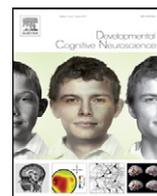




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Introduction and commentary

The feeling of motivation in the developing brain

Thought by itself moves nothing. . .

–Aristotle

Why does the hen submit herself to the tedium of incubating such a fearfully uninteresting set of objects as a nestful of eggs. . . Why does the maiden so interest the youth that everything about her seems more important and significant than anything else in the world? . . . What voluptuous thrill may shake a fly, when she at last discovers the one particular leaf, or carrion, or bit of dung, that out of all the world can stimulate her ovipositor to its discharge?

–William James

The quest to understand the origins and nature of human motivation—including the *affective* dimension of motives—has a long history. This extends back not only to the earliest roots of psychology, including the work of Wundt and James, but also to ancient Greek philosophers such as Heraclitus and Aristotle. Aristotle emphasized the role of desire (*orexis*) without which the human capacity for rational thought would lack any power to act. Likewise, as James considered why a hen would submit to the tedium of sitting on a nestful of eggs, he argued it was not based on some prophetic inkling of the goal of hatching, but rather was more likely akin to the *feeling* that underpins the human motive to prefer “to lie down on soft beds rather than on hard floors”.

That is, the most basic motive to adjust behavior is to *feel better*. To eat when hungry, to drink when thirsty, to seek shade from the hot sun, to seek excitement when bored, to rest softly when tired, to seek safety when frightened, to play, to work toward rewarding goals, or more broadly, to act in ways that increase enjoyable feelings such as joy, pleasure, and love, and/or to decrease aversive feelings such as pain, fear, and loneliness, represent the most natural source of motivations. Presumably, to a brooding hen it feels better to sit upon her eggs, than to do otherwise.

On one hand, this principle can appear so simple and universal as to seem trivial. On the other hand, understanding the specifics—such as how particular affective signals are shaped by learning and development in ways that can lead

to marked individual differences in motivations—represents a profound and compelling set of questions.

Recent rapid advances in the neurosciences—including cognitive, affective, and social neuroscience—are beginning to provide new approaches to these questions. An emerging body of work is focusing on the neural systems that underpin biological and psychological motives, including a growing emphasis on learning and development.

There are compelling reasons for these interests. Motivation represents a crucial aspect to almost all behavior and action—ranging from the most basic appetitive drives in simple organisms to the complex mix of thoughts and feelings that underpin the most inspired human passions. Moreover, this line of inquiry has great pragmatic relevance. The development of healthy (and unhealthy) motivations has enormous long-term consequences for human health and well-being. Motivational factors are crucial to understanding the developmental trajectories leading to a variety of high-stakes problems ranging from the development of alcohol and substance use problems and mental health disorders, to risk-taking and obesity. Motivation is equally important in understanding positive trajectories in education, exercise, sports, the arts, or becoming proficient in virtually any adult endeavor that benefits from practice and perseverance.

Clearly, there have been thousands of scientific articles written about motivation, and there is a great deal of disagreement about how to define and conceptualize various aspects of motivated behavior, including how to parse specific cognitive, affective, psychological, and social influences. We believe it is timely to approach these complex and important issues from the perspective of developmental cognitive neuroscience.

Our goal in this special issue is to collect a set of papers addressing several aspects of motivation with an emphasis on development within a general framework of cognitive/affective/social neuroscience. We sought to include a broad range of perspectives and varying conceptual and methodological approaches to this complex set of questions. We are very grateful to the authors (and reviewers)

whose work has resulted in the twenty one papers (9 reviews and 12 empirical studies) selected for this special issue, and we are pleased that these papers span an impressive range of topics, raise some compelling questions, and point to exciting future research.

As illustrated by a number of papers in this issue, some of the exciting research advances are using animal models in areas such as behavioral neuroscience to address intriguing aspects of the development of motivation. These papers cover a range of important topics that underscore the breadth and complexity of the developmental cognitive and affective neuroscience of motivation. Several papers focus on the study of play and other rewarding social behavior (Pellis and Bell; Trezza et al.; Cooke and Shukla; Siviy et al.), approaching questions about the motivations for social interaction during development in a variety of ways—ranging from neuropharmacological to theoretical behavioral angles. These are complemented by contributions that highlight the development of cognitive capacities underlying motivated behavior, including how cognitive strategies and abilities change during development (Johnson and Wilbrecht) along with their modulation by catecholamine neurotransmitters (Cain et al.). Other animal papers focus on issues surrounding the development of maladaptive motivations and impulses, and how these can be affected by drug use during development (Counotte et al.; Drescher et al.).

In addition to directly advancing understanding of animal behavior and motivation, there are important translational implications from these studies. One major principle underpinning the investigation of play and social motivations focuses on the importance of sensitive periods—the role of play and other positive social interactions during key developmental intervals as having profound and enduring effects on brain function and behavior. In a parallel way the same developmental windows of motivational learning may confer added vulnerabilities for the negative effects of drug use. There also are provocative translational implications for the animal studies focusing on cognitive capacities—for example, Johnson and Wilbrecht report that juvenile mice *outperformed* adult mice on a 4-choice foraging task in ways that raise compelling questions about the developmental trajectory of cognitive flexibility and learning in humans.

The theme of translational research is addressed directly in two comprehensive reviews that consider both animal and human studies—one by Gordon et al. focusing on oxytocin and social motivation across the lifespan, and one by Spear that focuses on the adolescent transition, and particularly, reward reactivity and sensitivity to aversions and their broad implications for adolescent vulnerabilities to risk taking and substance use.

As highlighted by several other papers in this issue, conceptual and methodological advances in neuroimaging are providing exciting progress and new insights in understanding the developmental trajectory of key aspects of motivation in humans. Several of these papers (Panbanabhan et al.; Ernst et al.; Gladwin et al.; Bjork et al.; Fairchild et al.) focus on adolescence as a key developmental window for maturational changes in motivation (and/or motivational learning), including an investigation into the

specific impact of testosterone on reward circuitry (Op de Macks et al.) and examination of the effects of specific genetic polymorphisms on attentional bias and alcohol use in adolescents (Pieters et al.). Harsay et al. address the importance of motivational incentives (and striato-cortical white matter pathways) in the aging brain.

Several of the human studies focus directly on reward circuitry, however other papers highlight the links between positive and negative reinforcers (Niznikiewicz & Delgado) and reward and punishment reversal learning relevant to adolescent decision making (van der Schaaf et al.). A few of the papers consider the integration of cognitive control and affective systems, including a review of dual-process models of addictive behavior (Gladwin et al.) neural response to challenge in adolescence (Strang et al.) and the influence of reward processing on inhibitory control (Panbanabhan et al.).

Taken together, these lines of investigation are providing new insights and hypotheses about the development of motivation. They are contributing to a growing foundation of studies, which in combination with future studies extending this work, can begin to be translated into testable hypotheses about promising targets and optimal timing for early intervention and prevention strategies for these high-stakes issues relevant to health, education, juvenile justice, and other important areas of social policy impacting youth.

However, taken together, these papers also highlight several gaps in our understanding. One of the greatest challenges, we believe, is the need for clarity in definitions and concepts related to the development of motivation. Across the papers in this special issue, there is a wide range of variations as to what specific aspect of motivation is being studied. This is not to suggest that the field needs a single all-encompassing definition of motivation, but rather that this complex set of processes may need to be parsed into some agreed-upon components—at least to promote advances in knowledge regarding the underlying neural systems and their links to specific aspects of behavior.

More specifically, this brings attention back to the set of issues highlighted by the Aristotle and James quotes at the beginning of this commentary, focusing on *the affective dimension of motivation—the feelings* that underpin motives and motivated adjustments in behavior. In terms of contemporary neuroscience this leads to questions about neural systems that generate and interpret these affective signals, as well as the role of learning and development in shaping individual differences in the feelings of motivation. This is not meant to imply that this affective dimension is more important, or independent of cognitive aspects of motivations. Clearly, the selection of goals and the appraisal as to the relative value of specific goals involves integration of both cognitive *and* affective processes. Rather, the point we are trying to highlight is the potential value of considering each of these dimensions separately in order to investigate their development (and their interactions), including how these are shaped by learning.

More generally, there is a need for broader conceptual models focusing on the development of motivation within a cognitive neuroscience framework, and efforts to conceptualize and define motivation from this perspective. Some of the papers in this special issue provide several

outstanding examples of taking positive steps in this direction. The next several years are likely to be an exciting time in the development of this budding field, with many opportunities to advance and refine these models, including empirical studies to test key features of these models.

Finally, we offer this commentary and set of papers in large part with the intention of stimulating further work and discussion of these interesting and important issues. We welcome commentaries and follow-up articles and

hope to consider another special issue on this topic in the future—one that is likely to reflect further exciting advances.

Ronald E. Dahl

Louk J.M.J. Vanderschuren

E-mail address: rondahl@berkeley.edu

(R.E. Dahl)

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