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Review

Cannabis: Exercise performance and sport. A systematic review

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ABSTRACT

Objectives: To review the evidence relating to the effect of cannabis on exercise performance.
Design: A systematic review of published literature
Methods: Tetrahydrocannabinol (THC) is the principal psychoactive component of cannabis.
A search was conducted using PUB med, Medline and Embase searching for cannabis, marijuana, cannabinoids and THC, in sport and exercise; the contents of sports medicine journals for the last 10 years; as well as cross references from journals and a personal collection of reprints. Only English language literature was reviewed and only articles that specified the details of a formal exercise program or protocol. Individuals in rehabilitation or health screening programs involving exercise were included as the study may have identified adverse reactions in the marijuana group. Review articles, opinion pieces, policy statements by sporting bodies and regulatory agencies were excluded.
Results: Only 15 published studies have investigated the effects of THC in association with exercise protocols. Of these studies, none showed any improvement in aerobic performance. Exercise induced asthma was shown to be inhibited. In terms of detrimental effects, two studies found that marijuana precipitated angina at a lower work-load (100% of subjects) and strength is probably reduced. Some subjects could not complete an exercise protocol because adverse reactions caused by cannabis. An important finding relevant to drug testing was that aerobic exercise was shown to cause only very small rises (<1 ng/mL) in THC concentrations.
Conclusions: THC does not enhance aerobic exercise or strength.

1. Introduction

Cannabis has been involved in sport for millennia and was one of the components of the "Fuscum Olympionico inscriptum" or the Olympic Victors Dark Ointment used for pain relief at the classic Olympics.[1] During the 19th century, cannabis preparations were in widespread use in Western medicine for a very wide number of indications such as analgesia, sedation, convulsions, asthma, appetite stimulation and muscle relaxation. Subsequently newer more effective and more easily administered medications were developed. In addition the varying composition of insoluble hemp preparations made dosing unreliable.[2]

Cannabis use is now very widespread in the general community, an Australian household survey found one third of participants over the age of 22 had used cannabis at least once and in the United States 12% of people 12 years have had similar exposure.[3,4] With increasing liberalisation of laws relating to cannabis and expansion into use as a medical agent increasing numbers of people will consider that cannabis in some preparation or other will have positive advantages in the sporting area.

The potential for cannabis to effect exercise and sport performance needs to be appreciated in relationship to its general pharmacology. In addition to the principal naturally occurring cannabis producing plants *Cannabis sativa*, *Cannabis indica* and *Cannabis ruderalis* there are numerous commercially and illegally cultivated hybrids. The female *C. sativa* produces the largest amounts of phytocannabinoids.[5] There are at least 66 phytocannabinoids in *C. sativa* and a total of nine cannabinoids belonging to the Δ9 group. Of the cannabinoid acids Δ 9 tetrahydrocannabinol (THC), cannabidiol (CBD), cannabichromene (CBC) and cannabigerol (CBG) are quantitatively the most important.[6] THC is a partial agonist at the principally central CB1 and peripheral CB2 receptors and is the principal agent inducing psychological effects.[6] THC in plants is mostly in the inactive form THC-COOH, sometimes referred to as THC acid. The active molecule, THC is released by combustion or chemical processes.[7]

THC is highly lipid and poorly water-soluble having low bioavailability which depends on the preparation and its route of administration. When inhaled (smoked) by a "heavy user" (undefined by the authors) about 23% is absorbed, oral administration is

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associated with erratic absorption high first pass metabolism and a bioavailability that is almost always <10%.[6] Intravenously THC concentrations initially fall rapidly but subsequent distribution and metabolism results in a $t_{1/2}$ β is up to 57 h.[6] Following intravenous is inhalation psychological "highs" commence at around 20–30 min and are maximal at 45–60 min when plasma concentrations are falling. THC is metabolised by CYP 2C9 and CYP3A4 predominantly to 11-OH THC and subsequently THC-COOH. The 11-OH metabolite has similar agonist properties a THC but is present in much lower concentrations.[8]

Acute psychological effects depend on the dose route of administration, experience of the user and include alterations in mood, perception and relaxation but also higher functions of perception, reaction-time learning and memory are impaired. The impairment of function persists for over three hours after single doses. Adverse effects usually occur after single large doses and include acute anxiety, panic attacks and hallucinations.[9,10]

Physiological effects can be divided into pulmonary and cardiac. In their meta-analysis of respiratory effects of cannabis, Tetrault et al.[11] considered that the effects of THC needed to be considered independently from the effects of other products of combustion. They concluded smoked marijuana and oral THC are bronchodilators and that long-term use is associated with respiratory symptoms of cough, wheeze and phlegm. The acute cardiovascular response is, universally, a dose dependent increase in resting heart rate and in individuals with high vagal tone it can increase resting heart rate from 55 to 120 bpm.[12] There is an elevation of systolic blood pressure with doses greater than 10 mg THC ($p < 0.01$) in some but not all subjects, with doses of 20–30 mg causing rises of up to between 10 and 45 mm. Chronic high doses of oral THC (210 mg/day for 14 days) resulted in tolerance developing with subsequent falls in systolic blood pressure of 7.9 mm, diastolic of 9.5 mm and heart rate of 9.5 bpm ($p < 0.01$), this tolerance rapidly disappearing after cessation.[13] Electrocardiography shows T wave changes and ventricular ectopic beats in some subjects.[12,14]

A number of serious adverse cardiovascular events have been associated with smoking cannabis. These include myocardial infarction, sudden death, cardiomyopathy, stroke, transient cerebral ischaemia and peripheral arteritis.[15]

Depending on the sport, drugs, illicit or otherwise, are taken for a variety of purposes. These include increasing strength, endurance, relieving pain or tremor and in some sports provide a feeling of calmness and relaxation. Concentrations of the endocannabinoid anandamide have been shown to be higher in runners and cyclists than sedentary controls after 45 min of exercise to 70–80% of predicted maximal heart rate at the <0.05 and <0.01 levels respectively.[16] This has been hypothesised as a possible factor in causing "runners high".[16] Surveys of sportspersons show varying patterns of use and a trend to lower use of cannabis and tobacco among sportspersons than in the general community. A survey of 1305 French sport students from six universities resulted in 1152 completed questionnaires showed highest use in those aged 18–24 with 31.8% using ≥10 "joints" in the previous 30 days. Of the study sample, 12.5% of the French students stated they used cannabis to enhance performance largely because of the relaxing properties of the drug.[17] A questionnaire conducted in elite Australian athletes from 8 national sporting organisations found that of the 974 who responded 21% had used cannabis in the past, defined as ever, but only 3.2% reported recent, defined as within the last 12 months, use.[18]

The World Anti drug Doping Agency (WADA) places a drug on its banned list if it either enhances performance, poses a risk to the athlete or is contrary to the spirit of sport.[19] Since 2004 cannabis has been on the banned list for all competition sport. Cannabinoid use is monitored by measurement of the metabolite THC COOH in urine. The initial detection concentration in urine was set at 15 ng/mL and resulted initial loss, and later reinstatement, of a gold medal for snowboarding. Subsequently the concentration was raised to a detection threshold of 150 ng/mL with a level of uncertainty of 15 ng/mL resulting in the decision limit now being 180 ng/mL.[20] From 2005 until 2012 cannabinoids ranked second or third behind anabolic steroids and stimulants in the annual WADA report of adverse analytical findings by accredited laboratories, with similar findings in Australia. When the detection threshold was raised to 180 ng/mL in 2013 cannabinoids dropped to 6th and subsequently 8th position in the WADA accredited laboratory reports.[21] All investigations assume THC as the principal active agent and there are no data relating to other cannabinoids

2. Method

A search was conducted using PUB med, medline and embase searching for cannabis, marijuana, cannabinoids and THC, in sport and exercise, as well as cross-references from journals and a personal collection of reprints. Only English language literature was reviewed and included only articles that specified the details of a formal exercise program or protocol. Individuals in rehabilitation or health screening programs involving exercise were included as the study may have identified adverse reactions in the marijuana group. Review articles, opinion pieces, policy statements by sporting bodies and regulatory agencies were excluded.

3. Results

Mainstream journals frequently contained reviews, personal opinions and policy statements about cannabis in sport. In spite of the large number of publications relating to the cardiovascular and respiratory effects of cannabinoids there were fifteen research papers including published conference abstracts that related specifically to, or reported on, the interaction of cannabinoids and exercise. Of these studies, 2 involved patients with proven coronary disease, 1 investigated exercise induced asthma. Four used submaximal exercise with one including a measure of strength, 3 used maximal exercise, 1 compared THC with synhexal (a cannabis analog) in a measure of strength, 2 studied the effect of exercise as an adjunct to drug rehabilitation, 2 measured the effect of exercise on plasma concentrations of THC (Table 1).

4. Studies in patients with coronary disease

Two studies investigated the effect of inhaled cannabis on patients with exertional angina who were not regular users of cannabis. All had >75% angiographically proven coronary stenosis in at least one major coronary vessel. Ten male subjects aged 41–53 years exercised without smoking (either a placebo cigarette or THC containing cigarette) then subsequently, in a double blind fashion where cannabis was delivered by smoking 10 puffs (3/4 of a cigarette) containing 18–20 mg THC.[22] In a second study, 10 males aged 43–55 years some of whom were participants in the earlier study, had exercise levels were compared with cigarettes containing nicotine 1.8 mg.[23] The endpoint in each study was the development of angina. When compared to placebo cigarette, marijuana containing cigarettes decreased exercise time when compared to the control exercise test by 48% ($p < 0.001$) while the placebo cigarette decreased work by 8.6% ($p < 0.001$), nicotine containing cigarettes also decreased exercise times but THC containing cigarettes caused a 50% shortening in time to develop angina $p < 0.001$.[22,23] The peak double product (BP X heart rate) reached were similar in each study. The effect of THC was probably due to the increased myocardial oxygen demands caused by the earlier increases in heart rate that commence within minutes of inhalation

Table 1
Summary of published studies.

Study	Subjects	Dose	Parameter	Result
Aronow and Cassidy[22]	10 males 41–53 years with 75% coronary artery occlusion	19.8 mg THC Vs placebo	Bike exercise to angina	Earlier onset of angina with THC
Aronow and Cassidy[23]	10 males 43–55 years with 75% coronary artery occlusion	18.9 mg THC Vs nicotine 1.8 mg	Bike exercise to angina	Earlier onset of angina with THC
Steadward and Singh[24]	20 males 21–27 years (18 finish)	18.2 mg THC Vs placebo	Bike exercise	Fall in peak work capacity (PWC 170)
			Grip strength	No change in hand grip
Avakian et al.[26]	6 males 21–27 years	7.5 mg THC Vs placebo	Bike exercise 40–50% VO2 max	THC caused increased peak double product, tachycardia persisted longer into recovery. Subjects considered exercise harder after THC
Benowitz and Jones[13]	12 males 20–27 years	Chronic oral increased doses to maximum of 210 mg	Modified Masters Step test	blunting of haemodynamic responses causing 2 unable to complete study
Renaud and Cormier[27]	9 males, 3 females 20–24 years	7 mg THC	Bike exercise to exhaustion	Decreased maximal workload $p < 0.05$
Shapiro et al.[28] (abstract) & Tashkin et al.[38]	10 males 19–59	20 mg THC	Bike exercise to exhaustion	All decreased exercise duration
Wong et al.[30]	13 males, 1 female 19–40 years, regular users	3.7 ± 0.82 g cannabis/week	50% VO2 max for 35 min bike exercise	Plasma concentration THC increased $p < 0.001$
Westin et al.[31]	5 males, 1 female 25–34 years, regular users	15–30 g hashish or equivalent/week	60–70% predicted maximum pulse rate for 45 min bike exercise	THC concentrations increased $p < 0.001$
Buchowski et al.[33]	8 females, 4 males 22–28 years	5.9 ± 3.1 joints per day	10 sessions of 30 min at maximum tolerated level on treadmill (~60% VO2 max)	Decreased cannabis use
Bailey et al.[34]	10 Drug free users ≥ 30 days 31–35 sex not stated	N/A	30 min of light exercise and 30 min of moderate exercise	cannabis craving decreased with moderate exercise
Maksud and Baron[35]	13 cannabis users, 18 cannabis + cigarettes users. 17 cigarette users, 17 used neither. All males	Smoked several times/week	Bike exercise to exhaustion	A fitness study on industry workers. No difference between cigarette smokers & cannabis users
Thaskin et al.[36]	5 females, 3 males 19–50 years	2% THC Vs isoproterenol 0.5%	Bike exercise 6–10 min, increasing exercise by 6–10 min or treadmill exercise	Inhibition of exercise induced asthma
Hollister et al.[25]	16 males 21–44, 12 receive THC and Synhexal	THC 30–60 mg Synhexal 50–200 mg	Finger ergograph	"Weakness was clearly demonstrable" no quantitation provided

but an additional direct effect on the coronary circulation could not be excluded.

5. Studies involving endurance and strength

Steadward and Singh selected 20 male subjects aged 21–27 subjects from out of 80 volunteers of which 18 completed the study.[24] In this study 18.2 mg THC was obtained from Mexican plants and the same preparation with THC removed was administered by pipe inhalation. Submaximal exercise was undertaken on a bicycle ergometer and grip strength using a hand-grip dynamometer. Three exercise studies were conducted. THC caused a fall in the peak work capacity PWC_{170} kgm/min from 1099.2 ± 55.01 with placebo to 829.9 ± 50.26 with THC ($p < 0.05$) but no change in hand grip in the dominant hand. No subjects could detect the THC preparation and three mistook placebo for THC. Only one other study has reported an effect on strength. This is the only study that also administered an analog cannabinoid formulation, synhexal, which was developed for use in alcohol withdrawal. In this investigation of 17 males aged 21–44, 16 received THC alone and 13 received synhexal, 12 received both THC and synhexal. One became unco-operative and was removed from the study. All were current non-users of cannabis and gradually increasing oral doses of THC (median 50 mg) or synhexal (median 100 mg) were administered. The investigators did not publish the experimental data from the finger ergograph component of the study but reported "Weakness was clearly demonstrated on the finger ergograph" and that it was similar for both drugs. [25]

6. Studies involving exercise

Avakian et al. conducted cardio-respiratory responses in 6 male chronic users aged 21–27 who had abstained from cannabis for 42 h.[26] Each subject smoked cigarettes containing 7.5 mg THC, placebo cigarettes and had a non-smoking control. Each exercised at around 50% of predicted V02 (750 kg/min at 50 rpm) for 15 min after smoking. THC produced an increased peak double product (BP X heart rate) (18,980 for control, 22,348 for marijuana, 19,536 for placebo) with the increased heart rate for marijuana persisting longer than placebo into recovery. All subjects considered that exercise was harder after THC. Only one study administered increasing doses of an oral formulation of THC.[13] In this investigation 12 males aged 21–27 who were chronic uses for a period of 2–6 years were studied. Each received 30 mg THC in sesame oil in an increasing dosage regimen to 210 mg that continued for 5 days. Chronic dosing resulted in falls in systolic (115.8– 107.9 mm) and diastolic (62.8–53.3 mm) pressures, in both cases $p < 0.01$. Exercise testing was undertaken on six occasions using a modification of the Masters Step Test. There was blunting of the rate rise in the early accelerating dose phase but the same maximal heart rate was obtained. The blood pressure response was impaired and two could not complete all phases of the study because of dizziness.

In three studies studies healthy subjects were exercised to maximal capacity after administration of measured doses of THC. Renaud and Cormier studied 9 male and 3 female subjects aged 20–24 who had remained marijuana free for one month. Exercise was conducted on a bicycle ergometer. They received cigarettes containing 7 mg (1.7% THC) and commenced exercise 17 min after smoking. When compared to a smoke free study there was a decrease in maximal work duration (16.1 min $\pm$ 4 Vs 15.2 min $\pm$ 3.3 $p < 0.05$) as a result of leg fatigue. Exercise induced bronchodilation induced by THC lasted longer than that produced by exercise.[27] Shapiro et al. reported the early incomplete results of his study as an abstract, concluding that exercise tolerance following marijuana smoking decreased exercise tolerance in seven healthy men by 5.5 min.[28] The final, complete investigation included 10 healthy males who smoked cigarettes containing 20 mg THC and placebo cigarettes, exercise was conducted on a bicycle ergometer commencing at 150 kg/min and increased by 150 kg/min at 5 min intervals until exhaustion. There were multiple physiological measures of tidal volume, respiratory rate, minute ventilation, oxygen consumption, CO_2 production, respiratory exchange ratio, end tidal volume, end tidal pCO_2, arterial blood pressure, heart rate and blood pH, PCO_2, pO_2, lactate, carboxyhemoglobin. One subject became "stoned" and ceased after 9.9 min (control result 29.4 min) and all but two others ceased because of fatigue at lower workloads after smoking marijuana. The only physiological measured that differed was the higher heart rate with marijuana. Not surprisingly the same conclusion was made in the larger investigation.[29]

7. Pharmacokinetic studies

Induced stress and fasting in rats has been shown to increase plasma concentrations of THC and THC COOH by mobilising drug stored in fat deposits. It is possible that if there was a similar effect in humans, it may have pharmacodynamic effects on the cardiorespiratory system. In addition to performance effects, this would have implications for situations where individuals are required to provide samples for analysis.

The first study in humans involved regular users recruited by media advertisements and interview. Of the 15 participants, one withdrew leaving 13 males and one female aged 19–40 whose consumption was 3.7 ± 0.82 g of cannabis/week. After baseline assessments were completed and one was excluded for health reasons. They exercised to 50% of their VO2 max on a stationary bike for 35 min 7 having fasted prior to exercise. Plasma THC levels were significantly elevated ($p < 0.001$) above control values on conclusion of the test but not 2 h later. THC-COOH concentrations were unaltered by exercise.[30]

A second study was conducted in a Norwegian drug rehabilitation program and recruited 5 males and one female (age range 25–34) who consumed 15–30 g of hashish per week for more than a month. All were randomly assigned to 24 h food deprivation with fluids allowed or equivalent or non-fasting and were exercised on a treadmill to 60–75% of predicted maximal heart rate for 45 min. Each subject completed both fasting and non-fasting arms of the study. Pre-exercise concentrations ranged from below the limit of detection (0.2 ng/mL) to 3.1 ng/mL. There were minor increases of 25% and 7% after exercise in the serum concentrations of THC and THC-COOH and lower increases after fasting similarly no increases were found in urine samples. Unfortunately the studies were conducted three to five days after admission, had body mass indices between 19 and 22 kg/m^2 when mobilisation of stores THC may have been reduced or initially low. The authors concluded that low intensity exercise such a jogging of overnight fasting would be unlikely to ". . . hamper interpretation in drug testing programs."[31] The detailed studies conducted by Huestis et al. have shown present urinary concentration of 180 ng/mL proscribed by WADA could never be reached by passive exposure and certainly not by exercise.[32]

8. Exercise in a rehabilitation setting

These studies of considerable value in determining safety of exercise in individuals taking cannabis. One study was undertaken to evaluate the value of exercise in decreasing craving for cannabis in cannabis dependent individuals. Cannabis had been used for between 1 and 15 years with weekly use of 7 to 140 'joints' each equalling 0.5 g dry cannabis. The exercise component comprised 10 sessions each lasting 30 min at 60% maximal tolerated level on a treadmill over a period of 2 weeks. 8 females and 4 males aged 24.8 ± 2.9 years who consumed 5.9 ± 3.1 joints per day completed the study. There was decease in cannabis use and improvement in some psychological parameters of compulsivity, emotionality, expectancy and purposefulness at the completion of the study. Apart from confirming the presence of THC in urine there were no further analytical studies and there were no reports of the effect of THC on exercise performance. No adverse reactions occurred during the study.[33]

Bailey et al. assessed the effect of exercise on cannabis craving in 10 individuals who had been drug free for 30 days. After a control period of minutes 30 min rest they exercised at 30 min light (45–50% predicted maximal heart rate) and moderate (65–70% predicted maximal heart rate). Cannabis craving was found to be decreased at the $p < 0.05$ level by moderate exercise using a visual analog assessment scale but did not alter a marijuana craving questionnaire.[34]

9. Exercise in an industrial setting

Concerns about the effects of cigarette smoking and cannabis use on the performance of industrial workers was discussed with responsible unions in Milwaukee, WI, USA. As result of these concerns, out of a pool of "about 300" male volunteers, four groups of individuals aged between 19–33 years were studied. These comprised of 18 cigarette and marijuana users, 13 users of marijuana alone, 17 users of cigarettes alone, and 17 who neither smoked cigarettes or marijuana. Drug screening was not undertaken prior to exercise. Each group exercised on a stationary bike with a 3 min warm-up at 50 W and increases of 25 W until volitional exhaustion. Apart from higher minute ventilation in smokers and perceived higher exertion in smokers, the peak levels of exercise were not different between the 4 groups.[35]

10. Exercise induced asthma

Exercise induced asthma is a common problem in sportspersons and is prevented by inhaled β2 agonists such as salbutamol. Thaskin et al. compared the bronchodilator properties inhaled isoproterenol 2 mL of 0.5% against 2% THC smoked from 500 mg marijuana cigarettes and placebo.[36] Bronchospasm was induced by either bicycle exercise for 6–10 min at incremental loads of 200–650 kp-m, or treadmill exercise at 1–3.5 mph (1.6–8.9 kmph) at 0–19% slope, as well as graded doses of methacholine. Three female and five males, four of whom had previously uses marijuana, took part in the investigation. Bronchospasm could not be reproduced in one subject. Pulmonary effects were measured by changes in specific airways conductance and percentage changes in thoracic gas volume. THC caused prompt reversal of exercise and methacholine induced bronchospasm. Previous users of marijuana experienced emotional changes with the THC but the others experienced only light-headedness or somnolence.[36] Cannabis use may mask positive exercise testing for bronchospasm and patients need to be specifically asked about its use prior to diagnostic exercise challenge.[37] Its therapeutic value in asthma though is less positive. In a later study of the effects in 11 healthy men and 5 asthmatics, by the same principal investigator, showed that inhaled THC sometimes caused bronchoconstriction as well as cough and or chest discomfort.[38]

11. Conclusions

There are surprisingly few scientific data relating to the effects of cannabis on exercise performance. There were no studies which have evaluated strength or athletic performance similar to what have been conducted using anabolic steroids or stimulants such as amphetamine. No papers specifically related to measures of sporting performance such as running times, weights lifted or accuracy in a target related event such as archery. Internet sites generally recommended sportspersons use cannabis for its relaxing and analgesic properties rather than increasing strength or speed. THC is a bronchodilator. The pulmonary effects would be of little value in sportspeople with asthma, exercise induced or otherwise, as there are more effective agents at present available which have lower adverse reaction profile. Acute administration causes THC induces tachycardia in all subjects chronic use results in lowering of resting blood pressure. The small number of scientific studies all show cannabis decreases aerobic performance or has no effect on it. There are no theoretical reasons to believe it could increase strength or endurance. It may impair abilities in extreme situations. There are claims that the psychological effects may have a calming effect before events but this has not been confirmed or disproved in a clinical trial. Apart from one case report of its use in a field reduction of a dislocated shoulder, there are no data to support claims that is possesses special analgesic or muscle relaxing properties for sportspersons.[39]

Cannabis is widely used as an adjunct to sporting activity and remains banned in sporting competition. Whether its use is contrary to the spirit of sport will remain a subject of continuing controversy. What can be said is that THC does not enhance performance in aerobic exercise and may adversely effect coordination in some sports. There are many case reports associating THC and analogs with adverse cardiac effects. These effects combined with the proven lowering of the anginal threshold pose a risk in the older athlete and those with unrecognised cardiac disease. In some states in the USA there are many medical conditions for which sportspeople may legally obtain cannabis. There is doubt as to the value of medically prescribed marijuana in some conditions for which it is able to be prescribed.[40] This may create challenges to allowing cannabis to be accepted as a therapeutic use exemption in the future.

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