The Teenage Brain: How does it Work?

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As was noted in the introduction, this is my second opportunity to address the Quest Club and while I stand before you with less trepidation than I experienced during that first reading, I assure you that with the passing of several more years of club membership the depth of my respect for you my fellow Questers has only grown. The range of topics considered, the quality of the presentations, and the now century-long history of this club is humbling. We are fortunate indeed to share in a unique form of intellectual fellowship and I am deeply grateful to be counted among the members of this honored organization. My constant regret has been that due to the demands of my position at the University I have not joined you on these Friday afternoon adventures of the mind as often as I had wished. I am here today, and happy to be so, to give this paper. I hope you derive a fraction of the enjoyment from the presentation as I have had in the research and writing.

Upon opening the email that specified the date and topic for this talk, my immediate reaction was one that perhaps has been shared by many in this room. My eyes grew wide and I said something like “Oh… … … No!”

“The Teenage Brain: How does it work?” Good grief! No wonder the last person assigned this topic resigned from the club.

I had hoped for a slightly more tangible topic. Perhaps The Loch Ness Monster, Big Foot, or even a discussion of the Aliens that carved the geoglyphs of the Nazca Desert. I suppose those easy topics must have been reserved for members with better attendance records. Complaining certainly was not going to help, so I set off “In Search Of: The Teenage Brain”.

While it is well understood that teenagers have a blob of goo that resides between their ears, calling that organ a brain is, at best, a questionable practice. Teenagers are possessed, … no, … sorry, … teenagers possess, many wonderful features and characteristics. Yet much like Dorothy’s friend the Scarecrow, it is not entirely clear what a teenager would do with a brain if in fact they had one.

But perhaps I am being unkind to our adolescent friends since, after all, we were teenagers once and we turned out just fine…

In preparation for this talk, I had one advantage to draw upon. The opportunity to interact with a real live teenager every day! What Quest talk could be complete without some empirical data to support the author’s conclusions? From this ready reservoir of observations I could easily consume all the time available today, and much more beyond, in describing anecdotes involving my fourteen year old son that have occurred since I was assigned this topic in order to illustrate both the workings and the idleness of the teenage brain. But given the fact that he might, at some point in the distant future, seek gainful employment in Northeast Indiana, perhaps I should not handicap his prospects by sharing details of his adolescent absurdities with this audience. Rather, I will take the more traditional Quest approach of discussing two aspects of the assigned topic in enough detail to document my scholarly efforts, while maintaining enough brevity to, I hope, retain your attention.

As I have come to learn, talking about "the teenage brain" is a risky proposition because stereotypes of adolescence and adolescents can lead to the inappropriate endorsement of an overstated notion of homogeneity among teens. The wide range of individual differences in adolescent behavior and cognitive capacity make clear that the adolescent brain, in terms of structure and function, is at best only a portion of a larger story of adolescent development.

With that caveat in mind I will focus not on teenagers in general but the specific topic of the teenage brain and begin, therefore, with a brief discussion of the origins and advancements of the field of developmental psychology, specifically as it relates to the study of adolescents.

Few fields of science have as clearly defined a point of origin as does the subdomain of adolescent psychology. G. Stanley Hall launched the systematic study of teenagers in 1904 with the publication of his two volume textbook *Adolescence: Its Psychology and its Relations to Physiology, Anthropology, Sociology, Sex, Crime, Religion, and Education*. I suppose when launching a field of scientific research there is no reason to be modest in your approach.

Hall was the first person to be granted a Ph.D. in Psychology in the United States. His dissertation director at Harvard was William James, brother of the novelist Henry James, and godson of Ralph Waldo Emerson. In passing, I would note that the James family and their role in America's intellectual history would be an facinating future Quest topic.

After Harvard, Hall went on to what would now be called a post-doctoral research fellowship with Wilhelm Wundt, the founder of the scientific study of psychology at Wundt's laboratory in Leipzig, Germany.

Returning to the United States Hall joined the Philosophy Department at Johns Hopkins University where he taught Psychology and Pedagogy. Building on his experiences in Leipzig, he established the first formal psychology laboratory in the United States where he became a leader in what became known as the "child study movement". Hall established the American Journal of Psychology in 1887 and in 1892 was elected the first President of the American Psychological Association. After a long and successful career he was re-elected as the 24th President of the APA near the end of his life in 1924.

While many of Hall's theories about adolescent development have subsequently been discredited, there is one aspect of his work that remains the subject of active study. Quoting from the audaciously titled text I mentioned earlier, Hall concluded that "at no time of life is the love of excitement so strong as during the season of accelerated development of adolescence, which craves strong feelings and new sensations."

Hall coined the term "Storm and Stress" to describe the spectrum of adolescent behaviors that fall into one of three general categories: conflict with authority (typically parents); mood disruptions; and risk-taking behaviors including substance abuse and crime. While Hall was certainly wrong in his attribution of these adolescent characteristics to a recapitulation of the lives of our primordial evolutionary ancestors, the role of the social and cultural context in which the adolescent matures is recognized to play a significant role in exhibited behaviors. Anthropologists, starting with the work of Margaret Mead in the 1920's, have documented the relative quiescence of the adolescent period in some non-western cultures while many psychologists, working mainly with members of western cultures, have continued to recognize and refine Hall's three categories of behavior.

At the turn of the last century Hall and his coworkers typically defined adolescence as beginning at age 14 and extending through age 24. Conversely, modern psychologists set the age range from 10 to 18. There are several reasons for the lowering of the starting point of adolescence. Medical evidence suggests that at the beginning of the 20^{th} Century the onset of puberty ocurred between the ages of 13 and 15, whereas in modern populations it occurs at or around age 10. While there certainly is a remarkable degree of variation among individuals of both genders, puberty typically begins at younger ages for girls than boys.

Today, scientists mark the initiation of adolescence by a biological process – the onset of puberty – but define the end of adolescence not by physiology but by sociological factors. In 1890 only 5% of Americans aged 14 to 17 were enrolled in high school. One hundred years later high school participation extended to more than 95% of individuals in that age range. Additionally the establishment of legal protections for children under 18 makes that age a natural divider among study populations. The latter portion of Hall's age range, from 18 to 24, is now described as emerging adulthood and is a fertile field of study for university psychologists who typically utilize college students as research subjects.

One of the most significant modern theories of human development was put forward by the Russian-American psychologist Urie Bronfenbrenner. While recognizing the importance of the immediate environment, Bronfenbrenner argued for the significance of the broader cultural environment as experienced during a child's development. By focusing on the interconnections between family, school, peers, the media, and organizations such as churches and social service providers, Bronfenbrenner argued that children and adolescents are active, rather than passive, participants in their development. As a co-founder of the national Head-Start program, key aspects of his theory have been put into practice with tens of millions of children and their families in the United States for more than fifty years.

Without question socio-cultural interactions play critical roles in adolescent development and the modern world saturates teenagers with an astonishing range of stimuli from the traditional print and broadcast sources to the more organic and dynamic linkages of social and digital media. Within this web of influences, however, there operates the very important and complex process of cognitive development. The greatest contributor to our current understanding of the changes in mental processing that occur during childhood and adolescence was Jean Piaget (pee-ah-jay).

Stressing that cognitive development was dependent upon the level of physical maturation and driven by an individual's active participation in the learning process, Piaget established four stages of cognitive development in his theory of genetic epistemology. The most significant part of his theoretical framework is the transition from a style of thinking that is based upon concrete operations to one that is characterized by an understanding of formal operations. Concrete operations are typically exhibited by children ranging from ages 7 to 11. With knowledge of the world based upon empirical evidence and physical manipulation, children at this stage of cognitive development tend to be very literal in their interpretation of observations and to subsequently face challenges when attempting to translate existing knowledge to new situations. Concrete learning gives way to the development of logical and systematic approaches to learning starting at about age 11 and continuing through age 15 to 20. Piaget devised the "pendulum problem" in the 1950's to establish if a child is utilizing concrete or formal processes. By asking subjects to evaluate which of several variables controls the speed of a swinging weighted pendulum Piaget was able to observe a marked transition from "trial and error" approaches of younger children to the systematic and structured approaches of hypothesis testing used by older adolescents.

Building on Piaget's work during the last half-century, psychologists have expanded the concept of formal operations from strictly scientific approaches to learning (that is hypothesis testing) to an understanding that includes the ideas of abstract and complex thinking as well as metacognition. The ability to undertake abstract thinking captures the concepts of formal logic, spatial and geometric processing, as well as the consideration of abstract concepts such as justice, faith, morality, and ethics. Complex thinking is defined by psychologists to be the ability to evaluate a situation or scenario on multiple levels leading to the use of both metaphor and sarcasm – a mode of communication <u>rarely</u> used by teenagers.

The third, and perhaps the most developmentally significant of the three characteristics of formal thinking is metacognition (that is, thinking about thinking). By becoming aware of their thinking processes, adolescents are able to accelerate learning. Pedagogical research has shown that academic performance can be enhanced by intentional instruction in metacognitive techniques. One aspect of formal thinking that is often challenging to adolescents is the analysis and interpretation of data presented graphically. The research of Bracha Kramarski strongly suggests that "graph sense" among adolescents is subject to improvement through metacognitive instruction that focuses on a series of strategic questions designed to highlight the solution process and help in identifying reasonable results.

During late adolescence and the period of emerging adulthood learners begin to recognize the limits of logical thinking. Psychologists call this stage of development postformal thinking because it occurs after the development of the formal strategies of adolescence. Characterized by a growing sense of pragmatism, postformal cognitive development allows for the recognition of the social and cultural context within which logic-based decision making must occur. When faced with a complex problem, postformal thinking provides mechanisms for a decision maker to consider opposing points of view through the establishment of a dialectical analysis with the goal of if not eliminating contradictions at least utilizing the strengths of multiple solution pathways in the search of some form of satisfactory reconciliation.

The final stage in cognitive development recognized by psychologists is the capacity, typically achieved in the late teens or early 20's, to engage in reflective thinking. Through the process of reflection the adolescent is able to evaluate the validity or applicability of a previously held belief. Reflective thinking proves disruptive to world views that are defined by stark contrasts such as right and wrong, us and them, fair and unjust. Advancing into this stage of cognitive development is typically associated with rapidly transforming views on social and political issues.

Having reviewed the stages of cognitive development that occur through the teenage years, it is now appropriate to evaluate how physiological developments are linked to and in many ways drive psychological change during adolescence.

Over the past decade scientists have made significant advances in the understanding of the physiology of cognition and the changes that occur during a child's growth and development. The principal mechanism for conducting this research has become the use of functional Magnetic Resonance Imaging (fMRI). I imagine everyone is at least generally familiar with the use of MRI images in diagnostic medicine. Based upon research that was awarded the 1944 and 1952 Nobel Prizes in physics and the 1972 Nobel Prize in Medicine, an MRI image is created by the vibrational resonance in an atomic nucleus when exposed to a static magnetic field and a varying electromagnetic field. This technique is especially powerful in the creation of high resolution and high contrast images of the soft tissues of the body.

In 1988 the Japanese physicist Seiji Ogawa, working at AT&T Bell Laboratories, recognized that changes in blood oxygen levels caused changes in contrast in MRI images of the brain. Using the property known of blood-oxygen-level-dependent contrast, or BOLD contrast, Ogawa was able to map the spatial distribution of brain activity associated with visual, auditory, and other sensory functions as well as, ultimately, the higher functions associated with cognition. By showing that BOLD contrast correlated with communication among nerve cells, scientists have for the first time been able to illustrate where thinking occurs within the brain.

The human brain grows very rapidly, increasing to 95% of adult size by age 6. Cognitive development is not, however, strictly dependent upon brain mass. Rather, it is change in the interconnectedness of the brain that is the most important factor in cognitive development. In order to understand these changes we need to consider the vertical organization of brain tissue. The brain's cerebral cortex, or gray matter, consists of six cellular layers that form a complexly folded outer covering of the central mass of axon connections known as the white matter. Within the cortex the brain cells, or neurons, are bundled into hundreds of millions of vertically arranged columns. Research has shown that each column is specialized to process a unique unit of information, perhaps to recognize a particular musical tone, frequency of color, or geometric shape. Each column is bundled with roughly 100 columns responsible for related functions. Each of the fifty or more functionally distinct areas of the brain is composed of thousands of these bundled macrocolums.

Synapes are the connections between neurons. From prenatal development through the first 18 months of life there is a significant increase in the density of snynaptic connections. Jay Giedd and colleagues at the National Institutes of Mental Health have demonstrated that there is a second and very important period of thickening (or overproduction) of synaptic connections that occurs with the onset of puberty.

Reaching a peak around ages 11 or 12, this second period of overproduction is then followed by an interval of reorganization and reduction in the neural complexity of the adolescent brain. Work by Elizabeth Sowell at UCLA has shown a significant reduction in gray matter density in the frontal lobes of subjects from late adolescence to early adulthood. Known as synaptic pruning, this process is controlled by environmental factors and is generally considered to represent the physiological reorganization of neural connection associated with the process of learning.

The final aspects of physiological change that I wish to discuss occur in the neurotransmitters during adolescence. Many of the changes in behavior exhibited by adolescents can be traced, at least in part, to changes in three important chemical messengers in the brain. Dopamine is associated with brain processes that control physical movement, as well as emotional responses and the sensations of pleasure and pain. Decreasing levels of dopamine among teens is linked to mood changes and an increasing lack of emotional control. Serotonin also plays a role in mood fluctuations and decreasing levels are associated with decreased impulse control and increased anxiety. Finally, changing levels of melatonin, which regulates circadian rhythms, results in an increased need for sleep among teens.

Living with a 14 year old provides the opportunity to experience, in a second-hand way, the effects of these chemical changes on a daily basis. I can assure you, in case you have forgotten, the effects of these chemical changes are very real.

Having discussed, at a basic level, some of the physiological aspects of the teenage brain, I wish now to move on to a topic that has garnered increasing levels of attention within the medical and educational communities. The diagnosis and treatment of adolescent traumatic brain injury, more commonly known as sports-related concussions, has changed dramatically in just the past few years.

I became interested in this topic when, in December during an early morning Junior High School basketball practice my son was involved in a head-to-head collision while participating in a rebounding drill. As would be typical he sat out for a few minutes and returned to complete the practice only to get caught under his chin by another player's shoulder. It is not clear if one or the other of these blows, or a combination, resulted in the injury he suffered. After practice, he and the rest of the team showered and headed off to classes. By second period he was not feeling well. By one in the afternoon he decided to go see the school nurse. After he rested without improving the school called his mom, and she called me. I scheduled an appointment with is pediatrician for right after school and met him at his bus stop.

Coming off the bus I would describe his condition as flu-like. He was listless, lethargic, his head was down and it was obvious to even my untrained eyes that he was injured. After visiting with his Doctor it was concluded he had suffered a serious concussion – certainly not a surprise. What was unexpected, however, was the recovery plan that was outlined.

On July 1, 2011, Senate Bill 93 became law in the State of Indiana. Quoting from the synopsis of that legislation: "…a student athlete who is suspected of sustaining a head injury or concussion [shall] be removed from play at the time of the injury… the student athlete may not return to play until the student athlete has been evaluated and received written clearance from a licensed health care provider trained in evaluating head injuries."

Additionally, the law requires that schools distribute, and parents of student athletes acknowledge receipt of, information outlining the law as well as the nature and risk of head injuries. While the law does not explicitly include middle grade student athletes, school corporations have extended the implementation of SB93's requirements to Junior High and Middle School sports teams. At the beginning of the basketball season I returned a form indicating I received information from the school. Like so many other permission forms parents are required to sign, I did not give the information much thought.

After two days out of school, over a week of sitting out of practice, and three trips to the doctor for progress checks, Ashby was cleared to practice and play. Happily he completed the season without further injury and the 8th grade Leo Lions defended their 7th grade ACAC conference championship with a win over South Adams at the Southern Wells "thunder dome" last month.

Why did the State of Indiana find it necessary to pass this law? What medical and educational evidence supports the legislation? And how have doctors and schools worked together to make the post-concussion return-to-play process more structured, controlled, and safe for student athletes? Moving beyond my previous lack of attentiveness to the school-provided information, I became interested in this state mandated protocol, not only due to the law's relationship to the health and well-being of my son, but also because of the connections to the topic of this Quest talk.

According to the Centers for Disease Control and Prevention approximately three quarters of the 1.7 Million cases of traumatic brain injury (TBI) that are reported annually in the United States occur in the form of concussions and related injuries. The age ranges most at risk are babies and toddlers ages 0 to 4, older adolescents aged 15 to 19, and adults ages 65 and older. In every age group TBI rates are higher for males than females.

A study published by the American Academy of Pediatrics found the highest rates of sports-related concussion occur, not surprisingly, in football, with a reported injury rate of 0.47 to 1.03 per 1000 athlete exposures. Girls' soccer was found to be the second most dangerous with an injury rate of 0.36 per 1000. Interestingly, injury rates in girls' basketball were three times that reported for boys, 0.21 versus 0.07 per 1000 athlete exposures. Similar results were found for all pairings of girls and boys sports. The origin of this difference is at least in part physiological, but I suspect there is also a strong reporting bias, with the parents and coaches of adolescent female athletes more likely to seek medical attention in response to a suspected injury.

Researchers have recognized that the signs and symptoms of concussions are presented in four ways: physical effects, cognitive effects, emotional effects, and altered sleep patterns. As you might imagine, the physical effects include headaches, nausea, vomiting, balance and visual impairment, fatigue, sensitivity to light and noise, as well as a dazed or stunned appearance. Likewise, concussions have a significant effect on cognitive ability, including the feeling of being mentally "foggy" or slowed down, difficulty concentrating or remembering, feeling confused or forgetful or having difficulty answering questions. When I took my son to the doctor that first afternoon, he clearly recounted the initial head-to-head impact he had sustained. It was not until the next morning, when he was complaining that his chin was sore, did he remember receiving the second blow. For that reason I now strongly suspect it was the second impact that was the greatest contributor to his injury.

The emotional effects of concussions include irritability, sadness, or nervousness. Likewise, sleep patterns can be altered in many ways. Concussion suffers are sometimes more drowsy, they might sleep more, or less than normal, or they may have difficulty falling asleep.

Current protocols for recovery, rehabilitation, and a return to play follow a strict set of sequential steps. Return to play is not recommended prior to five days after the injury and advancing through the required rehabilitation steps cannot occur faster than one step per day.

Stage 1 requires no activity, with complete physical and cognitive rest. Because a concussion is a functional rather than a structural injury, symptoms are typically found to increase with increased cognitive activity. Therefore, injured student athletes are frequently required to either refrain from cognitive activities such as school work, reading, and video games during an initial period of cognitive rest. One of the most harmful things an injured athlete can do is attend one of his or her teams' competitions soon after a concussion. The combination of noise, visual stimulation, and emotional excitement is highly detrimental to the healing process.

Stage 2 through 4 consists of increasing levels of aerobic activity, sport-specific exercise, and non-contact training drills. In Ashby's case, by the third or fourth day he was shooting free throws and participating in lay-up drills. Stage 5 of the recovery process allows for full-contact practice followed by a return to play.

Importantly, if at any stage the student athlete experiences a return or increase in symptoms they are required to go back one step in the rehabilitation process. It is this requirement that lead ultimately to three visits to the doctor for us.

While the state legislated protocols for returning to practice and play, as implemented by doctors and schools, represents a clear break from the past practice of "shaking off" a "bell ringing" head injury it is only part of the recovery process. Within the past year there has been an increasing focus on the "return-to-learn" process for adolescents. Christina Master and co-workers in the journal *Pediatric Annals* has pointed to the need to utilize a Cognitive Activity Monitoring log to track mental activity and the occurrence of physical and cognitive symptoms during and after school work. Additionally, Master strongly suggests the implementation of a set of school accommodations to be implemented including complete cognitive rest, part-day attendance, breaks in quite places during the school day, allowing additional time for assignments, gradual process of making up missed work, and no tests, exams, or timed essays until the student is tolerating a full day of school. Finally, Master argues that since school is the student's full time job, the return-to-learn protocol should be completed prior to the initiation of the return-to-play process discussed previously.

Injury is an inevitable part of sports. However, having experienced the implementation of these new post-concussion protocols as well as the challenge of evaluating a teenager's cognitive recovery, I suggested to my son that next time it would be much easier if he would just twist an ankle.

Thank you for the opportunity to share some of the things I have learned about the cognitive development of adolescents and the changing diagnosis and treatment of sports-related concussions. It would be a pleasure to respond to your questions and comments.

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