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Adolescent Brain Development and Drugs

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Abstract

New scientific discoveries have put a much different perspective on our understanding of adolescent behavior. Research now suggests that the human brain is still maturing during the adolescent years. The developing brain may help explain why adolescents sometimes make decisions that are risky and can lead to safety or health concerns, including unique vulnerabilities to drug abuse. This new science can be useful in revising prevention strategies to be more effective.

The emerging science of neuro-development is providing a new framework for viewing adolescent risk-taking, including decisions by young people to use alcohol and other drugs. This new research, aided by sophisticated brain imaging technology, has documented the surprising finding that the human brain is still maturing in significant ways during the adolescent years (Giedd, 2004). The way the brain develops during adolescence may help explain why youth sometimes make decisions that seem to be quite risky. Plus brain development research also shows that the maturing brain may be particularly vulnerable to the acute effects of drugs, and that drug use during adolescence may significantly increase a young person's risk for developing a substance use disorder later in life (Casey, Jones, & Hare, 2008).

This article will explore how adolescent brain development is a useful framework to understand adolescent drug use and abuse by looking at how brain development leads to risky behavior, how drugs affect brain development, and how we can use this knowledge in our prevention and intervention efforts. But first, we need to understand how the brain matures during adolescence.

What Neuroscience Says about Brain Maturation

The pioneering research of Jay Giedd and colleagues at the National Institute of Mental Health (Giedd, 2004) has produced evidence that the brain is still developing during adolescence and young adulthood. The brain grows an excessive number of connections between brain cells prior to adolescence, but at about age 11 or 12, the brain begins the processing of "sculpting" or pruning-back a significant proportion of these connections (Giedd, 2004). This pruning is a healthy process because it clears out unused wiring to make room for faster and potentially more efficient information processing. Also, pruning helps the brain to build the longer chains of nerve cells needed during adulthood for complex decision making. The pruning process appears to follow two general principles. One is the

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"use-it-or-lose-it" principle (Giedd, 2004), that is, the nerve cells that are frequently used during childhood are strengthened and the ones that are not activated or are infrequently used are eliminated. Dr. Giedd describes this principle in the following way: "Ineffective or weak connections are pruned in much the same way a gardener would prune a tree or bush, giving the plant the desired shape" (as quoted by Wallis, 2004; p. 58).

The second principle about the pruning process is that it tends to occur in the direction of back to front of the brain (Gogtay et al., 2004). The front area of the brain, particularly the pre-frontal cortex, is referred to as the "CEO of the brain." It is associated with logical reasoning and regulating impulses, and is the area believed to be primarily associated with guiding decisions that a person makes. During adolescent brain development, it is believed that the brain regions located further back, particularly the limbic region – which is associated with processing emotions and memories – matures earlier than the pre-frontal cortex region (Gogtay et al., 2004). As psychologist David Walsh writes, it is as if a teenager's brain has a fully functional car accelerator but the brakes have not been installed yet (Walsh, 2004, p. 72).

Implications for Understanding Adolescent Behavior

Scientists caution against drawing definite conclusions about the direct impact of brain development on adolescent behavior (Giedd, 2004). Human behavior has to also be considered in the context of social and cultural factors. However, it has been suggested that the non-uniform maturation pattern in which the limbic region (emotions) develops faster than the cortex region (reasoning) may significantly contribute to an increase in risk taking and novelty seeking by youth, particularly young teenagers (Dahl, 2004; Steinberg, 2004). Whereas risk taking during the teenage years may be normative and functionally adaptive as the adolescent strives for independence from adults, such behaviors may also contribute to an incentive to initiate drug use. Given the unique neurodevelopmental processes taking place during adolescence, trying out new experiences and taking risks (including drug use) is more likely among teenagers than among children and adults.

Furthermore, certain conditions may be ripe for risk taking by teenagers. These include situations in which a teenager is experiencing high emotion, in the presence of intense peer pressure, and faced with a perception that a short-term reward or positive outcome will be obtained. In these situations, the still-maturing "brake" circuitry in the front part of the brain may be particularly overwhelmed by the "accelerator" region compromising the ability to make thoughtful decisions (Reyna & Farley, 2006).

We know from experience that adolescents are capable of expressing and showing sound judgment, and their appraisal of risk is generally comparable to that of adults (Steinberg, 2004). Yet during highly emotionally situations, the teenager may be particularly prone to taking risks (Cohen et al., 2010). Adolescents, more so than adults, are more likely to be highly persuaded by the influences of peers (Steinberg, 2004). Also, because teenagers vary in their ability to control impulses control, these differences among youth in impulse regulation contribute to variability in risk taking (Iacono, Malone, & McGue, 2008).

However, we should not view adolescent-typical behaviors as always undesirable. From an evolutionarily perspective, adolescence is the period in which skills associated with independent living are acquired in order to successfully leave the protection of parents. From this perspective, engaging in high-risk behaviors may have had survival value as the young person, during the height of hormonal surges and the drive to seek out sexual partners, would leave the comfort of the home. Today, healthy forms of risk taking and novelty seeking can promote personal growth and create advantages in a competitive environment (Steinberg, 2008). It has been suggested that youthful risk taking behaviors

may even be necessary to successfully complete the brain pruning that leads to optimal efficient processing (Luna et al., 2001). In this light, healthy neurological development benefits from an environment whereby the adolescent has options for healthy and adult-supervised risk taking and novelty seeking.

The Developing Brain and Vulnerability to Drug Use

Developmental pathways of addiction most certainly involve several factors and processes, including the neurobiology of addiction, environmental factors, genes, and comorbidity (such as Conduct Disorder or Attention Deficit Hyperactivity Disorder) (Nestler & Malenka, 2004). However, insights about brain development provide additional clues as to why adolescence might be a particularly vulnerable period for developing a substance use disorder (Casey, Jones & Hare, 2008; Winters, 2009). As we have noted, brain maturation during adolescence may promote risk-taking and contribute to decisions to use drugs at an early age. Animal studies suggest that other biological factors may desensitize adolescents to the sedative effects of some substances (such as alcohol), compared to adults. Adolescent rats after alcohol consumption experience less disruption of motor function and less sedation than adult rats. A lowered sensitivity to the acute effects of alcohol by adolescents may contribute to high quantity drinking during the teenage years (Spear, 2002).

But the fact remains that several converging lines of evidence indicate that age is a risk factor that is associated with the onset of drug use during adolescence and young adulthood. Adolescence is a developmental period associated with the highest risk for developing a substance use disorder. Young people report higher rates of alcohol and marijuana abuse or dependence disorders compared to older age groups. Grant and colleagues (Grant et al., 2004) analyzed national data and found that among youth aged 15–20 years old, 12.2% met an official definition (DSM-IV; American Psychiatric Association, 1994) of an alcohol dependence disorder within the past 12 months. This rate was much higher than the other age groups (see Figure 1).

A related finding from epidemiological research is that the earlier the onset of drug use, the greater the likelihood that a person will develop a drug problem. For example, among youth who begin drinking at 11–12 years of age, 7.2% were found to have an alcohol use disorder (DSM-IV; American Psychiatric Association, 1994) within two years; for those who waited until age 21 to get drunk for the first time, the prevalence of an alcohol use disorder within two years after starting was 3.7% (Winters & Lee, 2008). Moreover, early age of onset rather than duration of use is a stronger predictor of the rapid progression of substance use disorders; individuals with earlier onset had a shorter time span from first exposure to dependence than did adult onset groups (Clark, Kirisci, & Tarter, 1998). Our focus here on age of onset of drug use as a risk factor is only part of the picture toward understanding the development of a substance use disorder. Indeed, other risk factors for drug abuse, such as delinquent peer influences, poor parental monitoring, and alcohol availability (Clark & Winters, 2002), may interact with early drug use to contribute to the progression toward a drug problem.

Drugs' Effects on the Brain

We do not know yet if or how drug abuse during adolescence affects the normal brain development processes, such as neuronal pruning. But there is a small but growing research literature suggesting that learning may be adversely affected by drug use during adolescence, particularly when use is frequent and heavy (Spear, 2002). Animal models have been used to examine this question. One has to be cautious in generalizing findings from animal research to understanding human behavior. However, animal models of drug use permit the use of research strategies that would not be ethical with humans, and animals

are affected by drugs in ways that are comparable to humans. For example rats show the acute effects of alcohol, including disruption in motor coordination, sedation, and social disinhibition (Spear, 2002). Animal studies from Linda Spear's lab have demonstrated that adolescent rats ingested with alcohol, compared to adult rats, reveal significantly more brain damage in their prefrontal cortex region (important for decision making) and in their working memory brain region (Spear, 2002). When adolescent rats have been repeatedly exposed to alcohol for a long-term period, they show dramatic brain damage in other brain areas, including regions associated with learning (basal forebrain) and language acquisition (neocortex). Human studies provide cautionary support to the animal findings that alcohol may deleteriously affect learning. Adolescents who have recently recovered from an alcohol dependence disorder revealed poorer performance on verbal and non-verbal memory compared to a control group with no history of alcohol dependence (Brown, Tapert, Granholm & Delis, 2000), and had reduced volume in the brain's memory region, the hippocampus; reduced volume is an indirect measure of memory ability (Tapert & Schweinsburg, 2005). Furthermore, there is a growing literature using adolescent animals that adolescents differ from adults in response to nearly all drugs of abuse, including nicotine, cannabis, and stimulants (Schepis, Adinoff, & Rao, 2008). This new body of science further reinforces concerns that all psychoactive substances can impact maturation during adolescence and may increase one's likelihood for developing a substance use disorder.

Informing Drug Prevention and Treatment with Brain Development Science

We contend that brain development science provides a valuable framework for optimizing the effectiveness of prevention and treatment programs and practices. This movement has already started in the context of how this science may help parents be more "prevention smart" when raising a child (e.g., books by David Walsh, *Why Do They Act the Way They Do?* and Laurence Steinberg, *You and Your Adolescent*). We address some possible applications of brain development science to prevention and treatment, including the parenting issue, below.

Reinforcing the Importance of Prevention and Treatment

The health significance of preventing drug use by youth and halting use if it starts is only further strengthened by the various risks created or, at minimum, enabled when a teenager with a developing brain uses drugs. The safest course for an adolescent is to refrain from all drug use while the brain is developing. A less ideal course is to delay the onset of drug use until as late as possible during the teenage years; doing so at least has the potential to reduce a young person's risk for developing a substance use disorder during adulthood. Of course, it is crucial for adolescents with a substance use disorder to reduce or abstain from use. The messages that highlight the social and legal consequences of drug use which reinforce the public health significance of prevention and treatment can now be bolstered with the consequences of early drug use on the developing brain.

Adjusting Prevention and Treatment Programs

There are several ways for prevention and treatment programs to integrate content and approaches based on the science of brain development. A major lesson from this science is that adolescents take risks in large part because their brain is wired to do so, and risk behaviors by teenagers may be evolutionally adaptive (Galvan et al., 2007). To simply educate youth about the dangers of risk-taking is a no-win struggle against biological processes. Teenagers need to be taught more refined decision-making skills to assist their "brake systems" to take control in the face of emotional and arousing situations, and when

peers are exerting a strong influence. In this light, we favor a focus on several teen-brain approaches for both prevention and treatment program:

1. teach youth about how their brain is developing (for a listing of resources, go to http://www.psychiatry.umn.edu/research/casar/);
2. encourage youth to engage in safe risk-taking, preferably with adult supervision and that engages the youth in personal growth rather than simply to satisfy the need arousal; and
3. promote a lifestyle that supports healthy brain development.

Whereas neuro-science has not yet provided any clear formulas for optimizing healthy brain maturation (Bruer, 1999), knowledge on the effects of drugs on the brain raises the strong possibility that using drugs during adolescence can interfere with healthy brain development and may cause significant alterations of normal processes (National Drug Institute on Drug Abuse, 2007).

It also stands to reason for programs and practices to focus heavily on teaching teenagers the skills that directly help them in decision making, particularly when they are faced with a situation that "challenges" the prefrontal cortex (for example, a social setting where peers are present and there are opportunities to take risks). Our research group is developing a "12-Step Program for Decision Making" for adolescents receiving drug treatment. We are hoping that a core component of treatment will explicitly teach these 12 decision-making skills, including impulse control, attention regulation, minimizing arousal, anger management, and taking healthy risks. One strategy we teach teenagers is the following: *red lig*ht - "pause and evaluate the situation;" *yellow light* - "consider several options and choose a suitable one;" and *green light* - "verbally and/or behaviorally respond with the choice you made, and evaluate the impact of your response."

Relevance to Parents

Educating parents about this new science of brain development can help them understand and respond to adolescent behavior. Below we provide some parenting tips that take into account the neuroscience of brain development.

Thoughtful Communication—The adolescent brain is still "under construction" and the teenager has a propensity to take risks. Parents will want to understand that this risk-taking is due to a brain maturational imbalance between competing brain systems (brakes and accelerator). In this light, parents need to be more tolerant of common annoying or even seriously compromising behaviors during adolescence. Rather than emotionally over-reacting to situations where the behavior of the adolescent was less than ideal, parents should engage in thoughtful communication about the situation. They should try to converse with the adolescent about his/her behavior and strongly encourage self-reflection about how the situation was handled, and how in the future the teenager could manage the situation in a different way. For example, the decision to get into a car with a friend who has been drinking is obviously a very risky behavior, but a very common one among adolescents and young adults. The problem lies in not being able to think through viable alternatives, especially when the adolescent has been drinking or using other drugs. Parents who discover that their adolescent has been a passenger in a vehicle where the driver was drinking can be rightfully upset, but must manage to use the situation as an example of how the adolescent's judgment was impaired and how he or she needs to think through situations much more carefully, especially those in which peers are involved, to avoid possibly life-threatening situations in the future.

Understand the Power of Peer Influence—Peers have a very strong influence on adolescents, including decisions to initiate and continue drug use, or try different types of drugs. Adolescents are likely to seek out risky behaviors, especially in the presence of their peers, despite knowing that their parents would disapprove of such behaviors (Steinberg, 2008). Rather than resigning themselves to the notion that they "do not matter as much as peers," parents should try to rise to the challenge of understanding how their child is influenced by particular peers and discussing the pros and cons of peer selection choices. Parents can get to know their adolescent's peer group and the parents of their natural peer group to try and set common rules such as curfews, disapproval of underage drinking, and unsupervised parties.

Science-based Messages—Parents now have more have scientific justification than ever for staying actively involved in their child's life throughout adolescence and into young adulthood. Teenagers tend to know what is right and wrong, so simply establishing rules and demanding compliance to them is not effective. Rather, parents need to focus on helping their teenager to anticipate settings and situations that give rise to risk behaviors, and making healthy choices in such situations.

Model Responsible Use—Brain development research reinforces the importance of raising a drug-free child. Responsible use of legal drugs by parents is an important component in support of this goal. Parents can still influence their child's risk of alcohol and other drug problems by their own patterns of alcohol and prescription drug use. For example, if parents do drink alcohol, modeling light to moderate patterns of consumption, not driving after drinking, and not encouraging underage drinking are all behaviors that will lessen the likelihood that an adolescent will develop a substance use problem later in life (Yu, 2003).

Summary

New scientific discoveries have put a much different perspective on our understanding of adolescent behavior. Research now suggests that the human brain is still maturing during the adolescent years and this neuro-development may promote risk-taking and novelty seeking. These traits may have had evolutionary value that promoted our survival as a human race. However, modern society provides an extended safety net for youth, with many young people living at home and remaining financially dependent on their parents long past the teenage years (Furstenburg, 2010). Thus, risk-taking behaviors once highly linked to survival value may now increase chances for harmful circumstances, including drug use and related drug problems (Kelley, Schochet, & Landry, 2004).

There are several lines of evidence suggesting that adolescents are uniquely susceptible to the short- and long-term effects of drugs. Early drug use may alter brain maturation, contribute to lasting cognitive impairment of certain functions, and significantly increase short- and long-term susceptibility for developing a substance use disorder. This body of science sharpens the urgency for prevention programs to promote a drug-free lifestyle and for drug-abusing youth to receive treatment earlier than later. An appreciation of adolescent brain development by parents, prevention specialists and treatment providers can inform responses to adolescent behavior, including drug use. We favor teen brain-friendly programs that focus on teaching decision-making skills to help adolescents face peer influences and situations that elicit emotions and arousal. This emerging science reinforces the importance of active parental involvement during adolescence and young adulthood, and the need to particularly focus on teaching and supporting decision-making skills for the teenager.

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Biographies

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Amelia M. Arria, Ph.D. received her undergraduate degree from Cornell University in Human Development and Family Studies, and a Ph.D. in Epidemiology from the University of Pittsburgh Graduate School of Public Health. She is the Principal Investigator of the College Life Study, a large NIDA-funded prospective study of college student health risk behaviors. She is the Scientific Director of the Parents' Translational Research Center at the Treatment Research Institute in Philadelphia, and collaborates with the Partnership for Drug Free America on new prevention initiatives. Her research focuses on the identification of risk and protective factors related to adolescent and young adult substance use. This article was supported in part by grants K02 DA15347 (Winters) and P50 DA027841 (Arria, Winters) from the National Institute on Health.

References

American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders. 4th ed.. Washington, DC: Author; 1994.

Brown SA, Tapert SF, Granholm E, Delis DC. Neurocognitive functioning of adolescents: Effects of protracted alcohol use. Alcoholism: Clinical and Experimental Research. 2000; 24:164–171.

Bruer, JT. The Myth of the First Three Years. NY: The Free Press; 1999.

Casey BJ, Jones RM, Hare TA. The adolescent brain. Annals of the New York Academy of Sciences. 2008; 1124:111–126. [PubMed: 18400927]

Clark DB, Kirisci L, Tarter RE. Adolescent versus adult onset and the development of substance use disorders in males. Drug and Alcohol Dependence. 1998; 49:115–121. [PubMed: 9543648]

Clark DB, Winters KC. Measuring risks and outcomes in substance use disorders prevention research. Journal of Consulting and Clinical Psychology. 2002; 70:1207–1223. [PubMed: 12472298]

Cohen JR, Asarnow RF, Sabb FW, Bilder RM, Bookheimer SY, Knowlton BJ, Poldrack RA. A unique adolescent response to reward prediction errors. Nature Neuroscience. 2010; 13:669–671.

Dahl, RE. Adolescent brain development: A period of vulnerabilities and opportunities. In: Dahl, RE.; Spear, LP., editors. Adolescent Brain Development: Vulnerabilities and Opportunities. Vol. vol. 1021. New York: Annals of the New York Academy of Sciences; 2004. p. 1-22.

Furstenburg F. Passage to adulthood. The Prevention Researcher. 2010; 17(2):3–7.

Galvan A, Hare TA, Voss H, Glover G, Casey BJ. Risk-taking and the adolescent brain: Who is at risk? Developmental Science. 2007; 10:F8–F14. [PubMed: 17286837]

Giedd, JN. Structural magnetic resonance imaging of the adolescent brain. In: Dahl, RE.; Spear, LP., editors. Adolescent Brain Development: Vulnerabilities and Opportunities. Vol. vol. 1021. New York: Annals of the New York Academy of Sciences; 2004. p. 77-85.

Gogtay N, Giedd JN, Luck L, Hayashi KM, Greenstein D, Vaituzis AC, et al. Dynamic mapping of human cortical development during childhood through early adulthood. Proceedings of the National Academy of Sciences. 2004; 101:8174–8179.

Grant BF, Dawson DA, Stinson FS, Chou P, Dufour MC, Pickering RP. The 12-month prevalence and trends in DSM-IV alcohol abuse and dependence: United States, 1991–1992 and 2001–2002. Drug and Alcohol Dependence. 2004; 74:223–234. [PubMed: 15194200]

Iacono WG, Malone SM, McGue M. Behavioral disinhibition and the development of early-onset addiction: Common and specific influences. Annals of Review of Clinical Psychology. 2008; 4:325–348.

Kelley, AE.; Schochet, T.; Landry, CF. Risk taking and novelty seeking in adolescence. In: Dahl, RE.; Spear, LP., editors. Adolescent Brain Development: Vulnerabilities and Opportunities. Vol. vol. 1021. New York: Annals of the New York Academy of Sciences; 2004. p. 23-32.

Luna B, Thulborn KR, Munoz DP, Merriam EP, Garver KE, Minshew NJ, et al. Maturation of widely distributed brain function subserves cognitive development. Neuroimage. 2001; 13:786–793. [PubMed: 11304075]

National Institute on Drug Abuse. Drugs, Brains, and Behavior – The Science of Addiction. 2007. (NIH Publication No. 07-5605). Retreived January 21, 2011, from http://www.drugabuse.gov/scienceofaddiction/

Nestler EJ, Malenka RC. The addicted brain. Scientific American. 2004 Mar.290:78–85. [PubMed: 14981881]

Reyna V, Farley F. Risk and rationality in adolescent decision making: Implications for theory, practice, and public policy. Psychological Science in the Public Interest. 2006; 7:1–44.

Schepis TS, Adinoff B, Rao U. Neurobiological processes in adolescent addictive disorders. The American Journal on Addictions. 2008; 17:6–23. [PubMed: 18214718]

Spear LP. The adolescent brain and age-related behavioral manifestations. Neuroscience and Biobehavioral Reviews. 2002; 24:417–463. [PubMed: 10817843]

Steinberg, L. Risk taking in adolescence: What changes and why?. In: Dahl, RE.; Spear, LP., editors. Adolescent Brain Development: Vulnerabilities and Opportunities. Vol. vol. 1021. New York: Annals of the New York Academy of Sciences; 2004. p. 51-58.

Steinberg L. A social neuroscience perspective on adolescent risk taking. Science Direct Developmental Review. 2008; 28:78–106.

Tapert, S.; Schweinsburg, AD. The human adolescent brain and alcohol use disorders. In: Galanter, M., editor. Recent Developments in Alcoholism: Vol XVII. Washington D.C: American Psychiatric Press; 2005. p. 177-197.

Wallis C. What makes teens tick? Time. 2004 May 10.163:57–65.

Walsh, D. Why Do They Act That Way? A Survival Guide to the Adolescent Brain for You and Your Teen. New York: Free Press; 2004.

Winters KC. Adolescent brain development and alcohol abuse. The Journal of Global Drug Policy and Practice. 2009 Fall;:3. http://www.globaldrugpolicy.org/.

Winters KC, Lee S. Likelihood of developing an alcohol and cannabis use disorder during youth: Association with recent use and age. Drug and Alcohol Dependence. 2008; 92:239–247. [PubMed: 17888588]

Yu J. The association between parental alcohol-related behaviors and children's drinking. Drug and Alcohol Dependence. 2003; 69:253–262. [PubMed: 12633911]

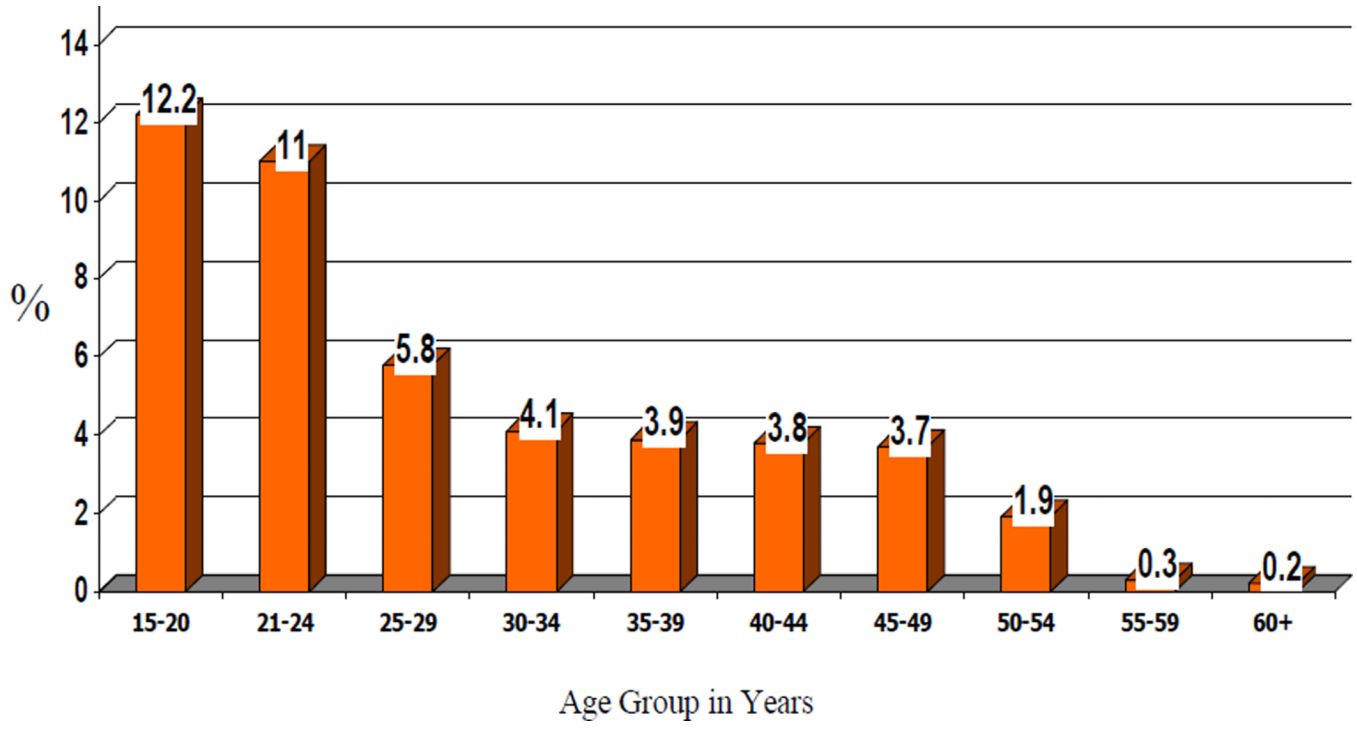

Figure 1.
Prevalence of Past-Year DSM-IV Alcohol Dependence: United States, 2001–2002 (Grant et al., 2004)