



Commentary

Developing developmental cognitive neuroscience: From agenda setting to hypothesis testing

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1. Heuristic models, agendas and analogies

“There is nothing more practical than a good theory”

(Lewin, 1951)

In this issue of Developmental cognitive neuroscience Shulman and colleagues (n.d.) and Nelson and colleagues (n.d.) present two heuristic models of cognitive development. Shulman and colleagues review the current evidence in favor of dual systems (DS) models, which suggests that enhanced risk taking in adolescents is the consequence of an imbalance between an early maturing motivational system involved in reward processing and a later maturing cognitive control system. They conclude with the viewpoint that the current literature seems to reaffirm the usefulness of these models. In a similar fashion, Nelson and colleagues (n.d.) presented an updated version of the social information processing model (SIP), a heuristic framework which links facets of social development (ranging from infant caregiver interactions to intimate relationships during adolescence) with functional changes in the developing brain.

Models are one of the central instruments of modern science (e.g. the double helix model of DNA, the billiard ball model of a gas, or the mind as a computer). However, not all models are alike and different types of models serve different functions in the process of scientific discovery (Frigg and Hartmann, 2006). The current models of adolescent brain development, including the ones presented in this issue, are often labeled as *heuristic models* (Casey, 2014; Crone and Dahl, 2012; Nelson et al., n.d.; Richards et al., 2013; Shulman et al., n.d.). However, it is not always clear what heuristic models are and what role they have. It is currently unclear if, and how, different heuristic models can be meaningfully compared, or to what extent they aid the formulation of testable hypotheses. Moreover, although there are many results that can be interpreted as being consistent with heuristic models, we will argue that such comparisons have only limited value and may even hamper further investigation of the underlying developmental mechanisms.

In this comment we provide a critical review of heuristic models, making specific references to the DS and SIP models, focusing on their ability to move the field of developmental cognitive neuroscience forward toward a mechanistic understanding of neural development. We aim to make a contribution to the debate around models by (1) providing further conceptual clarification and a framework to evaluate different types of models, and (2) by highlighting the benefits of a stronger commitment to cognitive models in order to generate testable hypotheses and integrate different levels of analyses (including neuroscience). First, we discuss the role of *heuristic models* in science as frameworks for inspiration and research agenda setting. Although heuristic models are by nature simplistic, we will suggest several principles that can be used to evaluate them. Next we discuss one direction that could be taken to foster the transition from *heuristic models* to *cognitive neuroscience models*, from agenda setting to hypothesis testing.

1.1. Heuristics and the context of discovery

The classic distinction between “context of discovery” and “context of justification” (Popper, 1959; Reichenbach, 1938) provides a good starting point in organizing the debate on the different models of adolescent brain development. That is the distinction between the context in which new ideas or hypotheses are generated, and the context in which those are defended. For instance, reading a novel (e.g. Romeo and Juliet) can lead to the generation of numerous different models of the adolescent mind. Whether the novel itself (context of discovery) may be overly simplistic or wrong is irrelevant for scientific progress, as long as the ideas from the novel are translated into testable theories (context of justification), living up to the stricter principles of science (e.g. falsifiability).

The term *heuristic* is of Greek origin meaning “serving to find out or discover.” Traditionally heuristics are considered to be part of the context of discovery (Polya, 1957). Indeed, on several occasions Albert Einstein used falsified theorems as heuristics to generate a novel hypothesis (e.g. Einstein, 1905). However, it has been recognized that within the social sciences heuristic models provide a ‘context of discovery’ that is less trivial. That is because these heuristic models in social science, such as the dual-systems (Casey,

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2014; Luna et al., 2013; Shulman et al., n.d.) and social information processing (Nelson et al., n.d.) models, have significant impact on budget streams and what type of research is performed and published. Therefore, heuristic models stand with one foot in the ‘context of justification’ (Nickles, 2006) and do require sufficient motivation and argumentation. This becomes even more important if these models are used to communicate the state of science to people outside the field of inquiry (e.g. policy and law-makers). Here, we suggest two criteria that can be used to evaluate the usefulness of heuristic models: *simplicity* and *specificity*. In the next section we will briefly address these criteria and apply them to the models presented in this volume.

“All models are wrong but some are useful”

(Box, 1976)

1.2. Simplicity

A heuristic model is by definition reductionistic, balancing simplicity and specificity against usefulness. Where *simplicity* refers to the number of elements or constructs that make up a model, *specificity* concerns the definition of these constructs. A model that is too complex or too unspecific would not be useful because it does not help constrain the hypothesis space, and does not provide clear starting points for research. However, a model that is too simple runs into the danger of being too restrictive in its agenda setting; not leaving enough room for plausible alternative explanations. Finally, a heuristic model that is too specific turns into the hypothesis it was supposed to inspire.

First, let's consider simplicity. In this context Shulman et al. (n.d.) discuss the triadic model proposed by Ernst et al., 2006. This model suggests that besides reward seeking and cognitive control, developmental changes in avoidance behavior, and corresponding neural systems (e.g. amygdala and insula), are necessary to explain adolescent risky decision-making in its complexity. However, Shulman et al. (n.d.) state that there is “*not much evidence to date indicating that the emotion/avoidance system and its developmental trajectory help to explain heightened levels of risk taking in adolescence*”. Thus, according to Shulman et al. it therefore does not warrant further review, nor is it considered a relevant extension of the DS model. In other words they prefer a simpler 2 systems model to a more complex 3 systems model.

There is reason to believe that in this case absence of evidence may be taken for evidence of absence. First, for most canonical behavioral tasks it is difficult to distinguish the contribution of increased approach from that of reduced avoidance on choice behavior (Luciana and Segalowitz, 2014). Second, considering the development of risk preferences we see that adolescents are consistently risk-averse, not risk-seeking, just less so than adults (for review see Defoe et al., 2015). Fourth, when we turn to the adult neuroscience literature there is ample evidence for involvement of the proposed avoidance network in risky decision-making (e.g. Bossaerts, 2010; Preuschoff et al., 2008; Xue et al., 2010). In sum, we consider a role for avoidance-related processes in risk taking very plausible. For these reasons such a system should not be easily dismissed, but considered a valuable part of a heuristic model.

If we turn to the SIP model we can see that this has so many moving parts (and their connections) that, even though they are organized in three nodes, it is challenging to derive specific hypotheses about neural mechanisms underlying social behavior. Still, there is some value in embracing this complexity and admitting to our lack of knowledge about which of the many component processes is most relevant for understanding developmental changes. In contrast to this view, the more restricted DS model may interpret changes in behavior related to social context directly in terms of changes in reward related striatal activity (e.g.

Chein et al., 2011). However, such a strategy may lead to overlooking that the changes in striatal activity are not due to changes in modulations of the striatum by regions involved in social cognition. For example, functional connectivity analyses have shown that the temporal parietal junction (TPJ) may modulate value computation in the striatum (Carter et al., 2012; Hare et al., 2010; van den Bos et al., 2013), and this social brain region is also known to show significant development across adolescence (Burnett et al., 2011; Güroğlu et al., 2011).

These examples illustrate that one should be aware of being too simplistic given its negative consequences for knowledge production (for similar arguments see Greenwald et al., 1986; Greenwald, 2012). This is particularly dangerous in context of neuroimaging studies when one may decide to focus at only a handful highly selected ROIs, justified in part by referring to a heuristic model. As a result, research is actively ignoring parts of the data that are collected, which will not even allow for serendipitous findings. For instance, based on the DS model this may lead to underreporting on the roles of the insula or TPJ in adolescent risk-taking. On the other hand, pursuing a heuristic that is based on only very little evidence will in the worst-case lead to several non-confirmatory studies. Thus, we would argue that in most occasions it is probably better to err on the side of openness, particularly when there are alternative hypotheses that are plausible and relatively well defined.

1.3. Specificity

Too little specificity diminishes the usefulness of a heuristic model, simply because it allows for a potentially unlimited number of hypotheses that are consistent with it. Additionally, when moving to the domain of hypothesis testing conceptual specificity is strongly related to classic issues of validity (construct, internal, external; MacKenzie, 2003), which requires both clarity of concepts and clear description of the relationship between the concepts. Here we will argue that for both heuristic models (DS and SIP) there is still room, and need, for further specification of the concepts. Given that the DS model is more specific in its descriptions compared to the SIP model we will use it as an example but most of the following general points also apply to the SIP and other heuristic models. Consider the following statement;

“Specifically, it proposes that risk-taking behaviors peak during adolescence because activation of an early-maturing incentive-processing system (the “socioemotional system”) amplifies adolescents’ affinity for exciting, novel, and risky activities, while a countervailing, but slower to mature, “cognitive control” system is not yet far enough along in its development to consistently restrain potentially hazardous impulses”

(Shulman et al., n.d.)

Some of the notions in this quote are further specified in the paper, such as the regions associated with each system. Still, other important notions, such as reward sensitivity, remain unspecified and thus leave quite some room for interpretation. As we will try to show, one of the consequences of this lack of specificity is that the model allows for the generation of a virtually unlimited number of testable hypotheses, which may be inconsistent with each other but that are all consistent with this general claim.

For example, reward sensitivity does not describe a cognitive or a neurobiological process. Still it is suggested that activity in the socio-emotional system (including ventral striatum) is associated with increased reward sensitivity. However, we striatal activity can represent different processes and reward sensitivity can mean different things. Thus, the consequence of such a definition is that any finding that shows greater ventral striatal activity in teenagers compared to other groups might count as evidence for

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