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Introduction to a special issue on reward and regulatory processes in adolescence

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Psychology as a science has always struggled with the complexity of motivation, once everyone dealing with the field accepted that much of human behavior is guided by unseen mechanisms of reward feedback. The implications for regulation of motivated behavior are obvious and a great deal has been written on the topic with respect to both animals and humans. The focus has shifted to adolescence as studies in the social neuroscience of this age cohort has become a major research interest in the last decade, bringing issues into the discussion on brain mechanisms as well as psychological ones. The notion of regulation has gone through an interesting historical route, first from being a force of disembodied Reason required to control animal motivations and stemming from outside the body in Cartesian dualism, and then to being part of the motivation system itself (in animals), and now reintegrated in humans as a function of the frontal lobes (presumably, present in nonhu-mans as well but to different extents). The period of adolescence for understanding the processes of reward and regulation is a natural focus given the major societal and parental concerns around qualitative changes in motivational targets and strategies. The onset of puberty has obvious major developmental implications in terms of changing expectations concerning social and cognitive regulation.

For the topics in this special issue, we need to deal not only with the complexity of motivation, but also maturation. Traditional child psychology did not incorporate the factor of brain growth because the brain had been thought of as being structurally more or less mature within a few years after birth. With improved methods in neuroscience, of course, we learned that aspects of structural brain change and functional neurodynamics can be measured right into young adulthood. The natural extension of this is to consider the whole lifespan as having a trajectory of brain growth and/or neurofunctional change, which is more or less the accepted view today. This is in strong contrast to traditional 20th century stage theories of psychological development that provide so many ingenious psychological mechanisms for maturation that do not include changes in brain structure based solely in cognitive or emotional constructivism. We are now in a position to explore an integration of this latter rich tradition with our new knowledge of changes in brain anatomy and function during adolescence.

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The application of this insight into prolonged brain growth into and through adolescence has been dramatic. It has become commonplace in the last 10 years to consider the complexities of the behavior of adolescents as at least partly due to brain maturation factors – changes in one behavioral repertoire sliding out of its balance formed in childhood because of changes in terms of which brain networks are dominant. There has been an emphasis in recent literature on reward processes and their neural substrates because of proposed links to risk-taking behaviors that become pronounced during the adolescent period. The central debates within the general field of adolescent development concern what balance of constructs we impose onto our mental model – from neuroscience versus psychological versus sociological perspectives – of what is driving an adolescent’s behavior. In other words, researchers differ on how much we should stress the importance of placing behavior into its context, that is, how much we should consider sociological and psychological variables as well as developmental milestones, such as pubertal stage, that likely influence which behaviors and motivations are prioritized by the adolescent as he or she transitions into full maturity.

In this special issue, we present papers that address adolescent reward sensitivity by focusing on different aspects related to the social neuroscience of the phenomenon. Two papers directly address the question of age and pubertal status: Van Duijvenvoorde, Op de Macks, Overgaauw, Moor, Dahl and Crone report on the intimate link between activity in the ventral striatum and media prefrontal cortex during a risk-taking activity in adolescence and the longitudinal prediction of reward sensitivity. Urosevic, Collins, Muetzel, Lim and Luciana address the difficult task of separating puberty and age factors in the prediction of reward hypersensitivity and the role of individual differences in striatal structure in reward processing. Also with respect to striatal activation in response to reward and loss anticipation, Lamm, Benson, Guyer, Perez-Edgar, Fox, Pine and Ernst examine the question longitudinally from mid-to-late adolescence. Padmanabhan and Luna review the complex relations between dopamine function, dopa-mine-related genes and their link to adolescent behavior. Continuing with functional imaging, Healey, Olino, Morgan, Musselman and Forbes explore clinical questions focusing on social anhedonia in late adolescence and the medial prefrontal cortex activity during feedback about being liked. This study on the pathophysiology of adolescent anhedonia implicates the social reward circuit. Two further papers round out the presentation of research results using new EEG technologies. Crowley, van Noordt, Wu, Hommer, South, Fearon and Mayes describe the importance of consistency of electrocortical responses as reflected in EEG intertrial phase consistency in response to win versus no-win feedback, and the changes from 10 to 17 years. Using another relatively new measure of EEG functioning, Lackner, Marshall, Santesso, Dywan, Wade and Segalowitz report that individual differences in anxiety and aggressiveness in young adolescents relates to EEG phase shifting and locking responses.

These papers present neural correlates of reward sensitivity and associated psychological states during adolescence. However, two further papers reflect positions not often expressed in the pages of this journal (or in the pages of any neuroscience journal), namely, that we may have the constructs the wrong way round. As neuroscientists, we are accustomed to considering the notion that some behaviors are controlled primarily by what we call “top-down” processes, meaning that behaviors are guided by goals usually consciously set or acknowledged. We also delight in describing behaviors that appear to be beholden to

“bottom-up” processes, meaning that behavior is directly related to stimulus input characteristics or by automatic motivations. While this division is in practice often hard to define, it has the intuitive appeal of the “controlled” versus “automatic” and sometimes the “cognition” versus “emotion” distinctions. Thus, we think of executive functions associated with the frontal lobes as regulating automatic motor and emotional responses when we are functioning well, and responses reflecting more automatic aspects of motor and emotional processes being dominant when we are operating at less than peak performance (and in fact, this may be part of the definition).

By analogy, we think of children as performing at lower peak performance than adults, that is, more automatically and less with executive function control. Adolescents then present us with an interesting middle ground – somewhat like children and somewhat like adults. It is this position that is questioned by Willoughby, Good, Adachi, Hamza and Tavernier and by Sercombe. As non-neuroscientists (a developmental psychologist and a sociologist, respectively) they remind us that our heuristic models have implications in the real world that may be dubious. Does the pre-frontal cortex, with its privileged access to executive functions, simply modulate emotional responses that would drive behaviors to approach or withdraw from the tempting or threatening stimulus, or does it underlie the approach and withdrawal functions? (Clearly Freud would have seen it both ways and perhaps so should we.) This will be an enduring issue, we feel, and as neuroscientists who may tend towards too much reductionism, we need to be reminded of this. Concluding this part of the section is a commentary we requested from Riddell and Pepler, who are working within a well-known clinical context with adolescents exhibiting behavior-control problems. Their view from the “outside” is a welcome and useful addition.

Although much of the current literature has focused on positive motivation or sensation seeking as a foundation for risk-taking behavior, we are also reminded among the papers within this issue that “motivation” is a broader construct. Ernst and her colleagues have offered a heuristic framework for approaching an understanding of adolescent behavior that incorporates positive motivation, avoidance motivation, as well as regulatory control: the Triadic Model. This type of model strikes us as valuable given its comprehensive focus. It challenges us to think broadly about the intersections and interactions among brain networks during this fundamental period of maturation.

One aspect of this special issue that is unusual for this journal is the inclusion of a short target paper – a summary of the Triadic Model by Ernst, Hale and O’Connell – with several commentaries to which she responds. Two of the four commentaries are shorter versions of the longer papers mentioned above by Willoughby et al. and by Sercombe, accompanying two others by Somerville, van den Bulk and Skwara and by Luciana and Segalowitz. We trust that these perspectives and the responses from Ernst et al. will provide useful ideas for us to keep in mind as we continue our research in this area of inquiry. We hope that this broad perspective on the issues will capture the excitement and possibilities of research with adolescents and youth.