

## Time and the Decider

(Draft of Commentary on: Shadmehr, R. & Ahmed, A.A. (2020) *Vigor: Neuroeconomics of movement control*. MIT.)

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### *Abstract*

Shadmehr and Ahmed's book is a welcome extension of optimal foraging theory and neuroeconomics, achieved by integrating both with parameters relating to effort and rate of movement. Their most persuasive and prolific data comes from saccades, where times before and after decision are reasonably determinate. Skeletal movements are less likely to exhibit such tidy temporal organisation.

Shadmehr and Ahmed (2020) give a compelling statement of optimal foraging theory incorporating effort and speed of movement, providing rich targets both for behavioural analysis and for neuroeconomic inquiry into the substrates of selection and control. Their most common and convincing illustrations concern saccades, which are a convenient target for neuroeconomics. Eye movements relative to the skull have a simple geometric organisation, with a correspondingly simple topographic representation. Each eye's movements depend on only six specialised muscles, and different movements are strictly mutually exclusive. Eyes rotate around their own centres of mass, making gravitational loads irrelevant. Relative to a stationary head, the relationships between efferent nervous activity and muscle activation, and between muscle activity and movement, are close to direct correspondence. Finally, the 'collicular burst' constitutes an uncontroversial culmination of the decision process, clearly demarcating processes before and after it. Varying the reward contingencies associated with cued saccade targets, thus manipulating the *consequences* of movements, while measuring neural activity upstream of oculomotor control is one of the founding experimental paradigms in neuroeconomics (Glimcher & Sparks 1992, Platt & Glimcher 1999). Early work measured activity at specific locations in topographic maps of possible movements in advance of cued and rewarded saccades, finding that activity related meaningfully to expected subjective value from those

movements, and predicted saccade selection.

Sherrington (1906) introduced the notion of a final common path, referring to the last neural stage at which competition between incompatible deployments of combinations of muscles can be resolved. He recognised that some different movements made conflicting demands on the same muscles. McFarland and Sibly (1975) in turn introduced the notion of a *behavioural* final common path to represent the control processes of a behaving organism, including both perceptual and motor competition. (The qualifier ‘behavioural’ distinguishes their proposal from Sherrington’s neural conception.) In highly compressed summary, McFarland and Sibly propose that the revealed preferences of an animal can be represented in a ‘candidate space’ where mutually exclusive actions and activities are ordered along dimensions according to relationships of ‘displacement’ over one another, determining a set of indifference curves. The determinants of the actions and activities of an animal can in turn be represented in a ‘causal factor space’ consisting of all variables causally relevant to the animal’s behaviour. This space is divided into a ‘cue space’ of external factors to which the animal is sensitive, and a ‘command space’ of internal factors. Considered abstractly, the task of behavioural ecology is to characterise the candidate space, and to determine the structure of the causal factor space, in principle being able to predict how changes in the causal factors will be expressed in behaviour. From this perspective neuroeconomics can be understood as applying tools of cognitive neuroscience to find the neural basis for value computations in the command space which explain the course of behaviour (Glimcher 2002). Much neuroeconomic research seeks to identify value representations and computations at or upstream of final common paths, something about which Glimcher (2011) is helpfully explicit. In the case of saccades from a stationary skull, for the reasons glossed above, this task is relatively tractable. Shadmehr and Ahmed’s treatment of vigor both articulates the relationships between speed of movement and returns from action, and confirms that neural processes of selection and control are sensitive to these relationships.

Skeletal movements and their corresponding control systems, though, exhibit interacting complications absent in saccades. They are rarely ballistic, involve many more muscles, and often deploy linked series of joints. Most of the enormous variety of possible movements are sensitive to bodily orientation, gravitational loading, inertia, and the disposition and properties of nearby surfaces, which can all change independently of, and because of, the

movement itself. As a result, activity in somatotopic maps in the motor cortex doesn't correspond nearly as neatly to bodily movement as it does with fixed-head saccades. The *functional* effects of different bodily movements can be substitutable to varying degrees, because different movements can achieve equivalent effects. Movements also stand in highly variable relations of mutual exclusivity, including cases where different goals can be pursued simultaneously. In consequence, the relationships between behavioural function and movement are neither simple nor direct, and opportunity costs harder to determine. Shadmehr and Ahmed are well aware of these considerations (see Shadmehr & Mussa-Ivaldi 2012), but it is worth focusing on their significance.

There are indeed topographic maps of the body, but the complex mappings noted above mean that different parts of them are relevant to different combinations of functions, movements and conditions. There aren't determinate final common paths corresponding only to those bodily resources relevant to an effect or function, since many can be achieved in multiple ways. (Some, but not all, ways of removing your spectacles involve your left elbow.) As Gallistel (1980) puts it, this implies that control of skeletal muscles must be expressed through a 'lattice hierarchy' in which the level at or before which competition over deployment of degrees of freedom must be resolved is highly variable. Any functional — as opposed to merely anatomical — topographic map or internal model for handling these relationships will have to be abstract and distributed. These considerations pose significant challenges to any attempt to study whole body vigor and its neural control with anything like the temporal specificity available in the saccade case.

Shadmehr and Ahmed, like McFarland and Sibly (1975), hold that selection is made in terms of a 'currency' which ranks states, or actions conditional on states, in ways that have contributed to success under natural selection (Spurrett 2019). McFarland and Sibly explicitly specify a *common* currency, but Shadmehr and Ahmed share the presumption of commensurability. McFarland and Sibly note that the hypothesised ranking process, since it should take "all relevant motivational variables" into account, must be "located at a point of convergence in the motivational organization" (1975: 290). That is, the supposed optimising over all of the relevant factors — including bodily needs and their relative evolutionary urgency, the expected costs and returns of available actions, the physics and geometries of the actions themselves in context of the physics and geometry of the environment — requires a place, a 'point,' where everything comes together. This rings a

Dennettian bell.

Dennett has argued that the notion of a determinate ‘finish line’ for the transition to consciousness is untenable over relatively short time-scales, in extended systems such as brains in their bodies which transmit information at finite speeds (Dennett 1991; Dennett & Kinsbourne 1992). In such cases the effective time-ordering of distal events about which information travels at finite speeds isn’t generally independent of where and how the determination is made. Dennett’s criticism of the pseudo-dualist view he calls ‘Cartesian materialism’, that is, is partly driven by reflection on the implications of the fact that “the ‘point’ of view of the observer must be smeared over a rather large volume in the observer’s brain” (Dennett 1991: 107). This reasoning isn’t only relevant to consciousness, and applies to decisions, selection and control. The shared issue isn’t consciousness, but the suggested unproblematic determinacy of times ‘before’, ‘of’ and ‘after,’ becoming conscious or being decided. Recall that we’re supposing that estimates of all relevant costs — in time, calories, etc. — and rewards in their many modalities are to be integrated into the common currency, and applied to select deployments of the whole body. If we suppose that action selection is comprehensively informed by converging communication from across an extended sensorimotor system, and that there is a definite moment of decision, we need selection to happen at a point, or for there to be a determinate boundary across the lattice hierarchy demarcating events before and after selection. And we must not help ourselves to a supernatural external viewpoint here: relationships of before and after must be settled by processes operating at the speed of neural activity.

Like Cartesian materialism, the view that selection takes place at a determinate moment, let alone at a point, is not openly *defended*. But other things people say and write suggest its influence. McFarland and Sibley’s passing reference to a ‘point of convergence’ may be one example. Shadmehr and Ahmed’s occasional remarks about the value estimating state of a whole agent at a ‘moment’, or to the rate of reward harvesting at an ‘instant’, and to a determinate ‘time of decision’ suggest it as well. These terms are, of course, meaningful in the mathematical models they are deploying. Those models can be expected to idealise and simplify neural reality, as Shadmehr and Ahmed are fully aware.

Nonetheless, if there can’t be a central executive able to integrate everything quickly enough to make selection and control of all skeletal movement consistently sensitive to a

single value function responsive to all available information, something else must be going on. If there was a central executive that delayed until all the information was in, the resulting hesitations would be obvious. (Imagine waiting for a whole body 'collicular burst' to determine whether to wave hello while walking.) A key feature of Dennett's positive view of consciousness is the simultaneous construction, revision and propagation of incompletely specified interpretations ('multiple drafts') of the sensorimotor situation, where contingencies in the flow of interaction can contribute to which achieve the celebrity of consciousness, and where represented time can come apart from the temporal course of the vehicles of content. We can imagine an analogous process for selection and control where parallel sensorimotor processes corresponding to opportunities in the environment and occasioned by internal needs estimate the expected costs and returns of taking those opportunities, and compete for execution as long as there's time. Cisek, independently of Dennett and focusing on action selection rather than consciousness, has imagined this, and called it the 'affordance competition hypothesis' (Cisek 2007). This does without the presumption of a determinate finish line by proposing that "the processes of action selection and specification occur simultaneously" (2007, p1586). On his view incoming sensory and bodily information selectively inform the generation of a number of incompletely specified candidate behaviours, which may be released into execution in advance of full specification. (The term 'affordances' is from Gibson's (1979) ecological psychology.) Cisek's affordance competition, that is, is a multiple drafts model of action selection and control, in which there's no mandatory bottleneck for all deployments, and specification can sometimes lag behind selection. Shadmehr and Ahmed show that if such a theory is to be taken seriously, candidate actions must vary in vigor, and processes of competition and selection be sensitive to relationships between vigor and reward rate.

It is a likely consequence of this type of view that value-sensitive computation — tracking needs, opportunities, expected costs and returns of candidate actions — is neurally widespread. Were it not so, the processes corresponding to different actions would be unsuited to flexible and swiftly expressed competition wherever needed in the lattice hierarchy. This picture, offered as a suggested way of talking and thinking that does without the implications of terms like 'moment of decision' including the implication of a determinate agent-wide time 'before' decision, is potentially consistent with what is revealed in many neuroeconomic experiments. When the expression of choice is severely constrained, when both the options themselves and the means of expressing them kept

strictly mutually exclusive, and when time itself is regimented with cues and delays, we might reasonably expect to find that both behaviour and neural processing fit our best theories most neatly. Our best theories should, for reasons Shadmehr and Ahmed convincingly articulate, be sensitive to the importance of vigor. That so many of our most compelling experiments don't discourage interpretation in terms of determinate moments of, and before, choice for the whole agent, however, may tell us less about control on the hoof and in the wild than it does about what it takes to bring value tracking neural processes into empirical focus.

## References

- Dennett, D. (1991) *Consciousness Explained*. Little, Brown.
- Dennett, D.C. & Kinsbourne, M. (1992) Time and the observer: The where and when of consciousness in the brain. *Behavioral and Brain Sciences*, 15: 183-247.
- Gallistel, C.R. (1980) *The Organisation of Action: A New Synthesis*. Lawrence Erlbaum.
- Gibson, J.J. (1979), *The Ecological Approach to Visual Perception*. Houghton Mifflin.
- Glimcher, P.W., & Sparks, D.L. (1992) Movement selection in advance of action in the superior colliculus. *Nature*, 355: 542-545.
- Glimcher, P. (2002) Decisions, decisions, decisions: Choosing a biological science of choice. *Neuron*, 36: 323-332.
- Glimcher, P. (2011) *Foundations of neuroeconomic analysis*. Oxford University Press.
- McFarland, D.J. & Sibley, R.M. (1971) The behavioural final common path. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, 270: 265–293.
- Platt, M.L. & Glimcher, P.W. (1999). Neural correlates of decision variables in parietal cortex. *Nature*, 400: 233–238.
- Sherrington, C.S. (1906), *The integrative action of the nervous systems*. Yale University Press.
- Shadmehr, R. & Ahmed, A.A. (2020) *Vigor: Neuroeconomics of movement control*. MIT.
- Shadmehr, R. & Mussa-Ivaldi, S. (2012) *Biological learning and control*. MIT.
- Spurrett, D. (2019) The descent of preferences. *British Journal for the Philosophy of Science*, axz020.