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Cognitive control, dynamic salience and the imperative toward computational accounts of neuromodulatory function

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Abstract:	We draw attention to studies showing that phasic arousal increases interference effects in tasks necessitating the recruitment of cognitive control. We suggest that arousal-biased competition models such as GANE may be able to explain these findings by taking into account dynamic, within-trial changes in the relative salience of task-relevant and task-irrelevant features. However, testing this hypothesis requires a computational model.

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Commentary Title: Cognitive control, dynamic salience and the imperative toward computational accounts of neuromodulatory function

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Abstract:

We draw attention to studies showing that phasic arousal increases interference effects in tasks necessitating the recruitment of cognitive control. We suggest that arousal-biased competition models such as GANE may be able to explain these findings by taking into account dynamic, within-trial changes in the relative salience of task-relevant and task-irrelevant features. However, testing this hypothesis requires a computational model.

Commentary:

Mather and colleagues' GANE model offers a compelling and neurobiologically principled account of how phasic arousal and the associated release of norepinephrine (NE) benefit perception and memory of salient, high-priority information at the expense of lower-priority information. Here, we draw attention to a directly relevant line of research that the authors do not address, concerning the effect of phasic arousal in tasks that necessitate the online recruitment of cognitive control. In such task contexts, exogenously salient but misleading aspects of the stimulus must be ignored in favour of less conspicuous but task-relevant information. Thus, there is competition for representation between stimulus features that have bottom-up salience and features that are assigned priority via the top-down deployment of attention. Participants are typically able to perform such tasks at a high level of accuracy, indicating that the task-relevant stimulus features generally win this competition. Yet, contrary to straightforward predictions of 'winner-take-more/loser-take-less' models of

arousal-biased competition like the GANE model, it has repeatedly been shown that a phasic arousal boost in such contexts leads to *increased* interference effects (i.e., decreased accuracy and a relative slowing of response times when the task-irrelevant feature and/or its associated response are incongruent with the task-relevant information; Böckler et al. 2011; Callejas et al. 2005; 2014; Correa et al. 2010; Fan et al. 2002; 2009; Fischer et al. 2010; Klein & Ivanoff 2011; MacLeod et al. 2010; Weinbach & Henik 2012; 2014).

Close examination of the behavior on cognitive control tasks has yielded an important insight that helps to reconcile winner-take-more models with this arousal-driven increase in interference effects. Specifically, empirical conditional accuracy functions (Gratton et al. 1988; Hommel 1994) and computational analyses (Cohen et al. 1992; Nieuwenhuis & de Klein 2012; White et al. 2011) indicate that the relative salience of task-irrelevant and task-relevant stimulus features on such tasks changes rapidly over the course of a single trial: Early in a trial the bottom-up salience of the task-irrelevant information dominates the competition, but as cognitive control develops, the top-down salience of task-relevant information increases and usually wins the competition. In such a scenario, instantiation of a winner-take-more regime via a phasic increase in arousal would initially serve to enhance the early dominance of the task-irrelevant information and, depending on the duration of the phasic arousal response, may make it more difficult for the task-relevant information to eventually win out. Thus, by drawing on the idea of dynamic, time-variant salience, GANE may in principle be able to explain the well-documented interactions between arousal and cognitive control.

A clear implication of time-varying salience is that the predicted neural and behavioral outcomes of the winner-take-more/loser-take-less effects of glutamate-NE interactions will be critically dependent on the timescale over which these interactions occur. We believe that this point poses a key challenge for the GANE model, because the level of analysis required to generate formal predictions of this nature is absent from the model in its current form; that is, a computational level of analysis that explicitly links neurobiology to behavior. In the domain of cognitive control tasks, without model simulations it is unclear whether the transient NE-mediated enhancement in processing occurs early in the trial when the task-irrelevant information dominates processing, later in the trial when cognitive control has prioritized task-relevant information, or both. Similar model simulations incorporating the timing of NE-mediated processing enhancements are also necessary to confirm whether GANE can account for the differential pattern of arousal effects on memory for stimuli occurring before and after arousing events (Sasaki et al. 2014).

In principle, GANE may be implemented in the form of a detailed biophysical model (e.g., Eckhoff et al. 2009; Wang 2002) that simulates the cascade of neurochemical events at the "NE hot spots" described by Mather and colleagues. This component of the model would need to interact with other biophysically-realized components that sustain associated cognitive functions (decision-making, cognitive control, memory) and generate task behavior, and the model predictions will depend on the interactions between these component processes and their relative timing. However, the fidelity of biophysical detail in such a model will likely trade-off with its ability to provide a unified explanation of the vast array of arousal-related behavioral effects reviewed in the target article.

An alternative, perhaps more feasible approach would be for Mather and colleagues to adopt a simplified computational model of NE function that captures the essential impact of NE-glutamate interactions on task performance, in a form that is computationally tractable and can therefore be leveraged to generate predictions based on GANE principles in a wide variety of behavioral contexts. Indeed, a class of connectionist models of NE function already exists that appears well-suited to such a pursuit. In these models, NE modulation is implemented as a multiplicative change in the input-to-output function of a task processing unit – otherwise known as a change in "gain" – and produces the critical winner-take-more/loser-take-less effects that GANE attempts to account for (e.g., Eldar et al. 2013; Servan-Schreiber et al. 1990). These models have been successfully adapted to explain neuromodulatory effects on perception and memory in a wide variety of task contexts, including those that require the online recruitment of cognitive control. Moreover, the model

components governing NE modulation can be implemented at multiple levels of abstraction, from single model parameters that are global and time-invariant (Eldar et al. 2013; Servan-Schreiber et al. 1990), to fine-grained sub-networks that operate on biophysically-realistic principles and afford precise control over timing (Gilzenrat et al. 2002; Nieuwenhuis et al. 2005; Usher et al. 1999). In our view, whether the research question of interest pertains to arousal/cognitive control interactions or otherwise, this type of broadly applicable, computationally tractable modelling framework will be necessary to generate and test precise predictions of the GANE model in the future.

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