Exploit Environmental Events and Explore New Behaviors: The Effects of Neuromodulation on Attention and Action-Selection

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Biological organisms have the ability to respond quickly to an ever-changing world. Because this adaptability is so critical for survival, all vertebrates have sub-cortical structures, which comprise the neuromodulatory systems, to regulate fundamental behavior by setting the organism's internal and behavioral states. In the vertebrate, the neuromodulatory systems include the cholinergic, dopaminergic, noradrenergic and serotonergic systems. Despite the different origination and chemical signatures of these neuromodulatory systems, there are several commonalities among them: (i) the origination is sub-cortical and consists of small pools of neurons (on the order of thousands in the rodent and tens of thousands in the human), (ii) each of these neuromodulatory systems is the locus of a particular chemical transmitter that is projected to broad areas of the brainstem, thalamus, and cortex, (iii) these neuromodulatory systems are reciprocally connected with the frontal cortex and parts of the limbic system, and (iv) the effect of these neuromodulatory systems on downstream targets is similar. Phasic neuromodulation (i.e. rapid increases in neuromodulatory activity) increases the signal to noise ratio of downstream neuronal targets such that neurons respond to stimuli and suppress their responses to distractions. That is, increases in neuromodulatory activity drive an organism to be more attentive when environmental conditions call for such actions. However, tonic low-level neuromodulatory activity results in downstream neurons responding more to distracters and noise. This response may cause an organism to be more exploratory when there are no pressing events. The main difference between these neuromodulators is that each system is triggered by different environmental stimuli. For example, the serotonergic system appears to be driven by stress or threats, the cholinergic system appears to be driven by attentional effort, the dopaminergic system appears to be driven by reward anticipation, and the noradrenergic system appears to be driven by novelty and saliency. The neuromodulatory system could have a profound and global effect on attention, learning, and action selection in the organism. In this talk, I will show, through simulations and neurorobotic experiments, how principles of the neuromodulatory system could provide a framework for controlling behavior such that agents attend to the appropriate contextual cues and are decisive when necessary, but indecisive when it is advantageous.