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Editorial

Adolescent Brain Development: Forging New Links?

Investigation of the brain by scientists from neurobiology, neuroimaging, biochemistry, and the behavioral sciences, utilizing the most sophisticated scientific technology available, is providing startling insights into adolescent development. Leaders in Adolescent Medicine and Health should forge new links with neuroscientists as we expand the purview of our research, training, and clinical programs into the neurosciences.

Most, if not all, health conditions during adolescence are biobehavioral. The expression of disease originates from a combination of genetic vulnerability, massive endocrine change during puberty, and environments that render adolescents at risk for these conditions. Figure 1 illustrates a simplified integrative model of the relationship between adolescent biology and behavior. The overlapping relationship between genetics and environment (family, school, and peers) as factors affecting the expression of individual biology and behavior is noted. Genetic background influences both biology (in this instance, adolescent brain development), and behavior. The environment, also, affects biology and behavior. In addition, genetic potential and environment may have an interactive effect on biology and behavior. These relationships are complex, and some are bidirectional.

We now know that the brain is critical in adolescent biologic and behavioral development. Specific triggers of somatic growth result from the secretion of releasing hormones from the hypothalamus (growth hormone-releasing hormone, thyroid-releasing hormone, gonadotrophin-releasing hormone, and corticotrophin-releasing hormone). These hormones are transported to the anterior pituitary gland and signal the pituitary to release the specific hormones that transform the end organs to produce and to release the products that drive somatic growth [1]. It is possible that the control of pubertal onset resides partially in genes in chromosomes 6 and 13, as has been reported in mice [2]. Grumbach [3] described the mechanism of the reactivation of the hypothalamus resulting in the secretion of gonadotrophin-releasing hormone.

In this edition of the *Journal of Adolescent Health* Giedd and colleagues describe the remarkable progress that has been made through the careful analyses of longitudinal magnetic resonance imaging (MRI) of the developing brains of children and adolescents, providing data on developmental anatomic trajectories of brain development during these periods. Finally neuroscientists are able to go under the ". . . leathery membrane, surrounded by a protective moat of fluid, and completely encased in bone . . ." to provide new insights into brain development. Changes in the brain during childhood and adolescent development that are being documented through exquisite imaging by Giedd and others [4] hold the promise for the development of hypotheses about the potential origins of behaviors that we have observed clinically for years. The author is cautious about drawing cause–effect conclusions from observations from MRI and behavior.

This study and other studies of longitudinal MRI data indicate that gray matter increases in volume until approximately the early teens and then decreases until old age [4–6]. The volume of white matter (reflecting myelination of axons) continues to increase during adolescence [5–7]. White matter volume of the frontal and temporal lobes increases into the fifth decade of life and decreases thereafter in men [8]. Yearly increases in the size of the corpus callosum (the connection between the right and left hemispheres, made up of white matter) are greatest during adolescence compared to adulthood [9]. A given capability, such as musical or athletic ability, may never be developed if not nurtured during childhood and adolescence [10].

Studies focusing on behavior, including cognitive development and novelty/risk-taking/sensation-seeking behaviors during adolescence, are ongoing [11–13]. Based on Piagetian theory [14] and clinical observation, it is known that during the adolescent years that most teenagers' thinking matures from concrete operational thinking, which is focused on the here and now, to formal operational thinking, with the development of the ability to think abstractly, plan for the future, and debate ideas. The maturation of the prefrontal cortex that regulates judgment, caution, and appropriate behavior is a relatively late

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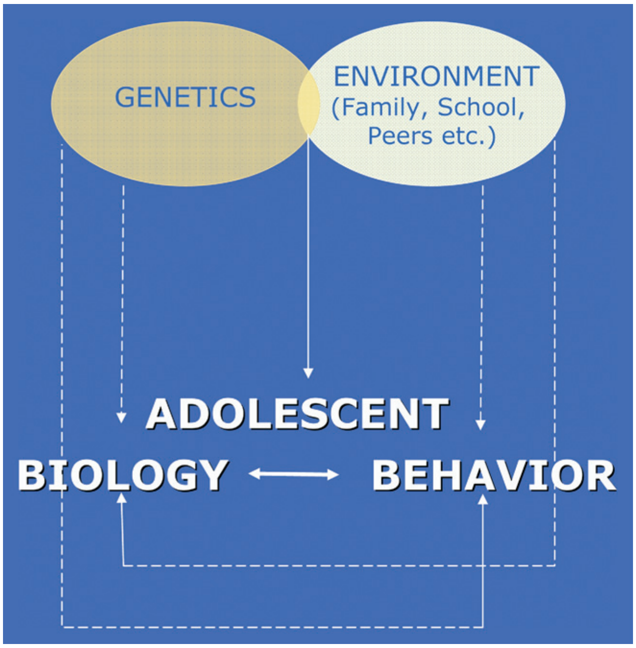

Figure 1. Integrative model.

adolescent, early adult event. Earlier stimulation of the limbic system, before the prefrontal cortex is developed, provides a "perfect storm" for asynchrony between the parts of the brain that affect adolescent novelty-seeking/sensation-seeking and constrains behavior. Novelty seeking/sensation seeking and risk taking is the basis for considerable growth during adolescence, as well as for the seemingly reckless behavior of some adolescents. Novelty seeking/sensation seeking and risk taking are topics of growing interest as adolescent brain development is defined better and as morbidity from adolescent risk taking mounts [11–13].

Adolescent self-esteem, family and school connectedness, and belief systems have been identified as protective factors for positive adolescent emotional health [15]. If one conceptualizes these elements of societal guidance as the "brake" for reckless adolescent behavior before the inhibitory prefrontal cortex is fully developed, then one can understand that our forefathers were correct in providing structure and guidance for developing adolescents through close family, school, and community relationships. What one hopes is that the adolescent will incorporate lessons learned from these institutions into their own repertoire, and that youth ultimately will be guided by a mature prefrontal cortex.

Finally, an example of a study integrating adolescent brain development and cognitive development follows. Over time, we can expect a proliferation of such studies using modern scientific techniques of neuroimaging and of behavioral evaluation. New data indicate a relationship between intelligence and trajectory of change of cortical thickness on MRI. Children and adolescents who have superior intelligence compared to those who have high or average intelligence on Wechsler testing have a different trajectory over time in both the thickness and thinning of the frontal lobes. Children with superior intelligence have thinner cortical thickness in the frontal lobes initially, then have a longer and steeper trajectory of thickening of the cortex during childhood and adolescence with waning during late adolescence compared with children and adolescents with either high or average intelligence [16].

The implication of our growing knowledge of brain–behavior mechanisms of adolescent conditions should provide insights into the risk of particular adolescents for morbidity and mortality. Preliminary data are promising so that as we begin to understand the complexity of and specificity of each of these conditions, we shall be able to diagnose and treat conditions earlier. The treatment can be targeted toward the underlying biology and behavior of vulnerable adolescents and their families. For several conditions such as the eating disorders, alcohol and cigarette smoking use/abuse, depression, schizophrenia, reproductive behaviors, we are learning about the role of genetics, neurotransmitters/neuropeptides, endocrine metabolites, and the environment in shaping adolescent behavior.

New insights about brain development during adolescence in the expression of adolescent health and disease should prompt us as leaders in Adolescent Medicine and Health to expand the reach of our discipline's scientific and training programs. Adolescent Medicine and Health training would be enhanced by including neural and cognitive scientists on our interdisciplinary faculties as we now include social workers, nurses, educators, psychologists, psychiatrists, gynecologists, and nutritionists. As we have done for years clinically, we in Adolescent Medicine and Health must continue to be the integrators of adolescent biology and behavior through expanded neuroscientific training and research. We can collaborate with neuroscientists and psychologists in understanding further adolescent brain development and behavior.

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