Performance and Health-Related Characteristics of Physically Active Males Using Marijuana

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Abstract

Lisano, JK, Smith, JD, Mathias, AB, Christensen, M, Smoak, P, Phillips, KT, Quinn, CJ, and Stewart, LK. Performance and health-related characteristics of physically active men using marijuana. *J Strength Cond Res* 33(6): 1658–1668, 2019—The influence of chronic marijuana use on the performance and health of physically active individuals has yet to be fully elucidated. The purpose of this study was to explore pulmonary function, aerobic and anaerobic fitness, strength, serum testosterone, cortisol, C-reactive protein (CRP), Δ-9-tetrahydrocannabinol (THC), 11-nor-9-carboxy-Δ-9-tetrahydrocannabinol (THC-COOH), and 11-hydroxy-Δ-9-tetrahydrocannabinol (THC-OH) concentrations in a physically active population either using or not using marijuana. Healthy, physically active males ($N = 24$) were compared based on their marijuana-use status: marijuana users (MU; $n = 12$) and non-users (NU; $n = 12$). Statistical analysis ($p = 0.05$) revealed no difference between groups for age, body mass, body mass index, body fat, forced expiratory volume in 1 second percentage, $\dot{V}O_2$max, anaerobic power output, strength measures, testosterone, or cortisol concentrations. Although not statistically significant, MU showed a trend to fatigue to a greater percentage of absolute power output than NU from the beginning to the end of the Wingate Anaerobic Power Assessment ($p = 0.08$, effect size = 0.75). C-reactive protein in MU (1.76 ± 2.81 mg·L^{-1}) and NU (0.86 ± 1.49 mg·L^{-1}) was not significantly different ($p = 0.60$) but placed MU at moderate risk and NU at low risk for cardiovascular disease. Anaerobic fatigue was the only performance variable to show a trend for difference between groups. These results suggest that marijuana use in physically active males may not have significant effects on performance; however, it may be linked to elevated concentrations of CRP which place users at a higher risk for cardiovascular disease.

Key Words cannabis, pulmonary function, anaerobic power, $\dot{V}O_2$max, inflammation

Introduction

Marijuana is the most common illicit drug used in the United States, with more than 8% of the general population and almost 20% of young adults (age 18-25) reporting use within the last month (11). Marijuana, which refers to products of the hemp plant (*Cannabis*) including flowers, stems, and leaves, contains at least 60 chemical compounds that are active cannabinoid alkaloids including delta-9-tetrahydrocannabinol, commonly known as THC (25). The legalization of marijuana for recreational use in several states across the United States has resulted in increased accessibility to the general population. Over the course of the past decade, the number of young adults who perceive risk associated with regular marijuana use has decreased (24). Despite the 1999 World Anti-Doping Agency (WADA) ban on marijuana, many elite athletes still report using marijuana (14). Marijuana is also a banned substance by the National Collegiate Athletic Association (NCAA). In 2009, 522 NCAA Division I athletes were anonymously surveyed about their marijuana use and 37% self-reported having previously used marijuana, with male athletes more likely to use than female athletes (30).

The use of marijuana is associated with a number of negative health outcomes including increased resting heart rate (HR), depression, and anxiety (34,39). However, marijuana use is also associated with various health benefits, such as a reduction in the occurrence of migraines, glaucoma, and seizures (44). Less is known about how regular marijuana use may influence the health of athletes and their ability to perform. Recent indications show that athletes are using marijuana for more than just pain management. Some suggest that many athletes are now under the impression that

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marijuana use can also help improve performance (8). Unfortunately, data supporting this approach are lacking.

The effects of marijuana use on pulmonary function have been studied since the 1970s. The acute effects of THC administration through inhalation and ingestion are associated with an immediate increase in airway conductance after inhalation that peaked at 15 minutes and lasted for up to 60 minutes (41). Airway dilation after marijuana administration is significantly increased and peaks at 3 hours and lasts for up to 6 hours after THC injection (41). Other studies (21,45) have shown that acute administration of inhaled THC causes bronchodilation in asthmatic patients. More recent research on pulmonary function shows that users experience an increase in forced vital capacity (FVC) when compared with nonusers (NU) (18,28,36). However, in 2 separate studies (2,18,25), when young, otherwise healthy, regular marijuana users (MU) are compared with NU, there were no differences in forced expiratory volume in 1 second (FEV_1).

Marijuana use is also associated with changes in cardiovascular function. Acute administration of THC elevates resting HR in human subjects by 30–50% (20). Treatment with synthetic cannabinoids, which mimic the actions of cannabinoids such as THC, also act to decrease blood pressure through suppression of cardiac contractility and reduced vascular resistance in rats (5). Males from working class backgrounds who were using marijuana multiple times per week displayed comparable $\dot{V}O_2$max values to NU (31). However, regular exercise was not considered as a factor in this study. There is no recent information about how marijuana use may alter cardiorespiratory fitness in athletes.

The optimal function of skeletal muscle is a major component of athletic performance. THC administration decreases mitochondrial oxidative capacity by 12–15% in mouse skeletal muscle (32). Administration of THC is also associated with an inhibition in Ca^{2+} release from the sarcoplasmic reticulum (SR) and a decrease in the Ca^{2+} sensitivity of the contractile apparatus, leading to skeletal muscle fatigue (33). This information suggests that marijuana use decreases mitochondrial function, reducing the skeletal muscle cell's ability to produce adenosine triphosphate during exercise, and limits the Ca^{2+} released from the SR; thus, interfering with excitation contraction coupling in the sarcomere. In humans, this action may be linked to an increased rate of fatigue during aerobic and anaerobic exercises, by interfering with the ability of muscle to produce and sustain force. Yet, this topic remains unexplored in the scientific community.

Finally, the use of marijuana has been linked to several biomarkers that relate to exercise training and recovery. Alterations in testosterone, the male sex hormone, and cortisol, a stress hormone, have shown indications to be influenced by marijuana use. Today, findings related to marijuana-related effects on circulating testosterone levels are equivocal. Testosterone concentrations in male subjects who chronically used marijuana have been observed to decrease (29) or show no difference as compared to a healthy, nonusing control (17). Cortisol concentrations positively correlate with marijuana use in a dose-dependent manner (37). C-reactive protein (CRP) concentrations, a global marker of inflammation, decrease with the acute administration of marijuana (3). Although concentrations of testosterone, cortisol, and CRP can influence athlete performance and ability to recover, no research has assessed the chronic effects of marijuana use on these biomarkers in athletes or physically active individuals.

Given the recent legalization of marijuana for recreational purposes in some U.S. states and the previous findings of marijuana on physiological systems related to athletic performance and health, the purpose of this study was to explore the pulmonary function, cardiovascular fitness, anaerobic power production, and blood biomarkers of physically active male MU and NU. It was hypothesized that the overall athletic performance and health of MU would be lower as compared to NU.

Methods

Experimental Approach to the Problem

Over the course of the 4 study visits, the marijuana use habits, health status, and athletic capabilities of MU and NU were assessed using a variety of tests including pulmonary function, cardiovascular fitness, anaerobic power production, and blood biomarkers. The week before each visit, participants were asked to maintain their normal dietary and hydration habits. Then, all participants were asked to abstain from vigorous exercise for 48 hours, and alcohol, caffeine, and marijuana use for 12 hours before testing in all 4 visits. During visit 1, participants filled out an informed consent, medical history, Physical Activity Readiness Questionnaire (PAR-Q), International Physical Activity Questionnaire: Short Format (IPAQ) and the Marijuana Use Measure (MUM). After the completion of the questionnaires, participants provided a venous blood sample. Visit 2 involved the collection of height, body mass, 7-site skinfold assessment, pulmonary function, resting HR and blood pressure, as well as a treadmill $\dot{V}O_2$max test. Visit 3 included handgrip strength assessments and a Wingate Anaerobic Power Assessment. During the fourth and final visit, participants underwent core stability and endurance assessments, as well as lower extremity strength assessments on a Biodex. Visits 1 and 2 were separated by at least 24 hours, visits 2 and 3 by at least 72 hours, and visits 3 and 4 were separated by at least 48 hours to ensure adequate recovery from testing.

Subjects

Male participants ($N = 24$, ages 19–39 years of age) who were either current MU ($n = 12$) or NU ($n = 12$), were recruited on a university campus in Colorado to participate in the study. In Colorado, marijuana products are legal for recreational use for those older than 21 years. To be eligible for the study, participants were required to be physically

Table 1. Marijuana use measures in MU.*†

	MU ($n = 12$)
No. of uses in the past 30 days	21 ± 9.32
Of days used, times used per day	1.79 ± 0.81
Age when first used marijuana	15.83 ± 1.64
Age when began frequently using marijuana	20 ± 1.76

Methods of use						
	Joint	Pipe	Bong	Vaporizer	Edibles	Dabs
Number	6	7	7	3	2	1

*MU = marijuana users.
†Use measures were self-reported through the marijuana use measure and data are presented as mean ± *SD*. Some participants reported multiple methods of use. e.g., 1 subject reported consuming marijuana through pipe, bong, and edibles.

active. Physical activity status was based on the American College of Sports Medicine guidelines for physical activity defined as at least 150 minutes of moderate intensity or 75 minutes of vigorous intensity exercise per week. Regular MU included individuals who were consuming marijuana products at least once a week for the past 6 months, and NU included individuals who had not used any form of marijuana in the past 12 months. Prior to conducting this study, the project was approved by the Institutional Review Board at the University of Northern Colorado. Before data collection, all participants were advised of the risks and benefits of participating in this study and signed the institutionally approved informed consent if they agreed to voluntarily participate.

Procedures

Visit 1: Physical Activity, Marijuana Use Questionnaires, and Blood Collection. Study participants completed a Medical History Form and a PAR-Q. Participants also completed the IPAQ (13). The IPAQ-short format is an instrument that can be used to obtain internationally comparable estimates of physical activity with adults aged 18–65 years. Developed for use in this study, participants reported information about their marijuana use habits by completing the MUM. The MUM was used to assess the frequency and method of marijuana use, as well as the age when first and regular consumption began, duration of regular marijuana use, and any medical reasons related to marijuana use (see Appendix, Supplemental Digital Content 1, http://links.lww.com/JSCR/A63).

Blood Collection. After completion of the questionnaires, participants confirmed that they had adhered to a 12-hour fasting period, a 12-hour restraint from caffeine, alcohol, and marijuana use, as well as a 48-hour restraint from strenuous exercise. A certified phlebotomist collected 30 ml of venous blood in Serum Separation Tube vacutainers. After sitting for 15 minutes at room temperature, samples were centrifuged at 10° C (10 minutes, 2,000 rpm) and serum aspirated, aliquoted, and stored at −80° C until analysis. To help standardize for diurnal variation in blood biomarkers, all blood samples were collected between the hours of 7:00 and 9:00 AM

Visit 2: Hydration Analysis. Participants were asked to empty their bladder into a collection container in a private lavatory. The sample's specific gravity was then analyzed using a PAL-10S (4410) urine-specific gravity refractometer (ATAGO, Tokyo, Japan). The refractometer was calibrated by pipetting 0.3 ml of water onto the analyzing surface and pressing the "zero" button. The water was then removed from the analyzing surface and wiped clean using a nonabrasive wipe. Once the analyzing surface was dry, the urine sample was swirled to resuspend any particulate that may have settled, and 0.3 ml was pipetted onto the analyzing surface. Any remaining urine sample was disposed of in the toilet.

Body Size and Composition Assessment. Participant height and mass (without shoes) were obtained using a stadiometer and a digital platform scale, respectively. Skinfold measurements were taken twice using the standard 7 sites (chest, midaxillary, triceps, subscapular, abdomen, suprailiac, and thigh) with a spring-loaded Lange Skinfold Caliper (Cambridge Scientific Industries, Inc., Cambridge, MA, USA). Each site was measured twice, going through all sites in the same order both times. If the 2 measures for a site differed by more than 2 mm, a third measure was taken. Averages for each site were then used to calculate body density and body fat percentage (19).

Pulmonary Function. Pulmonary function was evaluated by obtaining 3 separate pulmonary measures including FEV_1, predicted FEV_1, which factors in subject age, height, mass, sex, and ethnicity, and FEV_1%, which is defined as the ratio between FEV_1 and predicted FEV_1. These values were recorded with a SpiroLab-II spirometer (SDI Diagnostics, Easton, MA, USA). Using a disposable mouth piece, participants were asked to exhale as quickly and forcefully as possible into the spirometer turbine after a complete inspiration. This process was repeated 3 times, allowing for adequate rest between each trial. Of the 3 trials, the highest value obtained for FEV_1 was then used for statistical analysis.

Cardiorespiratory and Lactate Measures. Maximal oxygen consumption ($\dot{V}O_2max$) was assessed using the Bruce Ramp Protocol (9) with a TrueOne 2400 Metabolic Measurement System (Parvomedics, Model: MMS-2400; Parvomedics, Sandy, UT, USA). In this protocol, the participants walked/jogged on a Marquette Series 2000 treadmill (Marquette Medical Systems, Milwaukee, WI, USA) while the speed and incline were progressively increased until

Table 2. Individual MU marijuana use habits and mass spectrometry detection of THC, THC-COOH, and THC-OH.*†

MU participant	No. of uses in past 30 days	Of days used, times used per day	Detected presence of THC	Detected presence of THC-COOH	Detected presence of THC-OH
1	28	1–2	+	+	+
2	28	1–2	+	+	+
3	4	1	−	+	−
4	14	1–2	−	−	−
5	30	2	NA	NA	NA
6	30	3	NA	NA	NA
7	20	1	+	+	−
8	22	1	+	+	+
9	18	2	−	−	−
10	25	3	+	+	+
11	5	1	−	−	−
12	29	3	+	+	+

*MU = marijuana users.
†Data are from self-reported use on the marijuana use measure and from mass spectrometry analysis of the presence of THC, THC-COOH, and THC-OH. In the "Of Days Used" column, participants who reported the no. of times used per day as a range (i.e., 1–2) was averaged for data analysis (i.e., a range of 1–2 uses per day was averaged to 1.5 uses per day used). (+) indicates positive detection of chemical in participant's blood sample, whereas (−) indicates no detection of the chemical in participant's blood sample. NA indicates that no blood sample was able to be obtained from the participant.

the subject reached fatigue. Capillary blood lactate was measured after a finger stick with a Lactate Plus Meter (Nova Biomedical, Waltham, MA, USA) in the last 30 seconds of each 3-minute stage and immediately after termination of the $\dot{V}O_2$max test described above. Rating of perceived exertion was taken immediately after the termination of testing using the Modified Borg Scale (7).

Visit 3: Handgrip Measures. During visit 3, grip strength was evaluated using a handgrip dynamometer (Grip-D T.K.K. 5101; Takei, Niigata, Japan). Participants held the dynamometer in each hand in the anatomical supinated position with elbow extended. They were instructed to squeeze as hard as they could, without deviating from the starting position, and then release. This process was repeated for a total of 3 times with both dominant and nondominant hands alternating between each trial to allow for adequate recovery. The highest recording for each hand was used to create the participant's combined handgrip score.

Anaerobic Power Measurements. Anaerobic power assessment was completed using a Monark Cycle Ergometer 894-E (Monark Ergomedic, Vansbro, Sweden) using the Wingate protocol (6). Before the 30-second assessment, participants went through 2 warm-up sessions, each lasting 5 minutes, and followed by a 3–5-minute active recovery period. After the 2 warm-up sessions, participants were asked to pedal maximally against a resistance of 7.5% of their body weight in kilograms, for 30 seconds. The number of pedal revolutions completed by the subject were counted in 5-second increments and applied to the Wingate equations (6).

Visit 4: Lower Extremity Strength Assessment. Visit 4 data were collected from a total of $N = 22$ participants (MU; $n = 10$, NU; $n = 12$). Data were not obtained from 2 MU, as they were unable to return for the final study visit. Hip ($90° \cdot s^{-1}$), knee ($30° \cdot s^{-1}$), and ankle ($30° \cdot s^{-1}$) isokinetic strength was assessed in the dominant leg of each participant using the Biodex System 4 Isokinetic Dynamometer (Model: 835-110; Biodex, Inc., Shirley, NY, USA) after a 5-minute cycling warm-up at moderate intensity. Leg dominance was determined by asking which leg the person would choose to kick a ball with for maximum velocity and distance. After the warm-up period, participants were secured to the Biodex using Velcro straps. Participants were then asked to flex and extend each joint against a resistance arm at the controlled speed with 50, 75, and 100% effort, twice. The 50 and 75% efforts were used as warm-ups before maximal efforts. Maximum torque values for each joint direction were recorded.

Core Stability and Endurance. Core stability was then assessed through 4 static exercises: trunk flexion, back extension, and right-sided and left-sided planks using McGill's core endurance tests (4). All measurements were recorded in seconds to fatigue from start of the exercise to when the subject either gave up because of exhaustion, or had to be cued more than once to better maintain their position. The order of the 4 exercises was randomized for each subject.

Blood Analysis. At a later timepoint, after all blood samples had been collected from participants in visit 1, quantification

Table 3. Demographic and anthropometric measures.*†

	Overall ($N = 24$)	MU ($n = 12$)	NU ($n = 12$)	p	Effect size
Age	23.71 ± 4.78	23.33 ± 4.14	24.08 ± 5.50	0.71	0.15
Height (cm)	179.86 ± 7.53	178.93 ± 6.30	180.80 ± 8.77	0.56	0.24
Mass (kg)	81.41 ± 14.33	83.21 ± 18.03	79.60 ± 9.87	0.55	0.25
BMI ($kg \cdot m^{-2}$)	25.10 ± 3.58	25.85 ± 4.52	24.34 ± 2.26	0.31	0.42
Body fat %	11.89 ± 5.79	12.01 ± 7.36	11.77 ± 3.98	0.92	0.04
Resting SBP (mm Hg)	123.08 ± 8.23	121.67 ± 9.87	124.5 ± 6.33	0.41	0.34
Resting DBP (mm Hg)	70.5 ± 9.89	72.67 ± 12.22	68.33 ± 6.71	0.29	0.44

*MU = marijuana users; NU = individuals not using marijuana; BMI = body mass index; SBP = systolic blood pressure; DBP = diastolic blood pressure.
†Data are presented as mean ± *SD*.

of serum testosterone, cortisol, and CRP concentrations were determined using enzyme-linked immunosorbent assays (Alpco Diagnostics, Salem, NH, USA) with a BioTek microplate reader (Model ELx800; BioTek Instruments, Winooski, VT, USA). Intra-assay variations for testosterone, cortisol, and CRP were 2.80, 3.10, and 4.19%, respectively. Enzyme-linked immunosorbent assay concentration analysis for testosterone, cortisol, and CRP ($N = 21$, MU; $n = 10$, NU; $n = 11$) were unable to be obtained from 3 participants because of 2 participants feeling uneasy before serum collection, and 1 participant refused to provide a blood sample. Whole-blood samples were analyzed using liquid chromatography mass spectrometry (LC-MS/MS) for Δ-9-tetrahydrocannabinol (THC), 11-nor-9-carboxy-Δ-9-tetrahydrocannabinol (THC-COOH), and 11-hydroxy-Δ-9-tetrahydrocannabinol (THC-OH) using whole-blood samples at the Colorado State University Analytical Toxicology Laboratory in Ft. Collins, CO, using an established protocol (22). Briefly, samples were mixed with acetic acid, and then extracted by using a hexane and ethyl acetate mixture. The formed solvent was then decanted from the sample and dried using liquid nitrogen. The sample was then reconstituted using methanol and quantified using MS.

Statistical Analyses

Data were analyzed using SPSS (version 23; IBM Analytics, Armonk, NY, USA). Descriptive statistics, including mean and *SD*, were calculated for all outcome variables. All variables were tested for normalcy and homogeneity of variance, and log transformed if necessary. Student's *t*-test was used to compare groups with respect to all outcome variables ($p \leq 0.05$). All values presented are mean ± *SD*.

Effect sizes (ESs) were calculated to quantify if meaningful differences were present between MU and NU for all variables as per Thomas et al. (42).

$$ES = \frac{(M_1 - M_2)}{s_p},$$

Table 4. Hydration, cardiorespiratory fitness, and lactate measures.*†

	Overall ($N = 24$)	MU ($n = 12$)	NU ($n = 12$)	p	Effect size
Hydration (specific gravity)	1.014 ± 0.008	1.017 ± 0.007	1.012 ± 0.008	0.10	0.57
Resting heart rate ($b \cdot min^{-1}$)	65.7 ± 12.8	70.00 ± 15.34	61.10 ± 7.33	0.13	0.74
Absolute $\dot{V}O_2$ ($L \cdot min^{-1}$)	4.22 ± 0.86	4.21 ± 0.97	4.24 ± 0.77	0.94	0.03
Relative $\dot{V}O_2$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	52.12 ± 7.21	51.08 ± 8.88	53.16 ± 5.26	0.49	0.28
Relative $\dot{V}O_2$ at LT	36.03 ± 7.22	36.20 ± 9.99	35.87 ± 3.67	0.92	0.02
Relative $\dot{V}O_2$ at OBLA	42.10 ± 8.46	40.64 ± 10.90	43.43 ± 5.59	0.56	0.14
RPE at termination	9.2 ± 0.83	8.9 ± 0.90	9.5 ± 0.67	0.09	0.73
FEV1 (L)	4.39 ± 0.76	4.34 ± 0.49	4.43 ± 0.98	0.79	0.11
Predicted FEV1 (L)	4.69 ± 0.43	4.67 ± 0.40	4.73 ± 0.47	0.75	0.13
FEV1%	93.28 ± 12.68	93.31 ± 10.43	93.24 ± 15.10	1.00	0.01

*MU = marijuana users; NU = individuals not using marijuana; LT = lactate threshold; OBLA = onset of blood lactate accumulation; RPE = rate of perceived exertion; FEV1 = forced expiratory volume in 1 second.
†Data are presented as mean ± *SD*.

Table 5. Anaerobic power measures.*†

	Overall ($N = 24$)	MU ($n = 12$)	NU ($n = 12$)	p	Effect size
Peak power (W)	896.03 ± 167.12	920.55 ± 185.83	871.52 ± 150.17	0.49	0.29
Minimum power (W)	344.07 ± 79.28	324.70 ± 89.52	363.43 ± 65.66	0.24	0.49
Anaerobic fatigue (%)	60.88 ± 9.85	64.39 ± 8.89	57.38 ± 10.02	0.08	0.75
Capacity (KJ)	16.89 ± 2.66	16.97 ± 3.02	16.81 ± 2.39	0.89	0.06
Peak relative power ($W \cdot kg^{-1}$)	11.10 ± 0.94	11.17 ± 0.56	11.03 ± 1.24	0.73	0.15
Mean anaerobic power (W)	563.05 ± 88.74	565.66 ± 100.55	560.43 ± 79.62	0.89	0.06

*MU = marijuana users; NU = individuals not using marijuana.
†Data are presented as mean ± *SD*.

where M_1 is the mean for MU and M_2 is the mean for NU. Effect sizes were considered large if greater than or equal to 0.8, moderate if around 0.5, and small if less than or equal to 0.2. Pooled *SD* (s_p) was calculated using the following equation.

$$s_p = \sqrt{\frac{(N_E - 1)s_E^2 + (N_C - 1)s_C^2}{N_E + N_C - 1}},$$

N_E being the number (n) of data points for MU within variable (x) and N_c being the number (n) of data points for NU within variable (x). S_E and S_C are the *SD* for N_E and N_C, respectively, for variable (x).

Results

Participants

Participants ($N = 24$, MU; $n = 12$, and NU; $n = 12$) were of mixed cardiorespiratory and resistance-training backgrounds, and 18 of 24 participants were tested in the spring and summer months. All participants were determined to be physically active and met ACSM's recommendations for physical activity. Participants in the MU group self-reported engaging in 3.67 ± 2.15 days per week of vigorous activity for 1.29 ± 1.04 hours, and 3.92 ± 1.44 days per week of moderate activity for 1.70 ± 1.62 hours. Self-reported days of vigorous and moderate activity for NU were 4.90 ± 1.16 days per week for 1.29 ± 0.39 hours per day, and 3.83 ± 2.36 days per week for 0.98 ± 0.94 hours per day, respectively. There were no significant differences between the groups with respect to physical activity measures.

Self-reported marijuana use and nonuse was verified through MS analysis of venous, whole blood for THC and its primary metabolites THC-COOH and THC-OH in all MU and NU collected blood. There were no THC or THC metabolites detected in NU participant samples. Of the 10 MU participants, whose blood samples were collected and able to be analyzed for THC and its metabolites, the presence of THC ($n = 6$), THC-COOH ($n = 7$), and THC-OH ($n = 5$) was verified in 7 of 10 MU participants. Mean descriptive data of MU marijuana use habits are presented in Table 1 (as collected with the MUM) and individualized participant use habits, THC, THC-COOH, and THC-OH concentrations are presented in Table 2. Use of marijuana products ranged from 4 to 30 days of use over a 30-day period.

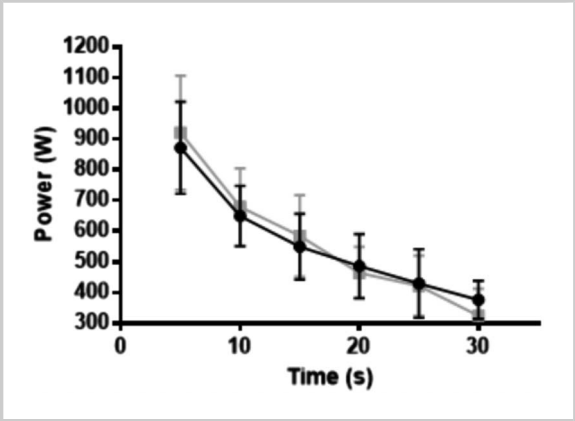

Figure 1. Power output during a Wingate assessment.

Descriptive Measures

Participants ranged in age from 19–39 years and there were no significant differences with respect to age, height, mass, body mass index, or body fat percentage between MU and NU (Table 3).

Pulmonary, Hydration Status, Cardiorespiratory Fitness, and Lactate Measures

Pulmonary measures of MU and NU for FEV_1, predicted FEV_1, and FEV_1% are reported in Table 4. Forced expiratory volume in 1 second ranged from 3.19–5.02 L for MU and from 3.17–6.20 L for NU. Participants in both groups (MU, $n = 1$ and NU, $n = 4$) were found to have an FEV_1% below 80%. No statistical significance was found between

Table 6. Core endurance, handgrip, and relative strength measures.*†

	Overall ($n = 22$)	MU ($n = 10$)	NU ($n = 12$)	p	Effect sizes
Back extension (s)	95.31 ± 38.72	77.50 ± 20.86	110.17 ± 44.47	0.09	0.22
Trunk flexion (s)	262.10 ± 199.33	197.70 ± 180.43	315.75 ± 205.67	0.10	0.17
Right-side plank (s)	97.55 ± 36.54	84.60 ± 10.94	108.33 ± 46.61	0.19	0.15
Left-side plank (s)	100.23 ± 28.62	92.3 ± 15.18	106.83 ± 35.64	0.31	0.12
Combined handgrip (kgf)	97.40 ± 13.71	102.33 ± 12.31	92.48 ± 13.73	0.12	0.75
Relative hip flexion torque (Nm)	1.40 ± 0.65	1.37 ± 0.94	1.43 ± 0.29	0.11	0.05
Relative hip extension torque (Nm)	1.42 ± 0.68	1.51 ± 0.88	1.36 ± 0.48	0.85	0.09
Relative knee flexion torque (Nm)	1.82 ± 1.24	1.67 ± 1.03	1.94 ± 1.42	0.46	0.06
Relative knee extension torque (Nm)	3.80 ± 2.15	3.46 ± 1.58	4.09 ± 2.57	0.44	0.07
Relative ankle plantar flexion (Nm)	0.66 ± 0.34	0.61 ± 0.31	0.70 ± 0.37	0.74	0.07
Relative ankle dorsiflexion (Nm)	0.40 ± 0.07	0.43 ± 0.07	0.38 ± 0.07	0.12	0.24

*MU = marijuana users; NU = individuals not using marijuana.
†Relative measures are standardized to subject's body mass taken during visit 4 before strength testing and are presented as mean ± *SD*.

pulmonary function variables FEV_1, predicted FEV_1, or FEV_1%. There was no statistical difference between MU and NU with respect to hydration, resting HR, absolute $\dot{V}O_2$max, relative $\dot{V}O_2$max, relative $\dot{V}O_2$ at lactate threshold, relative $\dot{V}O_2$ at onset of blood lactate accumulation, or rate of perceived exertion (RPE) at termination of exercise (Table 4). Rate of perceived exertion at termination of exercise during the $\dot{V}O_2$max assessment ranged from 7–10 in MU and 8–10 in NU, respectively.

Anaerobic Power Measurements

There was no significant difference between MU and NU with respect to peak power, minimum power, relative peak power, mean anaerobic power, or anaerobic capacity (Table 5). However, anaerobic fatigue, expressed as the percent decrease between subject's maximal power output and minimum power output, trended toward significance. The anaerobic fatigue for MU ranged from 46.15–76.92% with an average of 64.39 ± 8.89%, whereas NU anaerobic fatigue ranged from 40.00–69.23% averaging 57.38 ± 10.02% across the 30-second exercise bout. MU and NU average absolute power output through the Wingate Anaerobic Power Assessment are presented in Figure 1.

Muscular Strength and Endurance Measures

Static muscle endurance variables of core stability, including back extension, trunk flexion, right-side plank, and left-side plank, are reported in Table 6. No significant differences were observed between NU and MU for core stability or combined handgrip strength. Additional lower extremity strength measures normalized to body mass are reported in Table 6, and no statistical significances between the MU and NU existed.

Biomarkers of Inflammation and Stress

Values for serum testosterone, cortisol, the testosterone to cortisol ratio (T/C ratio), and CRP (MU, $N = 10$; NU, $N = 11$) are reported in Table 7. Ranges for testosterone levels in MU and NU were 3.85–11.20 $ng \cdot ml^{-1}$ and 1.75–19.46 $ng \cdot ml^{-1}$, respectively. No significant difference was observed between MU and NU with respect to testosterone, cortisol, T/C ratio, or CRP concentrations.

Table 7. Serum biomarkers.*†

	Overall ($N = 21$)	MU ($n = 10$)	NU ($n = 11$)	p	Effect size
Testosterone ($ng \cdot ml^{-1}$)	7.85 ± 4.84	7.13 ± 2.59	8.49 ± 6.32	0.56	0.07
Cortisol ($\mu g \cdot dl^{-1}$)	25.24 ± 11.48	23.23 ± 4.45	27.05 ± 15.44	0.83	0.08
CRP ($mg \cdot L^{-1}$)	1.27 ± 2.17	1.76 ± 2.81	0.86 ± 1.49	0.60	0.44
T/C ratio (%)	30.84 ± 13.81	32.19 ± 15.05	29.64 ± 13.28	0.70	0.06

*MU = marijuana users; NU = individuals not using marijuana; CRP = C-reactive protein; T/C ratio = testosterone to cortisol ratio.
†Data are presented as mean ± *SD*.

Discussion

The effects of marijuana on human health have been studied since the 1970s, where it was observed that inhalation of marijuana smoke led to an increased resting pulse rate (10). The current study presents novel findings related to chronic marijuana use on performance and health in physically active males using and not using marijuana. Findings from this study shed light on how chronic marijuana use affects pulmonary function, cardiovascular performance, anaerobic power production, isometric strength, muscular endurance, and biomarkers of health (testosterone, cortisol, and CRP) related to training and recovery. Results from this study do not support the initial hypothesis that chronic marijuana use impairs athletic performance and health status in physically active, male participants.

A number of studies have established a negative relationship between marijuana use and pulmonary function. For example, participants who smoked at least 1 joint per week for 5 years exhibited decreased FEV_1 values and decreased FEV_1/FVC ratios compared with nonsmokers (2). It is important to note that these previous studies (2,28,36) were limited to exploring lung function in MU using joints. In our study, the method of marijuana consumption was not limited to just marijuana joint users. Participants reported using a wide variety of methods for marijuana consumption including: joint, pipe, bong, vaporizer, dabs, and edibles. Still, all MU participants reported inhalation of marijuana in at least 1 form as their primary method of consumption. The FEV_1%, ratio constructed from the participants actual FEV_1, and their predicted FEV_1, has been established as an indicator of pulmonary obstruction if it is <80% (40). In this study, there was no difference in FEV_1 or FEV_1% between MU and NU. Although this project was exploratory in nature, these data suggest that chronic marijuana use has no effect on pulmonary function as related to FEV_1.

Results from this study did not reveal any significant differences with respect to cardiovascular function or performance in NU and MUs. Absolute $\dot{V}O_2$max across all participants averaged 4.22 ± 0.86 $L \cdot min^{-1}$ and showed no significant difference ($p = 0.94$). When $\dot{V}O_2$max was then normalized for participant body mass, there was no significant difference between the 2 groups ($p = 0.49$). The combined relative $\dot{V}O_2$max average of MU and NU was 52.12 ± 7.21 $ml \cdot kg \cdot min^{-1}$, and when used in conjunction with the average participant age 23.71 ± 4.78 years, classified the average participant as excellent (26). With no statistically significant findings between groups with respect to cardiovascular performance, it is possible that chronic marijuana use is not related to impairment of cardiovascular performance in comparable descriptive MU and NU.

No significant differences with respect to peak power, minimum power, mean power, or relative power between MU and NU were detected. However, there was a trend ($p = 0.08$, ES 0.75) for MU to experience a greater percent decrease in power output from the first to final stage during the 30-second Wingate Assessment. An ES of 0.75 suggests that there was a moderate-to-strong meaningful difference between groups. The possible mechanisms of this fatigue are not apparent, and may be associated with either reduced central nervous system activity, or occurring physiologically at the muscle. Activation of the membrane-bound cannabinoid receptor protein on skeletal muscle decreases the calcium sensitivity of the contractile apparatus, and makes skeletal muscle fibers more susceptible to fatigue (33), which supports our current findings. Individual stage power output over the course of the Wingate Test (Figure 1) revealed no significant difference between groups at any of the 6 stages throughout the test. Further ES analysis revealed no moderate or large meaningful differences between MU and NU power output in any stage except for the final stage, stage 6 ($p = 0.11$, ES = 0.67). Consequently, marijuana-related fatigue experienced at the end of an anaerobic power assessment is a viable area of exploration in future studies with larger sample sizes.

The results of this study revealed no significant differences between MU and NU with respect to respiratory health or cardiovascular and anaerobic performance, but suggested that chronic marijuana use was related to increased inflammation in the body. Previous studies show that well-trained individuals experience less of an inflammatory response after a structured exercise bout when compared with untrained individuals (16). An emerging potential mechanism of THC action has centered on its potential to alter inflammation. Some studies suggest that marijuana use may help control the inflammatory response (27). A previous study found that acute administration of THC to both frequent MU and NU caused a dose-dependent increase in cortisol levels through action on the hypothalamic pituitary access (37), decreasing the acute inflammatory response. Also, key cell populations of T-helper cells and lymphocytes contribute to the inflammatory response in humans, and elevated concentrations of cortisol have been shown to decrease the number of T-helper cells and increase the rate of apoptosis in lymphocytes (23), thus disrupting the normal immune response. There was no significant difference in serum CRP between NU and MU. Circulating CRP concentrations, which are generally accepted as a global marker of inflammation (35), averaged 1.76 $mg \cdot L^{-1}$ and placed MU into the moderate-risk category for cardiovascular disease compared with the low-risk category average of 0.86 $mg \cdot L^{-1}$ in NU (38). This information suggests that individuals using marijuana on a regular basis may not be experiencing the full range of the anti-inflammatory benefits associated with regular exercise and may place physically active males chronically using marijuana at higher risk for cardiovascular disease.

A strength of this study was that marijuana use was quantified not only through survey but was also verified using MS when possible. All blood samples were obtained

from participants in the morning between the hours of 7:00 and 9:00 AM after a 12-hour fast and 48-hour rest period, where participants refrained from strenuous exercise. This is important to note because factors such as diurnal cycle, recent food consumption, or recovery from physical stress can influence hormone and protein levels in the blood (43). Testosterone concentrations in both MU and NU were within normal ranges, and there were no differences between MU and NU (15). The lack of difference between MU and NU with respect to testosterone concentrations in this study is contradictory to previous literature (29), which demonstrated that the chronic use of marijuana significantly depressed testosterone levels in males. This study results also support previous findings (17) that suggest marijuana use has no effect of testosterone concentrations in a healthy male population. In addition, the technology related to the evaluation of hormones in the blood has progressed significantly since the previous findings were published in 1974. In our study, the concentrations of cortisol in MU and NU were found to be within normal ranges (1) and were reflective of morning cortisol levels, suggesting that participants of this study were not overtrained. Although the subjects in this study were not current competitive NCAA or professional athletes, a number of them had previously competed at the NCAA and professional level and still maintained a very active lifestyle. Overall average, relative $\dot{V}O_2$max for participants in the study ($N = 24$; 52.12 ± 7.21 ml·kg·min^{-1}) was considered excellent (26). Strength values for isometric knee extension torque are considered above average (12). These results indicate that although the participants were not currently competitive athletes, they were still performing at a high level.

A limitation of this study was the low number participants in each group. Post hoc analysis indicated an observed power ($p = 0.05$; $\beta = 0.0.52$) to detect differences in fatigue during the Wingate Test. Effect sizes were calculated to establish whether meaningful differences were present between the groups and noteworthy findings are reported above. A further limitation of this study was THC and its primary metabolites were not detected in all MU participants. However, this does not suggest that MU participants testing negative for THC and its metabolites should be considered NU. THC is the most common cannabinoid in marijuana, followed closely by cannabidiol (CBD). THC and CBD are only 2 of more than 60 cannabinoid compounds in marijuana that can exert effects on the body (25). It is possible that the participants were using marijuana products that contained very low concentrations or even no concentration of THC, and had greater concentrations of other cannabinoids, such as CBD. This study was unable to test for both THC and CBD; thus, only THC was assessed because it is typically the most prominent cannabinoid in marijuana products. Given this information, it is recommended that both THC and CBD be tested in future studies assessing participants using marijuana products.

Future studies should include larger sample sizes in addition to exploring these effects in physically active female populations and elite athletic populations to extend the current findings. Although THC concentrations were assessed using MS, there was wide variation in the reported frequency of use and the specific dose or strain of marijuana being used was not reported. It will be important in future studies to try and standardize the frequency and quantity of use, as well as method of use in participants. It is important to note that, although not significant, the rating of perceived exertion in MU ($p = 0.12$, ES = 0.75) at termination of maximal cardiovascular exercise is an area of research that may be associated with marijuana use and an altered perception of pain. Other marijuana use–related areas for future exploration identified in this study include hydration status ($p = 0.10$, ES = 0.57) and resting HR ($p = 0.13$, ES = 0.74). As presented in Table 6, muscle endurance and strength variables such as back extension ($p = 0.09$), trunk flexion ($p = 0.10$), relative hip flexion torque ($p = 0.11$), and relative dorsiflexion ($p = 0.12$) had similar p values to anaerobic fatigue, RPE, hydration, and resting HR but may not be viable areas of future exploration because of their small ES.

Practical Applications

Although chronic marijuana use was not determined to have significant positive or negative effects on the aerobic performance, pulmonary function, or muscular strength of physically active males, there was a nonsignificant trend for MU to show increased fatigability during power testing as compared to NU. In sports where power is important, coaches may want to encourage their athletes to refrain from chronic marijuana use. This study also showed that chronic marijuana use placed users in a higher-risk category for cardiovascular disease and this may be an important consideration related to the long-term health of individuals who are physically active.

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