BRAIN IMMATURITY AND JUVENILE DELINQUENCY: EMPIRICAL EVIDENCE, AGE-RELATED LEGAL DEBATE, AND ETHICAL CONCERNS

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I. INTRODUCTION

Adolescent brain science has permeated people's social life, media, and the juvenile justice system through legal theory, advocacy, and lawmaking.[2] During the past decade, an increasing number of longitudinal brain development research has revealed that adolescence is a unique developmental

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[2] *See generally* Terry A. Maroney, *The False Promise of Adolescent Brain Science in Juvenile Justice*, 85 NOTRE DAME LAW REVIEW 89–176 (2009); Elizabeth Scott, Natasha Duell & Laurence Steinberg, *Brain Development, Social Context, and Justice Policy*, 57 WASH. UJL & POL'Y 13 (2018); Laurence Steinberg, *Adolescent Brain Science and Juvenile Justice Policymaking*, 23 PSYCHOLOGY, PUBLIC POLICY, AND LAW 410–420 (2017).

period for brain growth and change.[3] Advances in noninvasive neuroimaging techniques have allowed researchers to quantify the structural and functional brain changes throughout adolescence and into adulthood, evidencing that the adolescent brain is immature and continues to develop until the age of 25.[4] Evidence of adolescent brain immaturity challenges the general assumption that 18 is the legal and social age of adulthood in public policy.

Researchers also link brain immaturity to adolescent decision-making processes to explain juvenile delinquency, as well as their normative

[3] See generally Jay N. Giedd et al., *Brain development during childhood and adolescence: a longitudinal MRI study*, 2 NATURE NEUROSCIENCE 861–863 (1999); Sara B. Johnson, Robert W. Blum & Jay N. Giedd, *Adolescent Maturity and the Brain: The Promise and Pitfalls of Neuroscience Research in Adolescent Health Policy*, 45 JOURNAL OF ADOLESCENT HEALTH 216–221 (2009); Elizabeth R. Sowell et al., *Mapping Continued Brain Growth and Gray Matter Density Reduction in Dorsal Frontal Cortex: Inverse Relationships during Postadolescent Brain Maturation*, 21 THE JOURNAL OF NEUROSCIENCE 8819–8829 (2001).

[4] Beatriz Luna & Catherine Wright, *Adolescent Brain Development: Implications for the Juvenile Criminal Justice System*, APA HANDBOOK OF PSYCHOLOGY AND JUVENILE JUSTICE. 91–116 (2016); Daniel Romer, Valerie F. Reyna & Theodore D. Satterthwaite, *Beyond Stereotypes of Adolescent Risk Taking: Placing the Adolescent Brain in Developmental Context*, 27 DEVELOPMENTAL COGNITIVE NEUROSCIENCE 19–34 (2017); Laurence Steinberg, *Should the Science of Adolescent Brain Development Inform Public Ppolicy?* 64 AMERICAN PSYCHOLOGIST 739–750 (2009).

impulsive and risk-taking behaviors.[5] The frontal lobe is associated with cognitive and executive functions, such as impulse control, planning, and decision-making.[6] However, it is the last brain region to mature.[7] While the frontal lobe develops inadequately and remains immature during adolescence, the limbic system becomes more mature and activates more effectively.[8] Accordingly, adolescents may lack of cognitive and executive control over instinctive or emotional drives.[9] They become highly sensitive to social reward, thereby exhibiting less rational, more risk-taking, more impulsive, and even delinquent behaviors.[10] Also, an adolescent brain shows few structural and functional activations in the frontal lobe and inefficient neural connectivity between cognitive control and

[5] Steinberg, *supra* note 4.
[6] Daniel J. Simmonds, Michael N. Hallquist & Beatriz Luna, *Protracted Development Of Executive And Mnemonic Brain Systems Underlying Working Memory In Adolescence: A Longitudinal Fmri Study*, 157 NEUROIMAGE 695–704 (2017).
[7] Johnson et al., *supra* note 3.
[8] Betty Jo Casey, Sarah Getz & Adriana Galvan, *The Adolescent Brain*, 28 DEVELOPMENTAL REVIEW 62–77 (2008).
[9] Laurence Steinberg, *A Social Neuroscience Perspective On Adolescent Risk-Taking*, 28 DEVELOPMENTAL REVIEW 78–106 (2008).
[10] *Id.*

rewarding systems.[11] Both brain immaturity and brain development imbalance mirror the stereotypical image of adolescents' impulsive, risk-taking or sensation-seeking, and delinquent behaviors.[12]

The association between adolescent brain development and their behaviors has made great legal implications. An issue that cannot be ignored in connection with the legal debates on juvenile justice is age. Questions arise from how to set the minimum legal age for substance use, how to determine their criminal responsibility, how to handle juvenile offenders fairly, and how to punish delinquency properly. Some scholars advocate for raising the minimum legal age for alcohol consumption and smoking due to adolescent brain immaturity, while others have concerns about such policies' efficiency

[11] Casey et al., *supra* note 8; *see also* Elizabeth Scott, Richard J. Bonnie & Laurence Steinberg, *Young Adulthood As Transitional Legal Category: Science, Social Change, And Justice Policy*, 85 FORDHAM LAW REVIEW 641–666 (2016).
[12] Casey et al., *supra* note 8; *see also* Laurence Steinberg, *The Influence Of Neuroscience On US Supreme Court Decisions About Adolescent's Criminal Culpability*, 14 NATURE REVIEWS NEUROSCIENCE 513–518 (2012).

and usefulness in decreasing juvenile delinquency.[13] Some researchers suggest that we should also raise the age for adult referral in the juvenile justice system, aiming to diminish potential harms and emphasize rehabilitation for juvenile offenders.[14] Whereas, opponents warn its potential unintended consequences, such as over-population in juvenile facilities, ineffectiveness on offenders who simply offend after the cutoff age, and the fairness for offenders who have delayed brain maturing processes.[15] These age-related legal debates with the

[13] RICHARD J. BONNIE, KATHLEEN STRATTON & LESLIE Y. KWAN, PUBLIC HEALTH IMPLICATIONS OF RAISING THE MINIMUM AGE OF LEGAL ACCESS TO TOBACCO PRODUCTS (2015); Lonn Lanza-Kaduce & Pamela Richards, *Raising The Minimum Drinking Age: Some Unintended Consequences Of Good Intentions*, 6 JUSTICE QUARTERLY 247–262 (1989); Debra Jones Ringold, *Boomerang Effects in Response to Public Health Interventions: Some Unintended Consequences in the Alcoholic Beverage Market*, 25 JOURNAL OF CONSUMER POLICY 27–63 (2002).

[14] David P. Farrington, Rolf Loeber & James C. Howell, *Young Adult Offenders: The Need for More Effective Legislative Options and Justice Processing*, 11 CRIMINOLOGY & PUBLIC POLICY 729–750 (2012).

[15] Chris L. Gibson & Marvin D. Krohn, *Raising The Age: Issues In Emerging Adulthood And Adult Court Referral Of Youthful Offenders*, 11 CRIMINOLOGY & PUBLIC POLICY 759–768 (2012); *see generally* Christina L. Lyons, REFORMING JUVENILE JUSTICE: SHOULD TEENS WHO MURDER BE TREATED AS ADULTS? CQ RESEARCHER BY CQ PRESS (2015), http://library.cqpress.com/cqresearcher/document.php?id=cqresrre2015091100.

underlying reasoning about brain development have lasted over more than a decade and reached its plateau.

In addition, the application of brain science in legal system engenders moral and social concerns virtually from its initial stage. Although many of the ethical concerns are not unique to brain science, there are good reasons to be aware of and further discuss them. For example, how should people understand the connection between brain, mind, and behavior? How can we draw inferences from the brain development evidence, along with neurotechnology, in the real world? Should we use it to identify certain adolescents as at risk? Could law enforcement agents rely on neuro-predictive information to detain or arrest or punish adolescents who have not yet committed a crime? These ethical issues are still unresolved today.

Understanding the role of brain development in determining maturity in a legal context will help us explain adolescent behaviors in a comprehensive manner. Proactively discussing adolescence brain

development will prevent policymakers from engaging in a series of actions that researchers would not recommend because of some academic mistranslations into policies, such as zero-tolerance policy and school resource officers.[16] Deliberate consideration of the implication of brain science will increase the effectiveness of prevention, intervention, or rehabilitation programs.[17]

In this Article, I focus on four aspects related to the relationship between adolescent brain research and legal implications: the evidence of brain research on adolescent immaturity; the evidence of adolescent brain development on our understanding of adolescent impulsive and delinquent behaviors; the implication of adolescent immaturity in two age-related legal debates; and the potential ethical concerns about applying brain science in law and justice system. For the purpose of this Article, I use "adolescents" to refer both adolescents and young

[16] Johnson et al., *supra* note 3.
[17] Theodore P. Beauchaine et al., *Ten Good Reasons To Consider Biological Processes In Prevention And Intervention Research*, 20 DEVELOPMENT AND PSYCHOPATHOLOGY 745–774 (2008).

adults aged from 16 to 24. When referring to "maturity," I do not suggest the end of brain development but consider it as an attainment of adult-like capacities. In-depth and extensive reviews of brain development in adolescence and a more detailed discussion of the findings are beyond the scope of this review.

II. BRAIN DEVELOPMENT AND LEGAL MATURITY

Brain development research has challenged the long-time assumption that adolescent brain is fully mature by the age of 18.[18] It has gradually changed the definition of maturity among laypeople, researchers, and policymakers. Currently, we lack consensus about using 16, 17 or 18 as the legal age cutoff for adolescence maturity in the juvenile justice system across states. Variations in defining legal maturity and determining the age cutoff exist when policymakers evaluate the age appropriateness for

[18] Arthur W. Toga, Paul M. Thompson & Elizabeth R. Sowell, *Mapping Brain Maturation*, 29 TRENDS IN NEUROSCIENCES 148–159 (2006).

adolescents to drink alcohol, smoke, serve in the military, vote, and engage in other legal activities.

Although the brain is malleable, adaptive, and constantly developing over the lifespan, its structural and functional changes for maturation during adolescence are more dramatic and noteworthy.[19] In general, four non-linear structural and functional changes occur in response to the social environments for adolescent brain maturity.[20] Understanding these changes can facilitate the current debate on redefining legal age for adolescence maturity in the juvenile justice system, as well as contribute to a different legal response to juvenile delinquency.

First, the density of gray matter experiences a shifting change.[21] Although both density and thickness of gray matter increase during pre-adolescence, the density has been found to decline dramatically during adolescence to adulthood and remain relatively stable thereafter.[22] The gray-matter

[19] *Id.*, at 151; *see also* Steinberg, *supra* note 4.
[20] Mark H. Johnson, *Functional Brain Development In Humans*, 2 NATURE REVIEWS NEUROSCIENCE 475–483 (2001).
[21] Toga et al., *supra* note 18; Johnson et al., *supra* note 3.
[22] Giedd et al., *supra* note 3.

loss is the result of selective synaptic pruning. Selective synaptic pruning is the process of eliminating rarely used synapses and neural connections to make a brain more efficient and specialized.[23] By measuring the gray-matter density in frontal, temporal, parietal, and occipital lobes, researchers have demonstrated that the gray-matter loss starts from dorsal parietal lobe and primary sensorimotor regions, then moves to the lateral and caudal temporal lobe, and finally reaches to the frontal lobe.[24] Prefrontal cortex (PFC) is the last area to show structural changes for brain maturation during post adolescence.[25] The dynamic pattern of the decreased gray matter density has revealed that brain regions with advanced functions and higher-order connections, such as PFC, only mature after the lower-order areas associated with the most basic

[23] Johnson et al., *supra* note 3.
[24] Nitin Gogtay et al., *Dynamic Mapping Of Human Cortical Development During Childhood Through Early Adulthood*, 101 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 8174–8179 (2004).
[25] Sowell et al., *supra* note 3.

functions, such as somatosensory and visual cortices, from the age of 4 to 21.[26]

Second, the volume of white matter increases linearly over time.[27] During adolescence, increased white matter volumes in PFC are reflective of axonal diameter and myelination, allowing nerve impulses to travel faster and more effectively and improving the integration of brain circuits.[28] As myelination continues to post-adolescence, volumes of white matter peak in early adulthood.[29] This increased efficiency of neural connections in PFC can lead to better cognitive and executive functions, such as learning from errors and previous experiences, planning ahead, delaying gratification, controlling impulsivity, and making legally relevant decisions.[30] However, myelination in the PFC may not occur until early 20s or even later.[31] Since volume changes

[26] *Id.*; Gogtay et al., *supra* note 24.
[27] Johnson et al., *supra* note 3.
[28] Steinberg, *supra* note 12.
[29] Signe Bray et al., *Synergistic Effects of Age on Patterns of White and Gray Matter Volume across Childhood and Adolescence*, 2 ENEURO 1–13 (2015).
[30] Johnson et al., *supra* note 3.
[31] *Id.*

in white matter mirror adolescence maturity more accurately, an estimation of adolescent maturity based on cortical thickness may be better to inform the legal age boundaries in the juvenile justice system than simply based on chronological age.[32]

Third, the distribution and density of dopamine (DA) receptors change in the neuro-circulation between PFC and limbic system which is responsible for processing emotions, rewards, and punishments.[33] Dopaminergic pathway activates from ventral tegmental area, to ventral striatum (VS), and then ramifies into orbital and ventromedial frontal cortex.[34] As a result of DA neurons being active in VS long before in PFC, adolescents tend to exhibit more sensation-seeking behaviors, focus on rewards, and behave more impulsively and

[32] Budhachandra S. Khundrakpam, Jussi Tohka & Alan C. Evans, *Prediction Of Brain Maturity Based On Cortical Thickness At Different Spatial Resolutions*, 111 NEUROIMAGE 350–359 (2015).
[33] Johnson et al., *supra* note 3; Steinberg, *supra* note 12.
[34] Romer et al., supra note 4; Dustin Wahlstrom et al., *Developmental Changes In Dopamine Neurotransmission In Adolescence: Behavioral Implications And Issues In Assessment*, 72 BRAIN AND COGNITION 146–159 (2010).

emotionally.[35] Although a DA pathway between striatum and orbitofrontal cortex exists before adolescence, the pathway for cognitive functions between striatum and medial prefrontal cortex only connects by early adulthood.[36] In addition, the densities of the DA receptor D1 and D2 increase more rapidly during adolescence than during both childhood and adulthood.[37] The significant increase of DA concentrations in both cortical and subcortical areas during adolescence specifically mirrors an adolescent's increased sensitivity to social reward and thrills.[38] In short, adolescence is a developmental period where the emotional (hot) brain matured before cognitive (cold) brain.[39] By the age of 18, the cognitive brain is more likely to be underdeveloped, but the hot brain may be mature enough.

[35] Steinberg, *supra* note 12; Scott et al., *supra* note 2; Fabien R. Naneix et al., *Parallel Maturation of Goal-Directed Behavior and Dopaminergic Systems during Adolescence*, 32 JOURNAL OF NEUROSCIENCE 16223–16232 (2012).
[36] Romer et al., *supra* note 4; Naneix et al., *supra* note 35.
[37] Wahlstrom et al., *supra* note 34.
[38] *Id.*; *see also* Romer et al., supra note 4; Scott et al., *supra* note 2.
[39] Romer et al., supra note 4; Steinberg, *supra* note 9.

Last, the connectivity between limbic system involving emotional processing and PFC is constantly strengthened after age of 18.[40] The neural connectivity between the amygdala, a limbic structure responsible for fear perception, and fear conditioning and the frontal lobe is denser during adolescence.[41] The basic integration of emotional and cognitive brain areas is crucial for emotional regulation, self-control, and inhibition of impulsivity.[42] Although these structural and functional connections do facilitate various brain circuits to communicate efficiently, the entire brain network is still less extensive and specialized during adolescence and early adulthood.[43] Apparently, the adolescent brain is not cognitively mature enough by the age of 18. Using 18 as a legal age cutoff in the

[40] Romer et al., supra note 4; Steinberg, *supra* note 12.
[41] Miles Gregory Cunningham, Sujoy Bhattacharyya & Francine Mary Benes, *Amygdalo-Cortical Sprouting Continues Into Early Adulthood: Implications For The Development Of Normal And Abnormal Function During Adolescence*, 453 THE JOURNAL OF COMPARATIVE NEUROLOGY 116–130 (2002).
[42] Johnson et al., *supra* note 3; Romer et al., supra note 4; Steinberg, *supra* note 12.
[43] Steinberg, *supra* note 12.

juvenile justice system may be problematic, let alone an even younger age.

Adolescence brain development, with considerations of individual differences, continues from adolescence to adulthood until at least the age of 25.[44] Compelling evidence from brain development research clearly challenges the traditional definition of adolescent maturity and the appropriate age cutoff in the juvenile justice system. When considering redefining legal maturity or resetting the legal age cutoff, policymakers should weigh more on the brain science evidence, as well as the associated cost and benefit, instead of one's ideology or normative rules. As brain science advances, it also provides valuable insights into the relationship between brain immaturity and antisocial/delinquent behaviors among adolescents and young adults.

[44] Toga et al., *supra* note 18; Romer et al., supra note 4; Steinberg, *supra* note 9.

III. BRAIN IMMATURITY AND JUVENILE DELINQUENCY

Brain immaturity is strongly associated with adolescents' limited abilities to make decisions and exert self-control.[45] Adolescents undergo structural and functional inefficiency or temporary deficits in brain activations and neural connectivity.[46] They are normatively unable to exert enough cognitive control over instinctive or emotional drives, thus behaving less rationally and more impulsively.[47]

Two adolescent characteristics, inability to delay gratification and lack of cognitive control, significantly increase their probability of engaging in antisocial and delinquent behaviors, especially for those living in high risk families and disadvantaged communities.[48] Similarly, the brain imbalance model

[45] Casey et al., *supra* note 8; Steinberg, *supra* note 12.
[46] Romer et al., supra note 4; Scott et al., *supra* note 2.
[47] Steinberg, *supra* note 9.
[48] Frank D. Mann et al., *Sensation Seeking And Impulsive Traits As Personality Endophenotypes For Antisocial Behavior: Evidence From Two Independent Samples*, 105 PERSONALITY AND INDIVIDUAL DIFFERENCES 30–39 (2017); Madeline H. Meier et al., *Impulsive And Callous Traits Are More Strongly Associated With Delinquent Behavior In Higher Risk Neighborhoods Among Boys And Girls*, 117 JOURNAL OF ABNORMAL PSYCHOLOGY 377–385 (2008).

has revealed two dynamics: (a) PFC develops inadequately and stays immature during adolescence, and (b) limbic system activates more than PFC.[49] Brain developing imbalance has reflected the universal stereotype of adolescent's impulsive, emotional, uncontrollable, and hotheaded behaviors.[50] The model further has theoretical and legal implications in explaining and responding to juvenile delinquency, as well as informing future juvenile law.[51]

Impulsivity is defined as an individual's tendency to react rapidly and impetuously to internal or external stimuli without clear planning or deliberate thinking of the negative consequences.[52] However, adolescent impulsivity consists of three forms: (a) motor impulsivity, in which impulsive action is reflective of a tendency to act without fully

[49] Casey et al., *supra* note 8.
[50] *Id.*; see also Steinberg, *supra* note 12.
[51] Scott et al., *supra* note 2.
[52] Samuel R Chamberlain & Barbara J Sahakian, *The Neuropsychiatry Of Impulsivity*, 20 CURRENT OPINION IN PSYCHIATRY 255–261 (2007); Gerard F Moeller et al., *Psychiatric Aspects of Impulsivity*, 158 AMERICAN JOURNAL OF PSYCHIATRY 1783–1793 (2001).

thinking about consequences,[53] (b) active impulsive choice, which indicates an adolescent's tendency to desire for relatively smaller but immediate rewards, instead of larger yet delayed gratifications,[54] and (c) active sensation-seeking or risk-taking behaviors.[55] Although research on impulsivity is across multiple disciplines, such as psychology, neuroscience, economics, neurochemistry, and behavioral genetics, this Article focuses on the perspective from adolescent brain development in juvenile justice and public policy.

A. Motor Impulsivity and Cognitive Control

Cognitive and executive functions, including an individual's ability to think, plan, working memory, and decision-making, are associated with prefrontal

[53] Naomi A Fineberg et al., *New Developments In Human Neurocognition: Clinical, Genetic, And Brain Imaging Correlates Of Impulsivity And Compulsivity*, 19 CNS SPECTRUMS 69–89 (2014).
[54] Romer et al., *supra* note 4.
[55] Casey et al., *supra* note 8; Steinberg, *supra* note 9.

cortex.[56] Given the fact that PFC has various substructures, in general, dorsolateral PFC (dlPFC) is associated with higher order executive and cognitive functions, while ventromedial PFC (vmPFC) is responsible for emotional regulations and motivational responses.[57] Specifically, the dlPFC development is associated with attention,[58] working memory,[59] long-term memory,[60] problem-solving ability,[61] and decision-making about

[56] Monica Luciana, *Adolescent Brain Development In Normality And Psychopathology*, 25 DEVELOPMENT AND PSYCHOPATHOLOGY 1325–1345 (2013); Torfi Sigurdsson & Sevil Duvarci, *Hippocampal-Prefrontal Interactions in Cognition, Behavior and Psychiatric Disease*, 9 FRONTIERS IN SYSTEMS NEUROSCIENCE (2016); Daniel J. Simmonds, Michael N. Hallquist & Beatriz Luna, *Protracted Development Of Executive And Mnemonic Brain Systems Underlying Working Memory In Adolescence: A Longitudinal Fmri Study*, 157 NEUROIMAGE 695–704 (2017).
[57] Luciana, *supra* note 56; Sigurdsson & Duvarci, *supra* note 56.
[58] Michael J. Kane & Randall W. Engle, *The Role Of Prefrontal Cortex In Working-Memory Capacity, Executive Attention, And General Fluid Intelligence: An Individual-Differences Perspective*, 9 PSYCHONOMIC BULLETIN & REVIEW 637–671 (2002).
[59] David A Markowitz, Clayton E Curtis & Bijan Pesaran, *Multiple Component Networks Support Working Memory In Prefrontal Cortex*, 112 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 11084–11089 (2015).
[60] Robert S. Blumenfeld & Charan Ranganath, *Prefrontal Cortex and Long-Term Memory Encoding: An Integrative Review of Findings from Neuropsychology and Neuroimaging*, 13 THE NEUROSCIENTIST 280–291 (2007).
[61] Sietske W. Kleibeuker et al., *Prefrontal Cortex Involvement In Creative Problem Solving In Middle Adolescence And Adulthood*, 5 DEVELOPMENTAL COGNITIVE NEUROSCIENCE 197–206 (2013).

automatic motor responses.[62] Also, vmPFC is involved in emotions and emotion-related information processing, with and without the requirement of cognitive abilities.[63] Antonio Damasio's somatic marker hypothesis has emphasized that medial PFC plays a crucial role in affective cognition and emotional decision-making.[64] VmPFC shows significant activations for self-referential affective stimuli, thus being important for emotional regulation and reinforcement evaluation.[65] Furthermore, vmPFC activation is strongly correlated with emotional cue detections, such as deliberately computing and

[62] Masamichi Sakagami, Xiaochuan Pan & Bob Uttl, *Behavioral Inhibition And Prefrontal Cortex In Decision-Making*, 19 NEURAL NETWORKS 1255–1265 (2006).
[63] Luan K Phan et al., *Functional Neuroanatomy of Emotion: A Meta-Analysis of Emotion Activation Studies in PET and fMRI*, 16 NEUROIMAGE 331–348 (2002).
[64] Antonio R Damasio, *The Somatic Marker Hypothesis And The Possible Functions Of The Prefrontal Cortex*, 351 PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON. SERIES B: BIOLOGICAL SCIENCES 1413–1420 (1996).
[65] John Douglas Steele & Stephen M Lawrie, *Segregation Of Cognitive And Emotional Function In The Prefrontal Cortex: A Stereotactic Meta-Analysis*, 21 NEUROIMAGE 868–875 (2004).

learning value signals from external and internal hints.[66]

Motor impulsivity is negatively associated with working memory and rule-based cognitive control.[67] Adolescents with lower working memory capacities resulted from immature or deficient dlPFC development are not only more likely to behave impulsively without deliberate thinking, but also less able to behave appropriately by referring to predefined rules or specific instructions.[68] The inverse relationship is unique to motor impulsivity among adolescents because lack of attentional and rule-based control, inability to consider the alternatives, and inability to foresee the negative consequences are the major characteristics.[69]

An age-related gap of adolescent brain development and functional connectivity between

[66] Phan et al., *supra* note 63.
[67] Eveline A. Crone & Nikolaus Steinbeis, *Neural Perspectives on Cognitive Control Development during Childhood and Adolescence*, 21 TRENDS IN COGNITIVE SCIENCES 205–215 (2017); *see also* Luciana, *supra* note 56; Romer et al., *supra* note 4.
[68] Noah A. Shamosh et al., *Individual Differences in Delay Discounting: Relation to intelligence, working memory, and anterior prefrontal cortex*, 19 PSYCHOLOGICAL SCIENCE 904–911 (2008).
[69] *Id.*

dlPFC and vmPFC also exists, with dlPFC maturing the last until adulthood.[70] The protracted maturation of dlPFC, compared to vmPFC, is manifested in adolescent under-developed cognitive and executive functions, yet relatively mature affective processing.[71] The gap corresponds with the fact that adolescents are able to make decisions about their behaviors, but these decisions are just more likely to be sloppy, emotion-oriented, rule-breaking, and impulsive.[72] Unlike adolescents, adults typically are able to perform deliberately evaluation and inhibitory control due to their relatively mature dlPFC, vmPFC, and other brain areas, such as anterior cingulate cortex (ACC), inferior frontal gyrus, fusiform gyrus, and frontal-striatal areas, as well as their functional connectivity.[73] A delayed

[70] Gogtay et al., *supra* note 24; Romer et al., *supra* note 4.
[71] Steinberg, *supra* note 9.
[72] Steinberg, *supra* note 12.
[73] Gogtay et al., *supra* note 24; Katya Rubia et al., *Linear Age-Correlated Functional Development Of Right Inferior Fronto-Striato-Cerebellar Networks During Response Inhibition And Anterior Cingulate During Error-Related Processes*, 28 HUMAN BRAIN MAPPING 1163–1177 (2007); for functional connectivity, *see* Kai Hwang, Katerina Velanova & Beatriz Luna, *Strengthening of Top-Down Frontal Cognitive Control Networks Underlying the*

development in dlPFC, compared to other subcortical regions for emotion processing, namely limbic system and VS, is generally linked to adolescent's motor impulsivity.[74] Undoubtably, motor impulsivity can lead to a higher probability of adolescents engaging in unplanned, hotheaded, and delinquent behaviors.

B. Active Impulsive Choice

Inability to delay gratification or actively making impulsive choice is related to impulsivity concerning temporal discounting (TD).[75] Temporal discounting tasks estimate an individual's subjective preference for smaller immediate rewards over larger delayed ones.[76] While people usually prefer small immediate

Development of Inhibitory Control: A Functional Magnetic Resonance Imaging Effective Connectivity Study, 30 JOURNAL OF NEUROSCIENCE 15535–15545 (2010).

[74] Casey et al., *supra* note 8.

[75] Fineberg et al., supra note 53; Romer et al., *supra* note 4; Steinberg, *supra* note 9.

[76] Michelle Achterberg et al., *Frontostriatal White Matter Integrity Predicts Development of Delay of Gratification: A Longitudinal Study*, 36 THE JOURNAL OF NEUROSCIENCE 1954–1961 (2016); Erik de Water et al., *Neural Mechanisms Of Individual Differences In Temporal Discounting Of Monetary And Primary Rewards In Adolescents*, 153 NEUROIMAGE 198–210 (2017).

rewards and even know that delayed returns are greater, the TD of adolescents is significantly steeper than that of adults.[77] In other words, adolescents are more likely to choose the small but immediate rewards than adults are.[78]

A voxel-based morphometry has revealed that greater TD is associated with lower gray matter volume in the vmPFC and insula, and greater gray matter volume in a subcortical region encompassing the VS.[79] Individuals with impaired vmPFC and insula tend to make disadvantageous choices and become insensitive to future rewards.[80] A significant age-related linear change in brain activations has

[77] Elizabeth A. Olson et al., *Adolescents' Performance On Delay And Probability Discounting Tasks: Contributions Of Age, Intelligence, Executive Functioning, And Self-Reported Externalizing Behavior*, 43 PERSONALITY AND INDIVIDUAL DIFFERENCES 1886–1897 (2007); Anouk Scheres et al., *Temporal Reward Discounting In Children, Adolescents, And Emerging Adults During An Experiential Task*, 5 FRONTIERS IN PSYCHOLOGY (2014).
[78] Anastasia Christakou, Mick Brammer & Katya Rubia, *Maturation Of Limbic Corticostriatal Activation And Connectivity Associated With Developmental Changes In Temporal Discounting*, 54 NEUROIMAGE 1344–1354 (2011).
[79] Scott Mackey et al., *Brain Regions Related to Impulsivity Mediate the Effects of Early Adversity on Antisocial Behavior*, 82 BIOLOGICAL PSYCHIATRY 275–282 (2017).
[80] *Id.*; *see also* Arthur D. Craig, *How Do You Feel? Interoception: The Sense Of The Physiological Condition Of The Body*, 3 NATURE REVIEWS NEUROSCIENCE 655–666 (2002).

indicated that the decline in TD from adolescence to early adulthood is associated with changes in the magnitude of those brain areas.[81] During adolescence, an inability to avoid making impulsive and immature decisions is overall associated with age-related increased VS activations and immature vmPFC functions.

A series of maturational changes in the steepness of TD are also associated with the strength in functional connectivity between vmPFC, dlPFC, and insula.[82] As mentioned before, the functional connectivity within-PFC substructures and between PFC and limbic system are not fully developed during adolescence. This further shows that the immaturity of an adolescent decision-making process may just be a consequence of the differential brain development trajectories.[83] Constantly making immature decisions or being vulnerable to immediate rewards will increase an adolescent's probability of engaging in antisocial and delinquent activities.

[81] Christakou et al., *supra* note 78.
[82] *Id.*
[83] Mackey et al., *supra* note 79.

C. Hot Cognition and Sensation-Seeking

Hot cognition refers to a network of brain regions regulating affective and motivational processes.[84] Cognitive control under cold cognition and sensation-seeking under hot cognition are linked with different neuronal circuits and have different developmental paths.[85] Sensation seeking is related to an individual's tendency to seek out novel and intense sensations and experiences.[86] Sensation-seeking behaviors may be high in subjective desirability, but also high in potential for harm.[87] Adolescents tend to engage in more risk-seeking behaviors overall, such as drive while drunk, drug experimentations, and unsafe sexual activities.[88] An inverted U-shaped pattern of sensation-seeking

[84] Thomas E Gladwin & Bernd Figner, *Hot Cognition And Dual Systems: Introduction, Criticisms, And Ways Forward*, NEUROECONOMICS, JUDGMENT, AND DECISION MAKING 157–180 (2015).
[85] Johnson et al., *supra* note 3.
[86] Marvin Zuckerman & D. Michael Kuhlman, *Personality and Risk-Taking: Common Bisocial Factors*, 68 JOURNAL OF PERSONALITY 999–1029 (2000).
[87] Stephanie Burnett et al., *Adolescents' Heightened Risk-Seeking In A Probabilistic Gambling Task*, 25 COGNITIVE DEVELOPMENT 183–196 (2010).
[88] Casey et al., *supra* note 8; Steinberg, *supra* note 9.

behaviors between childhood and adulthood, with its peak in adolescence, has been observed by many researchers.[89]

However, adolescents do acknowledge the risks associated with their choice or behaviors, similar to adults.[90] They are simply more likely to make decisions on short-term proximal rewards rather than on long-term ones and are more motivated by positive reinforcement than by negative reinforcement.[91] Because limbic regions are more mature vis-à-vis PFC, adolescent behaviors are mainly controlled by limbic system, compared to children whose limbic regions and PFC are both developing and adults whose brain developments are mostly completed.[92] Since adolescents experience many high arousal situations and are more

[89] Jacques Dayan et al., *Adolescent Brain Development, Risk-Taking And Vulnerability To Addiction*, 104 JOURNAL OF PHYSIOLOGY-PARIS 279–286 (2010); *see also* Burnett et al., *supra* note 87; Steinberg, *supra* note 9.
[90] Dayan et al., *supra* note 89; Steinberg, *supra* note 9.
[91] Jeffery Arnett, *Reckless Behavior In Adolescence: A Developmental Perspective*, 12 DEVELOPMENTAL REVIEW 339–373 (1992).
[92] Adriana Galvan et al., *Risk-Taking And The Adolescent Brain: Who Is At Risk?* 10 DEVELOPMENTAL SCIENCE (2007); Casey et al., *supra* note 8;

susceptible to peer influences, their emotional system tends to take over their cognitive control system, potentially making adolescents more prone to risk-taking behaviors.[93]

Furthermore, a neuroimaging study has indicated that neural circuitry undergoes major reorganization during adolescence, particularly in those brain regions related to the self and social cognition.[94] The "emotional brain" may play a significant role in this reorganization process. Developmental changes in brain regions involved in emotional processing (i.e., limbic system) in middle adolescence lead to heightened sensitivity to social and emotional rewards, as well as motivation toward reward-seeking.[95] The reward sensitivity is a crucial marker for an individual's high sensation seeking and impulsive behaviors.[96] Adolescent's increased

[93] Dustin Albert & Laurence Steinberg, *Peer Influences on Adolescent Risk Behavior*, INHIBITORY CONTROL AND DRUG ABUSE PREVENTION 211–226 (2011).
[94] Dayan et al., *supra* note 89.
[95] *Id.*; *see also* Albert & Steinberg, *supra* note 93.
[96] Anita Cservenka et al., *High And Low Sensation Seeking Adolescents Show Distinct Patterns Of Brain Activity During Reward Processing*, 66 NEUROIMAGE 184–193 (2013).

sensation-seeking behaviors may link to their more developed basal ganglia and VS.[97] A greater reward sensitivity is associated with increased activations in insula and nucleus accumbens in VS comprised of the brain reward system.[98]

Several theories have tried to explain the association between VS and adolescent sensation-seeking behaviors. On the one hand, Linda Spear has argued that since VS is hyporesponsive to rewards during adolescence, increased reward-seeking behaviors are needed to reach the same level of activation or the same level of reward feeling as for adults.[99] On the other hand, researchers have suggested that VS or the reward system is hyperresponsive during adolescence, leading to more sensation-seeking behaviors.[100] The immaturity of

[97] Galvan et al., *supra* note 92.
[98] Cservenka et al., *supra* note 96.
[99] Linda P Spear, *The Adolescent Brain And Age-Related Behavioral Manifestations*, 24 NEUROSCIENCE & BIOBEHAVIORAL REVIEWS 417–463 (2000).
[100] R. Andrew Chambers, Jane R. Taylor & Marc N. Potenza, *Developmental Neurocircuitry of Motivation in Adolescence: A Critical Period of Addiction Vulnerability*, 160 AMERICAN JOURNAL OF PSYCHIATRY 1041–1052 (2003); *see also* Dayan et al., *supra* note 89.

adolescent cognitive control system may result in the disproportionately increased activation of the VS motivational pathway.[101] This phenomenon may explain why adolescents are particularly susceptible to social rewards and motivated by immediate positive reinforcements. In turn, this association explains why adolescents have substantially more sensation-seeking or risk-taking behaviors, therefore leading to a higher probability of being delinquent.

D. Summary

Brain development research has shaped how people view juvenile delinquency today. All three types of impulsivity during adolescence: motor impulsivity, active impulsive choice, and sensation-seeking, are not just the results of negative social environmental influences, such as family adversity, neighborhood disadvantage, and school failure. Adolescent impulsivity and delinquency are also not unchangeable due to some permanent brain damages

[101] Chambers et al., *supra* note 100.

or genetic deficits. Combining previous brain development evidence, a brain maturational gap and a developmental imbalance have been highlighted in explaining juvenile delinquency. Adolescents' impulsive and immature behaviors, as well as the resultant delinquency, may be more related to differential brain growth trajectories, a rapid maturation of the emotional/reward system and a slow, prolonged development of the cognitive control system.

As adolescents generally desire for independence, adult identity, and social acceptance when interacting with the social world, they may not only lack of the ability to inhibit their impulsivity and evaluate a situation incorrectly, especially a high arousal one, but also sensitize to the reward value of risky behaviors due to brain immaturity.[102] This "nature" of adolescence makes them more likely to engage in impulsive, antisocial, and delinquent behaviors. However, as their cognitive control system matures, their ability to exert self-control,

[102] Albert & Steinberg, *supra* note 93.

coordinate emotions and reason, and make thoughtful decisions will increase, thereby automatically reducing their probability of engaging in delinquent behaviors.

IV. ADOLESCENT BRAIN AND AGE-RELATED POLICY DEBATE

Unlike adults, adolescents and young people between the ages of 16 and 24 are not fully mature. Their brains are still developing, making them more likely to exhibit impulsive behaviors in social interactions and are more sensitive to social and nonsocial rewards. This developmental nature especially put adolescents and young adults in a restricted and vulnerable stage in terms of public policy and legal processing. One question is about raising the minimum legal age (MLA) for drinking and smoking, and the other is about raising the minimum age for juvenile courts or the recommended adult referral age in the juvenile justice system. At present, the debate on raising the MLA for the use of substances tends to be less

fruitful, and has almost reached a bottleneck, while raising the age of the juvenile court is in a hot stage.

A. Brain Immaturity and Raising the Minimum Legal Age for Substance Use

From juvenile delinquency prevention perspective, policymakers have raised the MLA of smoking and drinking alcohol from 18 to 21 and still considering extending the age limit to even 25, since the tobacco markets and product promotions have increasingly targeted young adults.[103] By raising the MLA of accessing tobacco and alcohol products to age 21 or 25, policymakers not only expect a substantial reduction in smoking and illegal drinking prevalence, but also intend to prevent adolescents and young adults from engaging in delinquent behaviors.[104]

[103] RICHARD J. BONNIE, KATHLEEN STRATTON & LESLIE Y. KWAN, PUBLIC HEALTH IMPLICATIONS OF RAISING THE MINIMUM AGE OF LEGAL ACCESS TO TOBACCO PRODUCTS (2015); Pamela M. Ling & Stanton A. Glantz, *Why and How the Tobacco Industry Sells Cigarettes to Young Adults: Evidence From Industry Documents*, 92 AMERICAN JOURNAL OF PUBLIC HEALTH 908–916 (2002).
[104] Bonnie et al., *supra* note 103.

The logic of policymakers to translate evidence of adolescence brain immaturity into public policy is clear. Because their brains are not mature until 25, adolescents and young adults may lack of the ability to accurately perceive and estimate the cost and benefits of certain behaviors and foresee the consequences.[105] Furthermore, some regions of the brain that are critical to substance dependence are still developing for adolescents and young adults, thereby increasing an adolescent's vulnerability to substance use through the negative impacts on brain developments.[106] In the long run, exposure to substance during adolescence may increase the probability of a further delayed or dysfunctional cognitive development and a greater sensitivity to substance reward signals.[107] In the short term, any individual under the influence of substances tends to act irrationally, impulsively, or aggressively. Let

[105] Steinberg, *supra* note 9.
[106] Bonnie et al., *supra* note 103.
[107] Danielle S. Counotte et al., *Development Of The Motivational System During Adolescence, And Its Sensitivity To Disruption By Nicotine*, 1 DEVELOPMENTAL COGNITIVE NEUROSCIENCE 430–443 (2011).

alone adolescents and young adults whose brain reward systems are highly active and cognitive control systems are underdeveloped. Among 18- to 24-year-olds, 39% of binge drinkers admit to criminal or delinquent behaviors and 60% to disorderly behaviors.[108] Both situations can increase an adolescent's future probability of engaging in delinquent behaviors and having substance use disorders.

B. Concerns about Raising the MLA Policy

The above logic does make sense, but only to a certain degree. It is undeniable that children, adolescents, and young adults should not be exposed to any substance. But the key debate is which age limit should we choose, or should we continue to raise the MLA of drinking and smoking from 21 up to 25 years old? Should we keep fueling up the debate? At least three concerns need to be considered.

[108] Jasper Gerard, *Should We Raise The Age Of Legal Drinking?* 14 PUBLIC POLICY RESEARCH 31–35 (2007).

First, the legal age cutoff is arbitrary.[109] There may not be a noticeable difference between 21-year-old and 22-year-old individuals in terms of both brain developments and behavioral patterns. If policymakers raise the MLA up to 25 by only considering brain development research, then what about people aged 26 years old and people who go through longer protraction of brain development or have significant brain dysfunctions? Hence, the current age limit is fairly decent and robust, and that continuing to increase the MLA may not bring seemingly huge benefits. On the contrary, it may bring up the issue related to ageism and anti-ageism in the justice system. The potential harm and debate about the merits of criminalizing adolescent substance use also receive a greater recognition.[110] The problem now is not about raising the age or not, but it is about whether raising the MLA will achieve its potential benefits and substantially reduce

[109] Elizabeth Cauffman, Sachiko Donley & April Thomas, *Raising the Age*, 16 CRIMINOLOGY & PUBLIC POLICY 73–81 (2017).
[110] Mark Wolfson & Mary Hourigan, *Unintended Consequences And Professional Ethics: Criminalization Of Alcohol And Tobacco Use By Youth And Young Adults*, 92 ADDICTION 1159–1164 (1997).

adolescent substance use problems, thus leading to a decline in juvenile delinquency. But the evidence of the causal impact of changing such public policy on adolescent risk behaviors are inconclusive.[111]

Second, raising the MLA may have unintended consequences.[112] Analyses from the National Youth Tobacco Survey (NYTS) and the Monitoring the Future (MTF) survey have shown that three most common methods for adolescents to get cigarettes are: (a) someone offered it, (b) they asked someone else to give or buy it, and (c) they bought it by themselves.[113] In theory, since adolescents and young adults who are legal before the new policy now become illegal users, the demand for an illegal

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[111] *See generally* Jason M. Fletcher, *Estimating Causal Effects Of Alcohol Access And Use On A Broad Set Of Risky Behaviors: Regression Discontinuity Evidence*, 37 CONTEMPORARY ECONOMIC POLICY 427–448 (2019); Ralph W Hingson et al., *Impact Of Legislation Raising The Legal Drinking Age In Massachusetts from 18 to 20*, 73 AMERICAN JOURNAL OF PUBLIC HEALTH 163–170 (1983); Shari Kessel Schneider et al., *Community Reductions In Youth Smoking After Raising The Minimum Tobacco Sales Age to 21*, 25 TOBACCO CONTROL 355–359 (2016).
[112] *See generally* John Dinardo & Thomas Lemieux, *Alcohol, Marijuana, and American Youth: The Unintended Effects of Government Regulation*, 20 JOURNAL OF HEALTH ECONOMICS 991–1010 (1992); Lanza-Kaduce & Richards, *supra* note 13; Ringold, *supra* note 13.
[113] Bonnie et al., *supra* note 103.

substance should be tempered by increasing their perceived risk of being arrested and punished for buying or using them.[114] However, adolescents who are eager to use substances will always attempt to do so regardless of the legal age constraint.

No matter how the MLA policy changes, a subgroup of high-risk adolescents who should have been targeted by policy will not be affected. In addition, a boomerang effect in response to the MLA policy exists.[115] Boomerang effect lies in the theory of psychological reactance and is roughly defined as the state of being aroused in opposition to perceived threats to a personal choice.[116] In other words, this policy may result in an opposite rather than the intended effects on adolescents' substance use behaviors. Adolescents who do not normally use illegal substances may try to break this rule because they would think drinking demonstrates independence and individual freedom, thus reacting against school-based educational programs,

[114] *Id.*
[115] Ringold, *supra* note 13.
[116] *Id.*

warnings signs, and alcohol or smoking policies.[117] Unfortunately, these mandatory MLA policies may cause resentment and increase reactance.[118] For adolescent sensation-seekers, they may think breaking rules with the possibility of not getting arrested is cool and gives them the adrenaline or dopamine thrill. In either case, as adolescents age and consider the policy as too repressive, they may experience an increasing level of psychological reactance, thus making the MLA policy less effective or even counterproductive.[119]

Third, presumably, a group of adolescents can deliberately think through and have plans for the consequences of their behaviors. They will engage in underage substance use not because they act recklessly or irresponsibly, but because the policy rules them as illegal. Counterintuitively, increasing the MLA policy may lead to an increase in illegal

[117] *Id.*
[118] Jennifer B. Unger et al., *Attitudes Toward Anti-Tobacco Policy Among California Youth: Associations With Smoking Status, Psychosocial Variables And Advocacy Actions*, 14 HEALTH EDUCATION RESEARCH 751–763 (1999).
[119] *Id.*; *see also* Ringold, *supra* note 13.

substance use and juvenile delinquency.[120] There are unintended negative consequences of the MLA of alcohol laws.[121] Underaged drinkers may engage in alternative forms of crime to obtain alcohol and the arbitrary age limit may make them argue that the law is unfair, thus making the policy less effective.[122] After analyzing a large sample of students from 43 states over the years 1980–1989, researchers have revealed that raising the MLA of alcohol drinking even leads to a slight increase of marijuana consumption.[123]

Overall, the impacts of raising the MLA policy on substance use and delinquency prevention are mixed and have not reached its intended preventative effects. Relevance of brain research on immaturity and these age-related public policies is warranted. However, the degree of its implication in *changing* current MLA policies may be limited with few justifications due to at least three concerns

[120] Dinardo & Lemieux, *supra* note 112.
[121] Lanza-Kaduce & Richards, *supra* note 13.
[122] *Id.*
[123] Dinardo & Lemieux, *supra* note 112.

aforementioned. Moreover, raising the MLA of substance use from 21 to 25 may obtain a similar unproductive effect as raising the MLA from 18 to 21. Therefore, current legal age cutoff is reasonable. There is no need to repeat the history and fuel up the debate again. Policies like these should be settled with what it is now because little merit will be produced if we keep arguing back and forth.

C. Brain Development and Raising the Age for Adult Referral

Adolescent brain development research has its potential to inform how to determine an adolescent's culpability, how to set a proper punishment, and how to treat young offenders fairly in the legal system, with the aim of reducing delinquency and enhancing public safety yet not disrupting their future opportunities. However, researchers and policymakers should also acknowledge its limited legal relevance and precise implications in the legal system. Public policy should not rely too much on the rhetoric gloss of brain science because it

is neither advanced enough to explain criminal responsibility among individuals nor ready to make a huge contribution to policy reforms.[124]

Farrington and colleagues have directly proposed that the legislation should increase the minimum age for referral of adolescents to adult court up to 21, and preferably 24, based on the fact that their brain structures and functions are immature and similar to those of juveniles rather than adults.[125] Adolescents aged from 16 to 24 should be processed in juvenile courts rather than adult courts.[126] Furthermore, they have pointed out urgent needs to set up special correctional facilities, get a maturity discount for sentencing, provide risk assessments, and implement community programs to reduce future recidivism.[127] The logic of this call for reforming the referral policy regarding a juvenile's criminal responsibility and

[124] SALLY L. SATEL & SCOTT O. LILIENFELD, BRAINWASHED: THE SEDUCTIVE APPEAL OF MINDLESS NEUROSCIENCE (2013).
[125] David P. Farrington, Rolf Loeber & James C. Howell, *Young Adult Offenders: The Need For More Effective Legislative Options And Justice Processing*, 11 CRIMINOLOGY & PUBLIC POLICY 729–750 (2012).
[126] *Id.*
[127] *Id.*

culpability is straightforward and parallel to raising the MLA of substance use policy. Adolescents and young adults engage in various forms of delinquency partially because they are in a special brain developmental stage which predisposes them for impulsivity, aggressiveness, sensation-seeking behaviors, and high reward sensitivity.[128]

D. Concerns about Raising the Age of Referral

If all adolescents/young adults are less culpable because of their developing brains, then should policymakers equally consider reforming the policy for elderly adults because of a steady shrinkage of brain volume over the age of 35? Should every offender receive individualized sentencing and treatment because everyone's brain development is slightly different? Although there is an association between the unique nature of adolescent brain development and their impulsive behaviors, brain immaturity is only one aspect that can have an impact

[128] Casey et al., *supra* note 8; Dayan et al., *supra* note 89; Steinberg, *supra* note 9.

on juvenile delinquency.[129] Brain development evidence does not mean that adolescents lack culpability or criminal responsibility; it only shows that adolescents are rehabilitable and their brains are technically more malleable.[130]

Moreover, with several alternative considerations, simply raising the age for adult referral may not be as effective as it is expected to be.[131] First, according to the age-crime curve[132] and developmental theory, not all young offenders follow the same offending onset and desistence.[133] A Pittsburgh Youth Study has discovered that 52% to 57% of juvenile delinquents actually continue to

[129] Michael Rocque, Brandon C. Welsh & Adrian Raine, *Policy Implications of Biosocial Criminology: Crime Prevention and Offender Rehabilitation*, 40 JOURNAL OF CRIMINAL JUSTICE 306–312 (2012).
[130] Lyons, *supra* note 15.
[131] Gibson & Krohn, *supra* note 15.
[132] The age-crime curve: the prevalence of offending tends to increase from late childhood, peak in the teenage years (from 15 to 19) and then decline in the early 20s. This bell-shaped age trend, called the age-crime curve, is universal in Western populations.
[133] Terrie E. Moffitt, *Adolescence-Limited And Life-Course-Persistent Antisocial Behavior: A Developmental Taxonomy*, 100 PSYCHOLOGICAL REVIEW 674–701 (1993); Gibson & Krohn, *supra* note 15.

offend up to age 25.[134] Individual age-crime trajectory varies significantly and not all persistence patterns are identical.[135] Although adolescent brain development shows a relatively consistent pattern at the aggregated or normative level, individual differences in such developmental trajectories still exist. For example, some offenders have chronic offending careers, whereas others may be late bloomers who only start frequent offending after adolescence or young adulthood.[136] The late blooming is not a recent phenomenon and the risk factors associated with late-blooming trajectories are also different.[137] It is possible that some brain regions of late bloomers, such as PFC and limbic system, are delayed and function ineffectively, thus resulting in a late onset of impulsivity, sensation-seeking, and delinquency. Because of different brain development

[134] DAVID P. FARRINGTON & ROLF LOEBER, FROM JUVENILE DELINQUENCY TO ADULT CRIME: CRIMINAL CAREERS, JUSTICE POLICY, AND PREVENTION (2012).
[135] Alex R Piquero, J David Hawkins & Lila Kazemian, *Criminal Career Patterns*, *in* FROM JUVENILE DELINQUENCY TO ADULT CRIME: CRIMINAL CAREERS, JUSTICE POLICY AND PREVENTION 14–46 (2012).
[136] Gibson & Krohn, *supra* note 15.
[137] *Id.*

trajectories among individuals, how to justify that raising the minimum age of juvenile courts will reduce juvenile delinquency may be vague.

Second, research on the juvenile offender's personality traits (impulsivity, sensation-seeking, and reward sensitivity) have provided inconclusive results about the absolute and relative stability of cognitive control.[138] Cognitive control systems are malleable and responsive to social interactions.[139] Reshuffling the "good" and the "bad" is possible.[140] The development of cognitive control requires dynamic interaction between social and biological factors, rather than relying solely on neuroscience.[141] Although the debate on raising the minimum age of adult referral draws much attention from researchers and policymakers due to a compelling and robust evidence of adolescent brain immaturity and

[138] *Id.*
[139] Callie H. Burt, Ronald L. Simons & Leslie G. Simons, *A Longitudinal Test Of The Effects Of Parenting And The Stability Of Self-Control: Negative Evidence For The General Theory Of Crime*, 44 CRIMINOLOGY 353–396 (2006).
[140] *Id.*
[141] Kevin M. Beaver & John Paul Wright, *Biosocial Development and Delinquent Involvement*, 3 YOUTH VIOLENCE AND JUVENILE JUSTICE 168–192 (2005).

developmental trajectory, this policy recommendation is questionable and indecisive because no methodologically rigorous study has evaluated its effectiveness and necessity, in terms of juvenile delinquency rates, recidivism, overall psychological health, and potential negative outcomes.[142] At present, no empirical evidence has yet shown which policy or reform works best for adolescents and young adults.

As early as 2000, the Institute of Medicine and the National Research Council published a report entitled *From Neurons to Neighborhoods: The Science of Early Childhood Development*.[143] It proposed two critical agendas:

> The first is focused on the future and asks: How can society use knowledge about early childhood development to maximize the development of the nation's human capital and ensure the ongoing vitality of its democratic

[142] Gibson & Krohn, *supra* note 15.
[143] Jack P. Shonkoff & Deborah A. Phillips, FROM NEURONS TO NEIGHBORHOODS: THE SCIENCE OF EARLY CHILDHOOD DEVELOPMENT (2000). Jack P. Shonkoff & Pat Levitt, *Neuroscience and the Future of Early Childhood Policy: Moving from Why to What and How*, 67 NEURON 689–691 (2010).

> institutions? The second is focused on the present and asks: How can the nation use knowledge to nurture, protect, and ensure the health and well-being of all young children as an important objective in its own right, regardless of whether measurable returns can be documented in the future? The first agenda speaks to society's economic, political, and social interests. The second speaks to its ethical and moral values.

These two agendas should always be kept in mind for researchers who intend to use brain development evidence to inform public and legal policy.[144] It is indisputable that the intention of raising the age for adult referral is to create a rehabilitating and restorative juvenile justice system. Yet, this is just as Stephen Morse has warned, "be careful of what you wish for" (from a personal communication in 2016). Take juvenile offenders in Texas as an example. If all 17-year-olds in Texas (about 26,000 in 2014) were referred into the juvenile rather than the adult justice system, it would

[144] *Id.*

crash the juvenile justice system, contradicting with the goal of depopulating the juvenile facilities.[145]

E. Summary

Sometimes, a newly proposed legal policy solely based on neuroscience or biological theory may be conceptually misunderstood or based on non-empirical evidence.[146] Since public policy and prevention programs should be evidence-based rather than hypothetical, researchers and policymakers should avoid "brain overclaim syndrome" (BOS)[147] or over advocate for biological basis of juvenile delinquency.[148] Brain science can

[145] Lyons, *supra* note 15.
[146] Stephen J. Morse, *Criminal Law And Common Sense: An Essay On The Perils And Promise Of Neuroscience*, 99 MARQ. LAW REVIEW 39–72 (2015).
[147] Brain over-claim syndrome: a condition identified by Stephen Morse (2006). To some extent, it is a simple truism that the brain is involved with all things that comprise our human existence. Therefore, understanding the brain will help people to understand the human condition more fully. However, scientists are aware that neuroscientific findings may have social, psychological, legal, or ethical implications. But those evidences remain far from being decisive on larger social problems, including crimes.
[148] Jamie M. Gajos, Abigail A. Fagan & Kevin M. Beaver, *Use of Genetically Informed Evidence-Based Prevention Science to Understand and Prevent Crime and Related Behavioral Disorders*,

benefit policy making processes when they are relevant and necessary, but public policy reforms should not be based on adolescent brain research alone.[149] The contribution of brain research to legal policy and practice is not because it shows the normative differences between juveniles' and adults' brains and behaviors, but because it provides for the sources of such differences.[150] Simply raising the age of adult referral in juvenile court may not function as effectively as it is supposed to be with the whole justice system. The justification and relevance of using adolescent brain development evidence to inform such policy changes is still limited and under the question. Taken together, a radical reform in age-related public policy, such as raising the age for adult referral and raising the MLA of substance use, may be unlikely to occur in the foreseeable future. A continued debate on this issue may be futile.

15 CRIMINOLOGY & PUBLIC POLICY 683–701 (2016); Morse, *supra* note 146.
[149] Steinberg, *supra* note 9.
[150] Steinberg, *supra* note 12.

V. ETHICAL CONCERNS

Advances in brain research have certain implications in the justice system and practice, as well as raise new ethical issues. These issues arise because brain development evidence increasingly applies to understand a wide range of adolescents' behaviors, but the methodological, political, cultural, and social contexts of its applications and limitations are not well discussed. Significant attention to ethical concerns about brain science can be traced back to 2002.[151] An interdisciplinary research area, called Neuroethics, has emerged with the goal of examining "what is right and wrong, good and bad about the treatment of, perfection of, or unwelcome invasion of and worrisome manipulation of the human brain."[152] Neuroethics discusses ethical issues about what we can do with the brain development evidence along with neurotechnology, and how to draw

[151] Adina Roskies, NEUROETHICS STANFORD ENCYCLOPEDIA OF PHILOSOPHY (2016), https://plato.stanford.edu/entries/neuroethics/.
[152] STEVEN J MARCUS, NEUROETHICS: MAPPING THE FIELD (2002).

inferences from what we have known about it.[153] It is impossible to fully compass all the neuroethics topics; this review focuses only on ethical challenges related to the interconnection between brain development and the juvenile justice system.

A. Determination of Juvenile Culpability

When the justice system uses brain development research as evidence to redefine legal maturity age, explain juvenile delinquency, and reform public policy, neuroethics inevitably applies.[154] One major application of brain science is to determine a juvenile's mental state, culpability, and criminal responsibility. Some experts believe that adolescents' lack of emotional and cognitive capabilities to plan, foresee, and regulate their behaviors can help the law to determine, or

[153] Adina Roskies, *Neuroethics For The New Millenium*, 35 NEURON 21–23 (2002); MARTHA J FARAH, NEUROETHICS: AN INTRODUCTION WITH READINGS (2010).
[154] STEPHEN J. MORSE & ADINA L. ROSKIES, A PRIMER ON CRIMINAL LAW AND NEUROSCIENCE: A CONTRIBUTION OF THE LAW AND NEUROSCIENCE PROJECT (2013).

specifically mitigate, their culpability.[155] Along with this view, adolescents should not hold full criminal responsibility, even though their behaviors meet preliminary criteria for the crime charged.[156] Indeed, a landmark Supreme Court case, *Roper v. Simmons*, has overturned the death penalty for juvenile offenders.[157] However, the ruling itself does not solely rely on evidence of adolescent brain immaturity cited in the *amicus* brief.[158]

Some researchers have overemphasized adolescents' immature brain structures and functions in explaining juvenile delinquency and overgeneralized these findings into the legal domain.[159] They tend to ignore other life experience differences and social structural factors.[160] Law holds a normative or folk psychological assumption

[155] Morse, *supra* note 146.
[156] *Id.*
[157] *Roper v. Simmons*, 543 U.S. 551 (2005).
[158] Roskies, *supra* note 151.
[159] Suparna Choudhury & Sheehan Moore, *Locating Risk in the Adolescent Brain: Ethical Challenges in the Use of Biomarkers for Adolescent Health and Social Policy*, 18 AMA JOURNAL OF ETHICS 1199–1206 (2016).
[160] Daniel Romer, *Adolescent Risk Taking, Impulsivity, And Brain Development: Implications For Prevention*, 52 DEVELOPMENTAL PSYCHOBIOLOGY 263–276 (2010).

of people and behaviors.[161] Researchers and policymakers should be cautious in making decisions about individuals based on group data and need to take specific social contexts into consideration in understanding adolescent behaviors.[162] For example, adolescents' desires of sensation-seeking and sensitivity to rewards are possibly adaptive to particular social environments.[163] Brain development and plasticity is an experience-dependent process that can only be understood in social context.[164] Developmental brain scientists have also described the brain as socio-culturally situated.[165] What we want to know is in which ways the evidence of adolescent brain immaturity, along with a consideration of social factors in the legal context, should be relevant for assessing criminal

[161] Morse, *supra* note 14.
[162] Johnson et al., *supra* note 3; Steinberg, *supra* note 9.
[163] Susan M Sawyer et al., *Adolescence: A Foundation For Future Health*, 379 THE LANCET 1630–1640 (2012).
[164] Jess Nithianantharajah & Anthony J. Hannan, *Enriched Environments, Experience-Dependent Plasticity And Disorders Of The Nervous System*, 7 NATURE REVIEWS NEUROSCIENCE 697–709 (2006).
[165] Choudhury & Moore, *supra* note 159.

responsibility and determining adolescent culpability.[166]

Besides, there is a weak correlation between neuropsychological tests or brain scans of executive functions and actual real behaviors.[167] A gap exists in conclusions about the neurocognitive maturation in small, lab-based samples and the national statistics on adolescent risky or delinquent behaviors in a particular country.[168] Assessing real-world cognitive control and maturity among adolescents using brain science is far from certainty and accuracy, given natural individual differences in brain structures, functions, and plasticity especially during development.[169] Therefore, to what extent brain science can link to and make inferences about adolescent delinquent behaviors, as well as help determine juvenile culpability, warrants debate.

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[166] *Id.*; *see also* Jesper Ryberg, *Punishing Adolescents—On Immaturity and Diminished Responsibility*, 7 NEUROETHICS 327–336 (2014).
[167] Russell A. Barkley & Kevin R. Murphy, *Impairment in Occupational Functioning and Adult ADHD: The Predictive Utility of Executive Function (EF) Ratings Versus EF Tests*, 25 ARCHIVES OF CLINICAL NEUROPSYCHOLOGY 157–173 (2010).
[168] Sawyer et al., *supra* note 163.
[169] Morse, *supra* note 146.

After all, an attribution of legal responsibility can be a moral and ethical question.[170]

B. Identification of "At Risk" Adolescents

Another ethical issue comes from the use of brain evidence or neurobiological markers to identify certain impulsive characters or adolescents who are at real developmental risk.[171] The recognition of brain immaturity raises the question of how to identify who is simply immature or impulsive, who has an underlying mental health problem, and who is purely bad. In other words, we cannot distinguish and be certain of whether an adolescent's delinquent behavior is because of the developing brain or not.

Brain scientists have been aware of the ethical risk of identifying specific biomarkers or labeling certain adolescents or young adults as "at high risk."[172] Such a label may not only cause stigmatization by associating certain adolescents

[170] Stephen J. Morse, *Immaturity and Irresponsibility*, 88 THE JOURNAL OF CRIMINAL LAW AND CRIMINOLOGY 15–67 (1997).
[171] Choudhury & Moore, *supra* note 159.
[172] *Id.*

with brain development problems with impulsivity and delinquent behaviors, but also ignore the influence of the broader social environment.[173] This labeling effect may lead to determinism, such as eugenic movements, and interfere with potential delinquency prevention and/or intervention.[174] The social stigma can disproportionately impact the more vulnerable population, such as adolescents who suffer from family breakdowns, learning difficulties, and disadvantaged neighborhoods.[175]

C. Neuro-prediction for Future Dangerousness

A third line of concern is related to the neuro-prediction for adolescent future risky or delinquent

[173] Ilina Singh & Nikolas Rose, *Biomarkers in psychiatry*, 460 NATURE 202–207 (2009).
[174] *Id.*; *see also* Colleen M Berryessa & Cho K. Mildred, *Ethical, Legal, Social, And Policy Implications Of Behavioral Genetics*, 14 ANNUAL REVIEW OF GENOMICS AND HUMAN GENETICS 515–534 (2013).
[175] Choudhury & Moore, *supra* note 159; Stephen P. Hinshaw & Dante Cicchetti, *Stigma And Mental Disorder: Conceptions Of Illness, Public Attitudes, Personal Disclosure, And Social Policy*, 12 DEVELOPMENT AND PSYCHOPATHOLOGY 555–598 (2000).

behaviors.[176] When using neuroimages to predict future activities, researchers refer to a statistical probability of an occurrence of a behavior.[177] Such a prediction neither means that a predicted activity will definitely happen nor does it mean a person's future is determined.[178] However, researchers sometimes make this mistake or lack of clarifications when discussing their findings.[179] Such a mistake may lead to a misuse and misunderstanding of the neuro-prediction in a broader social context.

Aharoni and colleagues have found that error-related brain activity while performing a behavioral inhibitory task has predictive value for recidivism within four years of release, after controlling for other risk factors.[180] They suggest a potential neurocognitive biomarker for persistent antisocial

[176] Morse, *supra* note 146; Thomas Nadelhoffer et al., *Neuroprediction, Violence, and the Law: Setting the Stage*, 5 NEUROETHICS 67–99 (2012).
[177] Roskies, *supra* note 151.
[178] *Id.*
[179] *Id.*
[180] Eyal M. Aharoni et al., *Neuroprediction of Future Rearrest*, 110 PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES 6223–6228 (2013).

behaviors.[181] However, the key question is how to justify that a particular prediction is correct according to which type of standard.[182] At least we need to consider both the accuracy of the prediction itself and the base rate of inevitable prediction errors, because all methods have the problem of false positives and false negatives.[183] The major concern seems to come from the prediction part of neuro-prediction, rather than the neuro-element.[184] Even though neuro-prediction techniques can improve and produce more accurate and reliable results, overreliance on it for legal decision-making and post-punishment detection is problematic, crowding out the proportionality of punishment principle in the criminal justice system, especially in violence cases and/or among adolescents.[185] Neuro-prediction may not raise any new ethical concerns other than what traditional prediction methods have already done.[186]

[181] *Id.*
[182] Morse, *supra* note 146.
[183] *Id.*
[184] Nadelhoffer, et al., *supra* note 176.
[185] *Id.*
[186] Morse, *supra* note 146.

People who refuse to apply neuro-prediction for moral reasons tend to be concerned about any prediction method in the legal system, not just because of brain science.[187]

Moreover, obtaining adequate data, such as a person's genetic information and brain images, to ensure and increase prediction accuracy may put threats to one's privacy and autonomy.[188] The justification for such intrusion is a normative and debatable issue.[189] Who should be tested and whether this technique can be used without an adolescent's cooperation? Should parents have the right to get their children tested or should public officials have the ability to do so if adolescents show serious behavioral problems? How should the state or people respond if it has discovered an adolescent with the highest risk? Is it justifiable for the state to forcibly treat at-risk adolescents in order to prevent their future delinquency that hypothetically would have

[187] Nadelhoffer, et al., *supra* note 176.
[188] *Id.*; Nita A Farahany, *Searching secrets*, 160 UNIVERSITY OF PENNSYLVANIA LAW REVIEW 1239–1308 (2012);
[189] Morse, *supra* note 146.

done without treatments or interventions? Should it serve as a tool for reducing potential harms for society?

In an extreme situation, could law enforcement agents use predictive information to detain or arrest adolescents who have not yet committed a crime? Furthermore, should predictive data be admissible to determine sentence or parole decisions? Would that mean we could punish adolescents for crimes that they have not committed? When neuro-prediction is applied to the legal system prematurely, it can lead to difficult ethical and serious policy problems.[190] At the current stage, neuro-prediction is not sufficiently developed to impact public policy.[191] Hence, given the validity and reliability of problems relying on brain development data to make legal decisions, using neuro-prediction for adolescent future, dangerousness in both guilt/innocence phase and sentencing phase for legal argumentation and

[190] Roskies, *supra* note 151.
[191] Morse, *supra* note 146.

prosecution can result in unintended consequences and ethical challenges.[192]

VI. CONCLUSION

This Article tells an objective and cautionary tale. Developmental brain science has overwhelmingly evidenced the structural and functional immaturity of adolescent brains.[193] Such brain immaturity manifests in adolescent risky, impulsive, and delinquent behaviors.[194] Brain development evidence has not only changed our traditional definition of legal age for adulthood or maturity, but also facilitated our understanding of adolescent behavioral patterns and behavioral problems. However, public policy is debating to keep up with growing interest in brain science.[195] Many policy recommendations rush to rely exclusively on biological explanations for adolescent behaviors. Policymakers and researchers need to consider the

[192] *Id.*; Farahany, supra note 188; Nadelhoffer et al., *supra* note 176.
[193] Steinberg, *supra* note 9.
[194] *Id.*
[195] Johnson et al., *supra* note 3.

social context of brain development, as well as unintended consequences from policy reform. An ignorant and rash application of brain development evidence in the juvenile justice system can raise serious ethical issues that will jeopardize human rights and social values.[196]

The value of adolescent brain science to juvenile justice is not because it creates something new, but because it promotes our understanding of normative behaviors and explains the folk psychological concepts cited in the legal field.[197] The major contribution of brain science does not come from finding biological bases for adolescent immaturity and delinquency, but from highlighting the impact of the legal and social environments created for them.[198] Brain development evidence should not be used as an independent source to change or recommit to traditional juvenile justice values; it merely

[196] Roskies, *supra* note 151.
[197] Morse, *supra* note 146.
[198] *Id.*

reinforces the knowledge we have already had in the justice system and practice.[199]

Acknowledging the complex relationships between the brain, behavior, and social environment of juvenile delinquency can lead to better policy implications.[200] However, as policy scholar Robert Blank commented, "we have little evidence that there is an anticipatory policy. Most policies tend to be reactive."[201] Brain development research does not mean that adolescents lack culpability; it only shows that adolescents are rehabilitatable and their brains are technically more malleable.[202] Therefore, instead of reactively reforming policies and waiting for about 40% to 60% of juvenile offenders to desist offending naturally, it is better to proactively translate adolescent brain science into juvenile

[199] Katherine Hunt Federle & Paul Skendelas, *Thinking Like a Child: Legal Implications of Recent Developments in Brain Research for Juvenile Offenders*, LAW, MIND AND BRAIN 199–214 (2017).
[200] Johnson et al., *supra* note 3.
[201] Robert H. Blank, *Policy Implications of the New Neuroscience*, 16 CAMBRIDGE QUARTERLY OF HEALTHCARE ETHICS 169–180 (2007).
[202] Lyons, *supra* note 15; Steinberg, *supra* note 2.

justice policies and practices.[203] By identifying biological and social environmental risk factors, brain science can provide important insights into delinquency prevention and rehabilitation programs. Such collaborative, multidisciplinary efforts should be beneficial and promising.

[203] David P. Farrington, *Key Results from the First Forty Years of the Cambridge Study in Delinquent Development*, TAKING STOCK OF DELINQUENCY LONGITUDINAL RESEARCH IN THE SOCIAL AND BEHAVIORAL SCIENCES: AN INTERDISCIPLINARY SERIES 137–183 (2003).