Cognition 135 (2015) 10–13

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Developmental insights into mature cognition

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ARTICLE INFO

Article history:
Available online 7 December 2014

Keywords:
Cognition
Cognitive development
Concepts
Statistical learning
Executive function
Extended mind

ABSTRACT

Three cases are described that illustrate new ways in which developmental research is informing the study of cognition in adults: statistical learning, neural substrates of cognition, and extended concepts. Developmental research has made clear the ubiquity of statistical learning while also revealing is limitations as a stand-alone way to acquire knowledge. With respect to neural substrates, development has uncovered links between executive processing and fronto-striatal circuits while also pointing to many aspects of high-level cognition that may not be neatly reducible to coherent neural descriptions. For extended concepts, children have made especially clear the weaknesses of intuitive theories in both children and adults while also illustrating other cognitive capacities that are used at all ages to navigate the socially distributed aspects of knowledge.

1. Introduction

The growth of cognitive capacities through infancy and childhood is fascinating in its own right; but even if one has little interest in developing minds per se, developmental research has had a profound impact on the study of cognition in adults and shows every indication of having an ever larger influence in the future. Questions about the origins of thought and knowledge are becoming as fundamental to understanding almost any major issue in cognitive science as developmental biology has become to understanding mature biological systems (Gilbert, 2013). Studies with infants and children have transformed how we think about many aspects of cognition, including causal perception and cognition, number, folk physics, folk psychology, folk biology, speech perception, and grammar. Here, I consider three other cases where development provides new perspectives.

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http://dx.doi.org/10.1016/j.cognition.2014.11.023
0010-0277/

2. Statistical learning: ubiquitous but limited

Over the last two decades, we have learned that infants and young children can track statistical regularities in ways that go far beyond remembering the frequencies of single tokens. Preverbal infants track co-occurrences and conditional probabilities of speech sounds, non-speech sounds and visual patterns (e.g., Bulf, Johnson, & Valenza, 2011; Lany & Saffran, 2013), and this ability has been argued to play a major role in language learning. These developmental findings have supported the discovery of similar abilities in adult language processing (Conway, Bauernschmidt, Huang, & Pisoni, 2010) and in the visual system (Turk-Browne, Jungé, & Scholl, 2005).

However, developmental research is also illustrating the limits of statistical learning. Consider, for example, the proposal that children use the co-occurrence of labels with objects as a way of inferring object names (Yu & Smith, 2007). Although such statistical patterns can certainly support learning in carefully constructed situations, when the problem is examined in many naturalistic scenes, children and even adults struggle to isolate the relevant meanings (Medina, Snedeker, Trueswell, & Gleitman, 2011). Learning words is much more feasible with the support of rare but powerful "seed" episodes where a speaker showcases a potential meaning and the child posits a specific hypothesis (ibid; Trueswell, Medina, Hafri, & Gleitman, 2013). More broadly, critical constraints and starting states are often needed to help get infant statistical learning off the ground—a finding with direct relevance for adult models of statistical learning (Aslin & Newport, 2012).

Finally, infant work has inspired studies of statistical learning in other species. These comparative studies are crucial to understanding the uniqueness of human learning. For example, it might be claimed that humans' adeptness for learning transitional probabilities makes language acquisition possible. This view, however, is deflated by demonstrations that songbirds can easily learn such patterns at considerable levels of intricacy (Lu & Vicario, 2014). Thus, humans are not distinctive merely because we can engage in statistical pattern tracking far above that of classical associative learning. Tracking sophisticated patterns of environmental statistics may be quite common across many species as long as the information is set up in an ecologically appropriate context that supplies boundary conditions on what patterns to tabulate. The fragility of statistical learning in less appropriate contexts—in infants, in adults, and in other species (e.g., Medina et al., 2011)—highlights the critical role of these enabling constraints, and helps to clarify the role of statistical learning across domains of cognition.

The ultimate power and limits of statistical learning are still under vigorous debate (e.g., Marcus & Davis, 2013; Smith, Suanda, & Yu, 2014); but development may offer the clearest insights into both its power and limitations by revealing those domains where statistical learning dominates and those where it makes only very modest explanatory contributions.

3. The neural substrates of cognition: bounded insights

To what extent will detailed characterizations of brain structure and function illuminate the nature of cognition? Few questions are more controversial in cognitive science today with opinions ranging from views that purely behavioral studies are becoming nearly obsolete as we learn more and more about the brain, to views that much of high level cognition cannot be feasibly reduced to meaningful neural descriptions. Developmental research advances this debate by revealing those aspects of mind where neuroscience might be especially informative and those where brain structure and function have little explanatory power.

As success story, consider the hundreds of studies on links between fronto-striatal and fronto-amygdala feedback loops and behavioral regulation systems. Here, development has provided novel insights into the adult state. For example, the study of risk-taking and decision-making in adolescence has shown that, with increasing age, feedback from frontal cortex to striatal regions becomes stronger relative to input from subcortical reasons to the frontal regions (Casey & Caudle, 2013; Vink, Derks, Hookgendam, Hillegers & Kahn, 2104). This shift in turn has highlighted the importance of the full regulatory cycle in adult humans and how different links in the mature cycle might vary as a function of stress, fatigue, intoxication, psychopathology and aging. When brain development is linked to knowledge growth it is often through such inhibitory processes. Thus, theory of mind has often been studied through false belief tasks that set up a tension between what the participants know and what the protagonist knows, and where inhibition of one knowledge state involves executive function skills (Mahy, Moses, & Pfeifer, 2014). While changes in executive function may also be related to circuits specialized for processing social information (ibid), they may not offer much direct insight into how those circuits represent social information.

As knowledge structures undergo dramatic reorganization across the course of development, what other patterns of brain change—beyond executive function circuits—are linked to those cognitive changes? Here, the connections between brain and mind seem more limited. Consider, for example, the ways that the child's understanding of number changes in early childhood (Carey, 2009). Children undergo a dramatic shift in which several distinct aspects of number become conceptually integrated, apparently through the support of language. This transition in numerical knowledge may not be that sort of change that has any easily identifiable neural counterparts. Concepts and linguistic structures interact in a sophisticated and highly structured choreography that seems to defy step-by-step neural descriptions. Similarly, children's understanding of kinship terms changes radically in childhood such that all terms, because of their complementary meanings, tend to change at the same time (Keil, 1989). Will such clustered shifts in the meanings of closely related terms ever be apparent at the neural level? Of course, every cognitive change (when cognition is not considered in an extended sense) must supervene on a change at the neural level, but even dramatic correlations between MVPA patterns and particular "concepts" may never have enough fine-grained detail to illuminate how the structures of conceptual systems precipitate and guide change.

Developmental studies offer unique insights into the neural underpinnings of cognition. Because they involve the most dramatic cases of cognitive change, they often offer the most revealing connections to underlying changes in the brain. As fMRI and structural MRI studies of children become more common, they will reveal in qualitative ways where mappings between neural systems and cognition are informative and where they are largely opaque. Those differences in turn will suggest where neuroscience is likely to shed light on adult cognition.

4. Extended concepts: less and more

Cognitive science has struggled greatly with understanding what concepts actually are, with views ranging from those describing concepts as minimal, innate units of thought (Fodor, 1998), to claims that the very question is ill-posed (Machery, 2009). The study of conceptual development and change has become a central way to explore the problem. If concepts do indeed have enduring characteristics, those characteristics must be present across dramatic patterns of change. Studies of concepts in younger minds therefore suggest new views of concepts at all ages.

Consider, for example, the idea that concepts derive their nature from how they are embedded in larger-scale belief systems, sometimes known as the "concepts-in-theories" view (Murphy & Medin, 1985). This approach initially had great appeal because it helped to explain why causal coherence trumps correlation when people categorize. But the "theories" in which concepts are embedded are highly impoverished, especially in young children, whose theories seem so devoid of content that they could not reasonably disambiguate concepts. What theoretical relationships or beliefs do children have that help them distinguish tigers from lions or pears from peaches? Children might know a few surface features that allow them to categorize instances correctly, but they certainly do not know any specific internal features or any sorts of theory-based properties that distinguish such kinds. What, then, does it mean for their concepts to be embedded in theories if those theories cannot support basic contrasts? The inadequacies of children's theories quickly led to the realization that the vast majority of adults' theories are barely better.

The sparse nature of such intuitive theories raised the question of whether concepts at all ages were often nothing more than empty shells guided by a few perceptual pointers or other surface cues to referents. But a closer look revealed elaborate supporting knowledge structures of a more abstract kind in young children, which in turn has suggested the importance of such structures in adults. Even as children fail to know internal individuating features, they nonetheless see internal features as somehow "essential" to kind identity (Gelman, 2003)—an essentialism that has roots early in infancy (Newman, Herrmann, Wynn, & Keil, 2008). Young children also have some sense of the social structure of knowledge as a way of anchoring essences: They understand that knowledge across conceptual domains is clustered in distinct groups of experts and defer appropriately (Keil, Stein, Webb, Billings, & Rozenblit, 2008; Landrum, Mills, & Johnston, 2013), and they evaluate expert testimony through several cues to source credibility (e.g., Robinson & Einav, 2014).

These abstract causal patterns and deference patterns—critical for concept understanding in childhood—have direct implications for how concepts are represented in adults. We may not have much detailed knowledge about the essential differences between tigers and lions, but we may have a good sense of what those essential differences are like for all animals and what it means to be an expert in them. As a result we may often assume that we know word meanings directly when we only "know" them indirectly through others, causing us in turn to neglect the elaborate cognitions that guide deference (Kominsky & Keil, 2014). The causal knowledge that overrides mere association is not at the level of detailed theories in which concepts are embedded but instead consists of the same abstract causal patterns that enable us to defer effectively. These mechanisms for navigating the division of cognitive labor were first evident in children, who have even more impoverished theories, and are therefore especially reliant on ways to successfully defer. The challenge is now to understand in detail these more abstract knowledge structures that allow successful outsourcing of conceptual details at all ages.

5. Conclusions

Research on adult cognition clearly informs developmental research by characterizing the end state of development; but there may be equally important influences in the other direction. The three cases presented here illustrate different aspects of the insights offered by developmental research to cognitive science. For statistical learning, developmental research has highlighted a ubiquitous, automatic and implicit aspect of learning that occurs across many organisms, one while also suggesting explanatory limits of statistical learning as a stand-alone way to acquire knowledge. For the neural substrates of cognition, cases of dramatic cognitive change pose questions about informative neural counterparts. Development has helped uncover links between executive processing and fronto-striatal circuits and all the downstream consequences for cognitive functions and tasks; but development also highlights how other aspects of high-level cognition may not be neatly reducible to coherent neural descriptions even as those aspects are ultimately grounded in the brain. Finally, with extended concepts, we have seen how the hollowing out of the details of intuitive theories in children has made apparent similar gaps in adults while also illustrating sophisticated and early emerging cognitive capacities for navigating the socially distributed aspects of knowledge. This in turn is fostering new work on these neglected facets of meaning in adults. The lens of development continues to offer unique perspectives across the full sweep of cognitive science.

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