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Comment

On the organization of the perisylvian cortex: Insights from the electrophysiology of language Comment on “Towards a Computational Comparative Neuroprimatology: Framing the language-ready brain” by M.A. Arbib

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The Mirror System Hypothesis (MSH) on the evolution of the language-ready brain draws upon the parallel dorsal–ventral stream architecture for vision [1]. The dorsal “how” stream provides a mapping of parietally-mediated *affordances* onto the motor system (supporting preshape), whereas the ventral “what” stream engages in object recognition and visual scene analysis (supporting pantomime and verbal description). Arbib attempts to integrate this MSH perspective with a recent conceptual dorsal–ventral stream model of auditory language comprehension [5] (henceforth, the B&S model). In the B&S model, the dorsal stream engages in *time-dependent* combinatorial processing, which subserves syntactic structuring and linkage to action, whereas the ventral stream performs *time-independent* unification of conceptual schemata. These streams are integrated in the left Inferior Frontal Gyrus (lIFG), which is assumed to subserve cognitive control, and no linguistic processing functions. Arbib criticizes the B&S model on two grounds: (i) the time-independence of the semantic processing in the ventral stream (by arguing that semantic processing is just as time-dependent as syntactic processing), and (ii) the absence of linguistic processing in the lIFG (reconciling syntactic and semantic representations is very much linguistic processing proper). Here, we provide further support for these two points of criticism on the basis of insights from the electrophysiology of language. In the course of our argument, we also sketch the contours of an alternative model that may prove better suited for integration with the MSH.

The B&S model is effectively a cortical instantiation of the extended Argument Dependency Model (eADM) [3,4]. The eADM posits a cascaded architecture, in which an algorithmic-driven processing stream (∼ the dorsal stream in the B&S model) works in parallel to a plausibility processing stream (∼ the ventral stream). The former serves to assign thematic roles to incoming noun phrases based on “prominence” information (e.g., animacy, case marking, and linear word order) and to link these to the argument structures of incoming verbs, whereas the latter determines the most plausible combination of the arguments and the verb in a sentence, while ignoring (linear, hence

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time-dependent) surface structure. The outcomes of the two streams are integrated in a generalized mapping step (∼ lIFG function in the B&S model). Crucially, the eADM explicitly links processing in these different streams to Event-Related brain Potential (ERP) components. Of interest to the present argument is that the eADM postulates that difficulty in plausibility processing modulates the amplitude of the N400 component, whereas difficulty in integrating the outcome of this stream with that of the algorithmic-driven stream modulates P600 amplitude. The eADM shares this mapping with a number of other prominent multi-stream models, all of which have been motivated to explain so-called 'Semantic P600'-effects [13,21,14,11]. Crucially, it has been argued that none of these models can account for the full spectrum of these findings [7]. By contrast, the single-stream Retrieval-Integration (RI) model, in which syntactic and semantic processing is more integrated, does account for the data at hand [7,8] (see [6], for explicit computational support). These insights from the electrophysiology of language question the validity of a plausibility heuristic (or structure-independent semantic analyzer) (see also [19]), and thereby a conceptualization of the ventral stream as reflecting time-independent semantic processing. This supports Arbib's first point of criticism.

On the RI model, N400 amplitude does not reflect any compositional semantic processing, but rather the contextualized retrieval of the conceptual knowledge associated with an incoming word from memory (cf. [15,16,20]). P600 amplitude, in turn, does reflect compositional semantic processing: it indexes the integration of the meaning of an incoming word with the unfolding utterance interpretation. Cortically, the retrieval processes underlying the N400 are mediated by the left posterior Middle Temporal Gyrus (lpMTG; Brodmann Area 21), whereas the integrative processes underlying the P600 are mediated in the lIFG (BA 44/45/47) [8]. Hence, in contrast to the B&S model, on which the lIFG does not reflect any linguistic processing functions, the RI model posits the lIFG as the core computational epicenter for compositional semantic processing. Importantly, this view on the lIFG unifies a number of conflicting hypotheses on the role of this area (see [10,17], for reviews) by subsuming syntactic, semantic, as well as working-memory related, and control processes (see [8], for discussion on how the complex architecture of the lIFG could support such a diverse spectrum of functions). This view (which seems consistent with the MSH perspective on Broca's area) thus *subsumes*, but does not *limit* lIFG function to cognitive control. Indeed, it is unclear how the data that motivated this subsumption-based account, especially the data implying the lIFG in combinatorial semantic processing (e.g., see the evidence reviewed in [11]), could be reconciled with a *cognitive control*-only view on this region. This supports Arbib's second point of criticism.

As for the dorsal–ventral stream distinction, the RI model effectively assumes a reverberating circuit between the retrieval (lpTMG) and integration (lIFG) epicenters, requiring bidirectional connectivity between these regions. The dorsal and ventral pathways, and their respective sub-pathways (see [9]), support such a reverberating circuit between temporal and frontal regions (see [2], for a speculative proposal). However, it remains an open question which (sub)pathways are involved in bottom-up (lpMTG → lIFG), and which are involved in top-down (lIFG → lpMTG) computations. As of yet, the literature shows little consensus on the functional roles of the dorsal and ventral streams (e.g., [12,18,22,9,2,5]). At best, there appears to be some agreement on the involvement of the ventral stream in form to meaning mapping [12,9,5], supporting a bottom-up role for this pathway (consistent with the MSH). As for the dorsal stream, it has been suggested that one of its sub-pathways may be involved in delivering top-down predictions from the frontal to the temporal lobe [9]. However, others have proposed a precise mirror image of this dorsal–ventral stream distinction [2].

In sum, insights from the electrophysiology of language do not support a conceptualization of the ventral stream as subserving time-independent semantic processing. Moreover, it seems difficult to reconcile a *cognitive control*-only role for the lIFG with the data at hand, especially the data that imply the lIFG in combinatorial semantic processing (see [11]). We have argued that these insights support Arbib's criticism of the B&S model, and we have briefly sketched the contours of an alternative model, the RI model, [7,8], which posits a reverberating circuit between temporal (memory) and frontal (semantic integration) areas. It remains to be seen what the precise roles are that the dorsal and ventral streams play in this circuit, and hence, if and how the MSH and the RI model can be integrated. It may be precisely here where a synthesis between a computational neurolinguistics and a computational comparative neuroprimatology is the way forward.

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