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TECHNICAL NOTE

TOXICOLOGY

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A 2-Year Study of Δ 9-tetrahydrocannabinol Concentrations in Drivers: Examining Driving and Field Sobriety Test Performance*,†,‡

ABSTRACT: From November 1, 2010 through November 30, 2012, 1204 whole-blood samples were confirmed to contain THC alone or in combination with other drugs out of nearly 5000 Orange County, California, drivers suspected of driving under the influence of drugs. The goal of this study was to examine police reports and drug recognition expert evaluations of THC-positive samples within this 2-year time frame to determine whether there is a correlation between whole-blood THC concentrations and field sobriety tests performance on DRE and non-DRE evaluations. The FSTs prove to be sensitive to impairment by marijuana although as suspected, the findings of this study did not find a correlation between performance on field sobriety tests and the concentration of THC tested in whole-blood samples. Driving behaviors were also examined and found to be similar to those seen in alcohol impairment. Future studies examining DRE findings are needed to confirm the results.

KEYWORDS: forensic science, marijuana, field sobriety tests, driving, DUID, DRE

Driving under the influence of drugs (DUID) has become a growing issue nationwide and likewise in Orange County, California. Nationally, the amount of alcohol-related crashes has been on the decline, but drug-related crashes have increased (1,2). According to the 2007 National Roadside Survey, approximately 14% of nighttime drivers are positive for drugs in blood (3,4). In Orange County, California, nearly 5000 drivers were suspected of DUID from November 1, 2010 through November 30, 2012, which is more than double the number from the same time frame 10 years prior.

In 2012, the National Survey on Drug Use and Health reported that marijuana use in the United States has increased since 2007 to 18.9 million current (past-month) users, aged 12 years and older. This increase in ingestion is partially due to legalization of marijuana for recreational use in Washington and Colorado, along with the decriminalization in many other states. This increase makes marijuana the most common illicit drug in America (2). After alcohol, marijuana was also the most common drug among drivers fatally injured in a Washington study where 12.7% were positive for the psychoactive Δ^9-tetrahydrocannabinol (THC) or its inactive metabolite, 11-carboxy-THC (carboxy-THC) (5). These statistics reflect the national shift toward the social acceptance of marijuana use which creates an increased risk of individuals operating motor vehicles while impaired.

Driving a motor vehicle is a complex psychomotor and divided attention task. A dose-dependent relationship has been demonstrated in experiments testing psychomotor function and cognition, where the potential for impairment increases as THC concentration increases. In 1999, Robbe and O'Hanlon reported that marijuana consumption caused an increase in the standard deviation of lateral position (weaving), which is a measure of road tracking. The study also found that THC impaired car following, critical tracking, stop signal tasks, and executive functioning (6). The authors found that "THC induced performance impairments were severe and clinically relevant when compared to alcohol effects on the same tasks" (7). Studies have also shown that THC affects judgment and decision making as well as memory retrieval and learning (8). These are critical skills necessary for safe driving.

Additionally, epidemiological studies have shown that marijuana increases the likelihood that a driver will be involved in an unintentional motor vehicle crash. As THC concentrations increase in the blood, the odds ratio for crash risk also increases (9–11). One study revealed that a THC concentration of 2 ng/mL or greater in whole blood significantly increased the likelihood of having an accident, ultimately demonstrating a concentration-dependent crash risk (12). Researchers also found that crash risk was more elevated for men. A study from Australia that analyzed crash risk and culpability found that THC concentration of 5 ng/mL or greater increased the odds ratio to 6.6, which is similar to odds ratios of BAC 0.15% (w/v) and above (13). A meta-analysis involving the review of nine studies found an odds ratio of 1.92 for driving under the influence of marijuana at any concentration (10).

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The testing and tools that law enforcement use in the field must be sensitive enough to identify marijuana impairment, much like the tools used to evaluate alcohol impairment.

During an investigation, the officer may conduct a series of psychophysical tests, or standardized field sobriety tests (SFSTs or FSTs), to facilitate the decision for arrest. If drugs are suspected in the investigation, a Drug Recognition Expert (DRE) evaluation is often requested. The DRE evaluation is a powerful aid in determining whether an individual is under the influence of drugs and specifically which category of drug is affecting them. The program consists of twelve systematic and standardized steps that aid in determining whether an individual is impaired for the purposes of driving. Officers are trained to recognize whether the observed impairment is related to a medical condition/emergency or whether the impairment is due to a certain category of drug (14). A 2-year study in Oregon showed that face-to-face interaction with the suspect, physical evidence, and admissions made by the individual gave additional support to the opinion of impairment made by law enforcement. The recognition of individuals deemed under the influence of marijuana had an accuracy of 80.7% when the decision was solely based on suspect observation and DRE evaluation (15). The ultimate goal of the DRE program is to "help... prevent crashes, deaths and injuries caused by drug-impaired drivers (14)."

Even when a full DRE evaluation is not completed, many officers have additional training in the FSTs that allows them to complete a partial DRE evaluation. The evaluation of these FSTs is often used in the field and later in court to determine the ability of a subject to safely operate a motor vehicle. These evaluations often face criticism in their effectiveness in detecting impairment. However, numerous controlled and field studies have documented that FST performance is indicative of impairment (16–19).

There is limited documentation on how individuals perform on FSTs while under the influence of marijuana. Furthermore, there is little research regarding the use of marijuana and performance during a DRE evaluation. The goal of this study was to examine police reports and DRE evaluations of THC-positive samples within a 2-year time frame to determine whether there is a correlation with whole-blood THC concentrations, driving pattern, and FST performance on DRE and non-DRE evaluations.

Methods and Procedures

The Orange County Crime Laboratory (OCCL) serves 34 city law enforcement agencies, unincorporated areas, and state-patrolled roadways that comprise the County of Orange, California. In DUI cases, whole-blood samples are collected by licensed phlebotomists after swabbing the site with a nonalcoholic swab (zephiran chloride). The blood is placed into a 25-mL glass vial containing potassium oxalate (anticoagulant) and sodium fluoride (preservative) and mixed. The OCCL receives all toxicological samples obtained for drivers arrested for suspicion of DUI/DUID in Orange County. Samples submitted with driving charges are first tested for alcohol and other volatiles. If a sample contains less than 0.08% (w/v) blood alcohol content, it is tested for drugs. As a result, approximately 25% of drivers are tested for drugs and of these samples, approximately 30% screen positive for cannabinoids. At the time of this study, presumptive screening for phenethylamines, opiates, cocaine metabolite, benzodiazepines, and cannabinoids were also completed by enzyme-linked immunosorbant assay (ELISA) using kits from Immunalysis™ (Pomona, Ca, USA). Samples were considered positive for cannabinoids if they contained concentrations at least 20 ng/mL of 11-nor-9-carboxy-THC. Cannabinoid-positive samples were then confirmed by a solid phase extraction and a gas chromatograph/mass spectrometer (GCMS) selected ion monitoring (SIM) method to detect delta-9-tetrahydrocannabinol (THC) and its inactive metabolite, 11-carboxy-tetrahydrocannabinol (carboxy-THC). This method is described elsewhere (20). The limit of quantification (LOQ) for both THC and carboxy-THC is 2 ng/mL, and samples containing less than this value for each drug are reported as "not detected." THC concentrations were reported in whole numbers during the period of the study. All samples included in this study also had an alkaline/neutral drug screen by extraction of drug into an organic layer and analysis using a gas chromatography–nitrogen/phosphorus detector (GC-NPD) and GCMS. This method is also described elsewhere (21,22). This additional testing was to test for other potentially psychoactive substances, including prescription and over-the-counter drugs.

From November 1, 2010 through November 30, 2012, 1204 whole-blood samples contained THC alone or in combination with other drugs. Samples that contained THC during this time frame were eliminated from the study if they contained less than 8 mL of blood; which resulted in 172 samples being eliminated for insufficient volume. The volume requirement was to ensure that this study did not compromise active criminal cases which would need sufficient blood if additional testing was requested. Cases were also removed from the study if they were confirmed positive for other drugs, or if the officer suspected the presence of a drug that the OCCL does not test for, to ensure that the symptoms described in the police evaluations were due solely to the effects of marijuana ingestion. In total, 639 samples were eliminated from the study due to the presence of other drugs, eight of which were reported drugs OCCL does not test for. Police reports were obtained and reviewed for the remaining 393 case samples that were determined to contain only THC. Cases were further eliminated from the data set if for any reason the entire DUI investigation was not completed due to traffic collision or hospital transport, or if the researchers determined that the suspect was not actually driving (i.e., the suspect was the passenger of the vehicle). This left a remaining 363 cases that were evaluated in this study.

Drivers stopped for moving violations were separated from drivers stopped for nonmoving violations (i.e., expired registration, broken headlight). The subjects with moving violations were sorted into categories of the reason for the stop. Some drivers had multiple violations and were therefore counted more than once (equal to number of violations). The most frequent driving signs were calculated.

FST performance was evaluated based on the administration and criteria set forth by the National Highway and Traffic Safety Administration (NHTSA) manuals (14,16,23,24). It is most common for Orange County law enforcement officers to conduct the 3 NHTSA standardized and validated FSTs: the Horizontal Gaze Nystagmus (HGN), the Walk and Turn (WAT), and the One Leg Stand (OLS). Additionally, the Romberg (Modified Position of Attention) and finger-to-nose (FTN) tests are included if the officer is following DRE protocols. An inclusion to the DRE protocols also examines whether an individual displays Vertical Gaze Nystagmus (VGN) or Lack of Convergence (LOC). A brief explanation of each FST criteria is given below.

Eye Examinations

The preliminary eye tests are easily administered in the field or in controlled environments. In the HGN test, the subject is

asked to follow a stimulus from left to right with their eyes only, while keeping their head stationary. The officer is looking for six cues (three cues in each eye): lack of smooth pursuit (LSP); distinct and sustained nystagmus at maximum deviation; an angle of nystagmus onset prior to 45 degrees. The presence of four of six cues is indicative of impairment. VGN is similar to HGN, where the individual follows a stimulus up-and-down. VGN is marked as being present or not present and is an indication that the amount of drug is a high concentration for the individual. During the LOC test, the individual must follow a stimulus with their eyes in a circular direction. The officer observes whether the individual can cross their eyes appropriately as the stimulus is brought closer to their face without touching the nose (14).

Walk and Turn

During the WAT, the subject is asked to take nine steps on a real or imaginary line, turn in a prescribed manner, and take nine returning steps. During the examination, an officer is looking for eight cues: beginning the test before instructed to do so; being unable to maintain balance in the starting position during the instruction phase; having more than a 1/2 inch gap between the heel to toe steps; stepping off line while walking; using arms for balance by raising them more than six inches from the subject's sides; taking the wrong number of steps; stopping while walking; or making an improper turn. The presence of two of eight cues is indicative of impairment (14).

One Leg Stand

For the OLS, the subject is asked to stand on one leg for a period of thirty-seconds. The officer is looking for four cues: the individual putting their foot down during the test; using arms for balance by raising them more than six inches from their sides; exhibiting a sway of more than 1–2 inches total; or hopping to maintain balance. The presence of two of four cues is indicative of impairment (14).

Romberg

In this test, the individual estimates the passage of thirty-seconds with their head tilted slightly back and their eyes closed. A time estimation of ± 5 sec is within a normal range. An individual is noted to have sway if their body fluctuates more than 1–2 inches total (14).

Finger-to-Nose

For the FTN test, the subject tilts their head back, closes their eyes, and attempts to touch the tip of their finger to the tip of their nose. The officer observes whether the subject can successfully touch the tip of their finger to the tip of their nose and to what degree. Officers might note slow and searching, or failure to return the hand after touching (14). However, for the purpose of this study, only the number of misses was evaluated.

When both an arresting examination and a DRE examination were conducted on an individual, the DRE evaluation was preferentially used in the statistics. Additionally, there were individuals in the data set that refused certain FSTs, or FSTs were stopped by the officer for safety reasons, which accounts for the varying number of cases presented in the statistics of each FST data set. For each FST presented, the cues observed were tabulated and a THC concentration range (ng/mL) was examined.

To determine whether the concentration of THC in the blood varied significantly based on the number of cues present (in the OLS and WAT), the median concentration of THC was calculated for the presence of each potential number of cues. For example, the median concentration of THC for people with two cues on the OLS was tabulated. The median THC concentrations for each value were compared, and the two values that were the farthest away were used to conduct a paired *t*-test to determine whether there was a statistically significant difference between the two values. It can be inferred that if there is no statistical difference between the farthest values, then no statistical significance exists for those values that are closer together. The same analysis was conducted for the FTN test using the number of misses instead of cues.

The sensitivity of the WAT and OLS was also compared using a chi-squared analysis. For the purposes of the evaluation, the results were simplified to less than two cues (not meeting NHTSA's threshold) versus two or more cues (meeting the threshold). The other FSTs could not be compared in this way because they did not have an established NHTSA threshold of cues to establish likely impairment.

Results

The total number of cases that tested positive for THC alone was 363. Of the 363 cases reviewed, 116 (55.9%) individuals received a subsequent evaluation by a DRE officer. Males comprised 91.7% of the population ($n = 333$), while females only made up 8.3% ($n = 30$). The age range of subjects in the study was 16–67 years old, with an average age of 24.5 years. The range of THC concentrations tested in the samples was 2–60 ng/mL. The mean THC concentration was 9 ng/mL (median 6 ng/mL).

A controlled environment is critical to the DRE evaluations. As a consequence, DRE evaluations are generally separated from the time of driving by more time than an in-field (non-DRE) evaluation (as seen in Table 1). The average length of time between driving and the start time of the FSTs for a non-DRE examination was 33 min, whereas the average time between driving and the start time of FSTs for a DRE evaluation was 69 min. The average time interval between driving and time of blood draw was increased by approximately 39 min on cases where a DRE evaluation was subsequently completed. This is due to the increased amount of time it takes to complete the DRE twelve-step protocol.

TABLE 1—*The average time frame for DRE and non-DRE evaluations.*

	Time of Contact to FST Start (min)	FST to Time of Blood Draw (min)	Time of Contact to Time of Blood Draw (min)
DRE evaluations	69	123	193
Non-DRE evaluations	33	121	152

Driving Signs

The percentage in Table 2 refers to the percentage of moving violations (does not include nondriving-related violations). The top nine were included in the table because the percentages dropped to below five percent for the remaining driving signs.

TABLE 2—*Top 9 observed driving behaviors for marijuana driver.*

Driving Behavior	Number Observed	%
Speeding	61	24.0
Unable to maintain lane position	59	23.2
Ran red light or stop sign	33	13.0
Unsafe lane change	22	8.7
Collision	21	8.3
Going too slow	17	6.7
No headlights at night	14	5.6
No turn signals	14	5.6
Driving the wrong way	13	5.1

Other violations included fluctuating speed (n = 4), stopping at green light (n = 8), wide turns (n = 10), difficulty parking (n = 10), cutting off other vehicles (n = 2), failure to observe signs (n = 8), tailgating (n = 11), stopping abruptly or over the limit line (n = 7), rapid acceleration (n = 3), and slow to yield (n = 5). It should be noted that some subjects exhibited more than one driving behavior.

Field Sobriety Tests

The number of HGN cues exhibited by individuals is shown in Table 3. Fifty-four individuals were excluded from the statistics because they could not complete the test properly or the officer did not administer the HGN test. As HGN is not expected in subjects who ingest THC, it is not surprising that 78.6% of the 309 subjects exhibited zero cues. It should be noted that it is unusual and unexpected to have an odd number of cues in this test because both eyes normally perform similarly. Only one subject had an odd number of cues (3). The 27 subjects who exhibited HGN above threshold for impairment (four or more cues) had a THC concentration range of 2–18 ng/mL. Only 3.2% (n = 10) had the presence of VGN with a range of THC concentration from 2 to 18 ng/mL. About 86.1% (n = 204) of individuals displayed LOC. For 72 individuals, LOC was not administered.

TABLE 3—*Number of HGN cues present for THC-positive subjects.*

Number of Cues Observed	% of Individuals (n)
0	78.6 (243)
2	12.3 (38)
3*	0.3 (1)
4	2.9 (9)
6	5.8 (18)

*Because there are six cues in total (three for each eye), it is unusual to see three cues exhibited on HGN.

As shown in Table 4, the number of cues observed by the non-DRE officers during the WAT is consistent with the number of cues seen in evaluations completed by DRE officers. The overall percentage of subjects that had two or more cues present was slightly higher in the DRE officer evaluations. There was no correlation of number of cues present with the concentration of THC found in the blood. The THC median concentrations for the subjects with no or one cues on the WAT were lower than the median for subjects with two or more cues, but did not reach statistical significance. When each number of cues was evaluated for median THC concentration, none were found to be statistically significant in their differences. Despite having no correlation to THC concentrations, 87.8% (n = 288) of individuals in the study reached or surpassed the NHTSA threshold of two cues for the indication of impairment. There were 35 individuals where the test was not administered, the individual refused to complete the test, or the test was stopped by the officer before completion.

TABLE 4—*Comparison of walk and turn (WAT) cues present for non-DRE versus DRE evaluations for THC-positive subjects.*

Number of Cues Present	Non-DRE (n)	DRE (n)	Range [THC] ng/mL	Median [THC] ng/mL
0	2.3% (5)	1.8% (2)	4–12	6
1	11.6% (25)	7.1% (8)	2–28	6
2+	86.1% (186)	91.1% (102)	2–60	7
Total individuals	216	112		

Table 5 shows the comparison of the percentage of subjects who met or exceeded NHTSA's 2 cue threshold at various THC concentrations. The percentages were quite high for all THC levels. For the DRE evaluations, 100% of the subjects had two or more cues starting at 8 ng/mL THC. The same trend did not appear for the non-DRE evaluations.

TABLE 5—*Comparison of DRE and non-DRE evaluations of the WAT by percentage of subjects displaying more than two cues by THC concentration.*

ng/mL Interval	Percentage ≥2 Cues on DRE Evaluations (N)	Percentage ≥2 Cues on Non-DRE Evaluations (N)	Overall Percentage ≥2 Cues (N)
2–3	90.0 (20)	80.0 (25)	84.4 (45)
4–5	88.9 (36)	92.2 (51)	90.8 (87)
6–7	83.3 (18)	83.3 (36)	83.3 (54)
8–9	100 (13)	92.9 (28)	95.1 (41)
10–11	100 (5)	76.0 (25)	80.0 (30)
12–13	100 (4)	90.0 (10)	92.9 (14)
14–15	100 (2)	80.0 (19)	82.4 (21)
16–20	100 (8)	94.7 (19)	97.3 (27)
21–25	100 (4)	80.0 (5)	88.9 (9)
26–30	100 (3)	75.0 (4)	85.71 (7)
>30	No Subjects	100 (6)	100 (6)

Table 6 represents the number of cues exhibited by individuals during the OLS when tested by both non-DRE and DRE officers. Of the 325 individuals who completed the test, 10.2% (n = 33) of individuals displayed zero cues and 24.9% (n = 81) of individuals displayed one cue. The THC median concentration for the subjects with no or two or more cues was lower than the median for subjects with one cue, but did not reach statistical significance. When each number of cues was evaluated for average THC concentration, none were found to be statistically significant in their differences. Of those completing the OLS, 64.9% (n = 211) of individuals exhibited, two or more cues, with a THC range of 2–45 ng/mL.

TABLE 6—*Comparison of one leg stand (OLS) cues present for non-DRE versus DRE evaluations for THC-positive subjects.*

Number of Cues	Non-DRE (n)	DRE (n)	Range [THC] ng/mL	Median [THC] ng/mL
0	9.7% (21)	11.1% (12)	2–22	6
1	24.4 (53)	25.9% (28)	2–60	8
2+	65.9% (143)	63.0% (68)	2–38	6
Total individuals	217	108		

Whether an individual was likely, or not, to exhibit, at least the threshold of two cues did not appear dependent on THC concentration as shown in Table 7.

TABLE 7—*Comparison of DRE and non-DRE evaluations of the OLS by percentage of subjects displaying more than two cues by THC concentration.*

ng/mL Interval	Percentage ≥2 Cues on DRE Evaluations (*N*)	Percentage ≥2 Cues on Non-DRE Evaluations (*N*)	Overall Percentage ≥2 Cues (*N*)
2–3	75.0 (19)	64.0 (25)	68.9 (44)
4–5	63.9 (36)	68.6 (51)	66.7 (87)
6–7	66.7 (18)	66.7 (36)	66.7 (54)
8–9	53.8 (13)	64.3 (28)	61.0 (41)
10–11	100 (5)	68.0 (25)	73.3 (30)
12–13	50.0 (4)	70.0 (10)	64.3 (14)
14–15	50.0 (2)	60.0 (19)	58.8 (21)
16–20	72.2 (8)	68.4 (19)	70.3 (27)
21–25	75.0 (4)	80.0 (5)	77.8 (9)
26–30	66.7 (3)	75.0 (4)	71.4 (7)
>30	No subjects	66.7 (6)	66.7 (6)

In evaluating the Romberg test, a normal estimation of 30 sec is ±5 sec. The estimation of time was below 25 sec for 36.6% (n = 124) of subjects, within a normal range (25–35 sec) for 46.9% (n = 159) of subjects, and estimated above 35 sec for 16.5% (n = 56) of individuals. When there was an abnormal deviation of time, individuals tended to underestimate. This was also true when time estimations were compared by THC concentration interval. As demonstrated in Table 8, the results for the estimation of time in the Romberg test are consistent regardless of whether a DRE or non-DRE officer administered the test.

TABLE 8—*The percentage of individuals who underestimated, correctly estimated, and overestimated time during the Romberg test in non-DRE and DRE evaluations.*

Time Estimate	Non-DRE	DRE
24 or less seconds	36.6% (82)	36.5% (42)
25–35 sec	46.0% (103)	48.7% (56)
36+ sec	17.4% (39)	14.8% (17)
Total individuals (*n*)	224	115

Table 9 shows that the results for the number of misses observed are consistent for both the DRE and non-DRE officers. Examined further, 271 individuals were able to complete this test and 95.2% of those (n = 258) missed 1 or more attempts, 88.9% (n = 241) missed 2 or more attempts, 76.0% (n = 206) missed 3 or more attempts, and 64.2% (n = 174) missed 4 or more attempts. The median THC concentration was not significantly different based on the number of misses for the FTN test.

TABLE 9—*Number of missed attempts during the finger-to-nose test for DRE and non-DRE evaluations.*

Number of Misses	Non-DRE	DRE	Range [THC] ng/mL	Median [THC] ng/mL
0	6.0% (10)	2.9% (3)	2–26	6
1	6.6% (11)	5.7% (6)	2–22	5
2	14.5% (24)	10.5% (11)	2–19	6
3	10.8% (18)	13.3% (14)	2–53	8
4	20.5% (34)	27.6% (29)	2–36	5
5	15.1% (25)	19.0% (20)	2–40	8
6	26.5% (44)	20.1% (22)	2–38	6
Total individuals	166	105		

Table 10 demonstrates that the finger-to-nose test does not correlate the number of misses to the THC concentration. Although the number of misses does not correlate to concentration, it should be noted that this test does show that THC has the ability to impair spatial awareness for the majority of individuals tested.

TABLE 10—*Number of missed attempts during the finger-to-nose test by THC concentration.*

THC Concentration Range (ng/mL)	*N*	Average Number Missed
2–3	38	3.7
4–5	70	3.8
6–7	44	3.7
8–9	32	3.8
10–11	24	4.0
12–13	10	4.9
14–15	12	4.2
16–20	23	3.9
21–25	2	3.5
26–30	7	4.3
>30	4	4.5

Discussion and Conclusions

As males represent the dominant gender in the study, and are arrested at a lower average age (compared to females), the results are consistent with previous studies on marijuana. The mean concentration in cases where THC was the only drug present was surprisingly high. Jones (2008) reported similar findings, where the mean concentration of THC was higher in cases where THC was the only drug confirmed (3.6%) (25). The present finding of 9 ng/mL mean THC concentration could be partially due to the increased potency of marijuana due to hydroponics and evolving growing techniques. According to DEA-submitted cannabis samples, the mean THC percentage has steadily increased from 3.96% in 1995 to 12.55% in 2013 (26). The higher concentrations in the blood at the time of arrest could also be due in part to subjects using the drug closer to the time of arrest. Many subjects in this study were observed smoking in their vehicle immediately prior to the stop. Additionally, in Orange County, the prevalence of hash and butane oil extracts and the manufacture of concentrated food products have increased. The use of 2 ng/mL as the LOQ (as opposed to a lower LOQ) could also have increased the average level of THC detected due to the exclusion of lower results used in other studies. Using a lower LOQ would lead to potential additional data points below those used in this study. Including these numbers would lower the average THC concentration found. The amount that the average would lower would depend on the new LOQ chosen and how many samples were actually between the two values.

THC concentrations at the time of driving would be much higher than the average found in this study due to the time elapsed from driving to blood draw. However, in casework samples, there will always be a delay in testing so that an investigation can take place. Therefore, the THC levels found are representative of the casework encountered in Orange County and other places which will also have delays in the collection of blood.

In many studies, driving slowly has been reported as a common driving pattern for THC-impaired drivers (6). This study contradicts that notion by showing the most commonly seen driving behavior for THC-impaired drivers was actually speeding (24.0%). The next most common driving behavior was an

inability to maintain lane position (23.2%). As the observed driving is a consequence of the impairment caused by the drug, it is expected that the behavior will vary.

The majority of individuals did not display the four of six cues indicative of impairment on the HGN, which is expected. However, roughly 1/3 of those evaluated did display LSP, or the inability to closely follow a moving object, in both eyes. This was consistent with the findings of Papafotiou (2004) that LSP was significantly related to THC ingestion at 55 and 105 min postsmoking. The presence of LSP may signify where the individual is in their smoking cycle (17). According to the DRE matrix, VGN is not expected with cannabis use. Therefore, it was not surprising that there was such a small test population that actually displayed the symptom. LOC was a strong indicator of THC being present in the blood.

The WAT seemed to be the most sensitive in evaluating impairment by THC (for both DRE and non-DRE) as demonstrated by the higher percentage (when compared to the OLS) of subjects exhibiting two or more cues at all THC concentrations. A chi-squared analysis showed that the sensitivity of the WAT was significantly higher than the OLS ($p < 0.001$). This could be due to the lower demand to divide attention on the OLS. This finding is contrary to the DRE validation studies which indicated OLS was a better indicator of impairment for THC. Although it was determined to be less sensitive through our findings, OLS is still a useful tool to show potential impairment as about two-thirds of the people tested had two or more cues.

The Romberg test did not show specific impairment from THC. Roughly half of the people were within the "normal" acceptable range, while the other half either underestimated or overestimated. There was a clear trend toward people underestimating more often than overestimating. The poor correlation of impairment to the estimation of time on the Romberg test could be a result of the complexity of THC impairment, specifically stimulant, depressant, and hallucinogenic properties.

The finger-to-nose test does not appear to have a correlation to THC concentration as the average number of misses stayed around 4 regardless of concentration of THC found in the blood.

The analytical choice of a cutoff of 2 ng/mL does have an impact on the data collected. Many laboratories around the country are moving to lower detection limits for cannabinoids. A lower LOQ would add potentially impaired drivers to the pool to be studied. Previous studies have found impairment at levels below 2 ng/mL, so it is possible that correlations exist and are present below the levels examined in this study. Further studies at lower LOQs are recommended to assess this possibility.

Not every individual suspected of being under the influence of cannabis with THC in their blood performed poorly on every FST. This is further evidence that the FSTs, symptomatology, along with the presence of THC in the blood, should be used in totality to make the opinion of impairment for purposes of driving. Tolerance and the complexity of THC pharmacodynamics likely contributed to the lack of correlation to psychomotor task performance to THC concentrations.

In conclusion, the driving behaviors seen in THC-impaired drivers are similar to those seen in alcohol-impaired drivers. This is likely due to an overlap in effects as well as a limited number of ways impairment can manifest in driving. In addition, the field sobriety tests proved to be sensitive to impairment by marijuana. When multiple tests are used in conjunction with one another, the officer can be certain they are making a correct decision to arrest. Finally, whether the assessment of impairment was carried out by a DRE officer or not, the information from such tests was equally useful. As suspected, this study did not find a correlation between performance on field sobriety tests and the concentration of THC tested in whole-blood samples. Further studies examining DRE evaluations should be conducted to confirm these findings.

References

1. Romano E, Voas RB. Drugs and alcohol involvement in four types of fatal crashes. J Stud Alcohol Drugs 2011;7:567–76.
2. http://www.drugabuse.gov/publications/drugfacts/nationwide-trends
3. Lacey JH, Kelley-Baker T, Furr-Holden D, Voas RB, Romano E, Ramirez A, et al. 2007 National roadside survey of alcohol and drug use by drivers: drug results. Calverton, MD: National Highway Traffic Safety Administration: Pacific Institute for Research and Evaluation, 2009; Report No.: DOT HS 811 249.
4. Kay GG, Logan BK. Drugged driving expert panel report: a consensus protocol for assessing the potential of drugs to impair driving. Washington, DC: National Highway Traffic Safety Administration, 2011; Report No.: DOT HS 811 438.
5. Schwilke EW, Santos MI, Logan BK. Changing patterns of drug and alcohol use in fatally injured drivers in Washington State. J Forensic Sci 2006;55(5):1191–8.
6. Robbe HWJ, O'Hanlon JF. Marijuana, alcohol and actual driving performance. Maastricht, the Netherlands: Institute for Human Psychopharmacology, 1999; Report No.: DOT HS 808 939.
7. Ramaekers JG, Moeller MR, van Ruitenbeek P, Theunissen EL, Schneider E, Kauert G. Cognition and motor control as a function of delta 9-THC concentration in serum and oral fluid: limits of impairment. Drug Alcohol Depend 2006;85:114–22.
8. Wesley MJ, Hanlon CA, Porrino LJ. Poor decision making by chronic marijuana users is associated with decreased functional responsiveness to negative consequences. Psychiatry Res 2011;191:51–9.
9. Ramaekers JG, Berghaus G, Van Laar M, Drummer OH. Dose related risk of motor vehicle crashes after cannabis use. Drug Alcohol Depend 2004;73:109–19.
10. Asbridge M, Hayden JA, Cartwright JL. Acute cannabis consumption and motor vehicle collision risk: systematic review of observational studies and meta-analysis. BMJ 2012;344:e536.
11. Hartman RL, Huestis M. Cannabis effects on driving skills. Clin Chem 2013;59:478–92.
12. Kuypers KPC, Legrand S, Ramaekers JG, Verstraete AG. A case-control study estimating accident risk for alcohol, medicines and illegal drugs. PLoS One 2012;7(8):e43496.
13. Drummer OH, Gerostamoulos J, Batziris H, Chu M, Caplehorn J, Robertson MD, et al. The involvement of drugs in drivers of motor vehicles killed in Australian road traffic crashes. Accid Anal Prev 2004;36:239–48.
14. U.S. Department of Transportation: National Highway Traffic Safety Administration. Drug evaluation and classification training program: the drug recognition expert school – student manual. January 2007 ed. Washington, DC: U.S. Department of Transportation: National Highway Traffic Safety Administration, 2007.
15. Smith JA, Hayes CE, Yolton RL, Rutledge DA, Citek K. Drug recognition expert evaluations made using limited data. Forensic Sci Int 2002;130:167–73.
16. Adler EV, Burns M. Final report to Office of Highway Safety, State of California. Drug recognition expert (DRE) validation study. Phoenix, AX: Arizona Department of Public Safety and Southern California Research Institute, 1994; Report No.: 93-410-002 PSP 93-410-05, Task 1.
17. Papafotiou K, Carter JD, Stough C. An evaluation of the sensitivity of the standardised field sobriety tests (SFSTs) to detect impairment due to marijuana intoxication. Psychopharmacology 2005;180:107–14.
18. Stuster J, Burns M. Final report to Office of Highway Safety, State of California. Validation of the standardized field sobriety test battery at BACs below 0.10 percent. Santa Barbara, CA: Anacapa Sciences-National Highway Traffic Safety Administration, 1998; Report No: DOT HS 808 839.
19. Bigelow GE, Bickel WE, Roache JD, Liebson IA, Nowowieski P. Identifying types of drug intoxication: laboratory evaluation of a subject examination procedure. Baltimore, MD: Behavioral Pharacology Research Unit, John Hopkins University School of Medicine, 1985; Report No: DOT HS 806 753.
20. oD'Asaro J. An automated and simultaneous solid-phase extraction of delta-9-tetrahydrocannabinol and 11-nor-carboxy-delta-9-tetrahydrocann-

abinol from whole blood using the zymark rapid trace with confirmation and quantitation by GC-EI-MS. J Anal Toxicol 2000;24:289–95.
21. Jain N, Taylor R, Greutink C, Jain NC. Identification of underivatized basic drugs in urine by capillary column gas chromatograph. J Anal Toxicol 1986;10(5):205–8.
22. Watts VW, Simonick TF. Screening of basic drugs in biological samples using dual column capillary chromatography and nitrogen phosphorous detector. J Anal Toxicol 1986;10:198–204.
23. U.S. Department of Transportation: National Highway Traffic Safety Administration. Preliminary training for drug evaluation and classification: the pre-school – student manual. January 2007 ed. Washington, DC: U.S. Department of Transportation: National Highway Traffic Safety Administration, 2007.
24. Compton RP. Field evaluation of the Los Angeles Police Department drug detection procedure. Washington, DC: National Highway Traffic Safety Administration, 1986; Report No.: DOT HS 807 012.
25. Jones AW, Holmgren A, Kugelberg FC. Driving under the influence of cannabis: a 10-year study of age and gender differences in the concentrations of tetrahydrocannabinol in blood. Addiction 2008;103:452–61.
26. Rocky Mountain High Intensity Drug Trafficking Area (RMHIDTA). The legalization of marijuana in Colorado: the impact. Vol. 2, August 2014; http://www.rmhidta.org/html/August%202014%20legalization%20of%20mj%20in%20colorado%20the%20impact.pdf

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