schematics for Experiment 1 (a), 2 (b) and 3 (c).

Results

Experiment 1: The CNV is a Discrete Urgency Signature

As expected, choices were significantly faster (Fig 2a; $F(1, 24)=32.8, p<.001, \eta^2_p=0.37$) and less accurate (Fig 2a; $F(1, 24)=14.2, p<.001, \eta^2_p=0.58$) in the Speed Regime. Computational modelling indicated that a full drift diffusion model with an additional linear boundary collapse parameter provided a significantly better fit to behaviour than a model with fixed bounds (reduction in AIC from 37.57 to 14.71). The behavioural differences across Regimes were explained by a static lowering of decision bound in the Speed Regime, while there was no difference in the rate of collapse across Regimes. The CNV exhibited close correspondence with the model predicted bound adjustments: its pre-choice amplitude increased as a function of RT ($F(4,96)=3.4, p=0.01, \eta^2_p=0.13$), but was not influenced by Regime (Fig 2b; $F(1,24)=1.97, p=0.17, \eta^2_p=0.08$), and its amplitude at evidence onset was significantly larger (more negative) in the Speed Regime (Fig 2b; $F(1,24)=5.5, p=0.03, \eta^2_p=0.19$). Additionally, we found that unlike the Centro-Parietal Positivity (CPP), which traces evidence accumulation, CNV build-up was not significantly affected by sensory evidence strength (Fig 2c and d; $F(1,24)=0.42, p=0.52, \eta^2_p=0.02$).

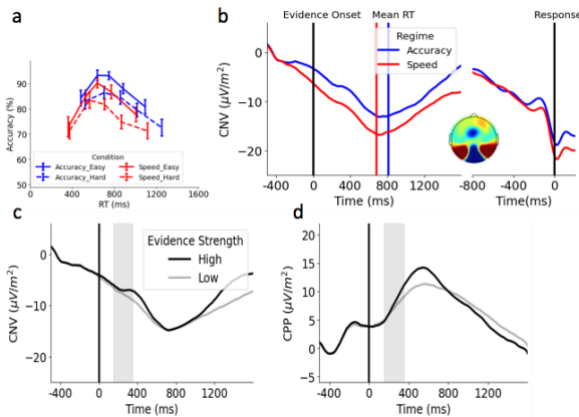


Figure 2: a) Accuracy plotted as a function of RT. b) CNV plotted as a function of Regime. c) CNV and d) CPP plotted as a function of evidence strength. Grey shading marks the interval for measuring signal slope as a function of evidence strength after removal of trials with RTs falling before the end of that interval.

Experiment 2: CNV is Movement-Independent

When participants had to withhold their response until the presentation of a response cue, we found that the CNV peaked and resolved to baseline well in advance of response execution (Fig 3a). Instead, its peak was more closely aligned to the termination of evidence accumulation, indexed by the CPP peak (Fig 3b).

Experiment 3: The CNV Traces Urgency in Continuous Monitoring Contexts.

Motor preparation, indexed by pre-motor beta band (15-30Hz) desynchronisation, increased during the ITI, consistent with a progressive narrowing of decision

boundaries as target onset probability increased. The addition of an urgency function, derived from fitting a 2nd order polynomial to beta during the ITI (Geuzebroek et al., 2023), significantly improved the fit of the drift diffusion model to behaviour (Reduction in AIC from 42 to 37). We found that the CNV followed a similar time course during the ITI (Fig 4), and the urgency functions derived from both signals were highly correlated (Accuracy: $r = 0.93$, Speed: $r = 0.99$).

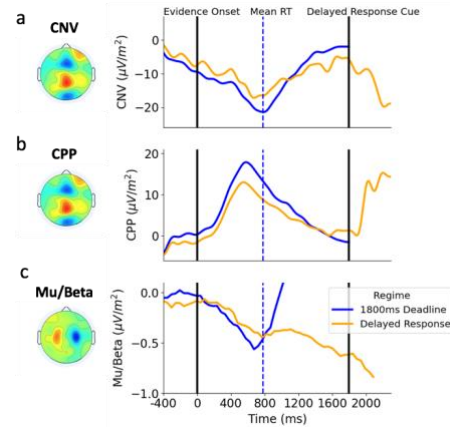


Figure 3: CNV (a), CPP (b) and Mu/Beta (c) in the 1800ms (blue) and Delayed Response (orange) conditions.

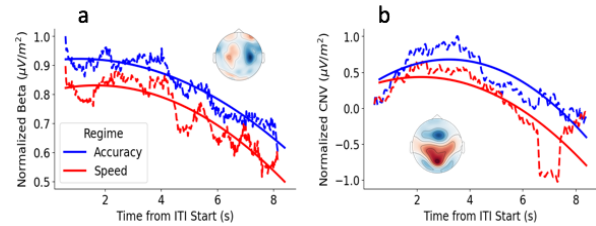


Figure 4: a) Normalized Beta (15-30Hz) and b) CNV plotted over the ITI as a function of Regime. Solid lines indicate the urgency function fit to each signal.

Discussion

In three experiments, we have shown that the CNV traces urgency across a variety of perceptual decision making scenarios. The apparent motor-independence of the CNV grants intriguing insights into the functional characteristics of urgency, as it suggests that urgency serves not only to speed up motor execution, but also to expedite cognitive deliberation. In isolating this novel urgency signature, we further highlight how non-invasive brain signals can be used to inform and constrain computational models, improving fits to behaviour and aiding model adjudication. Indeed, the evidence- and motor-independent nature of the CNV may render it particularly useful as a neural constraint, as one of the limitations that has been raised about using mu/beta signals to constrain urgency is that its build-up is influenced by evidence strength in addition to speed pressure and the passing of time.

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