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REVIEW ARTICLE

Visuospatial Processing Decline Due to Cannabis Consumption in Nondependent High School Students

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Abstract

Using cannabis (e.g., smoking marijuana) is becoming popular, partly due to a legalization trend across different countries. This tendency has resulted in cannabis consumption being accepted by society as if it were harmless. However, evidence shows that the use of this drug has detrimental effects on cognitive, academic, and professional performance, which tend to be larger in younger users (e.g., high school students). In this review article, we focus on the decline of visuospatial processing associated with cannabis consumption in nondependent or nonclinical high school students. We start by providing evidence of the pivotal role of visuospatial processing for learning. Next, we review experimental and correlational evidence of declines in visuospatial processing related to cannabis use. Three types of correlational studies are considered: (a) comparisons of declines between visuospatial processing and other cognitive tasks, (b) studies comparing declines between high school students and adult participants, and (c) stringent correlational studies (e.g., large samples, longitudinal data, twin studies). We also include evidence in abstinent cannabis conditions. We conclude that using cannabis may moderately impair visuospatial processing and learning in nondependent high school students, although the effects could disappear under abstinence and tend to be lower than on other cognitive functions. Instructional implications for educators and future research directions are discussed.

Keywords Visuospatial working memory processing · Spatial ability · Non dependent or non clinical high school adolescent student · Cannabis · Marijuana and marihuana

Cannabis or marijuana is the most popular illegal drug around the world. According to the two latest reports of the United Nations Office on Drugs and Crime (UNODC 2019; 2020), 188

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million people worldwide consumed cannabis in 2017 and the number raised to 192 million users in 2018. The UNODC (2020) also reported that, since 2007, cannabis users in the USA have consistently increased, and daily or near-daily consumption has doubled over the period 2009–2018. These rising numbers measured in the USA included high school students. For example, the UNODC (2019) observed an increase in consumption in students from eighth grade (9.4% in 2016 vs. 10.1% in 2017), tenth grade (23.9% vs. 25.5%), and twelfth grade (35.6% vs. 37.1%).

Furthermore, given that Canada, Uruguay, and some states in the USA have legalized recreational cannabis, consumption may have become more socially accepted (see Volkow et al. 2014) and less regulated (e.g., Cao et al. 2020). With increasing popularity and acceptance, cannabis consumption could be erroneously perceived as harmless by young users (e.g., Rudy et al. 2020). Nevertheless, the drug may lead to addiction and deleterious consequences on social, cognitive, academic, and professional achievement (see Broyd et al. 2016; Morin et al. 2019; Silins et al. 2014; Volkow et al. 2014).

Additional supporting evidence for such harmful consequences is provided in the integrative meta-analysis by Silins et al. (2014), which included a large dataset ($N > 2500$) of young participants. The study examined the effects of cannabis use on critical social and academic outcomes related to transitioning into adulthood, including high school completion, attainment of a university degree, cannabis dependence, use of other illicit drugs, and suicide attempts. Results showed that, compared with nonusers, students who were daily consumers of cannabis before turning 17 years old had 63% lower odds of completing high school, 62% lower chances of getting a university degree, 1800% higher odds of being cannabis dependent, 800% higher chances of using other illicit drugs, and 700% higher odds of attempting suicide. Hence, these clinical or diagnosed participants showed different adverse effects due to consuming cannabis daily. Also, the recent meta-analysis by Leung et al. (2020) showed that regular cannabis users, not necessarily everyday users, were at risk: 22% (18–26%) of users had a cannabis use disorder, and 13% (10–15%) presented cannabis dependence.

More alarming are the following two facts that need further awareness and, thus, are considered in the present review: (a) not only *clinical* consumption but also moderate nondependent use of cannabis can lead to negative effects, for example, on cognitive functions including visuospatial processing (e.g., Mena et al. 2013; Orr et al. 2019; Schoeler et al. 2016), and (b) the negative effects are usually larger for high school cannabis users, compared with adult users (e.g., Fontes et al. 2011; Leung et al. 2020; Lubman et al. 2015; Meier et al. 2012).

The main aim of the current review article is to describe the potentially negative effects of using cannabis on visuospatial processing in nondependent high school students. By *nondependent* or *nonclinical* participants, we considered high school adolescent students that had not been diagnosed by a medical specialist with a cannabis disorder or dependence. The specific aims of the current study are to provide evidence of the following: (a) positive relationships between visuospatial processing and school learning and (b) experimental and correlational studies showing that cannabis use may lead to a decline in visuospatial processing in nondependent high school students, which could affect their learning.

Although there is literature showing detrimental effects on visuospatial processing associated with cannabis consumption, our review focuses on high school students who are not frequent clinical drug users. Thus, the present study helps filling two research gaps: (a) the effects of cannabis use associated with different visuospatial processing tasks (e.g., tests of spatial working memory and tasks of visuospatial learning) and (b) the effects of consumption in nondependent high school students. In other words, the novelty of our approach in the cannabis effects literature is linking specific tasks (visuospatial processing) to specific participants (nondependent high school students). Next, we describe the link between visuospatial processing and learning.

Visuospatial Processing and Learning

Visuospatial processing involves mentally processing visual and spatial information in working memory (see Castro-Alonso and Atit 2019; see also Baddeley 2012). As a subcomponent of working memory, the visuospatial processor participates in tasks of perception, attention, memory, and learning (see Baddeley 1992; see also Gignac 2014; Jacob and Parkinson 2015; Jarrold and Towse 2006; Oberauer et al. 2018) that depend on working memory. There is accumulating evidence (e.g., Buckley et al. 2018; Castro-Alonso et al. 2019b; Castro-Alonso and Uttal 2019; Wai et al. 2009) showing that visuospatial processing is an essential asset for learning and thriving in professional disciplines, such as math and sciences.

Evidence also shows how visuospatial processing helps performance in school environments. In a recent systematic review of 35 articles investigating school-aged students, Allen et al. (2019) reported medium to large correlations between visuospatial processing and mathematics performance. To investigate the effects of particular visuospatial instruments on learning, Reuhkala (2001) conducted two experiments with a total of 115 school students from ninth grade (ages 15–16, 60% females). Results showed that two visuospatial processing tests (i.e., the Mental Rotations Test and the Visual Patterns Test; see Castro-Alonso et al. 2019a), but not other measures of verbal processing or executive functions, could predict performance in a standard mathematics test. In another study with school students from ninth grade ($N = 128$, 55% females), Kyttälä and Lehto (2008) investigated the relationship between different visuospatial processing instruments and different math tasks. It was observed that scores on the Mental Rotations Test predicted scores on a test of geometry and that scores on the Visual Patterns Test predicted scores on a test of mental arithmetic.

Also, in a study with 141 students (50% females) between 11 and 13 years of age, Giofrè et al. (2018) reported that both visuospatial and verbal working memory tests could predict a large portion of the performance variance in math and reading literacy tests. Moreover, additional variance in math was predicted uniquely by visuospatial processing. St Clair-Thompson and Gathercole (2006), who investigated 51 school students (47% females, $M_{age} = 11.75$ years), also observed these effects of visuospatial processing. As such, results showed that a dual visuospatial working memory task (i.e., the Spatial Span; cf. Castro-Alonso and Atit 2019) presented scores that correlated significantly with scores on standard curricular tests of English ($r = .45$), math ($r = .44$), and science ($r = .31$). Another visuospatial instrument, the Odd-One-Out Task, significantly correlated with performance on the tests of English ($r = .56$) and math ($r = .47$). In sum, a conclusion of this section is that the visuospatial processor of working memory contributes to academic achievement in school students.

Visuospatial Processing Decline Due to Cannabis

Given the importance of visuospatial processing for learning, factors disrupting this processing will, hence, hamper learning. Cannabis consumption is one of these factors (e.g., Becker et al. 2014). The effects of cannabis use on visuospatial processing can be *acute* or *long term* (e.g., see Curran et al. 2016). Usually, experimental designs are employed to measure acute or shorter-term effects, whereas correlational studies gauge effects that may last longer. Correlational methods, which have gathered more evidence, are also subdivided in this review for explanatory purposes. As shown in Table 1, we describe three types of studies yielding correlational evidence. Then, we include experimental and correlational studies in abstinence of cannabis, which investigate if the decline associated with the drug is sustained without consumption.

To assess the quality of the studies about visuospatial processing decline and cannabis, we adapted the clinical criteria of the U.S. Preventive Services Task Force reported by Harris et al. 2001; reprinted in 2020) for experimental and correlational research (see Table 2). The table shows the studies reviewed, how the quality criteria were or were not met, and how we gauged this information to rate the overall quality of the study. For example, for experimental evidence (see top of Table 2), we assessed two criteria: comparable experimental and control conditions and equal and reliable measurements in experimental and control conditions. By checking the degree of fulfillment with these criteria, we rated the experimental studies as *good* or *fair*. The same ratings were used for the correlational evidence. The criteria by Harris et al. (2001) are typically used in academic reviews that investigate quality evidence about medical practice (see Krist et al. 2020). Note that, although these criteria and ratings provide pertinent information, they are not without limitations, because sometimes studies appear to meet the criteria by not reporting their oversights.

Experimental Studies

Experimental evidence that we have rated as studies of *good* quality (see Table 2) support that cannabis consumption can produce acute or short-term negative effects on different visuospatial processing tasks. For example, Mokrysz et al. (2016) examined the effects of acute cannabis administration on 20 adolescents and 20 adult male cannabis users. A group of these participants used a dose of cannabis (i.e., about a third of a marijuana cigarette), and their performance was compared with that of a group who used a placebo. Both groups, which were equivalent in age, verbal IQ, and health, consumed the doses with vaporizers (see Table 2). Results on the visuospatial processing task following the n-back paradigm (see Castro-Alonso and Atit 2019; Castro-Alonso et al. 2019a) showed that performance of both adolescents and adults was impaired immediately after smoking cannabis. The effect size of this result ($\eta_P^2 = 0.48$) corresponds to a large size, according to the recent educational standards by Kraft (2020).

Makela et al. (2006) investigated the acute effects of sublingual cannabis (THC) on 19 adults (37% females) attempting two measures of visuospatial memory. In a within-subjects design, a group of participants received the drug before attempting both tasks once and 1 week

Table 1 Visuospatial processing decline due to cannabis consumption

Type of study
Experimental evidence
Correlational evidence
Visuospatial processing versus other cognitive tasks
High school students versus adult participants
Stringent studies (large samples, longitudinal data, twin studies)
Studies in abstinence conditions (experimental and correlational evidence)

Table 2 Quality assessment of the studies about visuospatial processing decline due to cannabis

Study	How the quality criterion was/*was not* met	Quality
Experimental evidence (A) Comparable experimental and control conditions. (B) Equal and reliable measurements in experimental and control conditions.		
Makela et al. (2006)	(A) Within-subjects design, counterbalanced order. (B) Conditions used sublingual spray; cannabis and drug metabolites were measured.	Good
Mokrysz et al. (2016)	(A) Conditions of same gender and equivalent in age, verbal IQ, and health. (B) Conditions used vaporizers; feeling "high" was reported.	Good
Roten et al. (2015)	(A) Conditions equivalent in age, gender, and nicotine use. *Conditions not equivalent in school enrollment*. (B) Cannabis metabolites were measured.	Good
Schuster et al. (2018)	(A) Conditions equivalent in age, gender, education, health, and drug use. (B) Cannabis metabolites were measured.	Good
Correlational evidence (a) Proper control of confounding variables between cases and controls. (b) Exclusion criteria apply equally to cases and controls. (c) Appropriate certainty of cases versus controls.		
Ehrenreich et al. (1999)	(a) Groups matched by age, gender, education, and health. (b) Groups did not use other drugs or had psychiatric disorders. (c) Cases used cannabis at least once a week; cannabis metabolites were measured.	Good
Fontes et al. (2011)	(a) Groups matched by age, education, and IQ. *Groups not matched by gender*. (b) Groups did not use other drugs. (c) Cannabis metabolites were measured.	Good
Gruber et al. (2012)	(a) Groups matched by age and IQ. *Groups not matched by gender*. (b) Groups did not use other drugs or had psychiatric disorders. (c) Cases used cannabis 2500 times in their lives; cannabis metabolites were measured.	Good
Harvey et al. (2007)	(a) Groups matched by age, gender, and psychological variables. *Groups not matched by conduct disorder symptoms*. (b) *Cases used more nicotine*. (c) Cannabis metabolites were measured.	Good
Jackson et al. (2016)	(a) Twins study. (b) *Cases had heavier use of other drugs and alcohol*.	Fair
Lyons et al. (2004)	(a) Groups composed of male twins, also matched by education and health. (b) Groups did not use other drugs. (c) Cases used cannabis at least once a week for 1 year, and had stopped using it for at least 1 year.	Good
Medina et al. (2007)	(a) Groups matched by age, gender, and income. (b) *Cases had used other drugs, alcohol, and nicotine*. (c) Cannabis metabolites were measured.	Fair
Meier et al. (2012)	(b) *Using other drugs or having psychiatric disorders was not controlled*, but corrected statistically.	Fair
Meier et al. (2018)	(a) Twins study.	Good
Mena et al. (2013)	(a) Groups matched by socioeconomic status and IQ.	Good
Owens et al. (2019)	(a) *Groups not matched by age, gender, education, use of other drugs (including alcohol and nicotine), and health,* but these factors were corrected statistically. (c) Cannabis metabolites were measured.	Fair
Pope Jr. et al. (1997)	(a) Groups matched by age, education, and IQ. (b) *Cases had used more hallucinogens*. (c) Cases used cannabis 29 days per month (median); cannabis and drug metabolites were measured.	Fair

Table 2 (continued)

Study	How the quality criterion was/*was not* met	Quality
Ross et al. (2020)	(a) Twin study. (c) Cases and controls were estimated with statistical models.	Good
Schweinsburg et al. (2008)	(a) Groups matched by gender and IQ. (b) Groups did not have psychiatric or drug disorders; *cases had used other drugs, and more alcohol and nicotine*. (c) Cannabis and drug metabolites were measured.	Fair
Winward et al. (2014)	(a) Groups matched by age, gender, education, and family addiction. (b) Groups did not have psychiatric or learning disorders. *Cases had used other drugs*. (c) Cannabis metabolites were measured.	Fair

These five criteria for quality assessment were based on Harris et al. (2001), reprinted in 2020. Italicized text marks reported problems to meet the criterion. Quality was rated as good or fair

later received a placebo before completing the tasks again. The other group received the treatment in a counterbalanced order (see Table 2). Results for one task, known as the Corsi Block Tapping Test (see Castro-Alonso and Atit 2019; Castro-Alonso et al. 2019a), showed that THC led to higher total errors for both genders, although the effect was more marked in females. In contrast, and unexpectedly, results for the other task, the spatial working memory instrument, showed that THC was not influential in males and *reduced* between-search errors in females. A follow-up study with a larger sample could help explaining these findings.

As this experimental evidence met the quality criteria in Table 2, these two studies were rated as good quality. This evidence supports that different forms of cannabis (e.g., cigarette smoking and sublingual THC administration) may produce acute impairment in different visuospatial processing tasks (e.g., a spatial n-back task and the Corsi Block Tapping Test). Also, the study by Mokrysz et al. (2016) supported that this effect could be considered large for educational achievement.

Correlational Studies

Comparisons Between Visuospatial Processing and Other Cognitive Tasks

We gathered diverse good-quality correlational evidence showing an association of cannabis use with different degrees of decline in visuospatial processing tasks. When these tasks are compared with other cognitive tasks (e.g., verbal or executive processing), the evidence is mixed, as there are studies showing three outcomes: (a) larger declines in visuospatial processing tasks, (b) smaller declines in visuospatial processing tasks, and (c) similar declines in visuospatial processing and other cognitive tasks.

Regarding the first outcome, there is some evidence showing that cannabis can be more deleterious to visual or spatial processing rather than other tasks of executive processing or working memory (e.g., Dörr et al. 2009). For example, a good-quality study is provided by Ehrenreich et al. (1999). They compared 99 young cannabis users, who were consuming weekly for at least 6 months, with 49 nonuser controls (matched by age, gender, education, and health; see Table 2). Five attentional instruments were used, including flexibility, working memory, and visual scanning. The only significant result was observed in visual scanning, in which longer reaction times were associated with early use of cannabis (between 12 and 16 years old). This finding showed a large effect size ($d = 0.48$) according to the benchmarks by Kraft (2020). In other words, starting to use cannabis at an age younger than 16 was related to being slower on visual scanning, compared with starting older or not consuming, and the size of this effect could be regarded as educationally large.

Similarly, the good-quality study by Harvey et al. (2007) with adolescents (between 13 and 18 years of age) also compared performance on cognitive tasks between cannabis users and nonusers. Results showed impairment on three measures, of which two were visuospatial (total errors in Spatial Working Memory and strategy in Spatial Working Memory). Assessing the quality of this study, we noted the minor problem that cannabis users also used more nicotine and presented more episodes of misconduct than nonusers (see Table 2).

By investigating the performance of 55 university students (44% females) on different cognitive tests, Pope Jr. et al. (1997) observed that females who smoked cannabis occasionally outperformed females who smoked cannabis more frequently in a test of visual working memory. This difference was not observed for males or in the other tests. Our assessment check, shown in Table 2, shows that the study had many strengths, including measuring cannabis metabolites and matching the groups by several variables. However, a problem was that heavy cannabis users had tried more hallucinogens, so this study was rated as *fair* in quality, as the use of hallucinogens could be confounding the results.

Concerning the second outcome, there is evidence showing that cannabis is more harmful to other cognitive tasks than to visuospatial processing (see also below Jackson et al. 2016; Ross et al. 2020). For example, in a good-quality study with 62 adult participants (23% females), Gruber et al. (2012) compared heavy cannabis users to nonusers while attempting different cognitive tests. Results showed impaired performance in cannabis users on tests of executive processing (Wisconsin Card Sorting Test) and cognitive control (Stroop Color Word Test). However, there were no significant differences between the users and the controls in tests of visuospatial processing (Rey-Osterrieth Complex Figure) or verbal memory (California Verbal Learning Test). In terms of quality, the study met several criteria, including the measurement of cannabis metabolites and including only heavy cannabis users (see Table 2), but a minor problem was that gender was not equivalent in the compared groups.

Also, the evidence of less decline in visuospatial processing has been observed in meta-analyses. For example, Schoeler et al. (2016) conducted a meta-analysis of 88 studies and 303 comparisons between cannabis users and nonusers in different cognitive tasks. The analysis, which included 7697 nonpsychotic participants, included tasks of working memory, immediate, and delayed recall, recognition, and learning. Concerning these subjects, results showed dose effects, as the decline was smaller in light cannabis users, compared with regular and heavy users. When considering the type of task completed by these participants, cannabis users tended to score lower on verbal tasks compared with visuospatial tasks. Schreiner and Dunn (2012) also conducted a meta-analysis, although smaller (33 studies, 1010 cannabis users, 839 nonuser controls). Results showed a decline in several cognitive domains (e.g., attention, executive, language, and leaning), but not in the perceptual-motor domain, which included visuospatial processing tasks.

Regarding the third outcome, there is also evidence that the decline can be equally important for any cognitive task. For example, Mena et al. (2013) studied nondependent high school students that belonged to three public schools. From a sample of 565 adolescents (M_{age} = 16 years), 40 consumers exclusively of cannabis were compared on a battery of cognitive tests to 40 participants who did not consume drugs, controlling for socioeconomic status and IQ (see Table 2). Results in this good-quality study showed significantly lower performance scores for cannabis users in most of the tests, including assessments of verbal memory, visual memory, and visuospatial ability.

In conclusion, high-quality correlational studies that have investigated associations between cannabis consumption and visuospatial processing have shown that this processing can sometimes be more or equally impaired than verbal or executive processing. However, several studies, including meta-analyses (Schoeler et al. 2016; Schreiner and Dunn 2012), suggest that there is more correlational evidence showing that visuospatial processing can be less affected than other cognitive functions. A likely variable that affects these differences is the age of the participants, described next.

Comparisons Between High School Students and Adult Participants

Although there are exceptions observed (see the abstinence study by Scott et al. 2018, below), high school and adolescent subjects usually show more significant cognitive and visuospatial declines due to cannabis consumption, compared with adults (e.g., Hooper et al. 2014). For example, there are two good-quality studies showing these age differences in general executive functions. Fontes et al. (2011) investigated 148 adult participants and compared executive processing between early cannabis users, later cannabis users, and nonusers. Results showed that early users, but not later users, had diminished executive functions, compared with nonusers. Similarly, Gruber et al. 2012; see also above) observed that those who started consuming cannabis earlier (before age 16) and smoked more frequently performed worse in a battery of executive tests, compared with the later users (after age 16). Even though these are two good-quality studies that included the high standards of measuring cannabis metabolites and matching the groups regarding confounding variables, gender was not equivalent in the groups (see Table 2).

There are also studies showing these effects of cannabis age of onset and visuospatial processing. Ehrenreich et al. (1999), in a good-quality study (described above), reported that a visual scanning task was performed slower by early users of cannabis (between ages 12–16) than by users who started later with the drug. In a large longitudinal study with 1037 participants (48% females), Meier et al. (2012) assessed auditory memory, working memory, rapid visual information processing, and visual associated learning. Measurements were taken during childhood, adolescence, and adulthood, from both users and nonusers of cannabis. As shown in Table 2, we rated this study as fair quality, because the use of other drugs was corrected post hoc with statistical models. Results showed that using cannabis for longer periods was more detrimental for test performance and that the most harmful effects were observed in participants that had started consuming in earlier adolescence years. However, Rogeberg (2013) reported flaws in the methods by Meier et al. (2012) and presented reanalyzed data, which supported concluding that the differences were arguably associated with socioeconomic status rather than cannabis consumption.

In conclusion, although additional quality evidence is needed, it appears that cannabis onset at a younger age impacts more substantially the later cognitive and visuospatial decline associated with its consumption. As reviewed by Lubman et al. 2015; see also Crane et al. 2013), such vulnerability in adolescent participants (e.g., high school students) when using cannabis from early ages can be related to the inhibition of white matter development and memory consolidation. Consequently, this earlier starting point in cannabis consumption would hamper the later neurological development needed for optimal performance in working memory and visuospatial processing tasks. A clearer picture of the negative consequences of cannabis on the visuospatial processing of adolescents is supported by correlational studies with rigorous research designs, described next.

Stringent Studies

Robust evidence can sometimes be obtained from correlational studies that follow any of these three strategies: (a) recruiting many participants, (b) measuring data longitudinally, or (c) employing twin comparisons that control for potentially confounding variables. However, if the strategies are pursued without a quality assessment (e.g., Harris et al. 2001), the study could also be biased.

For example, Owens et al. (2019) reported associations between cannabis use and hindered performance on a spatial n-back task. Although the study used the stringent strategy of a large sample ($N = 1038$ adults), the groups that were compared (cannabis users versus nonusers) presented differences in critical potentially confounding variables, such as age, education, and use of drugs (see Table 2).

Similarly, Jackson et al. (2016) showed that cannabis consumption was associated with a decline in both verbal processing and general knowledge, but not in visuospatial processing. Although this study used the three stringent strategies to investigate a large sample of twins measured longitudinally ($N = 3066$; 1297 cannabis users versus 1769 nonusers), a negative aspect was that cannabis users were also heavier users of other drugs (see Table 2). Thus, the findings that cannabis use could be associated with declined spatial n-back task performance (Owens et al. 2019) or verbal processing and general knowledge tasks (Jackson et al. 2016) warrant further confirmation supporting the findings of these two fair-quality studies.

The good-quality correlational studies that follow one or more stringent strategies tend to show that cannabis use is less associated with visuospatial processing than other cognitive and executive tasks. For example, Meier et al. (2018) extended a previous study (Meier et al. 2012). In this follow-up work, they included two of the stringent strategies: a large sample and twin data. This good-quality study was conducted on 18-year-old twins ($n = 974$ pairs) and showed on five measures of visuospatial processing that twins who used cannabis more frequently performed similarly to their cotwins who consumed less cannabis. In contrast to these null effects, a spatial working memory task (similar to the Corsi Block Tapping Test in backward direction) showed that twins who used more cannabis performed slightly worse than their cotwins who used the drug less frequently. In short, five out of six visuospatial processing measures did not show impairment, but one task, a spatial working memory instrument, showed a marginally negative effect caused by the frequent use of cannabis.

A recent good-quality twin study was conducted by Ross et al. (2020), who collected data twice, when the sample of 856 twin participants (51% females) was 17 years old and later at 23 years. The nine computerized cognitive measures included two visuospatial instruments: a spatial n-back task and a color-shape shifting task. The only significant result showing a difference between twin pairs was that increasing monthly cannabis consumption at age 17 was associated with a small decrease in the total cognitive measures at age 23. There were no specific effects on the two visuospatial processing tasks measured.

In contrast, a study showing a more substantial effect on visuospatial processing is provided by Morin et al. (2019), who followed two stringent strategies by recruiting a large sample and measuring data longitudinally. This population-based study initially enrolled 3826 seventh grade students from 31 schools (47% females) and assessed them yearly until reaching eleventh grade. Results showed that using cannabis was associated with a sustained decline in spatial working memory, as consumers that used the drug 1 year before showed impaired performance in two spatial working memory tests the year later.

To conclude, this section shows that stringent correlational studies that also follow quality criteria support that visuospatial processing may be less affected than other cognitive functions by cannabis consumption (see also the section above). Also, the most affected visuospatial processing tasks tend to be spatial working memory tasks. If these effects are sustained once cannabis is withdrawn is presented next.

Studies in Abstinence Conditions

Several studies under different periods of abstinence (e.g., Blest-Hopley et al. 2019; Bolla et al. 2002; Broyd et al. 2016; Meier et al. 2012; Schoeler et al. 2016) have shown that the detrimental effects of cannabis on cognition can sometimes be sustained. This means that high school students could be cognitively impaired by cannabis consumption even after weeks of abstinence. Nevertheless, regarding visuospatial processing, meta-analyses and both experimental and correlational studies have shown that abstinent cannabis users are as capable as nonusers at solving most of the visuospatial processing tests.

For example, the meta-analysis by Schreiner and Dunn (2012; see also above), which included cannabis abstinence longer than 25 days, showed that 388 abstinent cannabis users and 387 nonuser controls presented similar outcomes in several cognitive domains, including perceptual-motor tests of visuospatial processing. Similarly, the meta-analysis of 69 studies by Scott et al. (2018), which compared 2152 cannabis users to 6575 participants with minimal use, showed small associations between consuming cannabis and performance in the learning, delayed memory, attention, and executive functioning domains. For the visuospatial and the motor domains, the effects were nonsignificant. The adolescent and adult samples showed similar results. Furthermore, all effects tended to be nonsignificant in the studies with cannabis abstinence longer than 72 h, supporting that 3 days without the drug could revert its modest negative effects.

Concerning experimental evidence, in a study with 78 diagnosed adolescents of ages 15–21, Roten et al. (2015) compared cognitive performance of cannabis users, recent abstinent, and sustained abstinent. The three conditions were comparable in potentially confounding variables, except school enrollment (see Table 2), although it was reported that this issue did not affect the results. We considered it a minor problem not affecting the overall good quality of the study. Findings revealed that both abstinent conditions outperformed cannabis users in the domains of composite memory, verbal memory, and psychomotor speed, but not in visual memory.

In another good-quality experimental study, Schuster et al. (2018) recruited 88 adolescent participants aged 16 to 25 years. Controlling for variables such as age, gender, and drug use (see Table 2), the sample was divided into a group who continued using cannabis, and a group who had to sustain cannabis abstinence for 4 weeks. Results showed that the first week of abstinence was associated with better performance on a verbal memory task. However, abstinence did not lead to higher performance in the other attention tests or the two visuospatial memory tasks (including the spatial Corsi Block Tapping Test).

Regarding correlational data, the study by Schweinsburg et al. (2008) investigated nondependent high school students. Abstinent cannabis users and nonuser controls were compared on a spatial working memory task. In this study, which included 32 teenagers between 16 and 18 years of age (28% females), toxicological urine measurements were used to control for abstinence of 28 days in both groups. Although performance on the spatial task was not different between the two groups, abstinent users showed smaller brain activation in the zones associated with spatial working memory, which could indicate residual effects of cannabis.

Medina et al. (2007) compared 31 cannabis users (26% females), who were abstinent for 28 days, with 34 controls (26% females). Results on cognitive tests showed that abstinent cannabis users were outperformed by controls in verbal story memory, complex attention, and sequencing ability, but not in the visuospatial processing tasks.

The study by Winward et al. (2014) investigated 128 individuals, ages 16–18 years, who kept abstinent for 1 month from cannabis. Among other comparisons, a group of abstinent cannabis users was compared with a control group of nonusers. Compared with the nonusers, abstinent cannabis users presented lower performance in verbal memory and psychomotor speed. There were no differences between both groups on the two visuospatial tasks (Rey-Osterrieth Complex Figure Copy and WASI Block Design).

These three correlational studies (Medina et al. 2007; Schweinsburg et al. 2008; Winward et al. 2014) presented two common features: (a) they did not show significant effects on visuospatial processing for cannabis abstinent users, and (b) we rated them as fair-quality studies, as they did not control the potential moderating variable of participants using other drugs in addition to cannabis (see Table 2).

A good-quality study that controlled these and other variables between the comparison groups was reported by Lyons et al. (2004). Also, the study provided the stringent criteria of a male twin study, plus the quality check of an abstinence period of more than 1 year (see Table 2), to investigate 54 adult twins attempting a battery of 16 cognitive tests. There was only one significant finding in which the nonuser cotwin outperformed his cannabis-abstinent twin: the visuospatial intelligence task of block design. This effect showed a medium to large size ($d = 0.19$), according to the educational standard by Kraft (2020).

To conclude, experimental and correlational evidence (from meta-analyses and empirical studies) tends to support that, after an abstinence period, residual effects of cannabis on visuospatial processing, including spatial working memory tasks, may vanish. The studies tend to concur (excepting Lyons et al. 2004) that the adverse effects are more sustained in other cognitive functions. However, since some of the studies did not control potentially confounding variables (e.g., using other drugs and alcohol), further research with high school students is needed to support that the negative effects of cannabis on visuospatial processing can be fully reverted after an abstinence period.

Discussion

In this review article, we have described the importance of the visuospatial processor of working memory concerning learning and academic achievement. Thus, visuospatial processing alterations would likely interfere in successful learning. An example of this alteration is cannabis consumption, which could produce a more substantial decline in high school students, compared with adults. Although several studies have shown an association between cannabis consumption and cognitive decline in adolescents, the novelty of our approach is that we focused on the visuospatial processing of high school students who were nondependent cannabis users.

Our review suggests that the decline is more significant in general cognitive and executive tasks than specific instruments of visuospatial processing. Nonetheless, we have provided quality experimental and correlational evidence suggesting that the consumption of cannabis can be associated with lower performance in different visuospatial processing tests, especially those measuring spatial working memory. Results of abstinence studies suggest that these detrimental effects may not be sustained, but further quality evidence is needed to replicate these findings.

Only three studies (Ehrenreich et al. 1999; Lyons et al. 2004; Mokrysz et al. 2016) that showed significant visuospatial processing declines associated to cannabis provided the effect sizes of comparisons between cannabis users and controls. According to the recent educational benchmarks proposed by Kraft (2020), these effect sizes correspond to medium to large effects. In other words, although significant findings were not always observed, when they appeared, they indicated that the magnitude of the differences affecting visuospatial processing were educationally relevant. Further instructional research is necessary, both including measures of effect sizes and following quality criteria, to provide a more complete picture on the effects of consuming cannabis and high school students' visuospatial and working memory processing.

Instructional Implications

A first instructional implication that follows from the present review is that teachers and instructors should be aware that rigorous evidence shows an association between ongoing cannabis use and a decline in visuospatial processing (e.g., Blest-Hopley et al. 2019; Silins et al. 2014). As such, teachers and instructors should inform students that consuming cannabis could have negative consequences for their school achievement, independently of the current legalizing trends. In other words, the legalization of cannabis consumption, as if this drug were harmless, is unsupported by empirical data, and students could learn how to assess the type of research behind the legalizing agenda.

A second instructional implication is that the problematic effects of cannabis use could be more pronounced in younger high school students than in more adult consumers (e.g., Lubman et al. 2015), and this difference could be observed even in nonclinical and nondependent users (e.g., Orr et al. 2019). Consequently, educational campaigns against cannabis consumption should prioritize targeting high school and young consumers.

A third implication for education is related to the relationship between visuospatial processing and thriving in the math and science disciplines (see Buckley et al. 2018; Castro-Alonso 2019). In other words, the potentially deleterious effects of cannabis on visuospatial processing could be particularly problematic for high school consumers who dream of becoming future mathematicians or scientists. Moreover, cannabis consumption could be yet another influential variable leading to fewer of these professionals than those needed in modern society (see Bayer Corporation 2014). Hence, educational campaigns could prioritize students inclined toward these disciplines.

Limitations and Future Directions

One limitation of this study is that we reviewed the effects of cannabis on whole populations (mostly nondependent high school students) but did not consider potentially moderating individual differences. For example, *gender* could be an individual property to include in future studies, as it can influence both the effects of cannabis (e.g., Crane et al. 2013; Girgis et al. 2020; Makela et al. 2006; Pope Jr. et al. 1997; Skosnik et al. 2006) and visuospatial processing (e.g., Castro-Alonso and Jansen 2019; Castro-Alonso et al. 2019c; Lauer et al. 2019).

A second limitation also concerns a moderating variable that we excluded in the effects of cannabis on visuospatial processing. This moderator is *cognitive load*, which corresponds to the demands on working memory and visuospatial processing when learning (see Castro-Alonso et al. 2019b; Castro-Alonso and de Koning 2020; Sweller et al. 2011; Sweller et al. 2019). As suggested by Crane et al. (2013), a promising future direction is to investigate the detrimental effects of cannabis on learning under different conditions of cognitive load. For example, the effects of cannabis on processing information in different modalities, including those that are verbal, haptic, and visuospatial (see Baddeley 2012; see also Sepp et al. 2019) could be investigated while also considering different cognitive loads. Different lapses of time between using cannabis and attempting a cognitive task could also be investigated, considering that stressed or depleted working memory can be replenished after resting (see Chen et al. 2018; see also Leahy and Sweller 2019).

Conclusion

By reviewing recent good-quality literature, we provided experimental and correlational evidence of the undesirable effects of consuming cannabis on visuospatial processing in nondependent high school students. The conclusion is that visuospatial processing seems to be less affected than other domains of working memory and learning, and the effects could disappear under abstinence. However, we also conclude that using cannabis may moderately impair visuospatial processing and spatial working memory and that larger effects can be observed in younger and more frequent consumers. This implies that continuing high school consumers may be impaired in their academic achievement by using cannabis, which contradicts the current trend of legalizing recreational cannabis as if it were harmless.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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