Published in final edited form as:

Curr Addict Rep. 2019 December ; 6(4): 437–442. doi:10.1007/s40429-019-00287-7.

Behavioral Treatments for Adolescent Cannabis Use Disorder: a Rationale for Cognitive Retraining

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Abstract

Purpose of Review—Adolescent cannabis use represents a significant public health concern. Cannabis experimentation typically begins in adolescence and increases the odds of meeting criteria for cannabis use disorder. Cannabis use disorder is associated with numerous short- and long-term adverse consequences for adolescents, highlighting the critical need for efficacious behavioral treatments. This brief review aims to synthesize the state of the behavioral treatment literature on adolescents with cannabis use disorder and to discuss new pathways to leverage neuroscience to inform novel targets for behavioral intervention.

Recent Findings—To date, effective treatment options for adolescent cannabis use disorder that have been tested in randomized controlled trials include cognitive behavioral therapy, motivational enhancement therapy, and multidimensional family therapy. However, established behavioral treatment approaches focus on higher-order cognitive control and have only been modestly effective.

Summary—There is a need to develop new pathways that translate neuroscience findings into novel targets for behavioral interventions.

Keywords

Adolescent; Cannabis use disorder; Neuroscience; Brain; Behavioral treatment; Cognitive bias modification; Cue-reactivity

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Conflict of Interest Dr. Gray reports consulting work for Pfizer, Inc., outside of the submitted work. Dr. Lees, Dr. Jacobus, Dr. Squeglia, Dr. Aguinaldo, and Dr. Tomko declare no conflicts of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

Introduction

A substantial number of adolescents use cannabis, posing a significant public health concern both globally [1] and locally [2]. The 2017 Youth Risk Behavior Surveillance Study found that 36% of 9th–12th graders in the United States (U.S.) report lifetime use of cannabis [3] and approximately 6% of high school seniors report daily use [4]. Notably, the 2017 National Survey on Drug Use and Health in the U.S. reported that 2.2% of adolescents met the criteria for CUD based on the Diagnostic and Statistical Manual of Mental Health Disorders, DSM-IV [3, 5].

The shifting landscape of medicinal and recreational use of cannabis in the U.S. is coupled with increased approval of use and decreased perception of harm [4, 6, 7]. In a nationally representative survey of U.S. adolescents conducted in 2018, about 27% of 12th graders reported their perception of regular cannabis use as harmful (compared with about 60% two decades ago) [4]. To date, cannabis is the second most commonly used intoxicant after alcohol in adolescents and is the most commonly used substance (75%) post-discharge from substance use treatment [2, 8]. Decreasing perception of harm, increasing cannabis legalization, and high prevalence use rates in adolescent community and clinical populations are concerning, especially since adolescents who initiate cannabis use before age 18 are four to seven times more likely to develop a cannabis use disorder (CUD) and may be at greater risk for poor cognitive and psychological functioning [9–12].

To date, effective treatment options for adolescent CUDs that have been tested in randomized controlled trials are sparse and include cognitive behavioral therapy (CBT), motivational enhancement therapy (MET), and multidimensional family therapy (MDFT) [13]. Even with several behavioral treatment options available, effect sizes are modest, suggesting there is a need for improvement in the treatment of CUD in adolescence. Advances in adolescent cannabis research have facilitated a better understanding of the effects of CUD on the adolescent brain. By leveraging insights from the neuroscience literature, there is a potential to redefine novel targets for intervention and advance the efficacy of treatment for CUD in adolescents. This brief review aims to synthesize the state of the behavioral treatment literature on adolescents with CUD and to discuss new pathways to leverage the neuroscience literature to inform novel targets for behavioral intervention.

Adverse Effects of Cannabis

Adolescence is a critical period of rapid physiological, psychological, and neurocognitive development, coinciding with increased cannabis use [14–16]. Cannabis use during adolescence is associated with changes in brain development, neural functioning, and neurocognitive performance (i.e., learning, memory, executive functioning, and processing speed) [17, 18]. Academic adverse consequences have been linked to cannabis use, including academic unpreparedness, unsatisfactory academic performance, and increased delinquency [19]. Studies have also shown an association between cannabis use during adolescence and psychiatric disorders [20–24]. Moreover, heavy use of cannabis during adolescence has been linked to psychosocial problems later in life, including lower-income,

greater need for socio-economic assistance, unemployment, and lower life satisfaction in adulthood [25].

Short- and long-term emotional and physical symptoms associated with reducing and/or stopping cannabis use often result in continued use despite adverse consequences [26]. A cluster of abstinence symptoms, termed cannabis withdrawal syndrome (CWS), is recognized in the DSM-5 [27] and is common among adolescents in treatment. Approximately 40 to 75% of adolescents who have sought treatment for CUD experienced CWS [28, 29] and rates are even higher among adolescents with comorbid psychiatric conditions [30]. The presentation of CWS typically includes changes in emotions (i.e., anxiety, depressed mood, and irritability), a sensation of restlessness, decreased appetite, sleep difficulty, and cannabis craving. CWS usually peaks within the initial week of abstinence and symptoms can ensue for as long as 1 month. Though some research suggests that CWS is associated with relapse among adolescents [30], other studies have found that the presence of CWS was not associated with frequency of cannabis use following treatment [31, 32].

Efficacious Behavioral Treatments for Cannabis Use Disorder

To date, relatively few behavioral treatments have been tested in randomized controlled trials specifically tailored to adolescents diagnosed with CUD. The Cannabis Youth Treatment (CYT) investigation was a multi-site study consisting of two randomized clinical trials. The study aimed to test the efficacy and cost-effectiveness of five short-term interventions across four U.S. study sites with 600 adolescents, aged 12 to 18, who self-reported one or more DSM-IV criteria for cannabis abuse or dependence [5, 33]. The two primary outcomes of the study included days of abstinence over a 12-month follow-up period and the percent of adolescents in recovery (i.e., living in the community, abstinent, and no longer meeting criteria for a substance use disorder) at follow-up. In the first trial, participants were randomized into three different treatment groups. The first group received MET/CBT5 (n = 102), comprised of two individual MET sessions and three group CBT sessions, with the total duration of treatment lasting 6 to 7 weeks. The second group received MET/CBT12 (n = 96), which extended MET/CBT5 with seven additional CBT sessions in a group format, with the combined duration lasting 12 to 14 weeks. The third group received MET/CBT12/Family Support Network (FSN; n = 102), which extended MET/CBT12 by adding an FSN focus which included six parent education group meetings, four therapeutic home visits, referral to self-help support groups, and care coordination. In the second trial of the CYT study, participants were randomized into three different groups. The first group received MET/CBT5 (n = 100), as designed in trial one, and the second group received the adolescent community reinforcement approach (ACRA; n = 100). ACRA includes a combination of operant conditioning, skills training, and a social systems approach. MET/CBT5 included ten individual sessions with the adolescent, four sessions with caregivers (two of which are with the whole family), and a limited amount of case management over a period of 12 to 14 weeks. The third group received Multidimensional Family Therapy (MDFT; n = 100), to include 12 to 15 sessions (six with the adolescent, three with parents, and six with the whole family), and case management provided over a period of 12 to 14 weeks. In both trials, all groups improved in days of abstinence and percentage in recovery, and there were no

significant between-group effects (effect sizes were generally small, Cohen's $f = 0.1$). MET/CBT5 was the most cost-effective in trial one, and ACRA was the most cost-effective in trial two [33].

A 2011 treatment study conducted in the Netherlands enrolled 109 adolescents, aged 13 to 18, from two substance abuse treatment sites [34]. Participants self-reported a history of cannabis abuse or dependence in the year prior based on the Diagnostic and Statistical Manual of Mental Disorders, DSM-IV, criteria [5] and recent, daily cannabis use (≥ 26 days in the 90 days preceding baseline interview). Participants were randomized to receive either CBT (control group; $n = 54$) or MDFT (experimental group; $n = 55$), and complete follow-up assessments at four additional time points (3, 6, 9, and 12 months post-treatment). The CBT control group included 5 to 6 months of weekly outpatient therapy for 1 h with the adolescent and one family session a month for an hour. The individual adolescent sessions focused on motivation to change: (a) substance addictive behavior, (b) maladaptive behaviors, and (c) cognitions, through skills training and relapse prevention. The monthly family sessions were psycho-education and support focused. The MDFT experimental group comprised of 5 to 6 months of weekly outpatient therapy, for 2 h, with the adolescent, parent(s) and/or family, and school, courts, or other involved systems. The treatment was family-based and developmentally tailored to the adolescent's cannabis use while also targeting the adolescent's relationships with parents, family members, and systems that influenced the adolescents use (i.e., school, work, drug-using peers, and juvenile justice system). The study's primary outcome measure was the frequency of cannabis use (i.e., days of cannabis use and the number of joints smoked) in the 3 months since the last follow-up interview. Additional outcome measures included the percentage of treatment responders, percentage of recovered adolescents, number of property and violent crimes committed in the 3 months prior, and treatment retention [34]. MDFT (experimental group) did not report less cannabis use and/or cannabis-related behaviors as compared with CBT (control group) on any of the outcome measures. Adolescents in both treatment groups demonstrated substantial decreases in cannabis use and delinquency from baseline to 1-year follow-up, with treatment effects in the moderate range (Cohen's $d = 0.39–0.61$) [34].

The aforementioned studies are the only two investigations that have relied on randomized controlled trial design to test the efficacy of behavioral treatments specifically for adolescents with CUD. In summary, the current behavioral treatment options available that are tailored specifically for adolescent CUD are limited. They require active participation, some degree of higher-order cognitive control (e.g., CBT, MET, and MDFT), and have only been modestly effective [13, 33, 34]. In both randomized controlled trials described above, relapse rates remained relatively high 12 months post-treatment, across all treatment modalities (e.g., CBT, MET, and MDFT). In CYT (CBT/MET/MDFT), 50% of the participants experienced periods of recovery and relapse one or more times post-discharge, and about 67% reported substance use or related problems at the 12-month follow-up interview [33]. In the 2011 treatment study conducted in the Netherlands, participants used cannabis on 70% of days leading up to treatment and 50% of days at 12-month follow-up [34]. No treatment has been found to be superior for treating adolescents with CUD [34]. Existing treatments are limited and leave considerable room for improvement. Research that

focuses on how to supplement behavioral treatments with cost-effective, low burden, and accessible adjunctive treatments is needed.

Neuroscience Informed Behavioral Treatments

Cannabis use is linked to brain-based vulnerabilities in reward networks that influence cognitive control [35–37]. Thus, brain-based interventions that test novel neural targets and implicit neural processes could be an adjunct treatment option for adolescents with CUD [38–42]. Cognitive bias modification (CBM) paradigms have been developed to target and modify maladaptive cognitive biases (e.g., approach bias, attention bias) and have proven to be efficacious [43–45]. Computerized approach avoidance training (CAAT) is a computerized training program that focuses on modifying approach bias, which is the implicit bias to either approach or avoid a cannabis cue [46]. CAAT is cost-effective and accessible, thus making it a potentially suitable adjunct to psychosocial treatment. CAAT has been tested in several investigations with adult alcohol users and findings suggest that successful modification of approach bias towards alcohol cues is linked to decreased alcohol intake [47]. Promising findings have been reported in studies of community and clinical alcohol-dependent populations, and via online interventions, with 30% less alcohol relapse at 2 weeks post-treatment and up to 13% less relapse a full year post-training [43, 47, 48].

CAAT may be a particularly relevant treatment approach for adolescents with CUD since adolescents' cannabis use is highly dependent on setting and social context [49–51]. Exposure to cannabis and related paraphernalia and the expectation of cannabis provokes greater cravings among adolescent cannabis users relative to adults [52]. Our group conducted a multi-site pilot investigation of CAAT in a heavy cannabis-using adolescent sample [53]. Eighty non-treatment-seeking heavy cannabis users (ages 17–21) were recruited at two sites (California and South Carolina) and were randomized to complete six sessions of CAAT (experimental group) or CAAT-sham (control group), twice a week for 3 weeks. Heavy cannabis use was defined as a pattern of weekly cannabis use that was greater than or equal to one use per week for 52 weeks before study enrollment. The primary outcomes of this investigation included changes in cannabis approach bias and percent cannabis use days over study enrollment. This investigation demonstrated that the group receiving CAAT decreased approach bias towards cannabis cues and decreased cannabis use compared with the CAAT-sham group after 3 weeks of treatment [53]. While not statistically significant, greater cannabis avoidance bias from baseline to post-CAAT treatment was related to a trend-level decrease in cannabis use during treatment ($r = 0.21$; $p = 0.07$), suggesting a possible mechanism for changes in substance use. A subsample ($n = 40$) of adolescents from the larger randomized controlled trial completed a cannabis cue–reactivity task pre- and post-CAAT or sham training during a functional MRI scan. No significant cannabis cue-induced neural response changes were found pre- to post-CAAT training in either the experimental or sham condition. Some evidence was found that the experimental manipulation condition (i.e., CAAT) generated small-to-medium-sized cue-induced reductions in neural activation in the amygdala and prefrontal cortex despite the lack of statistical significance. It is possible that the relatively small sample size limited the ability to observe a significant group by time interaction in cue-induced neural activation. The lack of inclusion of treatment seekers, personally relevant cannabis cues, and a substantial

reduction in cannabis use in the substudy sample may also contribute to the lack of neuroimaging findings. Cannabis cues vary greatly, and cannabis consumption patterns are rapidly evolving (i.e., concentrates, edibles, vaping). Given this, it is critical that cues are personalized specifically for cannabis users that are relevant for adolescents. Continued research with larger sample sizes and cannabis cues that are personalized to match an individual's preferred product type and consumption pattern (e.g., flower, concentrate, edible) are warranted to explore potential mechanisms of CAAT as a treatment for adolescent CUD [54, 55].

Conclusion

Brain maturation continues throughout adolescence and cannabis has the potential to interrupt this critical stage of brain development, thus leading to substantial short- and long-term adverse consequences. The current behavioral treatments (CBT, MET, and MDFT) tailored specifically for adolescent CUD populations are limited, focus on higher cognitive control, and are only modestly effective. Our understanding of the effects of cannabis on the developing adolescent brain needs to be translated into the current behavioral treatment options. By developing novel targets for efficacious and accessible behavioral interventions, we can pave the way for translational neuroscience in preventing and treating adolescent CUD. Cognitive bias modification paradigms such as CAAT are potentially promising adjunct behavioral treatment option that leverage cognitive neuroscience, meriting testing via larger randomized controlled trials in adolescents with CUD [56].

Acknowledgments

Funding Information This work was supported by the National Institute on Drug Abuse, National Institute on Alcohol Abuse and Alcoholism, Eunice Kennedy Shriver National Institute of Child Health and Human Development grants, K12 DA031794, K23 AA025399, T32 AA013525, K23 AA025399, U01 DA041089, U01 DA041093, R21 DA047953, R01 DA042114, U01 DA041093, K12 HD055885, California Tobacco-Related Disease Research Grants Program Office of the University of California Grant 580264, and the National Health and Medical Research Council Postgraduate Scholarship Grant 1169377.

References

1. World Health Organization. Management of substance abuse: cannabis. World Drug Report 2018.
2. National Institute on Drug Abuse. Nationwide trends. 2018 Retrieved from https://www.drugabuse.gov/publications/drugfacts/nationwide-trends Accessed 12 Aug 2019.
3. National survey on drug use and health [database on the Internet]. Substance Abuse and Mental Health Services Administration. 2018 Available from: https://www.samhsa.gov/data/sites/default/files/cbhsq-reports/NSDUHDetailedTabs2018R2/NSDUHDetTabsSect5pe2018.htm. Accessed 31 Aug 2019.
4. Johnston LD, Miech RA, O'Malley PM, Bachman JG, Schulenberg JE, Patrick ME. Monitoring the future national survey results on drug use, 1975-2017: overview, key findings on adolescent drug use. 2018.
5. Diagnostic and statistical manual of mental disorders: DSM-IV. Fourth edn Washington, DC: American Psychiatric Association, 1994.
6. Center PR. In debate over legalizing marijuana, disagreement over drug's dangers. 2015.
7. Hurd YL, Michaelides M, Miller ML, Jutras-Aswad D. Trajectory of adolescent cannabis use on addiction vulnerability. Neuropharmacology. 2014;76(Pt B):416–24. 10.1016/j.neuropharm.2013.07.028. [PubMed: 23954491]

8. Mutter R, Ali M, Strashny A. Profile of adolescent discharges from substance abuse treatment. The CBHSQ Report: Substance Abuse and Mental Health Services Administration (US); 2013 https://www.ncbi.nlm.nih.gov/books/NBK343539/
9. National Institute on Drug Abuse. Is marijuana addictive? 2019.
10. Scott JC, Slomiak ST, Jones JD, Rosen AFG, Moore TM, Gur RC. Association of cannabis with cognitive functioning in adolescents and young adults: a systematic review and meta-analysis. JAMA Psychiatry. 2018;75(6):585–95. 10.1001/jamapsychiatry.2018.0335. [PubMed: 29710074]
11. Gobbi G, Atkin T, Zytynski T, Wang S, Askari S, Boruff J, et al. Association of cannabis use in adolescence and risk of depression, anxiety, and suicidality in young adulthood: a systematic review and meta-analysis; 2019 10.1001/jamapsychiatry.2018.4500.
12. Di Forti M, et al. Daily use, especially of high-potency cannabis, drives the earlier onset of psychosis in cannabis users. Schizophr Bull. 2014;40(6):1509–17. [PubMed: 24345517]
13. Sherman BJ, McRae-Clark AL. Treatment of cannabis use disorder: current science and future outlook. Pharmacotherapy. 2016;36(5):511–35. 10.1002/phar.1747. [PubMed: 27027272]
14. Casey BJ, Jones RM. Neurobiology of the adolescent brain and behavior: implications for substance use disorders. J Am Acad Child Adolesc Psychiatry. 2010;49(12):1189–201; quiz 285 10.1016/j.jaac.2010.08.017. [PubMed: 21093769]
15. Gray KM, Squeglia LM. Research Review: What have we learned about adolescent substance use? J Child Psychol Psychiatry. 2018;59(6):618–27. 10.1111/jcpp.12783. [PubMed: 28714184]
16. Keyes KM, Rutherford C, Miech R. Historical trends in the grade of onset and sequence of cigarette, alcohol, and marijuana use among adolescents from 1976-2016: Implications for "Gateway" patterns in adolescence. Drug Alcohol Depend. 2019;194:51–8. 10.1016/j.drugalcdep.2018.09.015. [PubMed: 30399500]
17. Blest-Hopley G, Giampietro V, Bhattacharyya S. Regular cannabis use is associated with altered activation of central executive and default mode networks even after prolonged abstinence in adolescent users: results from a complementary meta-analysis. Neurosci Biobehav Rev. 2019;96:45–55. 10.1016/j.neubiorev.2018.10.026. [PubMed: 30395923]
18. Scott JC, Slomiak ST, Jones JD, Rosen AFG, Moore TM, Gur RC. Association of cannabis with cognitive functioning in adolescents and young adults: a systematic review and meta-analysis. JAMA Psychiatry. 2018;75(6):585–95. 10.1001/jamapsychiatry.2018.0335. [PubMed: 29710074]
19. D'Amico EJ, Tucker JS, Miles JN, Ewing BA, Shih RA, Pedersen ER. Alcohol and marijuana use trajectories in a diverse longitudinal sample of adolescents: examining use patterns from age 11 to 17 years. Addiction. 2016;111(10):1825–35. 10.1111/add.13442. [PubMed: 27130360]
20. Chadwick B, Miller ML, Hurd YL. Cannabis use during adolescent development: susceptibility to psychiatric illness. Front Psychiatry. 2013;4:129 10.3389/fpsyt.2013.00129. [PubMed: 24133461]
21. Gobbi G, Atkin T, Zytynski T, Wang S, Askari S, Boruff J, et al. Association of cannabis use in adolescence and risk of depression, anxiety, and suicidality in young adulthood: a systematic review and meta-analysis; 2019 10.1001/jamapsychiatry.2018.4500.
22. Hall W What has research over the past two decades revealed about the adverse health effects of recreational cannabis use? Addiction. 2015;110(1):19–35. 10.1111/add.12703.
23. Jacobus J, Squeglia LM, Escobar S, McKenna BM, Hernandez MM, Bagot KS, et al. Changes in marijuana use symptoms and emotional functioning over 28-days of monitored abstinence in adolescent marijuana users. Psychopharmacology. 2017;234(23-24):3431–42. 10.1007/s00213-017-4725-3. [PubMed: 28900686]
24. Zehra A, Burns J, Liu CK, Manza P, Wiers CE, Volkow ND, et al. Cannabis addiction and the brain: a review. J NeuroImmune Pharmacol. 2018;13(4):438–52. 10.1007/s11481-018-9782-9. [PubMed: 29556883]
25. Meier MH, Caspi A, Ambler A, Harrington H, Houts R, Keefe RSE, et al. Persistent cannabis users show neuropsychological decline from childhood to midlife. Proc Natl Acad Sci. 2012;109(40):E2657–E64. 10.1073/pnas.1206820109. [PubMed: 22927402]
26. Simpson AK, Magid V. Cannabis use disorder in adolescence. Child Adolesc Psychiatr Clin N Am. 2016;25(3):431–43. 10.1016/j.chc.2016.03.003. [PubMed: 27338965]

27. American Psychiatric Association. Diagnostic and statistical manual of mental disorders: DSM-5 In: Diagnostic and statistical manual of mental disorders. 5th ed Arlington: American Psychiatric Association; 2013.

28. Greene MC, Kelly JF. The prevalence of cannabis withdrawal and its influence on adolescents' treatment response and outcomes: a 12-month prospective investigation. J Addict Med. 2014;8(5):359–67. 10.1097/adm.0000000000000064. [PubMed: 25100311]

29. Vandrey R, et al. Cannabis withdrawal in adolescent treatment seekers. Drug Alcohol Depend. 2005;78(2):205–10. [PubMed: 15845324]

30. Cornelius JR, et al. Cannabis withdrawal is common among treatment-seeking adolescents with cannabis dependence and major depression, and is associated with rapid relapse to dependence. Addict Behav. 2008;33(11):1500–5. [PubMed: 18313860]

31. Greene MC, Kelly JF. The prevalence of cannabis withdrawal and its influence on adolescents' treatment response and outcomes: a 12-month prospective investigation. J Addict Med. 2014;8(5):359–67. 10.1097/adm.0000000000000064. [PubMed: 25100311]

32. Chung T, et al. Cannabis withdrawal predicts severity of cannabis involvement at 1-year follow-up among treated adolescents. Addiction. 2008;103(5):787–99. [PubMed: 18412757]

33. Dennis M, Godley SH, Diamond G, Tims FM, Babor T, Donaldson J, et al. The Cannabis Youth Treatment (CYT) study: main findings from two randomized trials. J Subst Abus Treat. 2004;27(3:197–213. 10.1016/j.jsat.2003.09.005•• This is an essential multi-site study consisting of two randomized controlled trials that examined the effectiveness of motivational enhancement therapy (MET), cognitive behavioral therapy (CBT), family support network, adolescent community reinforcement approach (ACRA) and multidimensional family therapy, for the treatment of adolescent cannabis use disorder. The results found that participants in all treatment groups showed similar outcomes, with the most cost-effective being 5 sessions of MET/CBT and 12 sessions of MET/CBT and ACRA.

34. Hendriks V, van der Schee E, Blanken. Treatment of adolescents with a cannabis use disorder: main findings of a randomized controlled trial comparing multidimensional family therapy and cognitive behavioral therapy in the Netherlands. Drug Alcohol Depend. 2011;119(1-2):64–71. 10.1016/j.drugalcdep.2011.05.021 [PubMed: 21684088] •• This is an important randomized controlled trial examining multidimensional family therapy and cognitive behavioral therapy, as treatments for adolescent cannabis use disorder. The results found that participants in both treatment groups showed decreases in cannabis use, and neither treatment modality was superior to the other.

35. Lorenzetti V, Solowij N, Fornito A, Lubman DI, Yucel M. The association between regular cannabis exposure and alterations of human brain morphology: an updated review of the literature. Curr Pharm Des. 2014;20(13):2138–67. 10.2174/13816128113199990435. [PubMed: 23829361]

36. Hammond CJ, Mayes LC, Potenza MN. Neurobiology of adolescent substance use and addictive behaviors: treatment implications. Adolesc Med State Art Rev. 2014;25(1):15–32. [PubMed: 25022184]

37. Lichenstein SD, Musselman S, Shaw DS, Sitnick S, Forbes EE. Nucleus accumbens functional connectivity at age 20 is associated with trajectory of adolescent cannabis use and predicts psychosocial functioning in young adulthood. Addiction. 2017;112(11):1961–70. 10.1111/add.13882. [PubMed: 28547854]

38. Boyce CA, Lynne-Landsman SD. Integrating translational neuroscience to improve drug abuse treatment for adolescents. Psychol Addict Behav. 2013;27(2):547–51. 10.1037/a0032434. [PubMed: 23815451]

39. Feldstein Ewing SW, Chung T. Neuroimaging mechanisms of change in psychotherapy for addictive behaviors: emerging translational approaches that bridge biology and behavior. Psychol Addict Behav. 2013;27(2):329–35. 10.1037/a0031491. [PubMed: 23815447]

40. Morgenstern J, Naqvi NH, Debellis R, Breiter HC. The contributions of cognitive neuroscience and neuroimaging to understanding mechanisms of behavior change in addiction. Psychol Addict Behav. 2013;27(2):336–50. 10.1037/a0032435. [PubMed: 23586452]

41. Onken LS. Cognitive training: targeting cognitive processes in the development of behavioral interventions. Clin Psychol Sci. 2015;3(1):39–44. 10.1177/2167702614561512.

42. Verdejo-Garcia A Cognitive training for substance use disorders: neuroscientific mechanisms. Neurosci Biobehav Rev. 2016;68:270–81. [PubMed: 27236041]
43. Wiers RW, Eberl C, Rinck M, Becker ES, Lindenmeyer J. Retraining automatic action tendencies changes alcoholic patients' approach bias for alcohol and improves treatment outcome. Psychol Sci. 2011;22(4):490–7. 10.1177/0956797611400615. [PubMed: 21389338]
44. Manning V, Staiger PK, Hall K, Garfield JBB, Flaks G, Leung D, et al. Cognitive bias modification training during inpatient alcohol detoxification reduces early relapse: a randomized controlled trial. Alcohol Clin Exp Res. 2016;40(9):2011–9. 10.1111/acer.13163. [PubMed: 27488392]
45. Kakoschke N, Kemps E, Tiggemann M. Approach bias modification training and consumption: a review of the literature. Addict Behav. 2017;64:21–8. 10.1016/j.addbeh.2016.08.007. [PubMed: 27538198]
46. Gladwin TE, Wiers CE, Wiers RW. Chapter 15 - Cognitive neuroscience of cognitive retraining for addiction medicine: from mediating mechanisms to questions of efficacy. In: Ekhtiari H, Paulus MP, editors. Prog Brain Res: Elsevier; 2016;224:323–44. [PubMed: 26822365]
47. Eberl C, Wiers RW, Pawelczack S, Rinck M, Becker ES, Lindenmeyer J. Approach bias modification in alcohol dependence: do clinical effects replicate and for whom does it work best? Dev CognitNeurosci. 2013;4:38–51. 10.1016/j.dcn.2012.11.002.
48. Sharbanee JM, Hu L, Stritzke WGK, Wiers RW, Rinck M, MacLeod C. The effect of approach/avoidance training on alcohol consumption is mediated by change in alcohol action tendency. PLoS ONE. 2014;9(1):e85855 10.1371/journal.pone.0085855. [PubMed: 24465750]
49. Creswell KG, et al. Solitary cannabis use in adolescence as a correlate and predictor of cannabis problems. Drug Alcohol Depend. 2015;156:120–5. [PubMed: 26365838]
50. McCabe SE, et al. Social contexts of substance use among U.S. high school seniors: a multicohort national study. J Adolesc Health. 2014;55(6):842–4. [PubMed: 25156895]
51. Tucker JS, et al. Does solitary substance use increase adolescents' risk for poor psychosocial and behavioral outcomes? A 9-year longitudinal study comparing solitary and social users. Psychol Addict Behav. 2006;20(4):363–72. [PubMed: 17176171]
52. Mokrysz C, Freeman TP, Korkki S, Griffiths K, Curran HV. Are adolescents more vulnerable to the harmful effects of cannabis than adults? A placebo-controlled study in human males. Transl Psychiatry. 2016;6(11):e961 10.1038/tp.2016.225. [PubMed: 27898071]
53. Jacobus J, Taylor CT, Gray KM, Meredith LR, Porter AM, Li I, et al. A multi-site proof-of-concept investigation of computerized approach-avoidance training in adolescent cannabis users. Drug Alcohol Depend. 2018;187:195–204. 10.1016/j.drugalcdep.2018.03.007 [PubMed: 29679914] •• In this important multi-site proof-of-concept study, our group examined computerized approach avoidance training (CAAT) with heavy cannabis using adolescents. The results provide preliminary support for continued research of CAAT with larger adolescent sample sizes.
54. Karoly HC, Schacht JP, Jacobus J, Meredith LR, Taylor CT, Tapert SF, et al. Preliminary evidence that computerized approach avoidance training is not associated with changes in fMRI cannabis cue reactivity in non-treatment-seeking adolescent cannabis users. Drug Alcohol Depend. 2019;200:145–52. 10.1016/j.drugalcdep.2019.04.007. [PubMed: 31132681]
55. Wilson J, Freeman TP, Mackie CJ. Effects of increasing cannabis potency on adolescent health. Lancet Child Adolesc Health. 2019;3(2):121–8. 10.1016/s2352-4642(18)30342-0. [PubMed: 30573419]
56. Terry-McElrath YM, O'Malley PM, Johnston LD, Schulenberg JE. Young adult longitudinal patterns of marijuana use among US National samples of 12th grade frequent marijuana users: a repeated-measures latent class analysis. Addiction. 2019;114(6):1035–48. 10.1111/add.14548. [PubMed: 30614105]

Key points

1. Adolescence is a developmental period of rapid physiological, psychological, and neurocognitive changes that often coincides with the experimentation and use of cannabis.
2. Adolescent cannabis use disorder leads to short- and long-term adverse consequences. However, behavioral treatment options are limited and have only been modestly effective.
3. Further research is needed to translate neuroscience research and enhance behavioral treatments to reduce the considerable public health burden of adolescent cannabis use disorder.