Capturing nonlinear neural and diffusion-model informed behavioural dynamics of kinaesthetic awareness in wake-sleep transitions

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The goal of my research stay at the University of Cambridge, as part of my Master program in Amsterdam, was to obtain extensive training in experimental design and analytical tools for electropencephalography (EEG) in humans, deepening my skills in the computational aspects of cognitive neuroscience. In addition to these technical aspects, I followed a course "Open science, pre-registration, data-and-code sharing, communication tools, and the limits of interpretation". I can safely say that my experience in Cambridge fully lived up, and went beyond, these expectations. I developed skills in computational modelling using Python, pre-processing of TMS-EEG data in MATLAB, and got an understanding of Linux-based programming to run analyses on high-performance computers. Besides, through many conversations about study conceptualisation with my supervisor, Tristan, I learned a lot about experimental design, theory-driven study and analysis design, and theory of consciousness in general. These skills were fostered with the goal to capture neural and behavioural dynamics of decision-making in wake-sleep transitions, although I believe all of the above mentioned skills and knowledge are highly transferrable to further work in Amsterdam, developing analysis pipelines, and my future career in general. The NENS scholarship helped make this experience financially viable, for which I am very grateful.

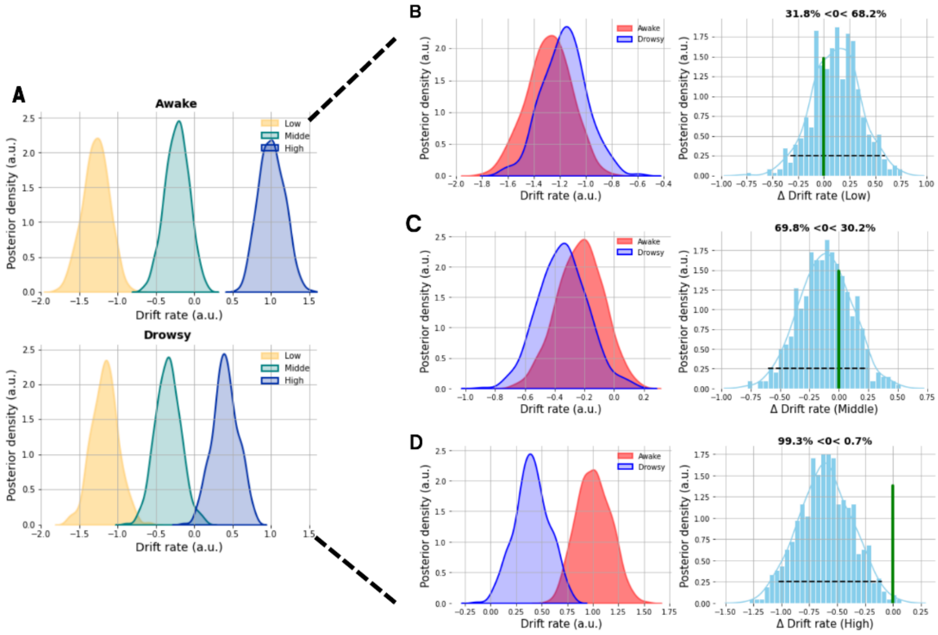
Briefly about the research: Drowsiness is pervasive and ubiquitous in our day-to-day activities, detrimentally impacting task performance in daily settings such as driving, but also in scientific settings. Participants are known to naturally fluctuate between several drowsiness stages during experimental tasks (Tagliazucchi et al., 2004), influencing arousal and attention, but likely also neural markers of interest and neural functioning in general. Nevertheless, our understanding of how drowsiness impacts cognition remains limited. Previous studies demonstrated the emergence of complex, nonlinear neurobehavioural changes across drowsiness stages, along with a seemingly compensatory redistribution of cognitive resources. Perceptual-decision making is seen as a window into cognition, and typically analytical frameworks such as signal detection theory (SDT) and psychophysical curve fitting serve to characterize task performance and putatively link this to neural markers. However, SDT does not allow inference of changes in the underlying process of decision-making across drowsiness stages, for example. Using drift-diffusion modelling (DDM), we obtained a more process-oriented view on decision-making. We performed secondary analyses on data from a companion paper (Noreika et al., 2017), in which blindfolded participants tried to detect finger movement in response to single-pulse TMS. The DDM parameterises the decision-making process into four variables: drift rate (*v*) indicates the speed of evidence sampling for a decision and boundary separation (*a*) the difference in subjective evidence threshold. Non-decision time (*t*) covers the perceptual encoding and motor implementation phase. Last, bias point (*z*) captures any *a* priori biases in response style.

Furthermore, we were interested in what neural markers index changes in these latent psychological variables, and what spatiotemporal pattern this brain-behavioural coupling would follow. We hypothesized neural markers of information, weighted symbolic mutual information (wSMI) in our case, to be more informative of behavioural dynamics than non-linear markers. For a more elaborate description of the conceptual framework and hypotheses, see this pre-registration form.

We successfully parameterised the decision-making process using hierarchical Bayesian DDM, indicating effects of drowsiness mainly in the central evidence accumulation stages (*see figure 1*), corroborating previous findings using SDT and psychophysical curve fitting (Xu et al., 2023). In addition, we found an asymmetrical modulation of *v* and *z* for high stimulus intensities (graphs not shown). Furthermore, visualisation of wSMI in spatiotemporal maps showed distinct patterns between awake and drowsy, indicative of differences in information exchange in response to single-pulse TMS (results not shown). However, these results are preliminary and require further investigation. This, together with a theory-driven approach to the brain-behavioural modelling, will be the focus of follow-up work.

Figure 1

Drift rate posterior densities across alertness states and stimulus intensities.



Note. Posterior densities for drift rate estimation across alertness states (awake vs. drowsy) and stimulus intensities (low, middle, high). ***A.*** Drift rate estimations in low (yellow), middle (green) and high (blue) stimulus intensities for awake (top panel) and drowsy (lower panel). ***B, C, D.*** Panels on the right represent awake vs. drowsy differences between posterior densities in low (top panel), middle (middle panel) and high (lower panel) stimulus intensities , with the green vertical line indicating zero difference in means, and the proportion of overlap indicating chance of a reliable difference (<5% = reliable non-zero difference). Black dotted lines indicate 95% Highest Density Interval (HDI).

Picture 1: Formal dinner with part of the lab

Picture 2: 10-year lab anniversary celebration with the extended lab

Picture 3: My farewell dinner