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CURRENT OPINION

Cannabis and Exercise Science: A Commentary on Existing Studies and Suggestions for Future Directions

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Abstract Policies regarding cannabis use are rapidly changing, yet public officials have limited access to scientific information that might inform the creation of these policies. One important area in which to begin investigations is the link between recreational cannabis use and health, specifically exercise. There are common anecdotal reports that cannabis decreases motivation, including motivation to exercise. On the other hand, there are also anecdotal reports that cannabis is used prior to athletic activity. In fact, the World Anti-Doping Agency includes cannabis as a prohibited substance in sport, partly because it is believed that it may enhance sports performance. At the current time, there is limited scientific evidence to support either one of these opposing lay perspectives. Given recent political, cultural, and legal trends, and the growing acceptance of recreational cannabis use, it is important to develop a more nuanced understanding of the relationship between cannabis and exercise, specifically the potential effects of use on exercise performance, motivation, and recovery.

Key Points

Currently, the specific relationship—positive or negative—between cannabis use and physical activity/sport, and the mechanisms that might mediate this relationship, are unclear.

Examination of the extant literature suggests potential biological and/or neurocognitive effects of cannabis use on exercise performance, motivation, and recovery.

Future research exploring the effects of cannabis use on sports and exercise behavior has the potential to make valuable contributions that will inform public policy, consumer decisions and, ultimately, public health.

1 Introduction

Policies regarding cannabis use are rapidly changing in the US. This is exemplified by the recent legalization of recreational use in Colorado, Washington, Oregon, Alaska, and the District of Columbia, and the fact that 23 states have passed legislation for medical cannabis, with several more states primed to decriminalize or legalize cannabis use [1]. Recent polls indicate that a majority of Americans (58 %) support legalization [2], and 69 % of Americans believe alcohol is more dangerous than cannabis [3]. Despite the growing public acceptance of cannabis use and strong opinions regarding the harm (or lack thereof) of cannabis, the public currently has almost no access to scientific information about the effects of cannabis on health more generally, or exercise specifically.

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While the limited literature on cannabis primarily focuses on harms associated with use, it is also possible that cannabis may have positive impacts on health. As just one example, data from representative national surveys have shown that frequent cannabis users are actually less likely to be obese than non-users [4]. This raises questions about whether cannabis might be associated with behaviors that are linked to lower rates of obesity, such as physical activity. Some studies have suggested that cannabinoids may exert positive effects on health by decreasing inflammation and decreasing pain [5], and it is possible that such properties might have implications for recovery from exercise. There are also anecdotal reports that cannabis is used prior to athletic activity to enhance performance. In fact, the World Anti-Doping Agency (WADA) includes cannabis as a substance prohibited in competition, and is currently pursuing cases in which an athlete tests positive for cannabis above 150 ng/ml, a threshold that was reduced tenfold in May 2013 from 15 ng/ml, with the intention of lessening the chance that an athlete tests positive for out-of-competition use. These guidelines are a clear reflection of a general expectation that cannabis use may acutely enhance sports performance [6], a perspective that contrasts with the perhaps more common anecdotal reports that cannabis decreases motivation, including motivation to exercise.

At the same time, it has also been shown that cannabis use can negatively affect motor control [7, 8], which could potentially lead to a variety of negative impacts on performance, and endanger the cannabis-using individual in question as well as third parties, an issue that is relevant for individuals participating at different levels of athletic competition, from elite athletes to recreational exercise. Taken together, at this point the specific relationship—positive or negative—between cannabis and health generally, or exercise in particular, and the mechanisms that might mediate this relationship, are unclear. As an effort to begin this process of discovery by summarizing what is currently known, this commentary will address potential biological and neurocognitive mechanisms of (i) the effect of cannabis on performance; (ii) the effect of cannabis on exercise motivation; and (iii) the effect of cannabis on recovery from exercise.

2 Cannabis and Athletic Performance

Anecdotally, cannabis has been reported as both beneficial and harmful to athletic performance [6], yet few empirical studies have been conducted, and those that do exist have limitations primarily in their external validity. There is also limited research indicating the prevalence of cannabis use by athletes, or possible reasons why athletes might use cannabis. In the realm of professional athletes, virtually no data exist on the prevalence of use since cannabis is banned by professional sports organizations, and discovery of its use can lead to suspension and fines. Furthermore, since cannabis is a schedule I drug and is still considered a controlled substance in many countries, testing positive for cannabis can even lead to criminal prosecution of the athlete. However, as cannabis legalization for recreational and/or medical use has come into public attention, several players and authorities from the National Basketball League (NBA), National Football League (NFL), and Major League Baseball (MLB) have made public statements in the media in support of cannabis use for managing sports-related pain and/or stress.

The picture is slightly clearer when looking at cannabis use in college athletes. In a 2012 study of substance use examining 20,474 college athletes from 23 different sports across more than 1,000 institutions, the National Collegiate Athletic Association (NCAA) found that 22.6 % of college athletes reported using cannabis in the past year, making it the most commonly used substance by athletes other than alcohol [9]. The data on potential reasons for cannabis use by athletes is limited. In the same 2012 study by the NCAA, the most common reasons for cannabis use by college athletes were not sports-related (34.6 %), while only a small minority of athletes stated that cannabis helps them improve sports performance (0.5 %) or deal with sports-related injuries (0.7 %) [9]. Additional data come from France, where students at French sports sciences universities reported using cannabis to enhance sports performance, especially for participants who practiced more extreme sports (e.g. windsurfing, skiing, snowboarding, and surfing). The authors interpreted these findings as indicating a potential relationship between sensation seeking, cannabis, and athletic participation [10]. In another study from France, cannabis use was also related to the practice of extreme sports, and was more common in participants who reported practicing sports for emotion-seeking reasons rather than health benefits [11]. In sum, we can conclude that a small subset of athletes has reported use of cannabis to enhance sports performance; however, it is unclear from these data what these athletes perceived the particular benefits of cannabis on performance to be.

To shed some light on the possible benefits, we highlight some of the experimental data on cannabis use and performance. Notably, more exhaustive reviews of the literature on cannabis and exercise performance have been conducted (see Huestis et al., Taskin et al., Pesta et al., and Saugy et al. [6, 12–14]), and thus we mention two representative examples. One early study compared athletic performance of individuals when they smoked cannabis with 1.3 % tetrahydrocannabinol (THC, the main psychoactive drug in cannabis) versus smoked a placebo versus did not smoke. This study found that when participants

smoked cannabis, they showed a significant drop in physical work capacity, as measured on a bicycle ergometer. However, on other performance measures, including handgrip strength, vital capacity, and expiratory flow rate, the conditions did not significantly differ [15]. Another study that measured the effect of cannabis smoking on a maximal exercise test found that when subjects smoked a 1.7 % THC cigarette right before exercise, they had a slightly reduced maximal exercise duration compared to when they did not smoke (15 min compared with 16 min). However, when participants smoked cannabis compared with when they did not, they experienced bronchodilation after smoking, an increase in metabolic rate (VO_2 and VCO_2), and an increase in ventilation [16].

Importantly, as is the case with other studies examining this relationship, both of these studies lack external validity in the sense that they used cannabis with a very low percentage of THC, a form that is uncommon in either recreational or medicinal use today. Although low-THC strains certainly exist (e.g. common strains given to children with seizure disorders have average THC less than 0.5 %), the vast majority of cannabis used by adults has a far higher percentage of THC; in 2012, average THC concentrations were greater than 15 %, compared with 4–5 % in the 1980s [17]. Additionally, both of these performance studies involve smoking cannabis cigarettes, a form of consumption that is not necessarily conducive to athletic performance due to the well-known adverse effects of smoke on the lungs. Athletes who are concerned with how smoke might create negative health outcomes might more commonly utilize vaporized or edible forms of cannabis. Other exercise performance studies summarized in the above-mentioned reviews administered isolated THC in capsules (e.g. Bird et al. [18], as cited in Pesta et al. [13], Ménétrey et al. [19] and Favrat et al. [20], as cited in Saugy et al. [14]), a form that is almost never used in the real world and neglects the fact that the cannabis plant contains up to 80 different cannabinoids and terpenes. Thus, it is unclear whether such findings would generalize in a real-world context.

Another crucial limitation of existing work on cannabis and exercise performance is the fact that these studies seem to look at only one aspect of performance—the effect of cannabis on physiological indicators of performance during exercise. There is no doubt that a large part of exercise performance is also perceptual; for example, ratings of perceived exertion during exercise can vary due to a variety of factors, such as anticipated duration of the activity ([21], listening to music [22], and even caffeine consumption [23]. Thus, it is reasonable to assume that there may be perceptual and/or cognitive effects of cannabis that may influence performance. For example, cannabis has been reported to decrease anxiety, and decreasing anxiety during or preceding participation in sports could have positive effects on performance. Anecdotally, athletes have reported using cannabis before competitions to enhance sleep quality, a reflection of one potential benefit of its anxiety-reducing properties. Additionally, the common cannabis users' experience of changes in the internal clock affecting estimation of time [24] could also impact sports performance, either positively or negatively. As we have done here, to some extent, previous reviews [6, 13, 14] have speculated on the potential for cannabis use to have either positive or negative psychological effects on exercise performance, given both anecdotal evidence as well as what is known about the broad psychological effects of cannabis use. However, no empirical work has specifically examined these effects in the context of exercise.

Clearly, additional data are necessary to fully understand the frequency and type of cannabis use among different age groups, across different sports and types of physical activity, and at different levels of athletic competition, i.e. recreational versus competitive athletes. At this time, the extent to which athletes believe that cannabis increases performance is not clear, nor is it clear whether there is any objective indication that cannabis increases or decreases performance, either psychologically or physiologically.

3 Motivation to Exercise: The Role of Endocannabinoids

Physical activity improves mood and increases positive affect to such a degree that regular exercisers commonly describe it as a 'drug' [25]. This idea is supported scientifically in that endurance exercise such as long-distance running has addictive properties similar to some drugs, causing withdrawal when stopped [26]. The phenomenon of the 'runner's high', a sensation experienced during and after exercise described by endurance athletes as involving indicators such as pain reduction, euphoria, decreased anxiety, and difficulties in estimating the passage of time, shows similarities to cannabis-induced highs [27]. Therefore, it is reasonable to assume that these experiences may be biologically comparable.

The feelings associated with the runner's high are commonly attributed to exercise-induced release of endorphins due to the reported hypoalgesic effects, opiate-like structure, and role in the stress response of these endogenous opioids [27]. However, it has recently been suggested that endorphins cannot be entirely responsible for the runner's high. In one study, plasma levels of endorphins were highest for cyclists who reported increased anxiety during exercise, and others have found that blocking opioid receptors during exercise does not block mood elevations, as would be expected if endorphins

were exclusively responsible [28]. Additionally, there is limited evidence that endorphins can cross the blood–brain barrier [27]. Instead, there are several potential neurobiological mechanisms connected to endocannabinoid (eCB) pathways that could serve to explain positive affective responses to exercise.

Since cannabinoid receptors interact closely with endogenous opioid receptors in the reward pathways of the brain, an eCB-modulated version of the runner's high would explain why regular exercise can become highly rewarding [29]. Laboratory studies conducted in animals and humans have suggested that acute exercise increases the release and circulation of eCBs [27, 30]. Moderate-to-high intensity endurance exercise such as biking or running has been shown to activate eCB systems. Sparling and colleagues trained male college students to run on a treadmill or use a stationary bike at 70–80 % of VO_2max, and found that exercise led to increased levels of the eCB anandamide in blood plasma [30]. This increase of anandamide has been proposed as a possible explanation for exercise-induced activation of analgesic symptoms in the brain [27].

eCBs may play an important role in the rewarding and positive effects of exercise, but animal studies have suggested that eCBs may also play a role in the motivation to exercise. Mice selectively-bred for voluntary running show a reduction in running behavior when injected with a cannabinoid receptor antagonist, and CB1 knockout mice also reduce voluntary exercise [31–33]. Thus, eCBs may play an integral role in the motivation to exercise. Others have posited that eCBs are important for 'in the moment' acute affective responses to exercise but play less of a role in long-term exercise maintenance [34].

eCBs likely modulate affective responses to exercise, largely because they are systematically connected to important brain areas involved in reward. The CB1 receptor is the most abundant G protein-coupled receptor expressed in the brain, and is particularly dense in the hypothalamus, pituitary, cerebellum, and mesolimbic dopaminergic reward pathways [35]. Two of the most commonly studied eCBs, anandamide and 2-arachidonoylglycerol (2-AG), which are synthesized in various central and peripheral tissues, act as agonists on the CB1 receptor, which in turn causes alterations in cognitive and emotional factors, neurogenesis, and levels of neurotrophins such as brain-derived neurotrophic factor (BDNF) [36].

Another way that eCBs affect the brain during and after exercise is through neurogenesis. Brené et al. found that wheel running increased neurogenesis in the hippocampus of depressed rats; running increased cell proliferation in the subgranular zone of the hippocampus, as well as increased concentrations of neuropeptide Y in the dentate gyrus. However, running did not have an effect on neurogenesis in nondepressed rats [37]. In another study, chronic wheel-running exercise in mice resulted in antidepressant-like behavioral changes, which researchers hypothesized resulted from neurogenesis [38]. An increase in eCB signaling in the hippocampus has been found to be required for exercise-induced increase in cell proliferation [39]. Therefore, hippocampal neurogenesis is a potential biological mechanism that explains long-term emotional alterations induced by exercise [34].

eCBs are also highly connected to dopamine pathways. Dopaminergic neurons of the mesocorticolimbic pathway are controlled by excitatory and inhibitory inputs modulated by CB1 receptors [35]. The connection to this system means that eCBs are involved in reward circuitry and, as such, participate in the addictive properties induced by different drugs of abuse [40]. Additionally, studies have shown that the eCB and dopaminergic systems mutually influence the performance of locomotor behaviors [35]. As such, it follows that the dopaminergic system involved in drug addiction, modulated by eCBs, is likely the reward pathway that is also involved in the addictive properties of exercise [41].

There is still much to be discovered about how various neurobiological systems involving eCBs affect acute and long-term affective responses to exercise. Given what is known about the role of eCBs, it is possible that some forms of exogenous cannabinoids may have beneficial effects on exercise motivation. Alternatively, cannabis use could potentially interfere with the function of eCBs and have negative effects on exercise motivation. We are not the first authors to suggest that further research is sorely needed in order to examine how cannabis might modulate the effects of exercise on the eCB system (see Pesta et al. [13]).

4 Recovery: The Role of Inflammation

Another obvious area in which cannabinoids may influence exercise behavior is recovery. Intense exercise produces a variety of mental and musculoskeletal effects, including soreness, pain, and stiffness, both immediately and after some delay [42]. These effects are likely related to the acute effects of exercise on the immune system and inflammatory processes. Specifically, acute exercise is known to act as a stressor on the body, resulting in the release of cytokines, including interleukin (IL)-1β, IL-6, IL-1 receptor antagonist (IL-1ra), and tumor necrosis factor-α (TNFα). Some of these cytokines have anti-inflammatory action and others have pro-inflammatory action [43, 44]. These are the same cytokines activated in response to a stressor or challenge to the immune system, although there

are important differences. The general consensus is that muscle-derived IL-6 is the cytokine that responds most robustly to acute exercise, and although it is a pro-inflammatory cytokine, it induces the release of IL-1ra, a potent anti-inflammatory cytokine, as well as suppressing TNFα, a pro-inflammatory cytokine [45]. In turn, it is the anti-inflammatory action of IL-1ra that has been linked to the suppression of pro-inflammatory cytokines associated with cardiovascular disease and type II diabetes [46].

Despite the long-term health benefits of exercise from the perspective of anti-inflammation, there is no doubt that, acutely, exercise is an inflammatory process that causes damage to muscle tissue, pain, and soreness—often referred to as delayed-onset muscle soreness (DOMS) [47]. Indeed, it is these negative consequences of physical activity that can decrease motivation to begin or maintain an exercise program in both healthy [48] and clinical [49] populations.

There is emerging evidence that cannabis reduces pain, muscle spasms, stiffness, and inflammation in humans [50]. Thus, it is not surprising that athletes might use cannabis to reduce these symptoms. Unfortunately, there is no experimental research in humans on how cannabis may impact recovery after exercise. However, there is a sizeable literature on the effects of specific cannabinoids, in particular cannabidiol (CBD), on inflammation and the functioning of the immune system in animal and cellular models and, more recently, in humans. The first studies (in the 1980s) suggesting that cannabinoids suppress inflammation reported that THC reduced levels of interferon (IFN)-α and IFNβ in animals challenged with lipopolysaccharide. Since then, a number of studies have suggested that cannabinoids modulate pro-inflammatory cytokines, including TNFα, IL-1a, IL-1B and CXCL8 (see Klein [51]). Only two studies have been conducted in humans, and both suggested that cannabis was associated with reductions in IL-6 and TNF [52, 53].

While not conclusive, this emerging literature may offer some insight into mechanisms that may mediate the anecdotal effects of cannabis as an aid in recovery from DOMS, and suggest future directions for human research. On the other hand, the anti-inflammatory properties of cannabis may interfere with normal recovery and adaptation. Studies in mice have demonstrated that the use of anti-inflammatory aids (i.e. ibuprofen) during exercise can reduce exercise-induced skeletal muscle adaptations [54]. Additionally, studies in humans [55, 56] have shown that ibuprofen and acetaminophen administration after exercise does not affect muscle inflammation or soreness after exercise. Therefore, if the anti-inflammatory properties of cannabis work through similar mechanisms, it is also possible that cannabis, depending on whether it is used during or after exercise, could have a negative effect, by mitigating the effects of training on muscle adaptations, or no effect at all on exercise-induced inflammation.

Future studies could examine the effects of cannabis on self-report measures of pain and muscle soreness following bouts of physical activity that differ in intensity and duration. Mediators including physiological indicators of the inflammatory process (e.g. cytokines) and other behavioral and physiological indicators of exercise adaptation and recovery could then be included.

5 Conclusions and Future Directions

Despite the growing acceptance of cannabis use, there is little scientific information about the effects of cannabis use on health and risk behaviors. This commentary has outlined a number of domains that may be the focus of future research, including the effects of cannabis use on exercise performance, motivation to exercise, and recovery from exercise. There are several design issues that will need to be addressed in future studies. As mentioned previously, cannabis includes more than 80 different cannabinoids and terpenes, many of which have different and even contradictory effects [57, 58], and the potency of key cannabinoids can vary dramatically from one strain of cannabis to another. For example, CBD is almost non-existent in many strains but may be as high as 18 % in other strains. Thus, future studies need to be as specific as possible in terms of the strain of cannabis that is being studied. In addition, route of administration may also be a critical factor. Blood levels of cannabinoids peak within seconds of the last puff and then drop rapidly when inhaling (e.g. smoking or vaporizing). In contrast, blood levels are slow to rise and remain elevated for longer periods of time when ingested orally, due to first-pass metabolism [59]. Given the paucity of data on cannabis and health behavior generally, and on cannabis and exercise in particular, there is great opportunity for the accumulation of new knowledge. Furthermore, this information is crucial at a time when the cultural, political, and legal environment regarding cannabis use is changing so rapidly. Studies that are conceptually tied to one of the three key areas described above (performance, motivation, and recovery) and that carefully address these key design challenges associated with cannabinoid potency and administration route, have great potential to make valuable contributions that will inform public policy, consumer decisions and, ultimately, public health.

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