Pushing the accelerator on enactive perception

How sensorimotor dynamics can constitute minds

Xabier E. Barandiaran

IAS-Research Centre for Life, Mind and, Society
Dept. of Logic and Philosophy of Science
UPV/EHU, University of the Basque Country

http://xabier.barandiaran.net
xabier.academic@barandiaran.net

Enactivism (Noë, 2005; Stewart, Gapenne, & Paolo, 2011; Thompson, 2007; Varela, Thompson, & Rosch, 1991) is far from the fashionable-new-hype following “Noë’s siren-call” that Prinz (2006) makes us believe. It follows the tradition of those that overcame the empiricist school that Prinz (2002) so enthusiastically vindicates: pragmatists. John Dewey summarized one of the central claims of enactivism over 100 years ago:

> Upon analysis, we find that we begin not with a sensory stimulus, but with a *sensorimotor coordination* (...) and that in a certain sense it is the movement which is primary, and the sensation which is secondary, the movement of the body, head and eye muscles determining the quality of what is experienced. (…) the real beginning is with the act of seeing; it is looking, and not a sensation of light. (Dewey, 1896, pp. 358–359, italics added).

Ever since, psychologists, neuroscientists and philosophers alike have tried to deepen into the sensorimotor nature of mind and experience. To some extent these attempts were reduced (by the epistemological demands of behaviourism) to a statistical notion of stimulus-response correlations, to be latter substituted by computational representationalism. Conceptual, mathematical and experimental constraints (that we have just started to unlock) were partly responsible for the limited scientific development of the early insights on the sensorimotor nature of experience made by phenomenology (Heidegger, 1991; Merleau-Ponty, 1942, 1944) and pragmatism (Dewey, 1896, 1925). Things have changed recently, but not enough. To put it in terms of neurodynamic researcher Walter Freeman:

> What allows us a fresh start now is our ability to image brain activity during normal behavior and to model our findings with the tools of nonlinear dynamics. However, these new data are being acquired under preconceptions embodied in old experimental designs, and we have to reinterpret them as they bring new concepts to light. (Freeman, 2001, p. 12)

These “preconceptions embodied in old experimental design” are still alive. Jesse Prinz (2000, 2002, 2006) has become one of the youngest and strongest supporters of some of them (with certain contributions of his own), “joining the front-lines” to defend the boundaries between perception and action against enactive and sensorimotor approaches to cognitive science. In "Putting the Brakes on Enactive Perception" (2006) Prinz makes a fierce attack on Noë's "Action in Perception" (2005), questioning dozens of Noë's arguments.

There is no room here to reply to each of the Prinz's critiques to Noë's book. I shall instead concentrate on three main subjects. First, I address some empirical neuroscientific issues that are central to Prinz's resistance to the enactive view and his neglect of motor function for perceptual awareness. The second aspect I will discuss combines both conceptual and neurodynamic aspects. I will propose a simulation model that illustrates a notion of dynamic coordination that is richer than the kind of causal-metaphysical assumptions underlying Prinz's work; both at the level of agent-environment interaction and at the neurodynamic level. Finally I shall identify the real challenge that some of the strongest position in enactivism have to face: the relationship between virtuality and sensorimotor coupling.

I

The first of Prinz's central claims I want to discuss is of an empirical nature: "[N]euroscience provides an overwhelming case for the view that perception is not essentially linked to action" (Prinz, 2006, p.11). Contrary to Prinz's clame, I will summarize some neuroscientific evidence showing that perception *is* "essentially" (more on this term latter) linked to sensorimotor dynamics at developmental, anatomical, and functional scales.

One of the most cited supporting evidence for enactive development comes from Held and Hein's experiments. Two kittens where reared by holding one immobile and attached to the other, so that both received the same sensory stimulation, yet only one had freedom to control movement. After a period of rearing kittens where tested in different perceptual tasks, where behavioural consequences should be able to asses whether the kitten was capable of correct visual discrimination. In one of these experiments the immobile kitten was put in front of a cliff (protected by a transparent glass on the floor) and walked through without noticing. Prinz dismisses Held and Hein's experiments (Held & Hein, 1963) by interpreting that the immobile kitten just "did not have enough experience walking on edges". To be fair, neither did the freely moving kitten (during rearing it did not confront walking on edges), yet it showed no incapacity to perceive the cliff and avoid it. However, I will concede to Prinz that some of these experiments might not be able to disambiguate with sufficient accuracy between perceptual dysfunction and perception-action coordination problems. Unfortunately for Prinz, and his categorical assertion that "the Held and Hein study was never replicated", latter studies have supported the perceptual dysfunction interpretation with further evidence coming from lesion studies on ocular muscles on kitten, identifying selective neuronal blindness for visual features orthogonal to the movements made by the occluded muscles (Buisseret, Gary-Bobo, & Imbert, 1978; Buisseret, Gary-Bobo, & Milleret, 1988).

Prinz wants to strengthen his claim against the developmental role of action for perception by claiming that "studies of human infants with muscle atrophy show that when humans are prevented from moving in early development, there is no decrement in the visual comprehension of space" (Prinz, 2006, p. 10). And yet, examples of spinal muscular atrophy do not invalidate sensorimotor accounts of perceptual development simply because head and saccadic eye movement are perfectly intact in those cases. The enactivist claim is not that all forms of motor function need be intact in order to develop "normal" perception. What is required is that the developing organisms have access to the way in which perspectival changes and movements affects sensory stimulation. However, developmental facts are not decisive. No matter how development occurs, current perceptual experience might not necessarily depend on motor activity. Simply put, physiological conditions for correct development are often different from the conditions necessary to correctly carry out physiological functions.

Perhaps the strongest of Prinz's claims regarding the actual lack of evidence for action in perception is the following:

> If the brain areas that are known (because of their behavioral consequences) to encode the motor consequences of visual stimuli are not implicated in visual consciousness, then there is no reason to think Noë's theory of consciousness is correct. Noë is forced to say that representations in the ventral visual stream are also involved in the coordination of action, but there is absolutely no evidence for this conjecture. All evidence implicates the dorsal stream. (Prinz, 2006, p.10)

Prinz is here referring to the "two stream theory of vision" (Goodale & Milner, 1992) which states that there are two distinct visual pathways: the dorsal stream (also referred as "vision for action") and and the ventral stream (or "vision for perception"). First, it is important to remark Noë's insistence on the fact that "the enactive approach is not committed to the idea that vision is for the guidance of action, so neither the fact that some visual processing is for the guidance of action, nor the fact that some visual processing is not, has any direct bearing on the enactive approach" (Noë, 2005, p.19). And yet, there is evidence for action in perception along the ventral stream (vision for perception). In a recent review of the two stream theory (Milner & Goodale, 2008) the authors of the theory remind us that "there is complementary evidence that supports a ventral-stream role in the planning of action" (p.776) and that "in most normal circumstances, our actions will be visually co-determined by complementary processing in both dorsal and ventral streams" (p.776). More importantly, they also take for experimentally confirmed that the ventral stream is used to coordinate sensorimotor tasks when the movements are awkward or not automatized. Visual illusions, that are processed only by the areas involved in the perceptual stream, have consequences for reaching and grasping when subjects are asked to do so with the left hand or in non-automatized situations (Gonzalez, Ganel, Whitwell, Morrissey, & Goodale, 2008). Milner and Goodale conclude that "only highly practiced actions with the right hand operating in real time and directed at visible targets presented in the context of high-level illusions are likely to escape the intrusion of ventral-stream perceptual control" (Milner & Goodale, 2008, p. 780). Thus it turns out that the vision-for-perception stream is actually involved in precisely those aspects of movement planning and execution that require conscious control. The empirical facts are far from Prinz's bold claim that there is "absolutely no evidence" for ventral stream involved in the coordination of action.

Part of Prinz's dificulty to include a role for action in perception is that he conceives a rather one-directional "object → eye → V1 → … → V4*" causation sequence, with some kind of "elusive marking" at * coming from attentional processes, that makes neural activity conscious, but ignoring any possible role of motor and pre-motor activity (Prinz, 2000). However, neurological evidence suggests early involvement of thalamo-cortical loops (LGN projecting directly to V1) on the emergence of perceptual experience, bringing together sensory and (pre-)motor dynamics into the constitution of neurodynamic correlates of perceptual awareness. The modulatory effect of LGN activity on visual perception is nowadays widely proven (Briggs & Usrey, 2011; Kastner, Schneider, & Wunderlich, 2006; Royal, Sáry, Schall, & Casagrande, 2005). Moreover, effects of saccadic eye movements on LGN alter "not only response strength but also the temporal and chromatic properties of the receptive field " (Reppas, Usrey, & Reid, 2002, p. 961) and motor planing has being shown to influence LGN activity (Royal et al., 2005). It is therefore untenable to claim that "V1 is a primary source of inputs to another region in which consciousness can rightfully be said to reside" (Prinz, 2000, p. 246) without even considering LGN as a proxy for motor influences on V1 and, consequently, on visual awareness.

II

The second aspect of Prinz's position and resistance to enactivism has to do with an impoverished conception of neurodynamic organization and agent-environment dynamics. "Every aspect of experience, from illusory contours to motion illusions, from phantom limbs to diffuse pains, can be correlated with some neuronal *response*." (Prinz, 2006, p.17, italics added). The term "response" is crucial at this point. Prinz offers no analysis of this term and it is reasonable to assume that he conceives this "response" as some kind of local state or activity. There is no consideration of large scale transient synchronization or any other kind of mesoscopic dynamic structure of brain activity and its sensorimotor coordination with the environment. It seems like the underlying conception of causation is a linear, sequential and atomic one. Prinz's neglect of the complex neurodynamics of brain and sensorimotor functioning could be further illustrated with the following statement: "functional organization is mirrored by the organization of the nervous system; functional components are anatomically distinct" (Prinz, 2000, p, 256). A linear one-to-one mapping between anatomical and functional structures, seems to be uncritically assumed. On what follows I will first consider interactive aspects of the dynamic constitution of experience and then move to internal (or strictly neuronal) aspects; showing how Prinz's underlaying metaphysics of causation falls short to make justice to the complexity of the interactive and neurodynamic processes that underlie experience.

Here is where Prinz's criticism to enactivism connects with a wider philosophical debate around extended cognition[1]. It has being argued that, despite the abundance of examples, proponents of sensorimotor coupling as constituting/causing cognition make very mild claims about the exact kind of coupling involved (Aizawa, 2010). In order to contribute to the ongoing debate around the causal vs constitutive role of sensorimotor dynamics for cognition (Adams & Aizawa, 2009; Aizawa, 2007; Block, 2005; Clark,

1 Note that conditions for perceptual awareness are stronger than those that might be imposed for extended cognition. Perceptual awareness does not supervene on all forms of distributed cognition.

2006; Lenay & Steiner, 2010), I will introduce a conceptual synthetic model of sensorimotor coordination: the *situated HKB* model (Aguilera, Bedia, Santos, & Barandiaran, in preparation; Santos, Barandiaran, Husbands, Aguilera, & Bedia, submitted). The model shows a minimal agent capable of performing phototaxis in a 2D environment by means of internal metastable regimes of the HKB equation's single variable φ. The crucial experiment is one in which the input of a freely-behaving agent is recorded and then played back into an identical but immobile agent. The "brain" dynamics of the immobile agent are qualitatively different from that of its freely-behaving twin, even if the structure of the sensory input is identical. The model illustrates and makes a proof of concept for the case that *neuronal metastable transients that are functional at the behavioural/cognitive scale might emerge from fine grained micro-dynamic sensorimotor compensations and coordinations.* There is no "state" or "response" of φ to a sensory perturbation that can be said (itself) to correlate with any particular functional contribution to phototaxis. It is through sensorimotor coupling that transient dynamics become functionally relevant. Prinz's critique to enactivisms rests on a narrow conception of sensorimotor dynamics as is apparent when he responds to Noë's account of visual stabilization by stating that:

> If this were true [that perception depends on sensimotor contact with the environment], it would show only that the world is a causal precondition for having some phenomenal experiences. It would *show only that the brain is incapable of entering certain configurations without external stimulation.* (Prinz, 2006, p. 16, italics added)

The situated HKB model shows a clear illustration of how sensorimotor coupling can go beyond the "entering a certain configuration without external stimulation". Again, stimulation is not a cause of brain dynamics. It is the environment and the sensorimotor embodiment that might become essential for the kind of sensorimotor↔brain coordination that characterize the neurodynamic patterns that correlate with perceptual awareness.

If we further consider that a) brains are in a continuous state of metastability in highly interconnected holistic dynamic cores comprising sensorimotor, emotional and higher--order centers (Chialvo, 2004; Rabinovich, Huerta, Varona, & Afraimovich, 2008; Tognoli & Kelso, 2009; Werner, 2007) and b) that transient coordinations correlate with perceptual awareness (Freeman, 2001; Llinas, 2001; Tononi, Sporns, & Edelman, 1994; Varela, Lachaux, Rodriguez, & Martinerie, 2001) then, it is reasonable to assume that neurodynamic coordination is the characteristic form of constitution of experience. Varela (1995) made the following calculation: at a spike travelling speed of 10m/s a spike wave would take about 40ms to make a return trip between both hemispheres (25cm travel). One such cycle will thus involved a frequency of 1000/40 = 25Hz. The gamma band (25-40Hz) is just above the minimum frequency required to synchronize the activity of the full brain (or, at least, the cortex). We need to add that the formation of a visual percept takes up to 100-200ms thus allowing for 3-5 cycles of whole brain reciprocal influence or coordination to take place. It is no coincidence that conscious experience and attentional phenomena (an essential part of Prinz's AIR theory of consciousness) have been systematically related to the gamma band activity (Crick & Koch, 1990; Jensen, Kaiser, & Lachaux, 2007).

We can now go back to Prinz's statement that "every aspect of experience can be correlated with some neuronal *response*" (and his defence of a direct mapping between anatomical → functional/representational → phenomenological units) to see how it falls short to capture the kind of interactive neurodynamics at stake.

III

Prinz states that "to support wide supervenience, Noë should show that, when we keep the brain fixed and change the environment, there can be changes in experience. He attempts no argument of this kind" (Prinz, 2006, p. 16) By now it should be evident that it simply makes no sense "to keep the brain fixed". That would amount to mental death. So does long term sensorimotor deprivation (Ebert & Dyck, 2004; Grassian & Friedman, 1986). Perhaps a more reasonable formulation of Prinz's concern is whether perceptual experience *always, necessarily and systematically* depends on *direct* sensorimotor coordination with the environment. At this point Prinz is right to suggest we should push the break on enactivism or at least slow it down. It is here where enactivism might have to re-negotiate the most radical forms of externalism and wide supervenience. But first it is important to remind ourselves that Noë's enactivism includes the notion of virtuality (and not only direct sensorimotor exercise with environmentally accessible features) as constitutive of perception:

> As a matter of phenomenology, the detail is present not as *represented*, but as *accessible*. Experience has content as a potentiality. In this sense, the detail is present perceptually in my experience virtually. Thanks to my possession of sensorimotor and cognitive skills, I have access to nearby detail. (…) [V]irtual presence is a kind of presence, not a kind of non-presence or illusory presence. (…) Qualities are available in experience as possibilities, as potentialities, but not as completed givens. Experience is a dynamic process of navigating the pathways of these possibilities. Experience depends on the skills needed to make one's way. (Noë, 2005, pp. 215–217)

Unfortunately, Noë remains mostly silent about the neural basis of this virtuality and its "mediation by knowledge of sensorimotor contingencies". I think this gap can be perfectly filled in in terms of the neurodynamic integration of virtual sensorimotor loops (i.e. those comprising coordination dynamics between premotor areas and sensory afferents). But this demands that we *internalize* virtuality (something that I doubt Noë will be ready to accept). The very notion of "external virtual presence" is a metaphysical and conceptual oxymoron. To claim that perception is a temporarily extended process doesn't save it, for Noë himself acknowledges that "experience is fractal, in this sense": no matter how much you directly engage with a specific feature of the environment, perceptual content will always include virtual aspects that are not directly in view. So, no matter how long you engage in sensorimotor interaction with the environment you will never fill all the gaps. And if knowledge of these present, yet virtual (i.e. not current), sensorimotor contingencies is constitutive of perception, it must have some neural basis. If enactivism wants to push the accelerator again, it needs first to slowly fill the conceptual and empirical gaps that explain how brains integrate virtual sensorimotor knowledge and direct sensorimotor coupling to give rise to perceptual awareness.

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