

Written Testimony
of

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Scientific evidence has emerged over the past three decades that shows unequivocally that there are continued changes in behavior and brain over the life span, especially during the prolonged period of adolescence that extends into the twenties.

The Timeline of Human Brain Development

Advances in MRI-based, noninvasive brain imaging techniques over the past three decades have led to an explosion of research charting the development of the human brain from childhood to adulthood. Prior to the widespread use of brain imaging for research in the 1990s, little was known about the extension of human brain development well into the 20s (and beyond), and how consequential this late brain development is for shaping experience- and age-related changes in thoughts, feelings, and behaviors. In the years since these early studies, hundreds of studies have accumulated focused on human brain development, and they converge on the conclusion that brain development continues well beyond the age of 18, the legal age of adulthood in the United States.^{1,2,3} In recognition of the emerging consensus among scientists in the field, the American Psychological Association published a resolution on August 3, 2022 reflecting the consensus that brain development continues beyond age 18 years.⁴ Moreover, the definition of adolescence is being reconsidered based on evidence of continued changes in brain,

¹ Mills KL, Goddings A-L, Herting MM, Meuwese R, Blakemore S-J, Crone EA, Dahl RE, Güroğlu B, Raznahan A, Sowell ER, et al. (2016). Structural brain development between childhood and adulthood: Convergence across four longitudinal samples. *Neuroimage* 141, 273.

² Giedd JN (2008). The teen brain: Insights from neuroimaging. *Journal of Adolescent Health*, 42, 335.

³ Giedd JN, Blumenthal J, Jeffries NO, Castellanos FX, Liu H, Zijdenbos A, Paus T, Evans AC, Rapoport JL (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature Neuroscience* 2, 861.

⁴ American Psychological Association, APA Resolution on the Imposition of Death as a Penalty for Persons Aged 18 Through 20, Also Known As the Late Adolescent Class, August 4, 2022, <https://www.apa.org/about/policy/resolution-death-penalty.pdf>.

neurocognitive, social and physical development that extends from 10 to 24 years.⁵ This period is characterized by periods of rapid, active change in the brain, followed by a slow “tapering” of change and eventual plateau.⁶ Many expert organizations like the World Health Organization already refer to young people (adolescents and young adults) as encompassing individuals 10-24 years and the United Nations has coined a new designation of “youth” for individuals 15-24 years in recognition that they share many still-developing attributes.⁷

MRI-based measures can assess the development of gray matter (the size of the brain’s major structures),⁸ white matter (the fiber bundles that represent communication pathways that link up distant brain regions),⁹ brain function (the degree to which collections of brain regions react to a presented cue),¹⁰ and brain connectivity (how brain regions coordinate their function, which is a signal of more efficient and sophisticated brain organization).¹¹ These measures can be computed for the brain as a whole, or for each of the four lobes of the brain (occipital, parietal, temporal, frontal). Figure 1 on the next page, published in the journal *Neuron*⁶ and discussed in the *New York Times*,¹² shows the age at which indices of brain development, based on group data, reach a developmental “plateau” (gray dots); as can be seen, across many brain regions (down the vertical axis) and across multiple measures (colored lines), most measures of brain development continue well into the twenties or even beyond. These measures show that brain development tapers off over a wide range of timelines, making it hard to pinpoint an exact age the average brain is “mature” - but every one of the measures continue to show change beyond the age of 18 years, with the majority of measures (five of the seven) showing a pattern of active development into the twenties. Importantly, across the measures, the frontal cortex that is implicated in impulse control, decision making and self regulation, consistently shows the latest development.

⁵ Sawyer SM, Afifi RA, Bearinger LH, Blakemore SJ, Dick B, Ezech AC, & Patton GC (2012). Adolescence: a foundation for future health. *The Lancet*, 379(9826), 1630-1640.

⁶ Somerville LH (2016). Searching for signatures of brain maturity: what are we searching for?. *Neuron*, 92(6), 1164-1167.

⁷ World Health Organization, February 22, 2024, <https://www.who.int/southeastasia/health-topics/adolescent-health>.

⁸ Frangou S, Modabbernia A, Williams SC, Papachristou E, Doucet GE, Agartz I, Aghajani M, Akudjedu TN, Albajes-Eizagirre A, Alnæs D, & Alpert KI. (2022) Cortical thickness across the lifespan: Data from 17,075 healthy individuals aged 3–90 years. *Human Brain Mapping*, 43(1), 431-51.

⁹ Lebel C & Beaulieu C. (2011). Longitudinal development of human brain wiring continues from childhood into adulthood. *Journal of Neuroscience* 31, 10937.

¹⁰ Somerville LH, Jones RM, & Casey BJ (2010). A time of change: Behavioral and neural correlates of adolescent sensitivity to appetitive and aversive environmental cues. *Brain and Cognition*, 72, 124.

¹¹ Dosenbach NU, Nardos B, Cohen AL, Fair DA, Power JD, Church JA, Nelson SM, Wig GS, Vogel AC, Lessov-Schlaggar CN (2010). Prediction of individual brain maturity using FMRI. *Science*, 329, 1358.

¹² Zimmer C, “You’re an Adult. Your Brain, Not so Much.” *New York Times*, 21 December 2016, <https://www.nytimes.com/2016/12/21/science/youre-an-adult-your-brain-not-so-much.html>.

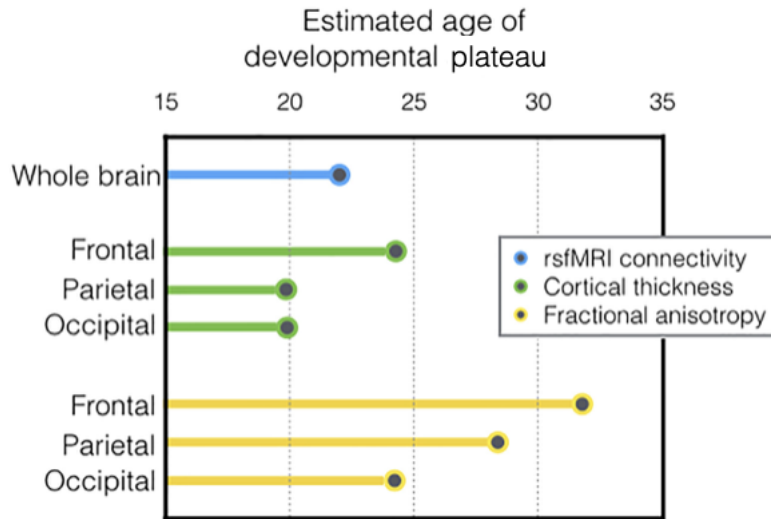


Figure 1: Average ages of developmental plateau (indicating stabilization) for connectivity and structural data from Somerville⁶. Resting-state functional connectivity (rsfMRI) data from Dosenbach et al.¹¹ and the other measures reflect data reported in Tamnes et al.¹³.

Behavioral Changes during Adolescence are consistent with observed Brain Changes

The brain has the potential for change throughout the life course but especially during the first few decades of life which has significant consequences for psychological development, namely in decision making, impulse control and emotional regulation. As highlighted in the APA resolution, the field consensus is that in many domains of functioning, individuals older than 18 (to at least age 20 years, per APA resolution) as a class are not meaningfully distinguishable from 17 year olds.^{1,11,14,15}

Next, we focus on the known interrelations between brain development and psychological characteristics that are relevant to criminal activity: a) a tendency to engage in risky decision making in youth; b) future oriented decisions and planning; and c) susceptibility to emotionally charged situations.

¹³ Tamnes CK, Østby Y, Fjell AM, Westlye LT, Due-Tønnessen P, & Walhovd KB (2010). Brain maturation in adolescence and young adulthood: regional age-related changes in cortical thickness and white matter volume and microstructure. *Cerebral Cortex*, 20(3), 534-548.

¹⁴ Cohen AO, Breiner K, Steinberg L, Bonnie RJ, Scott ES, et al. (2016). When is an adolescent an adult? Assessing cognitive control in emotional and nonemotional contexts. *Psychological Science*. 27, 549-62.

¹⁵ Casey BJ, Simmons, C, Somerville L, & Baskin-Sommers A (2022). Making the sentencing Case: Psychological and neuroscientific evidence for expanding the age of youthful offenders. *Annual Review of Criminology*, 5(7) 1-23.

Orientation toward risky decision making. Individuals in their late teens and early twenties exhibit a host of behaviors consistent with a drive toward risk-taking. The state of *psychological development* in the late teens and early twenties temporarily orients individuals toward making riskier decisions. Although this is not necessarily true for every youth, it is characteristic of them on average, when compared against other age groups.

One psychological factor that shapes an individual’s willingness to engage in risks is their level of *sensation seeking*, which is defined as, “the tendency to seek out novel, varied, and highly stimulating experiences, and the willingness to take risks in order to attain them.”¹⁶ Laurence Steinberg, a psychologist and leading expert on development in the late teens and early twenties, quantified sensation seeking in over 5,000 people aged 10-30 years across the world and found that sensation seeking varies greatly with age.¹⁷ It rises in the teenage years, peaks around age 19-20 years, and remains elevated well into the mid-twenties before it declines to low levels (see Figure 2). These findings on the development of sensation seeking parallel peak changes in the late teens and early twenties in brain activity when winning versus losing on a gambling task, based on data from a large longitudinal sample.¹⁸ Together these findings show a heightened inclination for risk taking and sensation seeking that extends into the early to mid-twenties.

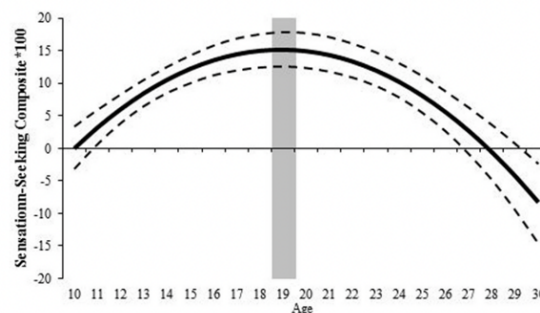


Figure 2: Average sensation seeking for individuals aged 10-30 shown in Steinberg et al.¹⁷. The bold line indicates the average levels of sensation seeking over this age range, with higher

¹⁶ Zuckerman M, Eysenck S, & Eysenck HJ. (1978). Sensation seeking in England and America: Cross-cultural, age, and sex comparisons. *Journal of Consulting and Clinical Psychology*, 46, 139-149.

¹⁷ Steinberg L, Icenogle G, Shulman EP, Breiner K, Chein J, Bacchini D, Chang L, Chaudhary N, Giunta LD, Dodge KA, & Fanti KA (2018). Around the world, adolescence is a time of heightened sensation seeking and immature self-regulation. *Developmental Science*, 21(2), e12532.

¹⁸ Braams, BR, van Duijvenvoorde, ACK, Peper, JS & Crone, EA (2015) Longitudinal changes in adolescent risk-taking: a comprehensive study of neural responses to rewards, pubertal development, and risk-taking behavior. *Journal of Neuroscience*, 35(18), 7226-7238.

values indicating greater endorsement. Note: There is a peak in sensation seeking around age 19 years (gray bar), but the window of elevated sensation seeking extends well into the twenties, compared against individuals in the upper twenties.

Development of the skills that support planning and decision making. There is scientific research showing that cognitive skills that form the basis of our decisions and actions continue to develop into the mid-twenties. This collection of skills is often described as “executive functioning” and includes subcomponents such as inhibitory control and planning (consideration of long-term consequences of action). While simple, self-paced, nonarousing cognitive tasks may show adultlike patterns of performance by the early to mid-teens,^{19,20} tasks that require strategic behaviors and decision-making under demanding conditions show steady improvements in executive functioning well into the twenties. Importantly, the development of a region of the brain called the prefrontal cortex and its connections with other brain networks facilitates improved executive functioning with age into young adulthood.²¹

One component of executive functioning is impulse control, which can be defined as the ability to plan and consider the consequences of our behaviors before acting. Engaging in many forms of criminal behavior is thought to emerge from acting on impulse (i.e., low impulse control). A large collection of research studies indicates that youth tend to act on impulse to a greater degree than adults especially in emotionally charged situations. Research has shown that the tendency to engage in impulsive behaviors wanes in the mid-to-late twenties. For example, a study examining impulsive, short-sighted decision-making in individuals ranging in age from 11-31 years found that impulsive behavior continues to decline throughout the twenties, and this age-related decline is associated with the functioning of brain systems important for choosing how to act.²²

Individuals also can control their momentary impulses by planning and anticipating the consequences of their actions. For actions that may result in negative long-term consequences, individuals would benefit from controlling any impulses to act “in the moment”. This is

¹⁹ Luna B, Garver KE, Urban TA, Lazar NA, & Sweeney JA (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development*, 75, 1357–1372.

²⁰ Steinberg L, Cauffman E, Woolard J, Graham S, & Banich M (2009). Are adolescents less mature than adults? Minors’ access to abortion, the juvenile death penalty, and the alleged APA “flip-flop.” *American Psychologist*, 64, 583–594.

²¹ Casey BJ, Heller AS, Gee DG, & Cohen AO (2019). Development of the emotional brain. *Neuroscience Letters*, 693, 29–34.

²² Christakou A, Brammer M, & Rubia K (2011). Maturation of limbic corticostriatal activation and connectivity associated with developmental changes in temporal discounting. *Neuroimage*, 54(2), 1344-1354.

measurable in psychological tests and experimental tasks. Steinberg and colleagues have used these tests to characterize age-related improvements in considering the long term consequences of actions (along with several related factors) in over 900 individuals ranging in age from 10-30 years.²³ They found that planning ahead before acting is continuing to improve during the 22-25 age range; it had not yet reached the level of older individuals aged 26-30 years.

This finding is in line with complementary research regarding the personality trait of *conscientiousness*, which refers to the planfulness and care people take in orchestrating their everyday behaviors.²⁴ Individuals with high conscientiousness tend to be dependable, orderly, planful, and efficient whereas individuals with low conscientiousness tend to be disorganized, careless, and lack self-discipline.²⁴ On average, conscientiousness continues to develop and grow into the thirties,²⁵ resulting in increasing planfulness and dependability with age by contrast to relatively lower scores in people younger than thirty.

Susceptibility to emotionally charged situations. Generally speaking, situations involving heightened arousal, excitement, or negative or positive emotional states can provoke impulsivity²⁶ and suboptimal decision making.²⁷ For youth, on average it is more challenging to keep one's own behavior in line with one's goals during these types of emotionally-charged situations than it is for adults.^{28,29} As we mature, we become more capable of behaving consistently in emotionally and non-emotionally charged situations (i.e., psychosocial maturity).

Research has shown that emotional cues can be disruptive to individuals in their early-to-mid twenties, similar to the ways in which they are disruptive in younger adolescents. Responding to emotional cues or cues that signal potential threat or reward (compared to neutral cues) can slow down information processing, indicating the emotional content has interfered

²³ Steinberg L, Graham S, O'Brien L, Woolard J, Cauffman E, & Banich M (2009). Age differences in future orientation and delay discounting. *Child Development, 80*(1), 28-44.

²⁴ MacCann C, Duckworth AL, & Roberts RD (2009). Empirical identification of the major facets of conscientiousness. *Learning and Individual Differences, 19*(4), 451-458.

²⁵ Roberts B. & Mroczek D. (2008). Personality Trait Change in Adulthood, *Current Directions in Psychology, 17*, 31.

²⁶ Johnson SL, Elliott MV, & Carver CS (2020). Impulsive responses to positive and negative emotions: parallel neurocognitive correlates and their implications. *Biological Psychiatry, 87*(4), 338-349.

²⁷ FeldmanHall O, Raio CM, Kubota JT, Seiler MG, & Phelps EA. (2015). The effects of social context and acute stress on decision making under uncertainty. *Psychological Science, 26*(12), 1918-1926.

²⁸ Somerville LH, Hare T, & Casey BJ. (2011). Frontostriatal maturation predicts cognitive control failure to appetitive cues in adolescents. *Journal of Cognitive Neuroscience, 23*(9), 2123-2134.

²⁹ Cohen AO, Breiner K, Steinberg L, Bonnie RJ, Scott ES, Taylor-Thompson K, Rudolph MD, Chein J, Richeson JA, Heller AS, Silverman MR, Dellarco, DD, Fair, DA, Galvan, A. & Casey, BJ (2016). When is an adolescent an adult? Assessing cognitive control in emotional and nonemotional contexts. *Psychological Science, 27*(4), pp.549-562.

with an individual's behavior.³⁰ Bos and colleagues showed that this emotional influence on behavior continues into the mid-twenties and is reflected in both compromised accuracy and less consistent responses when emotionally laden cues are present.³¹

These behavioral results are in line with complementary research demonstrating that the personality trait of emotional maturity continues to develop well into early adulthood and is still changing in the early twenties.³² Although historically, personality was assumed to develop early in life, personality traits, like brain and behavior, show continued development that extends into the twenties.

Psychosocial maturity is the capacity to maintain self-restraint, especially in emotionally-arousing contexts. It can be measured in individuals across a wide age range using validated questionnaires. Icenogle and colleagues conducted a worldwide study of when psychosocial maturity emerges in over 5,000 individuals.³³ They found that psychosocial maturity increases with age, and there are continued age-related increases throughout the twenties (see Figure 3 on next page). Adolescents show more psychosocial maturity than childhood, but there are also substantial gains throughout the twenties as can be seen in the upward sloping trajectory below that continues to rise from the early to mid to late twenties. These findings parallel continued brain development into the twenties (e.g.,³⁴).

³⁰ Ortner CN, Zelazo PD, & Anderson AK. (2013). Effects of emotion regulation on concurrent attentional performance. *Motivation and Emotion, 37*(2), 346-354.

³¹ Bos DJ, Dreyfuss M, Tottenham N, Hare TA, Galván A, Casey BJ, & Jones RM. (2020). Distinct and similar patterns of emotional development in adolescents and young adults. *Developmental Psychobiology, 62*(5), 591-599.

³² Roberts B. & Mroczek, D. (2008). Personality Trait Change in Adulthood, *Current Directions in Psychology, 17*, 31.

³³ Icenogle G, Steinberg L, Duell N, Chein J, Chang L, Chaudhary N, Di Giunta L, Dodge KA, Fanti KA, Lansford JE, & Oburu P. (2019). Adolescents' cognitive capacity reaches adult levels prior to their psychosocial maturity: Evidence for a "maturity gap" in a multinational, cross-sectional sample. *Law and Human Behavior, 43*(1), p.69.

³⁴ Schreuders E, Braams BR, Blankenstein NE, Peper JS, Güroğlu B, & Crone EA (2018). Contributions of reward sensitivity to ventral striatum activity across adolescence and early adulthood. *Child development, 89*(3), 797-810.

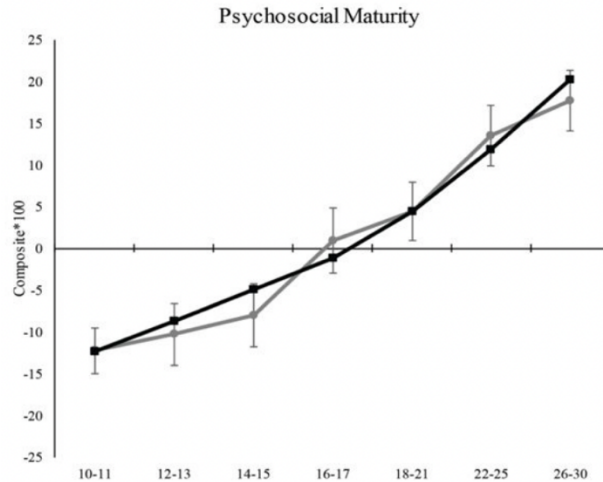


Figure 3: From Icenogle et al.³³ Average psychosocial maturity for individuals aged 10-30 years. The bold line indicates the average change over this age range in psychosocial maturity, with greater values indicating higher endorsement. Note: There is substantial change through the twenties with continued improvements from age 22-25 years compared to age 26-30 years.

Changes in criminal behavior parallel changes in brain and behavior with development

The studies above focus on transient changes in behavior during adolescence in typically developing populations. However, just as risk taking, impulsivity and susceptibility to negative influences decrease with age throughout adolescence and young adulthood, so too is there a decrease in criminal behavior. In fact, one of the longest-standing, most reliable patterns in criminology is the age crime curve depicted in Figure 4 showing that the vast majority of adolescents who commit crime eventually desist from such activity as they mature into adulthood. This pattern shows that criminal behavior peaks around 18 years of age, with a sharp decline particularly evident for violent crimes throughout the early to mid 20s.

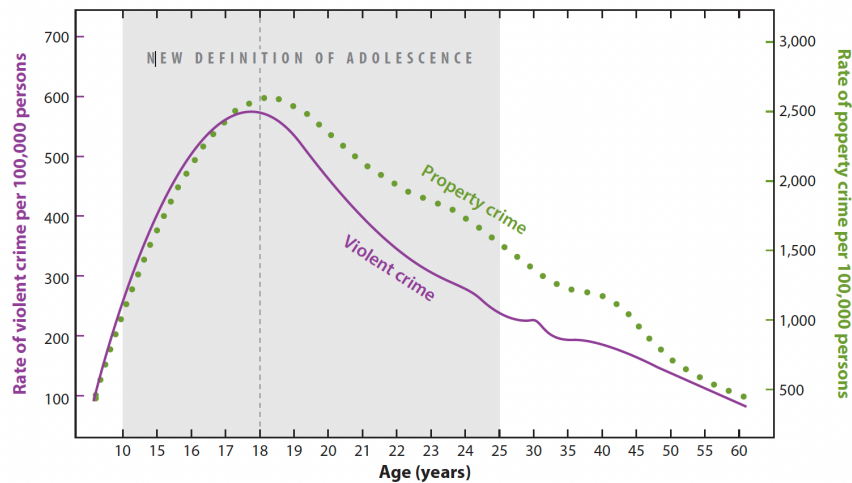


Figure 4: Age-crime curve depicting rate of violent and property crime per 100,000 persons as a function of age. The gray box indicates a new definition of adolescence based on evidence of continued neurocognitive changes from 10 to 24 years³⁵. Figure from Casey and colleagues³⁵ and based on publicly available data from the Bureau of Justice Statistics.³⁶

Although historically, criminal behavior and associated callous unemotional/psychopathic traits have been described as stable, emerging evidence shows change in the developmental course of these traits. For example, in more than 1,000 boys followed from childhood to adulthood, the majority of the boys who initially had high levels of psychopathic traits, showed decreases in these traits with development and no longer presented with psychopathic traits in adulthood.³⁷ These findings are consistent with a prior study examining the trajectories of callous-unemotional traits in a similarly large but independent sample of 1,170 justice-involved adolescent males.³⁸ Three groups of youth were identified as having low (27%), moderate (57%), and high (16%) levels of callous-unemotional traits. Youth in moderate callous-unemotional trait trajectories showed significant decreases in callous-unemotional traits from 16 to 24 years. Together, these studies indicate that callous-unemotional/psychopathic traits decrease with age in the majority of youth.

³⁵ Casey BJ, Simmons, C, Somerville LH, & Baskin-Sommers A (2022). Making the sentencing Case: Psychological and neuroscientific evidence for expanding the age of youthful offenders. *Annual Review of Criminology*, 5(7) 1–23.

³⁶ Bureau of Justice Statistics (2010). Arrest data analysis tool: national estimates. Bureau of Justice Statistics. <https://www.bjs.gov/index.cfm?ty=datool&url=/arrests/index.cfm>

³⁷ Hawes SW, Byrd AL, Gonzalez R, Cavanaugh C, Bechtold J, et al. (2018). The developmental course of psychopathic features: investigating stability, change, and long-term outcomes. *Journal of Research in Personality*, 77, 83–89.

³⁸ Baskin-Sommers AR, Waller R, Fish AM, & Hyde LW (2015). Callous-unemotional traits trajectories interact with earlier conduct problems and executive control to predict violence and substance use among high risk male adolescents. *Journal of Abnormal Child Psychology*, 43, 1529–1541.

Promising interventions are emerging for justice-involved youth with callous-unemotional/psychopathic traits. One promising intervention is from the Mendota Juvenile Treatment Center³⁹ and includes reward oriented toward specific goal behavior, empathy skill development, and ways to appeal to the self-interests of the incarcerated adolescents (youth-centered). Youth in this program were assessed over 2 to 6.5 years after being released from custody. The treatment condition was associated with reduced post-release recidivism relative to a comparison treatment condition (Figure 5). Importantly, both youth with low and high levels of psychopathic traits showed reduced recidivism. These findings suggest that it is inappropriate to say that these youth are “treatment resistant” or even less responsive to treatment, but rather it is more a problem of getting the right treatment.⁴⁰ Together, the findings suggest that extreme criminal behaviors and traits decrease with age from adolescence into adulthood but even more so with effective treatments.

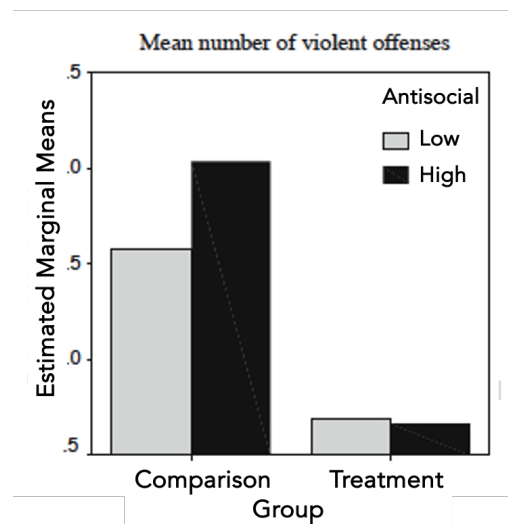


Figure 5: Treatment-related changes in violent offenses in adolescent offenders with low and high antisocial traits. The effect of the treatment was evident in youth with both high and low levels of antisocial traits, but especially so for high antisocial traits (black bars). Adapted from Caldwell (2011)³⁹.

³⁹ Caldwell MF (2011). Treatment-related changes in behavioral outcomes of psychopathy facets in adolescent offenders. *Law and Human Behavior*, 35(4), 275–287.

⁴⁰ Baskin-Sommers A, Chang S-A, Estrada S, Chan L. 2022. Towards targeted interventions: Examining the science behind interventions for youth who offend. *Annu. Rev. Criminol.*5:345-369

Summary

While research in this field remains ongoing, there is now a consensus that brain and behavioral development continues well into a person's twenties. This ongoing brain development parallels observed propensities for risky decision making, more short-sighted and impulsive actions, and heightened susceptibility to emotionally charged situations. We also see continued development in important personality traits related to self-regulation including consciousness and emotion regulation. Finally, emerging evidence shows similar changes with age in youth engaged in extreme behaviors with the majority of youth who engage in antisocial behavior showing a decline in criminal behavior with age; with targeted interventions, this decline is even greater.