Research Article

A Meta-Analysis of Cannabis Research: Evidence of Lasting Neurocognitive Effects Continues to be Lacking

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ABSTRACT

Objective: There have been widespread increases in cannabis use as recreational and medical use has become legal across the globe. Changes to the chemical makeup of cannabis may have changed residual effects experienced by individuals who use cannabis, and more individuals may be affected. **Method:** We conducted a meta-analysis examining the neurocognitive effects of cannabis after abstinence lasting a period of at least 25 days (Prospero: CRD42023466560). Databases used were PsychInfo, PsycArticles, PubMed, and Medline. Previous research has reported mixed results, with some studies finding significant differences between abstinent individuals who use cannabis and matched healthy controls, and others finding no evidence of significant differences. Bias was assessed using Joanna Briggs Critical Appraisal for Analytical Cross-Sectional studies and fail-safe N testing. Random-effects modeling and standardized mean differences were used to assess overall effects on neurocognitive functioning. **Results:** Our meta-analysis found no significant effects within the domains of overall effects (ES = 0.17), attention (ES = 0.22), forgetting/retrieval (ES = 0.31), learning (ES =0.29), or verbal/language (ES = 0.41). We identified a significant small effect size within the domain of abstraction/executive function (ES =0.27). However, due to the limited literature in this area, our analysis was under-powered and should be interpreted with caution. **Conclusions:** Limited conclusions can be made about the neurocognitive effects of cannabis after abstinence. We describe many deficiencies in existing studies of residual effects of cannabis and provide recommendations for improvement.

Key words: = cannabis; long-term effects; neurocognition; meta-analysis

Cannabis is the most widely used substance that continues to be illegal in many countries, yet rates of cannabis use disorder have steadily increased from 1990 to 2019 (Shah et al., 2024; United Nations Office on Drugs and Crime, 2023). Global policy changes related to legalization of cannabis could be responsible for increasing use trends and prevalence rates (Wang et al., 2024). Cannabis prevalence rates in the United States have been rapidly changing (Johnston et al., 2017; Substance Abuse and Mental Health Services Administraton [SAMHSA], 2020; United Nations Office on Drugs and Crime, 2015), and understanding potential adverse cognitive effects is increasingly important as cannabis becomes more accessible (Cohen et al., 2019). Manipulation of cannabinoid content has made more potent cannabis products available and has led to increased rates of negative reactions (ElSohly et al., 2016; Freeman et al., 2021; Jikomes & Zoorob,

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2018). Research on acute effects of cannabis documented deficits in neurocognitive domains (Murray et al., 2022) including differences in attention and working memory, learning, inhibition, information processing, and executive functioning (Adam et al., 2020; Miller et al., 2012; Thames et al., 2014). Cannabis is associated with greater impairment of cognitive functioning among adolescents compared to adults (Murray et al., 2022); however, some evidence suggests medicinal cannabis may improve cognitive performance (Olla et al., 2021). Overall, studies suggest cannabis results in deficits in performance on cognitive tasks during and shortly after the period of intoxication (Crean et al., 2011; Lovell et al., 2020; Scott et al., 2018), but evidence of residual effects on cognitive function after a period of abstinence is unclear.

Studies examining long-term effects of cannabis use varying methodologies, making it difficult to draw meaningful conclusions. Definitions of "residual" effects ranged from 24 hours to over a year of abstinence, yielding vastly different results (Hooper et al., 2014; Lorenzetti et al., 2021; Pardini et al., 2015; Thames et al., 2014; Winward et al., 2014). Other sources of variation include studies focused on individuals with substance use disorders (Hooper et al., 2014; Roten et al., 2015) or schizophrenia (Rabin et al., 2017), limited participant age ranges, and varying use duration (Hooper et al., 2014; Rabin et al., 2017; Roten et al., 2015). Although some studies interpreted results as evidence of residual cognitive deficits among individuals who use cannabis, findings from these studies were mixed. With varied definitions of long-term abstinence, some studies reported deficits in some cognitive domains and not others (Lorenzetti et al., 2021; Winward et al., 2014), and others found no residual cognitive deficits (Thames et al., 2014). Despite some studies presenting evidence of cognitive deficits associated with cannabis use even after cessation, other studies have found incongruous results (Cousijn et al., 2014; Hooper et al., 2014; Mooney et al., 2018), suggesting the impact of cannabis on cognitive function might improve over time with abstinence (Bosker et al., 2013; Curran et al., 2016; Pardini et al., 2015; Rabin et al., 2017; Roten et al., 2015; Schuster et al., 2018; Vadhan et al., 2011; Wallace et al., 2020).

Several reviews consolidated results of studies examining residual neurocognitive effects of cannabis (Crane et al., 2013; Curran et al., 2016; Dellazizzo et al., 2022; Figueiredo et al., 2020; Ganzer et al., 2016; Lovell et al., 2020; Scott et al., 2018), but most report conflicting findings and have limitations. One review concluded effects appear to subside after one month of abstinence (Curran et al., 2016). Meta-analyses have reported non-significant differences between healthy controls and individuals who had used cannabis and had been abstinent for at least 25 days (Schreiner & Dunn, 2012), and no significant differences when studies required abstinence for longer than 72 hours (Scott et al., 2018). Other studies, however, have reported evidence of minor to moderate effects of cannabis with minimal effects of prolonged abstinence (Lovell et al., 2020).

Reviews focusing on specific populations (e.g., individuals with psychotic disorders) limit generalizability of findings (Figueiredo et al., 2020; Ganzer et al., 2016; Rabin et al., 2017). One review that examined acute and residual effects did not define a timeframe for residual effects, making it impossible to distinguish between acute and lasting effects of cannabis (Dellazizzo et al., 2022). Scientists have defined cognitive domains differently, making comparison between studies difficult, further limiting understanding of the potential changes in the residual effects of cannabis on cognitive function (Lovell et al., 2020; Schreiner & Dunn, 2012). Conflicting results highlight the need for carefully designed reviews. We examined evidence of residual cognitive effects of cannabis based on data collected after legalization took effect in several U.S. states and several countries globally. Residual was defined as effects evident after prolonged abstinence (≥25 days).

METHODS

We followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Page et al., 2021). Due to a previous meta-analysis on a similar subject (Schreiner & Dunn, 2012), literature review was limited to data not included in this analysis, as well as articles published during or after 2011 to account for potential changes in strains of cannabis as well as changes related to legal status of cannabis (access, rates of use, methods of use) that were not captured in previous analyses (Schreiner & Dunn, 2012). Potency of cannabis products increased from 1995 to 2014 (ElSohly et al., 2016) and recreational cannabis use was legalized in 2012 (Farrelly et al., 2023), underscoring the need for an examination of residual cognitive effects of cannabis for studies published after 2011. We pre-registered on PROSPERO (CRD42023466560) prior to data extraction or analysis.

Eligibility Criteria

Included studies examined neurocognitive effects of cannabis after prolonged abstinence, operationally defined as at least 25 days, which was consistent with previous definitions (Lovell et al., 2020; Schreiner & Dunn, 2012). We included studies published after 2011 to account for changes in cannabis potency and availability globally; however, data could be collected prior. Our inclusion criteria required studies to have included a group of exclusive individuals who use cannabis and a control group of individuals who do not use drugs or had limited drug use. Included studies reported necessary information for calculating effect size (e.g., Hedge's g or standardized mean differences), a valid behavioral measure of neuropsychological functioning (e.g., Rey Verbal Learning Test), and had sober participants at time of testing. Studies with participants who had a history of psychiatric or neurological problems were included if problems were treated.

Exclusion criteria included the following: Meta-analysis or review, examination of acute cannabis effects, no neuropsychological testing, no human subjects, or focus on specific psychiatric population. See Table 1 for list of eligibility criteria.

Search Strategy

Searches were completed in PsycINFO, PsycArticles, and PubMed between March and July of 2023 using online databases to identify relevant studies. Search terms were (marijuana or marihuana or tetrahydrocannabinol or THC or cannabis) AND (neuro* or cognit* or assess* or abilit* or effect* or process* or impair*) AND (residual or long-term or abstinen* or abstain* or lasting or non-acute or persist*), consistent with previous meta-analyses (Schreiner & Dunn, 2012). Categorization of cognitive domains were selected for inclusion in analyses based on previous studies (Grant et al., 2003; Schreiner & Dunn, 2012; see Table 1).

Outcome Measures and Effects Measures

To assess overall effects on neurocognitive functioning, effect sizes were averaged across outcomes to create an overall neurocognitive performance outcome. Since studies included varied outcome measures, we followed guidelines described in Grant et al. (2003) and Schreiner and Dunn (2012) and focused on the following variables: abstraction/executive (e.g., decision making, ability to understand abstract concepts, impulse control), attention (e.g., ability to focus on a task), forgetting/retrieval (e.g., ability to recall learned information), learning (ability to encode information), motor, perceptual-motor, simple reaction time, and verbal/language (e.g., knowledge of language and vocabulary; Grant et al., 2003). Domains of overall effects, abstraction/executive, attention, forgetting/retrieval, and learning were included in analyses as others were not assessed (see Table 2 for more details). Studies included a valid behavioral assessment measure of neuropsychological functioning (see Table 3 for exhaustive list). Perceptual-motor, simple reaction time, and motor outcomes were not assessed because no relevant behavioral assessments were included in studies reviewed. Standardized mean differences were analyzed using a randomized effects model. Based on study sample sizes, Hedge's g was used to estimate effect size.

Statistical Analysis and Synthesis

Analyses were completed with R Statistical Software (v4.3.1;R Core Team, 2023) and packages dmetar, meta, metafor, metaforest, and ggplot2 (Balduzzi et al., 2019; Harrer et al., 2021; van Lissa, 2025; Viechtbauer, 2010; Wickham, 2016). Random-effects model accounted for heterogeneity of several factors within studies including outcome measures, population characteristics, and abstinence length as used in previous meta-analyses (Figueiredo et al., 2020; Lovell et al., 2020; Schreiner & Dunn, 2012). Hedge's g was used to correct for overestimation of effect (Borenstein et al., 2009; Schreiner & Dunn, 2012). Restricted maximum-likelihood estimator was used due to high heterogeneity ($I^2 \geq 0.75$; Veroniki et al., 2016). Significant findings were assessed using fail safe *N* tests and influence plots. Analyzed outcomes were abstraction/executive, attention, forgetting/retrieval, learning, motor, perceptual-motor, simple reaction time, and verbal/language. Tests of heterogeneity (Q statistic & I2 statistic) were conducted to evaluate variance in effect sizes.

Power Analysis

An *a-priori* power analysis was completed to estimate power for both fixed and random effects meta-analysis models at various levels of assumed heterogeneity (Griffin, 2021). Study size was estimated to be 112 based on average number of participants from previous studies (Hooper et al., 2014; Matheson & Le Foll, 2020; Schuster et al., 2018; Thames et al., 2014), and heterogeneity was assumed to be high ($I^2 = 0.75$) based on previous research (Schreiner & Dunn, 2012). A minimum of 6 studies would be needed to power analyses to detect a moderate ($d = 0.5$) effect size.

RESULTS

Study Selection / Characteristics

We identified 3,611 studies; 170 were possibly relevant based on titles and abstracts and were then reviewed by research team members based on inclusion criteria (see Table 1). If agreement could not be reached, a subject matter expert was consulted, and expert input was discussed by the research team. Seven of 170 studies met inclusion criteria and were included in analyses. Four studies were identified through reference review, with one additional study meeting criteria identified (see Figure 1 for more detail), resulting in eight studies. One study included in analyses used data collected prior to 2012 (Auer et al., 2016). Six studies included adult participants and two studies included adolescent participants. Abstinence periods ranged from 28 days to three months. Two studies had longitudinal designs, while six were one-time assessments of neurocognitive functioning. See Tables 1 and 2.

Risk of Bias

We used Orwin's Fail-Safe *N* test to examine publication bias. Fail-Safe *N* tests compute the number of missing studies with non-significant results (i.e., mean effect of 0) which would need to be added to analysis to result in an overall statistically non-significant effect (Borenstein et al., 2013; Long, 2001). Results of the Orwin Fail-Safe *N* test indicated only 10 studies with non-significant results would be needed to fail to reject the null hypothesis for the effect on executive functioning. This means if there are 10 studies that have not been published due to dissemination bias, the finding would no longer be statistically significant. To assess risk of bias, studies were checked using the Joanna Briggs Checklist for Analytical Cross-Sectional Studies (Joanna Briggs Institute, 2016). All eight studies met criteria required to assume minimal bias.

Overall Effects

Summary effect size (ES) for all cognitive domains was calculated by averaging across effect sizes for assessed outcomes. All eight studies were included in this analysis. Results indicated that the overall effect was not significant (ES = 0.17, 95% CI [-0.17, 0.50]). Tests of heterogeneity for this analysis were significant, $Q(7) = 19{,}233.47$, $p < .01$, $I^2 = 100\%$, $T^2 = 0.15$. Outlier analysis indicated two studies were outliers, and analyses were rerun (Delibaş et al., 2018; Winward et al., 2014). Results of second the analysis, including the remaining six studies, were not significant, but tests of heterogeneity remained statistically significant, $Q(5) = 16{,}445.48$, $p < .01$, $I^2 = 100\%$, $T^2 = 0.02$. See Figure 2.

Results examining abstraction/executive functioning for four studies indicated the effect size was significant (ES = 0.27, 95% CI [0.06, 0.47]). Tests of heterogeneity were also statistically significant, $Q(3) = 863.24$, $p < .001$, $I^2 = 99.70\%$, $T^2 = 0.02$. No outliers were indicated (see Figures 3 & 4). Results of Orwin's Fail-Safe *N* test indicated 10 additional studies with an effect size of zero would be needed to accept the null hypothesis.

Attention was included in five studies (see Figure 5) and results were not significant (ES = 0.22, 95% CI [-0.27, 0.70]). Tests of heterogeneity were significant, $Q(4) = 2{,}709.19$, $p < .001$, $I^2 =$

99.90%, $T^2 = 0.14$. Results of Verbal/Language analysis were not significant, $k = 3$; ES = 0.41, 95% CI [-0.91, 1.74], and tests of heterogeneity were significant, $Q(2) = 161.84$, $p < .001$, $I^2 = 98.80\%$, $T^2 = 0.28$; see Figure 6. Results examining Forgetting/Retrieval were not significant, $k = 4$; ES = 0.31, 95% CI [-0.35, 0.97]. Tests of heterogeneity were significant, $Q(3) = 41.16$, $p < .001$, $I^2 = 92.70\%$, $T^2 = 0.14$; see Figure 7. Two studies included assessments of learning and results were not significant, ES = 0.29, 95% CI [-2.75, 3.34]. Tests of heterogeneity were significant, $Q(1) = 2281.19$, $p < .001$, $I^2 = 100.00\%$, $T^2 = 0.12$; see Figure 8.

DISCUSSION

We conducted a meta-analysis to evaluate evidence of residual neurocognitive effects of cannabis that persist after a minimum of 25 days of abstinence (Grotenhermen, 2005). A previous meta-analysis included all available data collected before 2012 and showed no evidence of residual neurocognitive effects (Schreiner & Dunn, 2012). Substantial changes have taken place in subsequent years after legalization efforts encouraged proliferation of a wide variety of different cannabis products, including edibles, vape liquid, and smoked cannabis, many designed with higher potency than previously available cannabis (higher THC levels, sometimes combined with lower CBD levels; ElSohly et al., 2016; Freeman et al., 2021). Therefore, we focused on studies published after those included in previous review (after 2012), and we found only eight new studies that met inclusion criteria. Results indicated no significant residual effects of cannabis on overall cognitive functioning or on domains of attention, forgetting/retrieval, verbal/language, and learning based on a 95% confidence interval. Abstraction/executive function had a statistically significant, but small, effect size (Hedge's $g = 0.27$) indicating that healthy controls performed better than abstinent individuals who use cannabis (this analysis was underpowered). Design of included studies prevents a definitive conclusion related to long-term impacts on executive functioning (e.g., decision making, abstraction).

Our results show no statistically significant differences between individuals who used cannabis in the past and healthy controls when accounting for all domains. This contradicts previous research which found significant differences between abstinent individuals who use cannabis and healthy non-using controls (Dellazizzo et al., 2022; Lovell et al., 2020). Contrasting results could be due to less strict inclusion criteria, bias within included studies, over-reporting of results, or insufficient assessment of publication bias. Funnel plots may be inaccurate representations of publication bias, as they rely on subjective interpretation of visual data which may be influenced by factors other than publication bias (Kossmeier et al., 2019; Polanin et al., 2016).

Our results support other studies and meta-analyses that found as time of abstinence increases, effect sizes decrease or become non-significant (Schreiner & Dunn, 2012; Scott et al., 2018). Non-significant differences within the verbal/language domain are consistent with previous longitudinal research that found improvements after one month of monitored abstinence, demonstrating deficits in this domain improve (Roten et al., 2015). We extend this finding with no significant differences between individuals who used cannabis in the past and non-using healthy controls after a roughly equivalent period of abstinence (≥25 days). Our results related to attention support previous research demonstrating no significant differences between controls and individuals who used cannabis in the past after one year of abstinence (Pardini et al., 2015). Non-significant results in overall effects of cannabis, and in domains of learning, and forgetting/retrieval are consistent with previous meta-analyses (Schreiner & Dunn, 2012; Scott et al., 2018). Findings add to a growing literature suggesting there is almost no evidence of residual neurocognitive effects of cannabis after prolonged abstinence, particularly in domains of verbal/language, attention, forgetting/retrieval, and learning. Unfortunately, the design of studies that met inclusion criteria for this meta-analysis prevents definitive conclusions because of high heterogeneity and limited control of important variables (e.g., pre-exposure function, duration of use).

The small significant effect in abstraction/executive function suggests a possible small association between cannabis and long-term outcomes on decision making, working memory, or complex attention tasks. This should be interpreted cautiously, as the effect size was small and the analysis was underpowered to detect small effects. This finding is inconsistent with previous meta-analyses that found after prolonged abstinence (≥25 days) there was no evidence of statistically significant differences in abstraction/executive function (Lovell et al., 2020; Schreiner & Dunn, 2012). Inconsistency of outcomes could suggest this result is spurious or represents a shift in effects since 2011, and additional studies are necessary to make this determination. Only one study estimated preexposure functioning (prior to first cannabis use; Thames et al., 2014). Methods of estimating preexposure functioning are also limited by requiring comparison with a full WAIS-IV or estimating full-scale IQ scores and not scores within specific domains (Bright & van der Linde, 2020; Shura et al., 2020). Without data of pre-cannabis use functioning, it is impossible to detect change. Previous research has indicated poorer executive functioning in childhood predicts adolescent substance use, suggesting differences may be present prior to use (Cavalli et al., 2023; Gustavson et al., 2017). Without properly controlling for previous executive functioning, it is impossible to implicate cannabis as causal. Included studies also had varying sample sizes, with only two studies having more than 100 participants (Auer et al., 2016; Meier et al., 2022). Auer et al. (2016) and Meier et al. (2022) had large sample sizes with imbalanced groupings, which may affect outcomes (Liang et al., 2020). Effects of cannabis on executive functioning should be explored in future studies.

Literature Limitations

Results of our study support four previous meta-analyses on this topic (Curran et al., 2016; Grant et al., 2003; Schreiner & Dunn, 2012; Scott et al., 2018) but contradict three other meta-analyses (Figueiredo et al., 2020; Ganzer et al., 2016; Lovell et al., 2020). Several variables could be impacting these results. We identified 32 meta-analyses and reviews with many studies included in multiple reviews, suggesting studies published prior to 2012 are continuing to influence results despite significant changes to the chemical makeup of cannabis (Smart et al., 2017). These meta-analyses were all published within the last 10 years, suggesting this is an important area of research. However, lack of original studies that properly control for confounding variables published within this time frame is cause for concern.

As highlighted in our meta-analytic review, a major limitation of the current literature is the lack of assessment of neurocognitive functioning before cannabis use. As a result, we cannot determine the degree to which there might be a return to baseline neurocognitive functioning after discontinuation of cannabis use. Baseline neurocognitive impairment (e.g., executive functioning, attention) could also serve as a predisposing risk factor for substance use, which is not captured by the current studies we reviewed. For example, some individuals use cannabis to manage ADHD symptoms or medication side effects (Stueber & Cuttler, 2022). Lack of understanding of baseline neurocognitive functioning potentially adds to the uncertainty as to whether neurocognitive impairment existed prior to drug exposure, potentially confounding study results.

An additional limitation of the literature is that the definition of prolonged abstinence as 25 days may be inadequate. THC is lipophilic and can remain stored in body fat, including brain myelin, for long periods of time following chronic use and can be re-released into the blood stream (Chayasirisobhon, 2020; Wong et al., 2013). THC can be detected in body fat for up to four weeks after last cannabis use (Johansson et al., 1989). As such, 25 days of abstinence may be insufficient to determine if neurocognitive effects are a result of "residual" THC effects or the result of THC still present in the body.

Another area of concern is lack of diversity in sampling. Participants in many of studies were predominantly white, male, right-handed individuals. One study had a majority Black sample (Auer et al., 2016) but found no effect when accounting for race. It is important that studies consider evidence that some neurocognitive tests are biased against non-white individuals, and norms used for comparison groups often under-represent individuals from non-white groups (Gasquoine, 2009). Under-representation of marginalized groups in research has lasting and far-reaching consequences. The four studies included in our analysis did not report race or ethnicity (Delibaş et al., 2018; Meier et al., 2022; Riba et al., 2015; Zimmermann et al., 2019). Excluding Auer et al. (2016), the remaining studies had substantially more white participants (n = 168) than Black participants (n = 42) or "other" participants (n = 31). This limits our ability to draw conclusions based on variables race acts as a proxy for (e.g., socio-economic status), and further contributes to white individuals being used as the standard comparison group and could contribute to ongoing bias in research, as many neurocognitive assessments include demographic based norms (Gasquoine, 2022; Putzke et al., 2002). Biological sex is another variable to account for related to neurocognitive effects, with previous research highlighting differences in performance within specific domains of function (Roalf et al., 2014). Deficits have been identified for male individuals who use cannabis in psychomotor function and in visuospatial tasks for female individuals who use cannabis (Crane et al., 2013). Included studies appeared to be well balanced with 676 male participants and 712 female participants. However, several studies did not report clear characteristics of included groups or only reported percentages (Auer et al., 2016; Riba et al., 2015; Thames et al., 2014). Our findings cannot be clearly generalizable across some demographic groups.

Study Limitations

There was a lack of studies meeting basic inclusion criteria. Most common factors leading to exclusion were absence of one or more of the following: prolonged abstinence requirement (n = 27), standardized behavioral assessments (n = 23), or healthy control group for comparison (n = 18; see Figure 1 for full selection flowchart). Using terms such as "residual" and "long-term" are misleading, as many studies reviewed required less than 24 hours of abstinence. The half-life of THC varies based on frequency of use, and the half-life of THC with chronic cannabis use has been reported to be 5 to 13 days (Chayasirisobhon, 2020). Studies that require only one or two days of abstinence with chronic cannabis use are reporting on cannabis effects with more than half the original dose still in the plasma of participants. Describing results as "residual" or "long-term" effects adds to misconceptions about lasting effects of cannabis on neurocognitive functioning because acute effects are mistaken for residual effects. Use of survey data instead of standardized behavioral assessments is a critical flaw because self-report on cognitive function is subjective and has poor reliability and validity (Herreen & Zajac, 2017; Rabin et al., 2015). Lack of healthy controls makes it nearly impossible to conclude that any observed effects resulted from cannabis use. Metaregression analyses examining factors including duration of use, race/ethnicity, and biological sex could not be completed due to high heterogeneity across studies, small number of studies, inconsistent reporting, and lack of power for analyses. We were limited our ability to properly control for variables of interest, which limited our ability to interpret data with certainty.

Recommendations

Beyond the limitations of this meta-analysis, limitations of the existing literature make it difficult to draw definitive conclusions. We recommend that studies examining residual neurocognitive effects of cannabis be longitudinal in nature, with optimal studies examining cohorts of individuals from non-use to use with validated baseline measures of cognitive functioning. Ideally, assessment of neurocognitive functioning would occur before exposure to cannabis, immediately after abstinence, and again after prolonged abstinence. A comparison group of matched individuals who had not been exposed to cannabis would also be necessary. Such studies could be developed using robust, longitudinal data sets such as the Adolescent Brain Cognitive Development (ABCD) study, which is the largest long-term study of brain development and child health in the United States (Jernigan et al., 2018). Another potential approach could be utilization of blinded, placebo-controlled trials of therapeutic cannabis in a medical population. However, it would be important to account for the effects of various medical conditions that could cause cognitive impairment (e.g., treatment of chronic pain with opioids). We also recommend that studies include diverse groups of individuals, utilize validated measures of neurocognitive functioning, and assess longer periods of abstinence to capture true residual neurocognitive effects and not effects from active THC.

Conclusion

Many reviews on this topic (n = 36) use the same studies and report conflicting results. No previous reviews conducted *a-priori* power analyses raising concerns regarding reported small effects. Previous reviews also failed to use consistent methods (e.g., domains examined, search terms used), limiting comparisons between them. Serious problems are common in the existing literature including lack of behavioral assessments and control groups and failure to require abstinence greater than 12 hours. Among studies that met inclusion criteria for our empirical meta-analytic review, different outcome measures were used, variables were inconsistently controlled (e.g., duration of use), or group sizes were uneven. All these issues contribute to heterogeneity, increase the number of studies needed to power analyses, and limit the ability of meta-analyses to synthesize and analyze the data. Many studies were published with titles indicating a focus on residual or long-term effects of cannabis on neurocognitive functioning. However, we found fewer than 10 studies that included data collected after 2010, included healthy controls, and used standardized behavioral assessments. Several studies included data from the 1980's. Currently available cannabis has higher levels of THC, lower levels of CBD, and is likely to have different psychoactive properties (Jikomes & Zoorob, 2018; Levinsohn & Hill, 2020; Lorenzetti et al., 2020; Smart et al., 2017). Currently, there are insufficient data to provide a clear picture of residual effects of cannabis on neurocognitive functioning. This does not mean cannabis use is free of lasting neurocognitive effects, but we cannot draw definitive conclusions based on existing data. Future studies should better control for confounding variables and lack of diversity sampling in the following ways: 1) consider the use of longitudinal cohort studies to establish baseline functioning; 2) oversample for participants from diverse backgrounds including considerations for sex, gender, race, and ethnicity to ensure generalizability of findings; 3) reconsider duration of abstinence to account for the lipophilic nature of THC; and 4) use appropriate neurocognitive tests along with baseline assessments to determine changes in neurocognitive functioning.

Table 1. *Inclusion and Exclusion Criteria*

Inclusion Criteria	Exclusion Criteria
1. Includes group of cannabis only users	1. Study is a meta-analysis or review
2. Includes control group of nonusers or limited drug use	2. Study only examines acute effects of cannabis on cognitive function
3. Study reports necessary information for calculating effect size (e.g.,	3. Neuropsychological testing is not included in the study
4. Study uses a valid behavioral measure of neuropsychological functioning	4. Study does not have any human subjects (i.e., animal studies)
5. Participants are not under the influence of any substances during testing	5. Study focuses on specific psychiatric populations
6. The use of other substances both past and present is addressed	
7. History of psychiatric and neurological problems is addressed	
8. Published in 2012 or later	
9. There was no exclusion for country of data collection	

Note. Inclusion and exclusion criteria are based on previous meta-analyses examining the residual cognitive effects of cannabis (Grant et al., 2003; Schreiner & Dunn, 2012).

Table 2. *8 Independent Samples Meeting Inclusion Criteria*

Study	Users	Control	Abstinence Period	Domains	Age Group	Location	Study Design	Duration
Auer et al. (2016)*	81	531	30 days	Ex, L	Adults	United States	Longitudinal	25 years
Delibaş et al. (2018)	30	30	30 days	A	Adults	Turkey	Cross sectional	One-time assessment
Hooper et al. (2014)	33	37	3 months	A, Ex, F	Adolescents	United States	Cross sectional	One-time assessment
Meier et al. (2022)	59	196	30 days	Ex, F	Adults	New Zealand	Longitudinal	27 years
Riba et al. (2015)	16	16	28 days	A, F	Adults	Spain	Cross sectional	One-time assessment
Thames et al. (2014)	41	49	28 days	A, Ex, L	Adults	United States	Cross sectional	One-time assessment
Winward et al. (2014)	20	55	1 month	A, F, V	Adolescents	United States	Cross sectional	One-time assessment
Zimmermann et al. (2019)	19	18	28 days	V	Adults	Germany	Cross sectional	One-time assessment

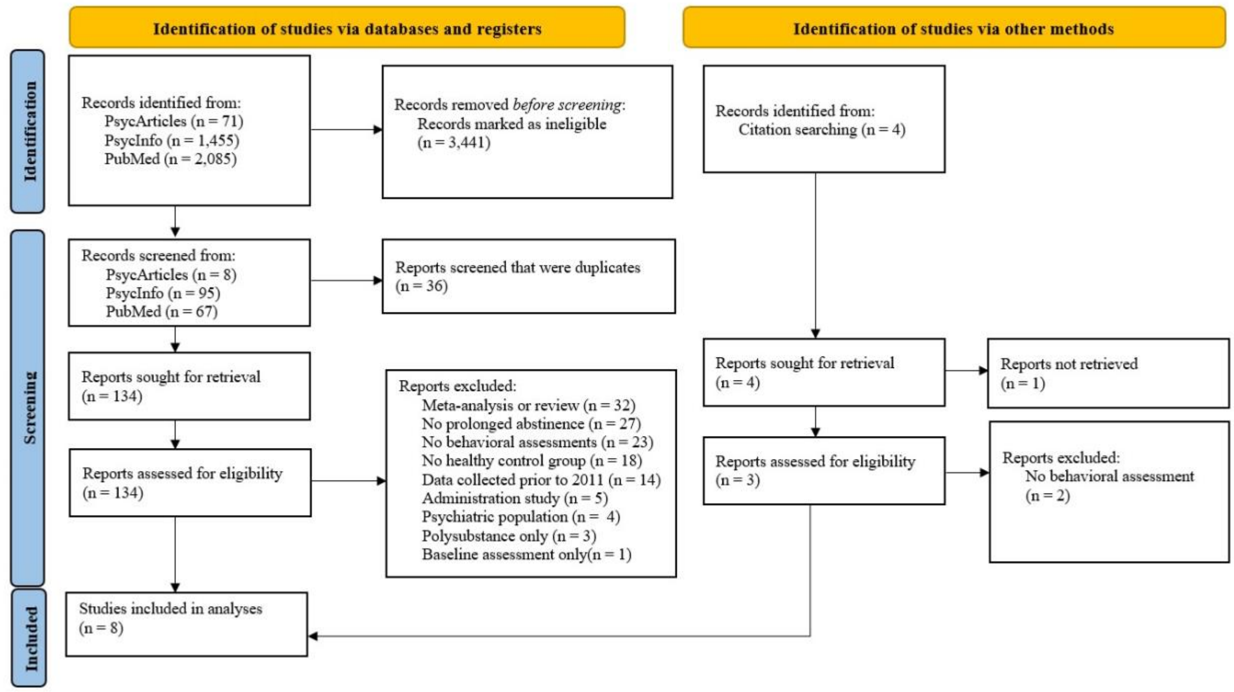
Note. Attention (A); Abstraction/Executive Functioning (Ex); Forgetting/Retrieval (F); Learning (L); Verbal (V).*Study used data collected from 2011, but not included in previous meta-analyses.

Table 3. *Outcome Measures in Assessed Domains*

Neurocognitive domain	Outcome Measures
Abstraction/Executive	Digit symbol substitution test, digit, Weschler Adult Intelligence Scale(WAIS)-IV digit span, Trail Making B, Stroop Test, Delis-Kaplin Executive Functioning System (DKEFS) color-word interference, DKEFS Trail Making Condition 4, California Verbal Learning Test (CVLT) intrusions, Woodcock Johnston (WJ)-III Auditory Working Memory, Animal Naming, Weschler Memory Scale (WMS) Months Backwards
Attention	Trail Making A, Iowa Gambling task*, Continuous Performance Test II
Forgetting/Retrieval	CVLT-II Recall, BVMT-R, Rey-Osterrieth Complex Figure Delay, Wide Range Assessment of Memory Learning (WRAML)-2 Verbal memory, Hopkins Verbal Learning Test-Revised(HVLT-R) Delayed, Deese-Roediger-McDermott paradigm
Verbal/Language	WASI Vocabulary, WST, WAIS-IV Verbal Comprehension Index
Learning	Brief Visual Memory Test-Revised, HVLT-R Immediate and Delayed subtests, Rey Auditory Verbal Learning Test (RAVLT)

Note. *Previous research has indicated the Iowa Gambling Task loads more onto attention than executive functioning (Gansler et al., 2011; Schreiner & Dunn, 2012

Figure 1. *Study Selection Flowchart*



Adapted from Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

Figure 2. *Forest Plot: Overall Effects*

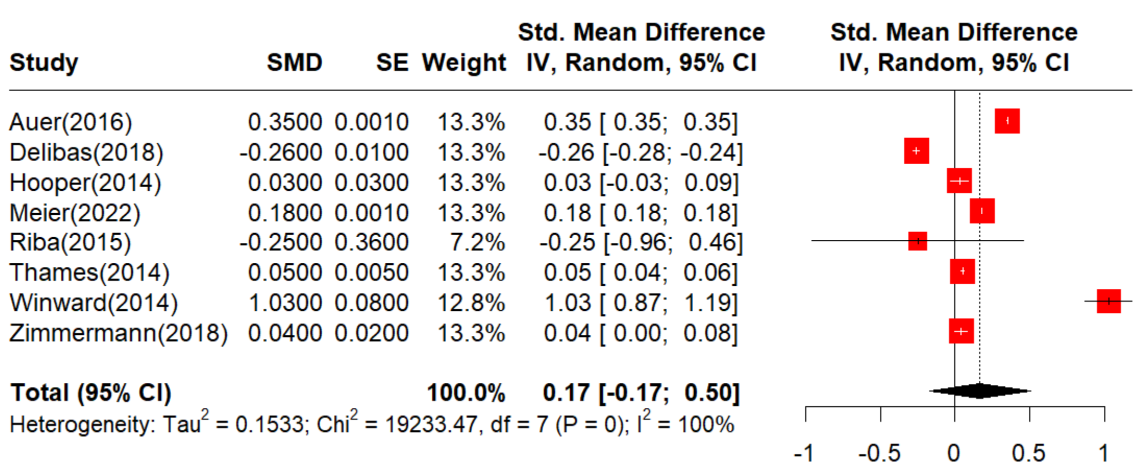


Figure 3. *Forest Plot: Abstraction/Executive Functioning*

Study	SMD	SE	Weight	Std. Mean Difference IV, Random, 95% CI
Thames(2014)	0.4500	0.0100	25.3%	0.45 [0.43; 0.47]
Hooper(2014)	0.1900	0.0300	24.1%	0.19 [0.13; 0.25]
Auer(2016)	0.1700	0.0004	25.4%	0.17 [0.17; 0.17]
Meier(2022)	0.2600	0.0100	25.3%	0.26 [0.24; 0.28]
Total (95% CI)			**100.0%**	**0.27 [0.06; 0.47]**

Heterogeneity: Tau^2 = 0.0162; Chi^2 = 863.24, df = 3 (P < 0.01); I^2 = 100%

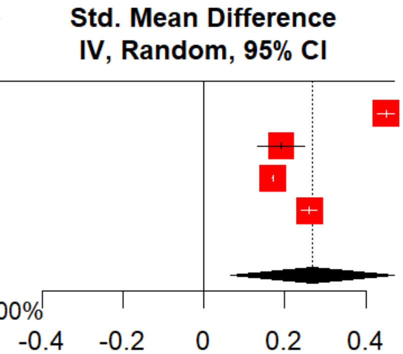


Figure 4. *Forest Plot: Attention*

Study	SMD	SE	Weight	Std. Mean Difference IV, Random, 95% CI
Delibas(2018)	-0.2600	0.0100	22.6%	-0.26 [-0.28; -0.24]
Hooper(2014)	0.3400	0.0500	22.2%	0.34 [0.24; 0.44]
Thames(2014)	0.4700	0.0100	22.6%	0.47 [0.45; 0.49]
Winward(2014)	0.5800	0.1000	21.1%	0.58 [0.38; 0.78]
Riba(2015)	-0.2500	0.3600	11.6%	-0.25 [-0.96; 0.46]
Total (95% CI)			**100.0%**	**0.22 [-0.27; 0.70]**

Heterogeneity: Tau^2 = 0.1365; Chi^2 = 2709.19, df = 4 (P = 0); I^2 = 100%

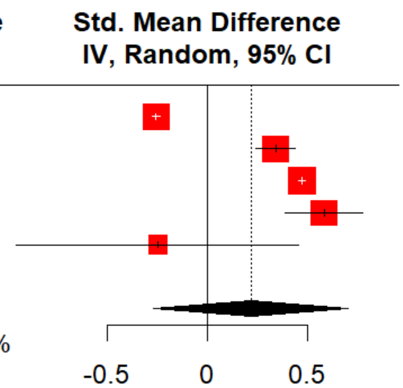


Figure 5. *Forest Plot: Verbal/Language*

Study	SMD	SE	Weight	Std. Mean Difference IV, Random, 95% CI
Winward(2014)	1.0300	0.0800	32.8%	1.03 [0.87; 1.19]
Zimmermann(2018)	0.0400	0.0200	33.6%	0.04 [0.00; 0.08]
Meier(2022)	0.1800	0.0010	33.6%	0.18 [0.18; 0.18]
Total (95% CI)			**100.0%**	**0.41 [-0.91; 1.74]**

Heterogeneity: Tau^2 = 0.2807; Chi^2 = 161.84, df = 2 (P < 0.01); I^2 = 99%

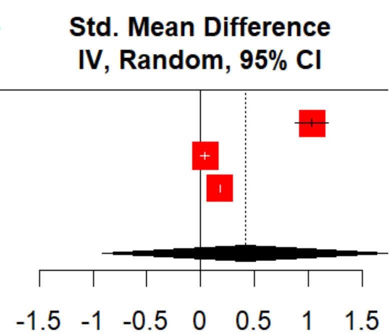


Figure 6. *Forest Plot: Forgetting/Retrieval*

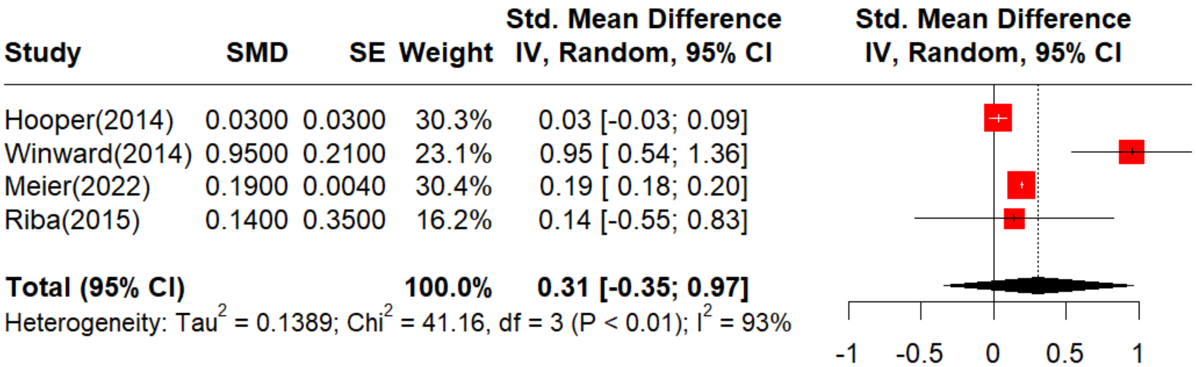


Figure 7. *Forest Plot: Learning*

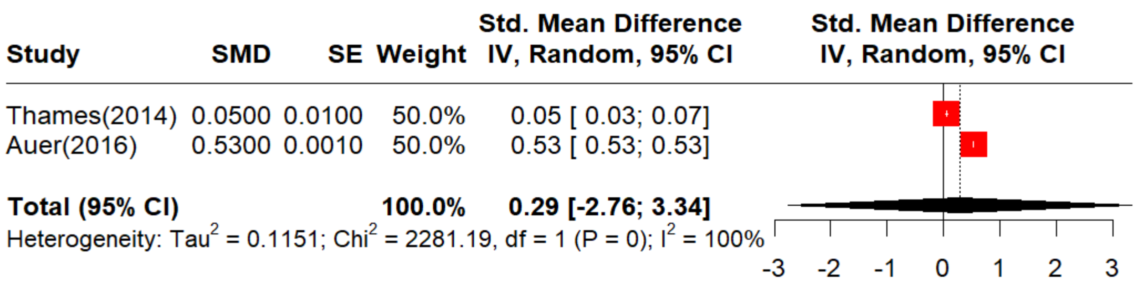
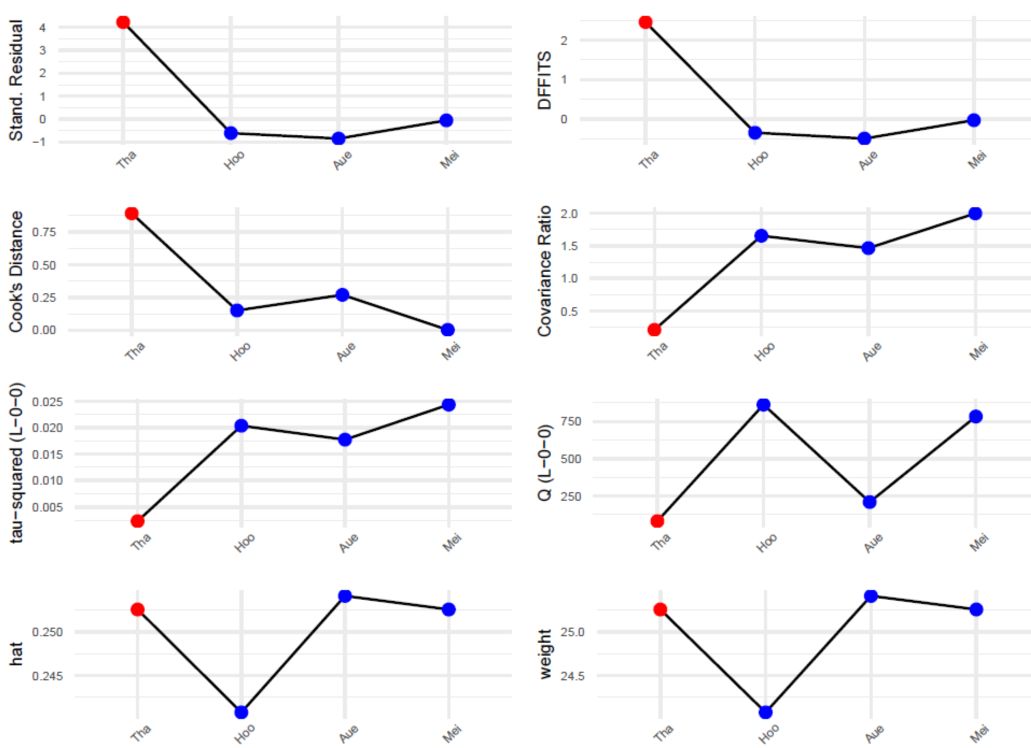


Figure 8. *Influence Plots for Abstraction/Executive Functioning Analyses*



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