Effects of cannabidiol and delta-9-tetrahydrocannabinol on plasma endocannabinoid levels in healthy volunteers: a randomised double-blind four-arm cross-over study

Running Title: Influence of cannabinoids on endocannabinoid levels

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Key Words: THC; CBD; endocannabinoids; anandamide; 2-arachidonoylglycerol; cannabis

Abstract

Background

The effects of cannabis are thought to be mediated by interactions between its constituents and the endocannabinoid system. Delta-9-tetrahydrocannabinol (THC) binds to central cannabinoid receptors, while cannabidiol (CBD) may influence endocannabinoid function without directly acting on cannabinoid receptors. We examined the effects of THC co-administered with different doses of CBD on plasma levels of endocannabinoids in healthy volunteers.

Methods

In a randomised, double-blind, four-arm cross-over study, healthy volunteers (n=46) inhaled cannabis vapour containing 10mg THC plus either 0, 10, 20 or 30mg CBD, in four experimental sessions. The median time between sessions was 14 days (IQR=20). Blood samples were taken pre-cannabis inhalation and at 0-, 5-, 15- and 90-min post-inhalation. Plasma concentrations of THC, CBD, anandamide, 2-arachidonoylglycerol (2-AG) and related non-cannabinoid lipids were measured using liquid chromatography-mass spectrometry.

Results

Administration of cannabis induced acute increases in plasma concentrations of anandamide (+18.0%, 0.042ng/ml [95%CI: 0.023–0.062]), and the non-cannabinoid ethanolamides, docosatetraenylethanolamide (DEA) (+35.8%, 0.012ng/ml [95%CI: 0.008–0.016]), oleoylethanolamide (OEA) (+16.1%, 0.184ng/ml [95%CI: 0.076–0.293]), and N-arachidonoyl-L-serine (ARA-S) (+25.1%, 0.011ng/ml [95%CI: 0.004–0.017]) ($p<0.05$). CBD had

no significant effect on the plasma concentration of anandamide, 2-AG or related non-cannabinoid lipids at any of three doses used. Over the four sessions, there were progressive decreases in the pre-inhalation concentrations of anandamide and DEA, from 0.254ng/ml [95%CI: 0.223–0.286] to 0.194ng/ml [95%CI: 0.163–0.226], and from 0.039ng/ml [95%CI: 0.032–0.045] to 0.027ng/ml [95%CI: 0.020–0.034] ($p<0.05$), respectively.

Discussion

THC induced acute increases in plasma levels of anandamide and non-cannabinoid ethanolamides, but there was no evidence that these effects were influenced by the co-administration of CBD. It is possible that such effects may be evident with higher doses of CBD or following chronic administration. The progressive reduction in pre-treatment anandamide and DEA levels across sessions may be related to repeated exposure to THC or participants becoming less anxious about the testing procedure and requires further investigation.

Introduction

Cannabis is the world's most used illicit drug,[1] and regular use is associated with adverse effects on mental health and cognition.[2–6] On the other hand, one of its constituents, cannabidiol (CBD) is a novel candidate treatment in psychiatry.[7–10]

The main psychoactive component of cannabis, delta-9-tetrahydrocannabinol (THC), is a partial agonist at G-protein-coupled cannabinoid receptors type-1 and type-2 (CB_1 and CB_2).[11,12] THC is responsible for the 'high' from cannabis use as well as its adverse effects. CBD is the second most abundant phytocannabinoid in cannabis and has relatively low affinity for the orthosteric binding sites of CB_1 and CB_2.[13] The endogenous ligands for these receptors are endocannabinoids such as anandamide [AEA] and 2-arachidonoyl glycerol [2-AG]).[12,14] Both AEA and 2-AG are high affinity CB_1 receptor agonists, while AEA has lower affinity for CB_2.[15] The endocannabinoid system has been implicated in the regulation of brain development, synaptic plasticity and neuronal signalling.[14,16,17]

The mechanism by which CBD exerts its effects is unclear. In preclinical studies CBD can act as a negative allosteric modulator at the CB_1 receptor, but it does not alter the subjective effects of cannabis associated with THC binding to CB_1 receptors.[13,18–21] One hypothesis is that CBD inhibits AEA metabolism, leading to an upregulation in AEA signalling.[22] In vitro experimentation has shown that CBD can reduce AEA degradation by inhibiting both its cellular reuptake via the anandamide membrane transporter and its hydrolysis by the intracellular enzyme fatty acid amide hydrolase (FAAH).[23] Other putative mechanisms of action of CBD include inhibiting the metabolism and/or inducing the synthesis of N-

acylethanolamines (NAEs).[24,25] Members of the NAE family include AEA, docosatetraenylethanolamide (DEA), oleoylethanolamide (OEA) and stearoylethanolamide (SEA). While non-endocannabinoid NAEs such as DEA, OEA and SEA either do not or weakly exert direct action via CB_1 or CB_2, they do have endocannabinoid-like properties.[26,27]

Acute intravenous administration of THC has been shown to transiently increase plasma levels of AEA and 2-AG, through unclear mechanisms.[28] In contrast, cross-sectional studies suggest that chronic cannabis use can downregulate AEA and possibly upregulate 2-AG signalling.[29–31] However, the acute dose-effects of inhaled THC and CBD in quantities naturally present in cannabis on circulating endocannabinoids have yet to be established.

The aim of the present study was to examine the effects of THC and CBD on plasma endocannabinoid levels and related non-cannabinoid lipids. Four preparations of cannabis were used, each containing a fixed dose of THC, but a different dose of CBD. We hypothesised that i) Administration of THC would lead to a transient increase in plasma AEA and 2-AG, and that ii) these effects would be modulated by co-administered CBD in a dose-dependent manner.

Materials and Methods

Study Design

Randomised, double-blind, four-arm cross-over study. Healthy volunteers were studied on four occasions. In each session they received a dose of cannabis vapour containing 10mg THC plus CBD at a dose of either 0, 10, 20 or 30mg. These doses were designed to reflect the doses of THC and CBD typically found in recreational cannabis.[32]

Ethics

The study was approved by the KCL Research Ethics Committee (RESCMR-16/17-4163). Written informed consent was obtained from each participant. The study was conducted in compliance with the principles of Good Clinical Practice and the Declaration of Helsinki (1996) and registered on Open Science Framework (https://osf.io/kt3f7) and clinicaltrials.gov (NCT05170217).

Study Drugs

Raw cannabis plant material was provided by Bedrocan BV, Netherlands. Bedrocan (batch release specifications: 0.1% CBD, 22.6% THC), Bedrolite (7.5% CBD, 0.3% THC) and placebo (<0.1% cannabinoids) were prepared in order to administer CBD:THC in 4 different ratios: 0:1, 1:1, 2:1 and 3:1. In all 4 preparations, the dose of THC was 10mg (two standard THC units)[33], whereas the dose of CBD was 0mg (0:1), 10mg (1:1), 20mg (2:1), and 30mg (3:1), respectively. Placebo cannabis was used to equalise the weight of each preparation (Table 1).

Participants

Participants were aged 21-50 years, had used cannabis at least once previously, had used cannabis < once weekly on average over the last 12 months, were not taking medications (excluding contraceptives), and had no psychiatric or medical history. Details of recruitment and full inclusion/exclusion criteria are listed in the Supplementary Materials (pp2).

Procedure

The study was conducted at the NIHR Wellcome Trust Clinical Research Facility at King's College Hospital. Each participant attended a screening visit at which a physical and mental health examination and assessment for study eligibility were undertaken by a physician. Participants also practiced the vapour inhalation technique with an air-filled balloon.

Experimental Visits

Each participant attended four experimental visits, with a minimum 7-day wash-out between visits. Participants were asked to abstain from illicit drugs for the duration of the study, and from alcohol, tobacco and vaping 24 hours before each visit, verified by a urine drug screen, alcohol breath test (BAC=0) and carbon monoxide breath test (CO<10ppm). Experiments began at either 10:00 or 12:00. An intravenous cannula was inserted, and the baseline blood sample was drawn 30 minutes (95%CI: 29–33) prior to drug administration.

The order that participants received the four cannabis preparations (CBD:THC ratios) was randomised. Drug was administered by inhalation using a Volcano Medic Vaporizer (Storz & Bickel, Germany), following the protocol from Lawn et al., 2016.[21] Cannabis was vaporized

at 210°C into a covered polythene balloon with a valve mouthpiece, which prevented loss of cannabinoids between inhalations. The same balloon was filled twice using the same cannabis to ensure the full dose was administered. A standardised inhalation procedure was repeated until both balloons had been emptied. During the study visit participants also completed cognitive and psychological assessments; see Supplementary Materials (pp4).

Blood Collection and Analysis

Venous blood samples were collected into lithium-heparin tubes 30 minutes pre-cannabis inhalation, immediately after the final inhalation (0-min), and at 5-min, 15-min, and 90-min post-inhalation. Samples were centrifuged at 4^{o}C, divided into two cryovials, stored at -20^{o}C until all samples from that day had been collected, then moved to a -80^{o}C freezer.

Plasma concentrations of CBD and THC were determined using High Performance Liquid Chromatography–Mass Spectrometry (LC/MS) at the Mass Spectrometry Facility, KCL.[34] Plasma concentrations of AEA and 2-AG, their precursor arachidonic acid (AA), and six biologically-related endogenous fatty acid ethanolamides: N-arachidonoyl-L-serine (ARA-S), DEA, OEA, SEA, alpha-linolenoylethanolamide (aLEA) and gamma-linolenoylethanolamide (gLEA) (eFigure 1) were quantified using a validated Ultra-High Pressure Liquid Chromatography (UHPLC)-MS method (Dickens et al., 2020)[35] at the Turku Metabolomics Centre (Turku Bioscience, Finland). As it was not possible to separate 1-AG and 2-AG in plasma due to rapid isomerisation,[36] the quantity was reported as total AG (henceforth described as '2-AG').

Statistical Analysis

All analyses were completed using R, version 3.3.2.[37] Missing values were imputed using multiple imputation chain equations (MICE; mice package version 3.13.0)[38] after confirming no detected of deviation from missing completely at random (MCAR) based on Little's MCAR test. All analyses were completed using linear mixed models (lme4 package version 1.1-26).[39]

The primary outcome of the effects of different CBD:THC ratios on plasma analyte level was measured as peak effects (Model 1) and area under the curve (AUC; Model 2) of mean plasma concentrations. Peak effects (i.e., estimated Cmax) were determined as the plasma concentrations at the timepoint at which they were at the highest (estimated Tmax). AUC values were calculated after baseline correction using the spline method (DescTools package).[40] The CBD:THC ratios (0:1, 1:1, 2:1, 3:1) were coded as a categorical variable. Participant ID was coded as a categorical variable and included as a random effect to account for dependency between repeated measures. Estimated marginal mean (EMM; emmeans package version 1.5.2-1)[41] differences were calculated for all 6 contrasts (0:1 vs 1:1, 0:1 vs 2:1 etc). Models 1 and 2 were fully adjusted by including pre-inhalation plasma concentration (continuous variable) and visit number (categorical variable; visit 1, 2, 3, 4), to account for within-subject differences, as well as the number of days between each of the four experimental visits (continuous variable) to account for the possible carry-over effect of repeated exposure to THC.[30,31] For time between experimental visits, one outlier value was identified using Rosner's generalised extreme Studentised deviate test (GEST; EnvStats package version 2.7.0)[42] and excluded.

The secondary outcome of the effects of THC on plasma analyte levels was assessed by Model 3. The effect of THC alone was determined by analysing plasma levels following administration with THC only (0:1 CBD:THC ratio), excluding all other visits (Model 3a). Mean plasma concentrations at each of the timepoints (categorical variable; pre-inhalation, 0min, 5min, 15min and 90min) were compared, including participant ID as a random effect. EMM differences were calculated for all 10 contrasts (pre-inhalation vs 0min etc.) The fully adjusted Model 3a included the visit number and time since last visit variables. To maximise statistical power, the analysis was then repeated to include all experimental visits (Model 3b). The fully adjusted Model 3b included the CBD:THC ratio, visit number and time since last visit variables.

Exploratory analyses assessed changes in plasma analyte levels over the experimental visits (Model 4). Model 4a compared pre-inhalation concentrations of the analytes between the 4 visits, with participant ID as a random effect. EMM differences were calculated for all 6 contrasts (visit 1 vs visit 2 etc). In post-hoc analyses, we assessed whether any identified effects were influenced by CBD. Pre-inhalation levels of analytes at visits 2, 3 and 4 (Models 4b, 4c and 4d, respectively) were compared with total CBD dose from previous visits (categorical variable). Models 4a, 4b, 4c and 4d were fully adjusted by including the time since last experimental visit variable.

Post-hoc analyses to explore sex differences in endocannabinoid responses to THC and/or CBD were performed by adding sex (categorial variable) as an interaction term to the predictor variable in each model.

EMM differences were corrected for multiple comparisons using the Tukey adjustment method and are presented along with p-values and 95% confidence intervals.

Results

64 potential participants were randomised, of whom 46 completed all four experimental sessions and contributed data. Demographics and physical characteristics are shown in Table 2. Median inhalation time was 17 minutes (IQR=11). The median time between experimental visits was 14 days (IQR=20).

Plasma CBD & THC concentrations

Figure 1 shows the mean plasma concentrations of the endocannabinoids, plus CBD and THC for comparison, versus time, stratified by CBD:THC ratio. The peak and AUC THC concentration remained similar across the four conditions ($p>0.05$), and there was a dose-dependent increase in peak and AUC plasma CBD as the CBD:THC ratio increased ($p<0.001$, eTable 1).

Comparison of CBD:THC ratios

There were no significant differences in either peak or AUC plasma concentrations for any of the endocannabinoids or related non-cannabinoid lipids between CBD:THC ratios (Figure 1, eFigure 2, eTable 1). The estimated Tmax was 0min for AEA, aLEA, ARA-S, DEA, OEA and SEA, 5min for AA and gLEA, and 90min for 2-AG. For gLEA, the lowest plasma level was selected since levels decreased post-inhalation.

Effect of drug administration

THC alone

When limiting data to the visits where cannabis containing only THC was administered (0:1 CBD:THC ratio), mean DEA concentration rose by 37.8% (0.013ng/ml [95%CI:0.005–0.020], t(180)=3.273, p=0.011) at 0min post-inhalation, before falling to pre-inhalation levels by 5min (Figure 2). While the mean AEA concentration was greater at 0min than at 5min, 15min or 90min ($p<0.05$), it was not significantly higher than pre-inhalation (+17.0%, 0.040ng/ml [95%CI:0.010–0.070], t(180)=2.633, p=0.069) (Figure 2). There were no significant changes in plasma levels of any of the other the endocannabinoids or related non-cannabinoid lipids (eTable 2, eFigure 3).

Overall effect of THC

The above analysis was extended to include all experimental visits (i.e., including those in which THC was co-administered with CBD). Plasma levels of AEA, DEA, OEA and ARA-S increased significantly post-cannabis inhalation (eFigure 4). Mean AEA concentration rose by 18.0% (0.042ng/ml [95%CI:0.023–0.062], t(858)=4.298, $p<0.001$), mean DEA concentration rose 35.8% (0.012ng/ml [95%CI:0.008–0.016], t(858)=5.797, $p<0.0001$), mean OEA concentration rose 16.1% (0.184ng/ml [95%CI:0.076–0.293], t(858)=3.332, p=0.008), and mean ARA-S concentration increased 25.1% (0.011ng/ml [95%CI:0.004–0.017], t(858)=3.326, p=0.008) immediately post-inhalation, before falling to pre-inhalation levels by 5min. There were no significant changes in plasma levels of any of the other analytes (eTable 3).

Effect of visit order on endocannabinoid levels

Between visit 1 and visit 4 the mean pre-inhalation AEA concentration fell by 23.6% (0.060ng/ml [95%CI:0.024–0.096]), t(135)=3.278, p=0.007), and the mean pre-inhalation DEA concentration fell by 29.1% (0.011ng/ml [95%CI:0.003–0.019], t(135)=2.779, p=0.031) (Figure 3). After adjusting for time between visits, the decrease in baseline DEA no longer reached statistical significance (p=0.086) (eTable 4). Post-hoc analyses showed that none of pre-inhalation concentrations of AEA and DEA at visits 2, 3 and 4 were associated with the total dose of CBD received at the previous visits (p>0.05) (eTable 5). There were no significant changes in pre-inhalation plasma levels of any of the other analytes across experimental visits (eTable 4).

Sex differences

There were no significant sex differences between the endocannabinoids or related non-cannabinoid lipid responses to THC or CBD, with the exception of Models 3b and 4a for SEA. However, these results were found to be caused by two outliers, identified using Rosner's generalised extreme Studentised deviate test, and were no longer significant when these outliers were removed; see Supplementary Materials (pp50).

Discussion

To our knowledge, this is the first study to investigate the acute effects of co-administered THC and CBD on plasma endocannabinoid concentrations. Its strengths include the use of a double-blind, within-subjects design, which mitigated against potential placebo effects related to CBD, as well as inter-individual differences in response to THC and CBD. Restricting participation to infrequent cannabis users reduced the risk of prior cannabis use impacting circulating endocannabinoid levels.

We did not detect an effect of the CBD:THC ratio in cannabis on the plasma concentration of any of the tested endocannabinoids or related lipid compounds. Previous research has indicated that CBD may enhance AEA signalling. Leweke et al.[22] reported that treatment with 800mg of oral CBD for 14 days led to an increase in AEA and OEA in patients with psychosis, with AEA serum levels increasing 1pmol/ml (equivalent to 0.348ng/ml) after 28 days. However, another study found that 200mg of CBD daily for 13 weeks had no effect on plasma levels of AEA, 2-AG or OEA in patients with type-2 diabetes .[43] The absence of an effect on plasma endocannabinoids in our study may have been due to the administration of single doses of CBD at relatively low dosages. Comparing doses between oral and vaporised CBD is difficult due to the differences in pharmacokinetics between formulations; CBD undergoes significant first-pass metabolism,[44] and its absorption and elimination is slower when taken orally versus inhalation.[45] Nevertheless, an oral dose of 800mg CBD will produce much greater systemic availability of the drug than our maximum inhaled dose of 30mg CBD.[45] The doses of THC and CBD that we used were designed to reflect those typically found in recreational cannabis.[32] As typical 'joint' contains between 300-350mg of

cannabis material,[46] it would not be possible for cannabis used recreationally to provide quantities of CBD equivalent to an 800mg oral dose.

The inhalation of vaporised cannabis containing 10mg THC led to transient increases in plasma levels of AEA and the endocannabinoid-like lipids DEA, OEA and ARA-S. These findings are consistent with those of Thieme et al.,[28] who found that plasma AEA increased by 0.060ng/ml 30min after an IV dose of 0.1mg/kg IV THC. However, we did not detect the increase in plasma 2-AG reported by Thieme et al. Walter et al.[47] found that 20mg THC given orally (as dronabinol) produced higher concentrations of AEA, OEA and 2-AG after 2 and 3 hours compared to placebo. In contrast, Kearney-Ramos et al.[48] did not detect any changes in either plasma AEA or 2-AG after the inhalation of an estimated 30mg THC in 26 near-daily cannabis users. This may be explained by frequent cannabis use leading to compensatory adaptations in the ECS, examples including reductions in circulating endocannabinoids and CB_1 receptor availability.[49–52]

The increase in AEA, DEA, OEA and ARA-S plasma concentrations immediately post-drug administration could be due to a direct effect of THC on either their synthesis or degradation. It's also possible that THC indirectly increased endocannabinoid levels via enhanced catecholaminergic and glucocorticoid signalling, which are known to cause significant increases in plasma endocannabinoid concentrations.[53–57] THC may also have simply displaced the endogenous ligands which have a similar protein binding profile, particularly ligands of the GPR55 receptor which include AEA, OEA and ARA-S.[58–60]

Pre-inhalation levels of AEA and DEA decreased in a stepwise fashion between the first and final experimental visit. Differences in CBD dose between sessions did not alter these results, suggesting that CBD was not a factor. However, repeated doses of THC have been shown to downregulate AEA and 2-AG signalling in the rat striatum.[31] Similarly, in humans, frequent cannabis users have lower cerebrospinal fluid (CSF) concentrations of AEA than infrequent users.[30] Our results are unlikely to be due to a direct pharmacological action of THC on the synthesis or degradation of AEA, as adjusting the model for time between experimental sessions (minimum 7 days) had no significant impact, and pre-inhalation plasma samples taken at each visit consistently found no measurable THC or CBD post-washout. Another possible explanation is that as participants became increasingly familiar with the experimental sessions, there may have been a reduction in the stress associated with the procedure. Stress can induce glucocorticoid and catecholamine responses that can increase AEA release.[53,54] Future studies may wish to explore if the gradual decrease of baseline AEA represents a conditioned response to the experimental setting.

Certain limitations should be considered in the interpretation of the data. CSF levels of AEA are not correlated with those in peripheral blood, so plasma levels of endocannabinoids do not necessarily reflect those present in brain.[61] The duration of cannabis inhalation varied significantly between participants and between experiments, with a median duration of 17 minutes. Future studies should consider methods to standardise duration of inhalation. Because the absorption of cannabinoids will have started before the end of the inhalation period, referring to the first timepoint as “0min” is not strictly accurate. This also limits our ability to compare the sampling timelines of the present study with those of Thieme et al. or Walter et al., as the routes and durations of administration were different.[44,62] It is possible

that food consumption could have impacted levels of endocannabinoids.[63,64] Our participants were asked to eat their usual breakfast, but it's timing and content were not controlled. The study did not include a placebo THC condition, so we cannot exclude the possibility that the inhalation procedure itself, rather than THC administration, produced changes in AEA, DEA, OEA and/or ARA-S.

Conclusions

Inhalation of vapourised cannabis increased levels of plasma AEA and several endocannabinoid-like lipids, but there was no evidence that CBD influenced any of these effects. It is possible that the doses of CBD were either too low to have measurable influence, and/or that CBD affected central but not peripheral endocannabinoids. There was a progressive reduction in the plasma concentrations of AEA and DEA across successive experimental sessions, which could reflect a downregulation of endocannabinoid signalling with repeated THC administration, or habituation with the testing procedure.

Author Disclosure Statement

AE has received speakers' honoraria from GW Pharmaceuticals. AE's position is funded by, and LC and JS are supported by, the National Institute for Health Research (NIHR) Biomedical Research Centre for Mental Health at South London and Maudsley NHS Foundation Trust and King's College London. RMM has received speakers' honoraria from Janssen, Lundbeck, Otsuka, and Sunovian. All remaining authors report no conflicting interests.

Funding Information

This study was fully funded by a Research Grant from the Medical Research Council UK (MR/P006841/1). The funder was not involved in the design, data collection, analysis, interpretation, write up or the decision of where to publish.

Abbreviations Used

2-AG, 2-arachidonoylglycerol; AA, arachidonic acid; AEA, anandamide; aLEA, alpha-linolenoylethanolamide; ARA-S, N-arachidonoyl-L-serine; CBD, cannabidiol; CSF, cerebrospinal fluid; DEA, docosatetraenylethanolamide; ECS, endocannabinoid system; FAAH, fatty acid amide hydrolase; gLEA, gamma-linolenoylethanolamide; NAE, N-acylethanolamine; OEA, oleoylethanolamide; SEA, stearoylethanolamide; THC, delta-9-tetrahydrocannabinol.

Author Contribution Statement

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Tables and Figures

CBD:THC ratio	0:1	1:1	2:1	3:1
THC dose (mg)	10	10	10	10
CBD dose (mg)	0	10	20	30
Bedrocan cannabis (mg)	44.2	42.5	40.7	38.9
Bedrolite cannabis (mg)	0.0	132.8	266.1	399.5
Placebo cannabis (mg)	394.2	263.1	131.6	0.0

Batch specifications of cannabis products: Bedrocan - 22.6% THC, 0.1% CBD; Bedrolite -0.3% THC, 7.5% CBD; placebo - <0.1% THC, <0.1% CBD.

Table 1. Depiction of cannabis preparations

Variables	N (%)	Mean (SD)
Gender		
Male	25 (54.3)	
Female	21 (45.7)	
Age		26.62 (4.94)
Ethnicity		
White	21 (45.7)	
Asian	10 (21.7)	
Mixed	3 (6.5)	
Black	1 (2.2)	
Other	11 (23.9)	
BMI (kg/m^2)		23.72 (2.57)
Body Fat (%)- Male		15.56 (5.50)
Body Fat (%)- Female		25.50 (6.33)
Days since last use of alcohol		4.17 (4.62)
Alcohol use/month (days)		8.02 (4.86)
eCigarette use (ever)	12 (26.1)	
Daily eCigarette user	1 (2.2)	
Tobacco use (ever; separate from cannabis)	34 (73.9)	
Daily tobacco user (separate from cannabis)	3 (6.5)	
Use tobacco with cannabis	36 (78.3)	
Age of first cannabis use		17.67 (2.46)
Years of cannabis use		6.63 (4.68)
Cannabis use/year		8.91 (12.67)

Table 2. Demographics of participants at baseline

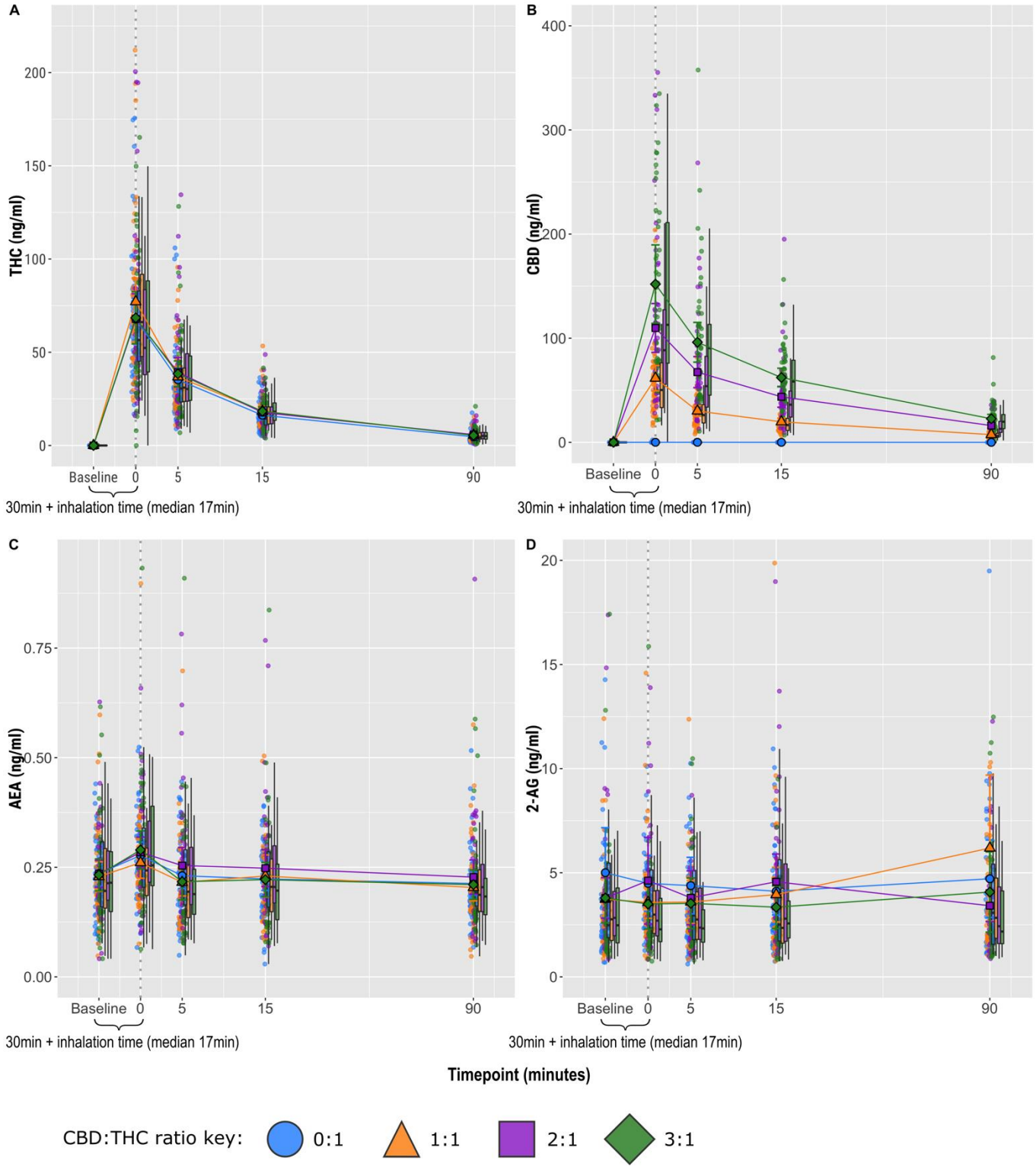

Figure 1. Plasma concentration-time graphs, stratified by CBD:THC ratio.
A. delta-9-tetrahydrocannabinol (THC), B. cannabidiol (CBD), C. anandamide (AEA),
D. 2-arachidonoylglycerol (2-AG), reported as total AG.
Circles show individual data points, larger shapes show mean values and boxplots show median and interquartile range.

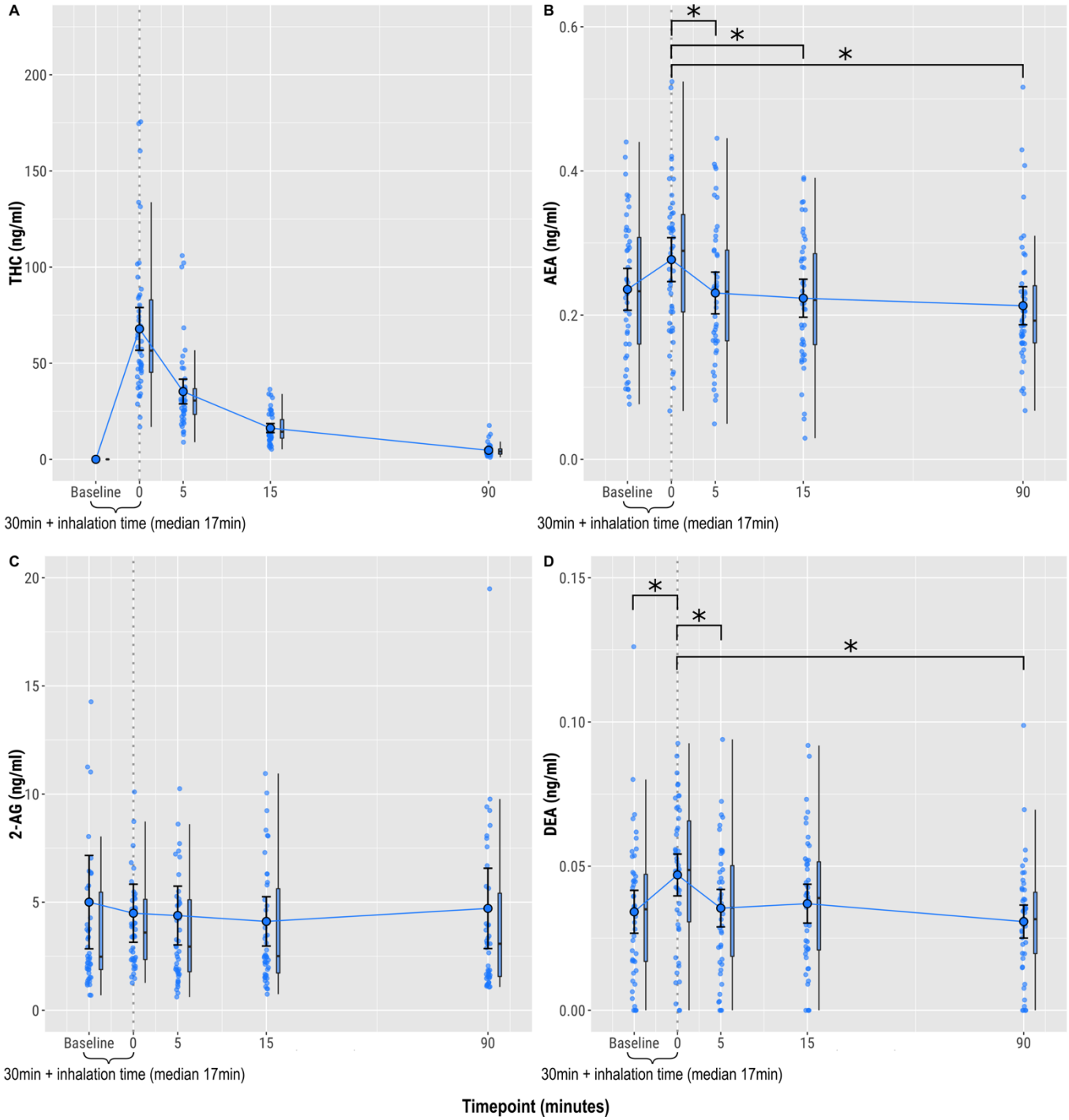

Figure 2. Plasma concentrations following administration of 10mg THC, 0mg CBD (0:1 ratio).
A. delta-9-tetrahydrocannabinol (THC), B. anandamide (AEA), C. 2-arachidonoylglycerol (2-AG) reported as total AG, D. docosatetraenylethanolamide (DEA).
Circles show individual data points, larger circles show mean values and boxplots show median and interquartile range.
* = $p<0.05$

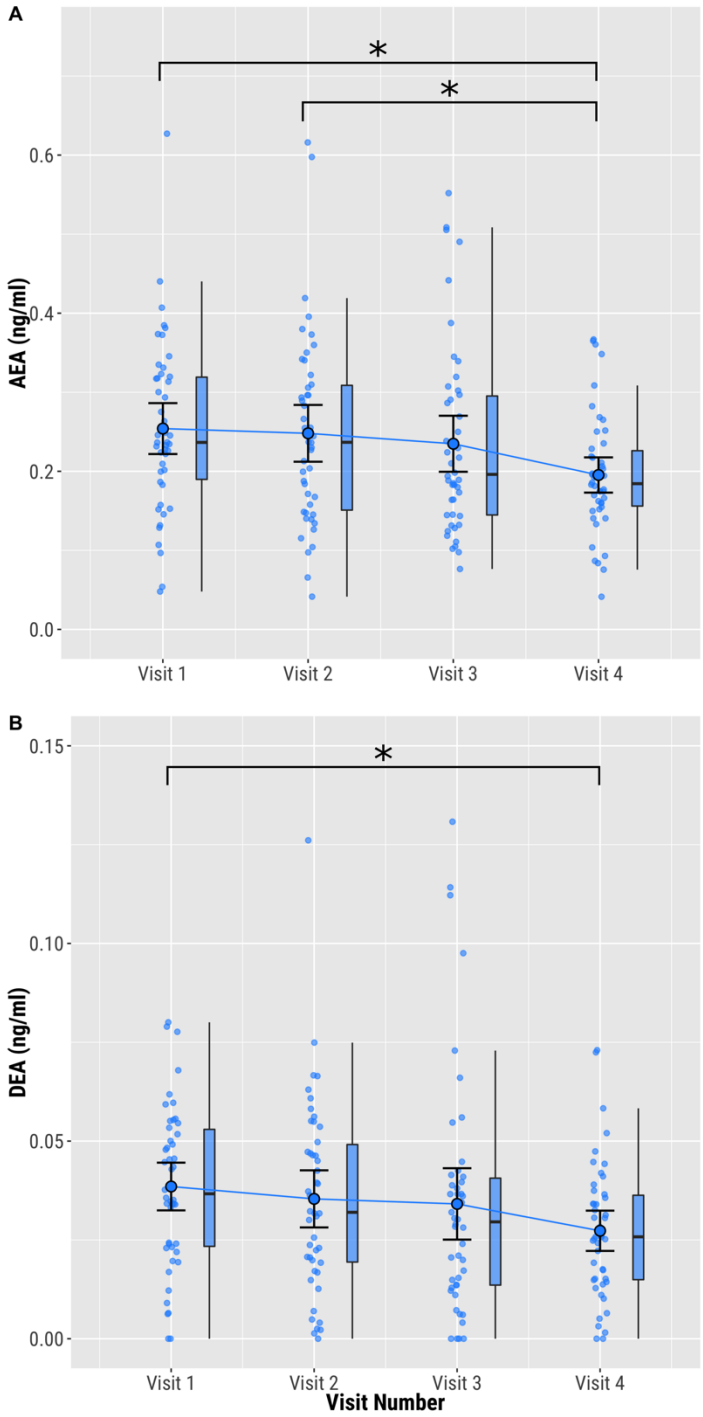

Figure 3. Pre-inhalation plasma concentrations vs. visit number.

A. anandamide (AEA),
B. docosatetraenylethanolamide (DEA).

Circles show individual data points, larger circles show mean values and boxplots show median and interquartile range.

* = $p<0.05$