Summary of Adolescent Developmental Science in re Juvenile Life Without Parole

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In a series of US Supreme Court decisions, evidence from the developmental science of adolescence, including developmental neuroscience, has been cited in support of decisions eliminating capital punishment for juveniles and restricting the use of mandatory sentencing to life without parole for juveniles. This summary is intended to provide a brief descriptive overview of the developmental science cited in those decisions, and of the continuing scientific progress in the relevant fields of research.[1] The overview covers five topics: immaturity of the prefrontal cortex and executive functions; the elevation of socioemotional and incentive systems; the developmental maturity mismatch between those two brain systems; the implications of current research for the prospects of rehabilitation among juvenile offenders; and a note on scientific methodology.

- **Immaturity of Prefrontal Cortex (PFC) and Executive Function (EF)**
    - *Executive Function, judgment, and decision making*. The prefrontal cortex of the brain (the PFC) has long been understood to have the principal function of carrying out what are known as the "executive functions" (EF). These include basic functions such as working memory and planning, as well as the direction of cognitive resources (known as "effortful control") and, especially relevant here, impulse control (also known as the "inhibition of prepotent responses") and

[1] A recent summary of the developmental science used in *Thompson v. Oklahoma* (1988), *Roper v. Simmons* (2005), *Graham v. Florida* (2010), and *Miller v. Alabama* (2012) can be found in L. D. Steinberg, (2013): *The influence of neuroscience on US Supreme Court decisions about adolescents' criminal culpability, Nature/Neuroscience, 14,* pp. 513-518. This summary draws on that and its citations, along with other publications, including: Keating, D. P. (2012). Cognitive and brain development, *Enfance, 3,* 267-279; Keating, D. P. (2014); Adolescent thinking in action: Minds in the making. In J. Brooks-Gunn, R. M. Lerner, A. C. Petersen, & R. K. Silbereisen (Eds.), *The developmental science of adolescence: History through autobiography*. NY: Psychology Press. (Pp. 257-266).

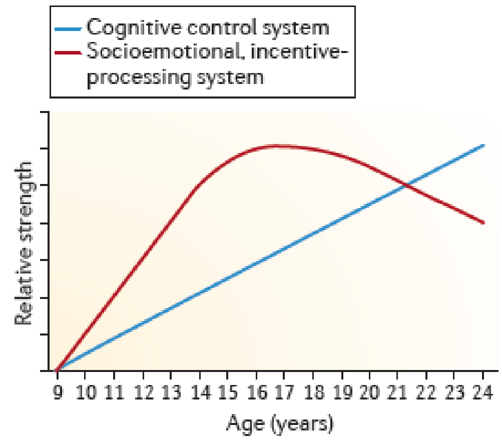
decision-making in complex situations. The PFC is known to begin developing in early childhood and to continue that development through the childhood, adolescent, and early adult years, showing full adult maturity in the early to mid-20s.[2] It is the functioning, and especially its immaturity, that is referenced in discussions of suboptimal adolescent judgment, especially in complex decision-making contexts that include competing demands. Another key aspect of the PFC is that it has limited capacity. When fully engaged in one task involving effortful control, it has limited or no capacity to undertake additional tasks that require judgment. This has two implications: (1) having embarked on a plan to undertake a risky behavior, the execution of that plan may use up available PFC resources, compromising the individual's ability to adjust behavior when circumstances warrant; (2) engagement with other activities that demand PFC resources, such as dealing with emotionally arousing situations, may make the limited PFC resource unavailable.

- *Governance of other brain systems*. In addition to the EF developments just described, the PFC shows development in a related function, the governance of other brain systems. This is also a gradual series of developments, as peripheral systems are brought more fully under the direction of the PFC. (This is the basis of the colloquial designation of the PFC and its projections to other brain regions as the "top brain.") It is not until the early to mid-20s that the ability to delegate tasks efficiently to other brain systems, relieving the PFC of its role to maintain effortful control and freeing up PFC space for other demands. Until that maturation has occurred, the ability of the rational, analytic, judgment, and governance functions of the PFC to override unanalyzed, poor decision-making is limited. This is a gradual process, so the maturational mismatch will on average be more marked the younger the individual.

[2] This is found in research on the structure of neural circuitry, in neuroimaging in active performance situations, and in cognitive and behavioral evidence. The last section of this overview provides a brief description of the scientific methods used in the research described here and throughout the summary.

- **Elevation of Socioemotional and Incentive Systems**
  - *Incentive systems*: Beginning in early to mid-adolescence, there is a sharp increase in what are termed "incentive systems" that entail complex neural circuitry, including emotional arousal (associated most strongly with the amygdala), sensation seeking (mediated by activity in the ventral striatum), and the heightened experience of rewards (mediated by a sharp increase in dopamine receptors) – a coordinated limbic system often referred to colloquially as the "bottom brain". These developments also coincide with (and may be partially explained by) significant changes in the hormonal balance associated with pubertal shifts, principally as an activation of the HPG-axis (hypothalamic-pituitary-gonadal) whose endpoint is the production of the steroids testosterone and estrogen (among others). These developments are observed behaviorally and cognitively as a significant increase in exploratory and sensation seeking behaviors during this same period of development when the governing capabilities of the PFC are limited (a mismatch described further below).
  - *Benefits over risks*. There is substantial evidence that the factors above lead adolescents to focus more heavily on the benefits of risky behavior than on the possible negative consequences of their actions. This is not because adolescents are incapable of understanding or evaluating possible consequences of risky behavior, which under conditions of "cold cognition" (where nothing that is upsetting, arousing or incentivizing is activated) is roughly the same as adults. Rather, they value the potential benefits of the behavior more highly than adults, altering the risk/benefit ratio in favor of undertaking unwise risks.
- **Developmental Maturity Mismatch (DMM) (dual process models)**
  - *Divergent developmental pathways*: The developmental pathways of the "top" and "bottom" brain diverge, with the limbic system advancing rapidly from early adolescence while the prefrontal system continues to grow, but at a slower pace, not reaching adult levels until the mid-20s. The term used to describe this is a "developmental maturity mismatch" (DMM), with significant consequences for

the levels of all kinds of risk behaviors during the adolescent period. A schematic figure illustrates this[3].



The behavioral and cognitive evidence converges with the developmental neuroscience evidence here, with highly similar age-risk behavior profiles for a number of areas, including crime (the age-crime curve), accidental injuries, serious driving mishaps, and so on. All show peaks by mid-adolescence, with gradual drop-offs until an asymptote in the mid-20s or so.

- *Dual process models*: The DMM is one version of a more general finding, known as dual process models. The research here is that when performing a complex decision making task, there are two systems functioning. One is a rational, judgment based system that takes considerable cognitive effort. The second is a more automatic, "intuitive", non-analyzed system that is accessed more often (because it requires less time and energy). This occurs for automated tasks (especially in domains where expertise is high) but also for "hot" cognition where there are competing demands – for example, from arousal and incentive systems.

- **Rehabilitative Prospects**

In addition to mitigation of sanctions owing to diminished culpability by reason of developmental immaturity, another implication of the developmental neuroscience evidence is that there are increased prospects for further developmental growth among juveniles. This is supported by the evidence above that major changes continue during this period. In addition, there is very substantial evidence for neural plasticity by way of "synaptic pruning." Simply put, neural circuitry is shaped by the individual's experiences, such that the resulting mature circuitry is not settled until the mid-20s. (Some plasticity continues throughout life, but never again as strongly as in adolescence.)

[3] This version is from Steinberg (2013, see fn 1), although it has appeared in several publications.

This potential for positive change was noted as a significant factor in recent Supreme Court decisions.

- **Note on Scientific Methodology**

The evidence above is an integration of several kinds of research methodologies, and it is useful to understand the sources of evidence.

  - *Structural neuroscience*: This refers to evidence on the changing structure of the "static" brain, that is, when it is not performing a task. There are several methods for this, but the most prominent currently is diffusion tensor imaging (DTI), collected during a session of magnetic resonance imaging (MRI). This allows the characterization of the size of various parts of the brain, how they differ with age, and how they are connected with each other.
  - *Functional neuroscience*: This assesses how the brain is working while it is engaged in a task, most prominently in functional MRI (fMRI) and various forms of electrical encepholography (EEG), such as evoked response potential (ERP). These use different physical methods (blood flow in fMRI, electrical signals in ERP), but they have the same goal, to elucidate the time and location of brain activity.
  - *Cognitive and behavioral evidence*: In addition to the brain imaging evidence above, there are large amounts of behavioral and cognitive evidence that are relevant to the DMM, including self-reports of sensation seeking, impulsivity, and risk judgments, among others, as well as performance on cognitive tasks that assess EF, risk-reward trade-offs, and others.
  - *Convergence of findings*: With respect to the confidence that is warranted with respect to the findings described above, one of the most important criteria (used in this summary) is to focus on findings where there is a convergence of findings across methods and content. Specifically, where the same developmental pattern emerges from structural brain imaging, functional brain imaging, cognitive and behavioral evidence, and the epidemiology of risk behavior, we can have strong confidence in the major findings.
  - *Continued consistency of convergent evidence*. These overlapping areas of research have received ample attention before and since *Miller*. This new work continues to provide strong support for the general conclusions drawn above.