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Young Drivers and Adolescent Neurocognitive Brain Development

Young people (ages 16 through 25) are dramatically over represented in Washington motor vehicle crashes. Nearly one-fourth of all traffic fatalities in our state are in that age group. Moreover, almost a third of traffic fatalities resulted from crashes involving a 16-25 year old driver. Young drivers in fatal crashes are more likely to commit serious driving errors, such as speeding. Researchers have long known that young drivers are troubled by a combination of inexperience and immaturity, and numerous prevention programs have been created to address the undue risks they pose. Most programs have focused on providing adolescents with information and warnings meant to steer them away from high risk behaviors. These programs have proven relatively unsuccessful.

For all young people, adolescence (starting with the onset of puberty) begins a series of progressive changes in emotional experience, physical sensation, and social interaction that together mark the end of childhood and begin the prospect of adulthood. Since the advent of functional brain mapping enabled researchers to visualize the brain during behavioral tasks, neuroscientists have pieced together a refined portrait of the brain remodeling that underlies the behavioral and emotional changes associated with adolescence. This model describes a rapidly forming imbalance between the brain's *socioemotional reward prediction* (SERP) system and the *cognitive control* (CC) system. This imbalance results in adolescents who seek reward through sensation and interaction without having enough experience and neural capability to make safe and reasonable behavioral choices.

One of the keys to understanding this imbalance lies in a critical part of the brain's dopamine system, which contains neurons involved in many aspects of human motivation and learning. Prior to puberty, the dopamine pathways in the SERP and CC are remodeled to make way for more refined connections. The outcome of this remodeling is an increase in dopamine activity in the CC, especially a dramatic increase in activation of the SERP in the absence of sufficient control capability. A great deal of research has confirmed that a keystone part of the SERP, the *ventral striatum* (VS), is where reward motivation and error prediction are activated in the human brain. That is the area that now becomes hyper-sensitized to the presence of potentially rewarding experiences for adolescents.

The end result of these remodeling and related brain development processes is more efficient communication among all brain areas coordinating motivation, learning, and behavior, giving rise to young adults who are better able to clearly perceive the changing conditions of their lives and adapt successfully to them. In the meantime, though, young people are subject to a hyper-emotional urge for the rewards of new and exploratory experiences, even without an effective CC system to limit the possible consequences. Young males are especially vulnerable to the hyper-sensitization in the VS, making them more likely to engage in such self-destructive behaviors as driving under the influence of drugs and alcohol and speeding, particularly in the presence of peers.

Note: These research summaries are not implied to be the full extent of review that could be conducted on these topics. Research and review was focused on the most recent literature available, with attempts to identify appropriate meta-studies (a comprehensive review of many studies) that have already been conducted.

Because the SERP functions as a reward processing center and an error prediction unit, young people feel a pleasurable urge to explore and learn about the world in new ways, sometimes while taking risks they have not engaged in previously. Along with this new urge for behavioral exploration comes a powerful drive to spend more time in the company of peers, for doing so is experienced as rewarding. Taking risks in the presence of other young people is often felt as pleasurable, though later when under solitary and emotionally cool conditions, the same young people will often acknowledge that avoiding risky situations in the first place would have been a more sensible course.

Owing to the relatively abrupt onset of this imbalance between the SERP and CC circuitry, younger people are particularly prone to making poor choices. Several studies on decision making have shown that not only do they take longer to make decisions, but they also rely on different brain areas than adults. Adults have generally learned to rely on recall of somatic markers, which are memories associated with specific bodily states experienced in similar prior situations. Young people tend to engage in more logical processes when making risk-related decisions because they simply lack the developed CC system that will come later with life experience. For example, when young people were asked obvious questions by researchers, such as whether it is a good idea “to swim with sharks”, “to drink a bottle of Drano”, or “to set your hair on fire”, young people took significantly longer to answer than adults. This shows that just giving young adolescents detailed information on the risks they will face cannot equip them to handle the new and powerful motivations they are experiencing.

However, the process of gaining better control over impulsive behaviors is not simply a matter of developing a better “brain brake”, though ultimately better wiring in the CC is helpful. Developing this control involves a lengthy process of trial and error learning that generates a series of more refined feedback loops both in the SERP and in the CC. The process of developmental maturation is encoded as learning (experiencing successes or failures) at the neural level, and as with any process of learning, it takes time and repetition. In an example of this refinement through learning process, one area of the SERP contains specific neurons that compare the level of reward actually experienced with the level of reward anticipated prior to engaging in the risky behavior to balance expectations and outcomes for better future decision making.

The extreme vulnerability of young people cannot be prevented or side stepped in the interest of certain safety, for it is an essential part of development. This period of learning, while absolutely critical to a healthy development process, is obviously also a perilous time for young people. Young drivers are bound to make some poor choices during this unbalanced period of biological vulnerability, but giving them limited freedom in which to gain driving experience is necessary. The community’s job is to balance the need for this learning against the dire potential costs. It is particularly important for adults to understand and identify scenarios posing the highest risks to young drivers, such as riding or driving with peers or driving under the influence of drugs and alcohol, and take protective measures. Such steps as raising the driving age to eighteen, developing psychometric tests that identify the riskiest of adolescent drivers, and teaching young people to identify and cope with their most vulnerable states, will sustain and protect young people throughout their lives.

<u>Reference Summaries</u>:

Baird AA, Fugelsang JA, Bennett CM (April 2005). **"What were you thinking?": An fMRI study of adolescent decision making**. Presentation at 12th Annual Cognitive Neuroscience Society Meeting, New York.

This study compared decision making by adolescents and adults. The study posed a series of questions about obviously risky activities to both subject groups, e.g., Is it a good idea "to jump off a roof?", "to swim with sharks?", "to set your hair on fire?", or "to drink a bottle of Drano?", as well as questions about non-risky activities, e.g., is it a good idea "to go for a walk?". The study found no difference between adult and adolescent responses on the non-risky questions, but adolescents took over 150 milliseconds longer than adults did to answer questions about risky situations. Moreover, fMRI images indicated that adults relied much more heavily on somatic markers (i.e., mental images based on stored memories that evoked strong visceral responses), while adolescents relied much more heavily on effortful reasoning located in the prefrontal cortex. This study confirmed that adolescents are less able than adults to rely on "gut-level" responses resulting from the combination of experience and developmental maturation.

Blakemore SJ, and Robbins TW. (2012). **Decision making in the adolescent brain**. *Nature Neuroscience*. **15**:1184-1191.

This study was a review of behavioral and brain fMRI studies showing heightened sensitivity of the adolescent VS to expectations of reward, compared to the same brain area in children and adults. It describes the reduced ability of adolescents to inhibit a pre-potent response to certain perceptual stimulus patterns. The study defines adolescence as 'the period of life that starts with the biological changes of puberty and ends at the time at which the individual attains a stable, independent role in society' (p. 1184). The authors also present findings from their own stoplight driving game study. They found that adolescents (ages 14-18) actually made fewer risky choices in the game than 19-22 year olds and were about equal in that regard with 24-29 year olds. However, risky decisions by adolescents increased by roughly 25 percent when in the presence of peers, compared to a drop of about 5 percent for 19-22 year olds under the same condition. The authors also reviewed the dual-processing model described by Steinberg (2008) and others and present their own fMRI support for the presence of over-activation in the VS of adolescent brains.

Chein J, Albert D, O'Brien L, Uckert K, and Steinberg L (2011). **Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry**. *Developmental Science*. **14**:F1-F10. doi:10.1111/j.1467-7687.2010.01035.x.

This study reviews the dual-processing theory of neurocognitive development and presents new findings from a series of stop-go driving and other tests with adults and adolescents, which were conducted concurrently with fMRI imaging, both while alone and also while being observed by peers watching in separate rooms. Adolescent risk taking did not significantly differ from that of adults in the alone condition, but adolescents were far more likely to engage in risky choices while being watched by peers. The fMRI data showed heightened activation among adolescents in the VS and *nucleus accumbens* (the midbrain areas mediating reward expectancy) resulting from being observed by other adolescents.

Gardner M and Steinberg L (2005). **Peer influence on risk taking, risk preference, and risky decision making in adolescence and adulthood: an experimental study**. *Developmental Psychology*. **41**:625-635.

This study reported experimental findings comparing risk taking in a stop-go driving game (called 'Chicken') among adolescents (13-16 year olds), youths (18-22 year olds), and adults (age 24 and older), both while alone and in groups. Results showed that risk taking while alone declined as age increased, but that both adolescents and youths were highly likely to take excessive risks while grouped with peers, and adolescents were more than twice as likely to do so as youths. During the driving game, younger subjects were likelier to let their vehicles continue moving forward for a longer time after the yellow light appeared, and also to prematurely restart vehicles after initially stopping. In the group condition, males were much more likely to value the benefits of risk taking than were females, but this difference was not observed during the alone condition. The study also showed that the risk levels for adults did not vary significantly between the alone and group conditions.

Reyna VF (2008). **A theory of medical decision making and health: fuzzy trace theory**. *Medical Decision Making.* **28**:850-865.

In this study the authors compared the triage decisions of medical students, younger specialists, and older specialists with regard to nine hypothetical patients presenting with different levels of cardiac risk symptoms. While younger specialists were just as able as their more experienced colleagues to recall detailed information regarding cardiac profiles and other details (in some cases they had better recall than the older specialists), their triage decisions were poorer than those of more experienced clinicians, who instead relied on more "gut-level", mental image memories to make their judgments. This study provided convincing evidence that "gist-based intuition" generally requires less information processing but leads to better outcomes than verbatim recall reasoning.

Reyna VF (2004). **How people make decisions that involve risk: a dual-processes approach**. *Current Directions in Psychological Science.* **13**:60-66.

This study presents the fuzzy-trace theory (FTT) of memory; the idea that people rely on the gist of information and its bottomline meaning, as opposed to verbatim details in judgment and decision making. This idea explains why precise information about risk is not necessarily effective in encouraging prevention behaviors or in supporting medical decision making. Reyna proposes that traditional theoretical reliance on verbatim memory is upended by new evidence that FTT often provides a better predictive model of decision making than verbatim theory. However, she argues that in reality people need both kinds of reasoning but should use FTT whenever possible due to its inherent advantages.

Reyna VF and Farley F (2006). **Risk and rationality in adolescent decision making: implications for theory, practice, and public policy**. *Psychological Science in the Public Interest.* **7**:1-44.

In a review of major developmental findings comparing younger children, adolescents, and adults, this study refutes the notions (1) that adolescents believe they are invulnerable and (2) that they take more risks because they are unable to perceive and reason effectively about those risks. The authors develop the theory of "gist-based" reasoning and provide evidence that such gut-level decision making is a hallmark of mature, effective reasoning in adults. This study also challenges the notion that adolescents are homogeneous in their choices regarding risky situations. In fact, the authors find three distinct types among adolescent decision makers:

> "Mature young adults are already more able to use gist-based reasoning in making decisions, and though they generally appreciate verbatim information about risk taking, they use it less than gist-based thinking in making their own decisions. Risky Deliberators are more problematic for prevention programs, since they are likely to analyze the risk claims made by educators and deduce that they are faulty. For example, when confronted by the claim that drunk driving will kill you, a risky deliberator will discount it based on the reality that people he or she knows regularly drive drunk and are still alive. Risky Reactors are those adolescents most likely to perceive risk taking itself as rewarding, particularly in the presence of peers. These adolescents are the least likely to be affected by interventions because risk taking for them is spontaneous and disjoint from rational contemplation of risks and benefits." (p. 33)

The article recommends the development of psychometric instruments that include behavioral measures to successfully distinguish the different kinds of risk takers and avoiders. This would be crucial for matching adolescents with the kinds of programs that are likely to be effective for them.

Saddoris MP, Cacciapaglia F, Wightman RM, and Carelli RM (2015). **Differential dopamine release dynamics in the nucleus accumbens shell and core reveal complementary signals for error prediction and incentive motivation**. *Journal of Neuroscience*. 35:11572-11582.

This article demonstrates the functional differentiation within neural structures found to be critical in the mid-brain dopaminergic reward processing and prediction aspect of the dual-processing theory proposed by Steinberg (2008) and others. The article also reviews aspects of the development of the CC system, making the point that complex neural feedback systems including several brain structures are involved in learning and motivation. Thus, the development of cognitive control by adolescents appears to combine both neurophysiological development but also learning processes that contribute to maturation through the encoding at the level of fine structures.

Steinberg L (2008). **A social neuroscience perspective on adolescent risk-taking**. *Developmental Review*. **28**:78-106.

This article summarizes the dual-processing theory of adolescent neurocognitive development. A comprehensive review of major findings is integrated into a perspective complete with recommendations for limiting the potential outcomes of the high risk behaviors commonly observed among adolescents. Steinberg cites research showing the current informational and warning based programs (e.g., DARE) have been largely ineffective, and he shows that the work of cognitive scientists has contributed toward developing better "gist-based' models of mature decision making. He also reviews neurobiological research that used fMRI to demonstrate critical brain areas involved in these cognitive processes. Steinberg concludes: 'There is probably very little we can or ought to do to either attenuate or delay the shift in reward sensitivity that takes place at puberty, a developmental shift that likely has evolutionary origins. It may be possible to accelerate the maturation of self-regulatory competence, but no research has examined whether this can be done. We do know that individuals of the same age vary in their impulse control, "planfulness", and susceptibility to peer influence and those variations in these characteristics are related to variations in risky and antisocial behavior".

Smith AR, Chein J, Steinberg L (2014). **Peers increase adolescent risk taking even when the probabilities of negative outcomes are known**. *Developmental Psychology*. **50**:1564-1568.

This article updates Chein, et al. (2011) and provides new information regarding the nature of adolescent risk posed by the presence of peers. Specifically, in a probabilistic gambling task, adolescents who believed that they were being observed by peers in a neighboring room were significantly more likely to engage in high risk gambling than their peers who believed they were alone. Even though the odds of winning and losing in the game were made explicit to all participants, hyper-sensitization to the presence of peers induced excessive risk taking among those who believed that peers were watching them.