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# Optimizing adolescent brain development

Adolescence – the transition from puberty to adult status – is a period of profound contradiction. It is marked by peaks in strength, agility, and resilience to illness. Yet, morbidity and mortality increase two- to three-fold[1]. It is also a time of great leaps in cognition and behavioral competence, yet the period during which 75% of mental disorders emerge[2].

These phenomena are two sides of the same neurodevelopmental coin[3]. The adolescent brain does not mature by becoming larger, but by becoming more interconnected and more specialized. Increased connectivity is driven by ongoing myelination, a process by which axons are wrapped with a cellular insulation that markedly increases communication efficiency (100x conduction speed, 30x faster reset time), unlocking the wide range of capabilities that emerge during adolescence. Specialization proceeds by a one-two punch of overproduction followed by selective elimination according to the demands of the environment. This is the engine of evolution and the way by which almost all of complexity in nature arises.

The connectivity and specialization are inextricably bound. As myelination progresses, it releases inhibitory molecules, such as Nogo-A, that constrain the brain's adaptability[4]. This creates a trade-off between a rapid maturation of fixed skills versus a prolonged maturation maintaining "plasticity" useful for adaptation to novel environments. *Homo sapiens* evolution has led to the most extreme choice of the second path in all of nature, including compared to our fellow human species, the Neanderthals[5]. Protracted neuroplasticity is both the strength and vulnerability of our species.

Metaphorically, brain maturation resembles a sculpture more than a painting. While individuals may come into the world as different "blocks of granite", understanding the sculpting process helps reveal the "masterpiece" within. This has been a central goal of adolescent neuroscience. Large scale investigations, such as the Adolescent Brain Cognitive Development (ABCD) study, integrate imaging, genetic, environmental and behavioral measures to explore what factors guide the sculpting process in healthy or unhealthy ways.

The ABCD project, following about 12,000 9-10-year-olds through the second decade of life, now generates approximately one publication per day. Findings consistently indicate that development is not driven by a single dominant factor, but by the interaction of many. Hundreds of variables have been identified as having influence, including activities, diet, sleep, social connections, and screen time. Within this complex landscape, several domains emerge as especially tractable targets for intervention and policy, including socioeconomic factors, education, use of digital media, and expectations.

Many ABCD study associations between biological and behavioral variables are substantially attenuated when socioeconomic factors are taken into account, underscoring the pervasive role of social determinants of health[6]. Youth in disadvantaged environments experience higher rates of trauma and chronic stress, greater exposure to environmental toxins such as lead, reduced access to health care, and fewer opportunities for cognitive and educational enrichment. Addressing these intergenerational conditions – through improvements in housing, nutrition, education, and access to care – offers one of the most promising and scalable approaches to improving adolescent outcomes.

Education can be understood as the process of creating environments to which the brain adapts in ways that serve both immediate and future functioning. Schools are the predominant environment of adolescents, where crucial opportunities are available to influence brain development. Advances in artificial intelligence (AI) offer the potential for increasingly personalized learning, while emerging technologies provide new ways to assess learning readiness and engagement. Classroom-based sensing approaches can integrate remote motion detection to estimate heart rate, heart rate variability, and breathing. Natural language processing and environmental sensors capturing temperature, lighting, humidity, smells, air quality, and other contextual features provide a comprehensive picture of the learning environment. These technologies also enable simultaneous assessment of multiple individuals, allowing study of synchrony between teachers and students – a key component of social neuroscience and effective learning.

Data science and AI are well suited to integrating these complex data streams in real time to optimize educational experiences. These same technologies facilitate earlier identification of mental illness, which affects approximately one in seven adolescents. Tragically, the average time between onset of illness and any form of treatment is ten years[7], which is especially concerning given the greater effectiveness of interventions in younger, more plastic brains. Despite challenges related to implementation, privacy and ethics, these advances hold significant promise for improving both educational and mental health outcomes.

The digital revolution has dramatically transformed the way teens learn, play and interact[8]. Within this broader upheaval, the effects of social media on adolescent health have become a lightning rod of public concern, with Australia becoming the first country to implement nationwide limits on social media use for those under 16 years. As part of debates regarding the optimal amount of screen time, it is commonly asserted that use of digital media is "unnatural", because it was not part of our evolution. Setting aside that, by that definition, reading is not natural either, the allure of digital media is actually highly aligned with deep-rooted evolutionary traits of adolescence – specifically, the drive for social connectedness, appetite for novelty, and desire for data[9]. Like fire or any powerful tool, digital technologies can be used, misused or abused. The question is no longer whether they will impact adolescent lives, but whether we will apply the best available science to shape policy governing their design, incentives and safety.

Adolescents are frequently portrayed negatively, despite decades of well-replicated research demonstrating that, in many respects, they function far better than their stereotype suggests. The vast majority of adolescents traverse this period without marked disturbance. Regrettably, negative perceptions are often internalized by adolescents themselves. This has implications far beyond fairness, because expectations influence behavior, sometimes in powerful ways. This impact is particularly consequential during adolescence, when teens are forming their identities, values, competencies, aspirations, and sense of purpose. The influence is so pervasive that it often goes unnoticed, and is perpetuated not out of malice, but out of habit. On the positive side, it is also one of the most actionable influences. By examining and revising our assumptions, we can all contribute to optimizing adolescent development by allowing for some missteps during a time of tumultuous biological adaptations, while maintaining appropriately high expectations.

The adolescent brain is not a defective adult brain. It has been forged by evolution to have distinct features from those of a child or an adult – not simply a smooth average in between. Our protracted plasticity has ensured our survival as a species. Adolescence is not a time to be managed, but a time whose potential has to be maximized. As we navigate the path from plasticity to policy, optimizing adolescent brain development will require coordinated evidence-based action across multiple domains. This includes intensifying efforts to mitigate the intergenerational effects of socioeconomic factors; leveraging advances in AI and emerging technologies to transform educational environments; actively shaping public policy and research to enhance the benefits and reduce the risks of digital technologies; and re-examining societal and personal expectations of adolescence to promote a more balanced and evidence-based view of youth.

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