No evidence for discontinuity between infants and adults

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Based on studies of infant gaze, developmental psychologists have ascribed abstract cognitive functions to young infants. In their thought-provoking article, Blumberg and Adolph ([1], from hereon B&A) consider the implications of developmental neurobiology for these claims. While in adults, abstract cognitive functions depend on cortical circuits, B&A hypothesize that the developing cortex is too immature to drive gaze in the youngest infants. If this is true, then subcortical regions must be driving all observed gaze behavior in young infants. And if infants' gaze relies on entirely distinct neural mechanisms from those underlying abstract adult cognition, B&A argue, "claims of developmental continuity between infant and adult cognition are suspect" (p. 233). Here, we challenge this line of reasoning, and instead argue that the available, though admittedly limited, neural data from young human infants suggests remarkable continuity between infant and adult minds and brains.

First, B&A hypothesize that all looking behavior in young infants are driven by subcortical mechanisms, which they use to argue that young infants cannot be engaging in cognition. However, B&A themselves acknowledge that in adults, all cognitive processes rely on systematic and recursive loops between *both* cortical and subcortical regions (p. 243, see also [2]). For example, numerical cognition in adulthood evokes activity in parietal cortex, but also on in subcortex [3]; visual categorization is accomplished in the ventral temporal cortex, but also in the superior colliculus [4]; cognitive control evokes activity in frontoparietal cortical networks, but also in the periaqueductal gray and other midbrain nuclei [5]. Cognition, and the behavioral outputs of cognition, is not exclusively driven by cortex, in people of any age. Thus, the strong reverse inference that B&A make, from subcortically mediated behavior in infants to non-cognitive processes, is unjustified.

Second, the essential part of B&A's argument for developmental discontinuity is the absence of cortical control over eye movements in infancy. In adults, multiple cortical brain regions project to the superior colliculus, the primary midbrain structure controlling eye movements (Figure 1A). B&A claim that these projections from cortex to subcortex are not yet functional in early infancy. Note that B&A grant the flow of information between the same structures in the opposite direction: Subcortical structures process and relay information to the cortex. This flow of information is structurally organized similarly to adults, as early as has been measured. Neuroimaging of human infants 6 months or younger have found systematic topological organization [6] and task-driven activation of all the major cortical networks [7], including by high-level vision [8], language [9], social cognition [10], and control of attention [11]. Despite this remarkable consistency of the network organization between infancy and adulthood, B&A suggest that, before infants are 3-6 months old, this functionally organized cortical activity is epiphenomenal, and plays *no* causal role in infants' behavior like eye gaze. Cortical activity, they argue, is occurring in young infants *only* to organize neural representations that will be useful for driving behavior later in development, and thus is qualitatively discontinuous with adult abstract cognition.

We see no support for such a categorical shift from early to late infancy. Instead, the same data are consistent with gradual, continuous change (Figure 1B). Cortical functional organization and connectivity patterns do undergo protracted development over the first year of life, altering the tuning, speed, and precision of neural activity. Yet the starting state for this development is architecturally and functionally similar to adult brain organization. Thus another possibility, to explain the same observations, is that the balance of influence shifts continuously during the first year within a developmentally stable architecture of cortical-subcortical loops. Initially, input from subcortical to cortical regions may dominate, driving learning. Over the first year, the balance of influence may shift to the cortical regions. This hypothesis, like the hypothesis presented by B&A, goes well beyond existing data, and could be tested in future empirical studies, including those that link cortical activity to looking behavior in infants younger than 6 months of age, following work in older infants [e.g., 12].

In summary, the persistent role of the subcortex, and a gradually increasing involvement of the cortex, in generating behaviors would explain all of the data presented by B&A. But this proposal would also suggest that infants' cognitive abilities *are* the structural and functional precursors of adults' cognitive abilities. Thus, the existing behavioral and neural evidence is perfectly consistent with continuity between human infant and adult minds.

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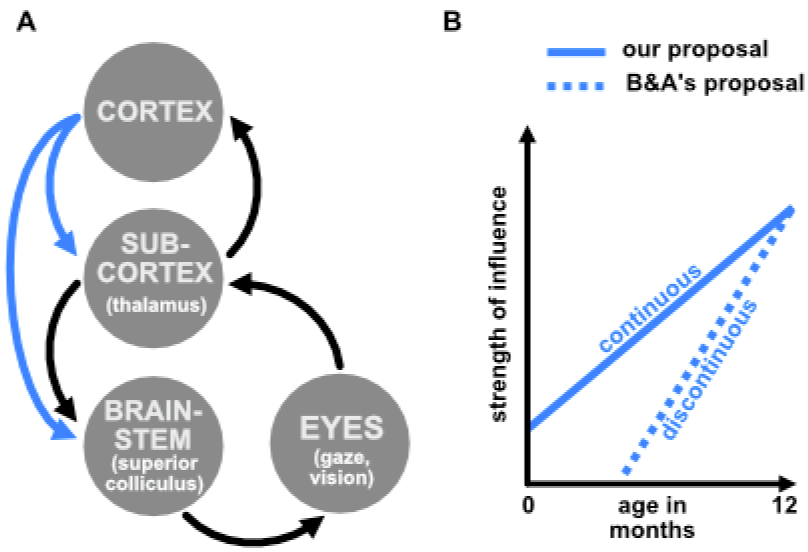

[Figure also attached as a PDF, as part of this submission]

Figure 1. (A) Circuit underlying vision and gaze in infants and adults. Visual information flows from eyes to cortical regions in both infants and adults. The debate concerns when cortical regions begin to influence eye movements (blue arrows). **(B)** Alternative proposals for the strength of cortical influence over development. While B&A propose that cortical regions have no influence before age 3-6 months, and thus argue for developmental discontinuity in the neural basis of cognition, we propose that cortical regions begin with weak influence that gradually strengthens, consistent with continuity in the neural basis of cognition.