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Drug Recognition Expert (DRE) examination characteristics of cannabis impairment

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ABSTRACT

Background: The Drug Evaluation and Classification Program (DECP) is commonly utilized in driving under the influence (DUI) cases to help determine category(ies) of impairing drug(s) present in drivers. Cannabis, one of the categories, is associated with approximately doubled crash risk. Our objective was to determine the most reliable DECP metrics for identifying cannabis-driving impairment.
Methods: We evaluated 302 toxicologically-confirmed (blood Δ^9-tetrahydrocannabinol [THC] ≥1 μg/L) cannabis-only DECP cases, wherein examiners successfully identified cannabis, compared to normative data (302 non-impaired individuals). Physiological measures, pupil size/light reaction, and performance on psychophysical tests (one leg stand [OLS], walk and turn [WAT], finger to nose [FTN], Modified Romberg Balance [MRB]) were included.
Results: Cases significantly differed from controls ($p < 0.05$) in pulse (increased), systolic blood pressure (elevated), and pupil size (dilated). Blood collection time after arrest significantly decreased THC concentrations; no significant differences were detected between cases with blood THC <5 μg/L versus ≥5 μg/L. The FTN best predicted cannabis impairment (sensitivity, specificity, positive/negative predictive value, and efficiency ≥87.1%) utilizing ≥3 misses as the deciding criterion; MRB eyelid tremors produced ≥86.1% for all diagnostic characteristics. Other strong indicators included OLS sway, ≥2 WAT clues, and pupil rebound dilation. Requiring ≥2/4 of: ≥3 FTN misses, MRB eyelid tremors, ≥2 OLS clues, and/or ≥2 WAT clues produced the best results (all characteristics ≥96.7%).
Conclusions: Blood specimens should be collected as early as possible. The frequently-debated 5 μg/L blood THC per se cutoff showed limited relevance. Combined observations on psychophysical and eye exams produced the best cannabis-impairment indicators.

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1. Introduction

Drugged driving increased in recent decades, even as driving under the influence (DUI) of alcohol decreased (Berning et al., 2015). In the recent 2013–2014 National Roadside Survey, drug prevalence in weekend nighttime drivers increased to 20.0% from 16.3% in 2007 (Berning et al., 2015). In an effort to combat drugged driving, the Drug Evaluation and Classification Program (DECP) was developed by the US Department of Transportation National Highway Traffic Safety Administration (NHTSA) and the International Association of Chiefs of Police (IACP) (International Association of Chiefs of Police, 2013a, 2015a, 2015b). When an officer suspects alcohol or drug impairment at the roadside based upon observations and results of standardized field sobriety tests (SFSTs; i.e., horizontal gaze nystagmus [HGN], one-leg stand [OLS], and walk and turn [WAT] tests validated to predict 0.08% blood alcohol concentration [BAC] (Stuster and Burns, 1998; Stuster, 2006)), the arrest is made and a drug recognition expert (DRE) evaluation is requested when the suspect's BAC is not consistent with observed impairment. A DRE is a police officer trained in the DECP and certified to conduct examinations of drug-impaired drivers. The DRE drug influence evaluation occurs at a precinct, jail or similar location as soon as possible (Richman et al., 2004). DREs utilize a standardized 12-step procedure combining medical, psychophysical, and observational evidence to formulate an opinion regarding

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the drug category(ies) (CNS depressants, CNS stimulants, hallucinogens, dissociative anesthetics, narcotic analgesics, inhalants, cannabis) likely causing the impairment (Clarkson et al., 2004; Cochems et al., 2007; Heishman et al., 1996; Kunsman et al., 1997; Logan, 2009; Richman et al., 2004; Smith et al., 2002).

Cannabis, the most common illicit drug detected in drivers (Berning et al., 2015; Legrand et al., 2013; Pilkinton et al., 2013), is associated with approximately doubled crash risk (Asbridge et al., 2012; Li et al., 2012). Its prevalence increased 48% in weekend nighttime drivers since 2007, with 12.6% positive for its primary psychoactive compound Δ^9-tetrahydrocannabinol (THC) in blood and/or oral fluid (Berning et al., 2015). However, polypharmacy is common and cannabis is often detected in combination with other drugs (Legrand et al., 2013); this presents challenges for evaluating impairment due to cannabis only. Cannabis impairs divided attention, a crucial driving skill, particularly in occasional smokers (Ramaekers et al., 2009; Theunissen et al., 2012; Desrosiers et al., 2015). The 12-step DRE evaluation includes four tests specifically designed to target and challenge this ability. Previous research evaluated SFST performance for cannabis after controlled administration, with mixed results (Bosker et al., 2012a, 2012b; Downey et al., 2012; Papafotiou et al., 2005a, 2005b). However, limited data exist evaluating cannabis-impaired individuals undergoing the full DRE evaluation (Heishman et al., 1996; Schechtman and Shinar, 2005).

The objective of this investigation was to evaluate toxicologically confirmed cannabis-only cases for which DRE examinations were conducted and cannabis intake successfully identified. In these cases, the officer's opinion was cannabis impairment only, providing data to identify cannabis' characteristic effects on cognitive and psychomotor function. We sought to determine the most reliable DECP metrics and optimal combinations of metrics for identifying cannabis driving impairment. To achieve this aim, our approach was to examine the most cannabis-sensitive outcomes for combinations of observations with discrete outcomes that produced the best overall cannabis impairment indication.

2. Methods

2.1. Study population

Inclusion criteria for this investigation were: cases with an available complete DRE evaluation, including face sheet and narrative report that contained the reason for the traffic stop; DRE opinion reporting impairment by cannabis only; no breath alcohol detected; blood toxicological results reporting quantifiable THC, with no non-cannabinoid drugs detected; and suspect did not admit to taking any drugs other than cannabis (to prevent self-reported cannabis intake as the reason for correct identification). Individuals aged ≥60 years were excluded from cases and controls (International Association of Chiefs of Police, 2013a, 2015a), because of possible age limitations described in the original SFST validation studies and included in the SFST training curricula (Stuster, 2006; Stuster and Burns, 1998).

2.2. Control population

Police officers and volunteers evaluated as part of DRE training programs served as a comparison group for these data. Although toxicology was not performed, all police officers reported no impairing drug use. For all controls, the DRE opinion was "not impaired".

2.3. Evaluation procedures

The DECP evaluation process is a systematic, standardized 12-step procedure based on observable signs and symptoms to determine (a) whether a suspect is impaired; (b) whether impairment is due to drugs or a medical condition; and c) if drugs are suspected, the category(ies) likely causing impairment (International Association of Chiefs of Police, 2013a, 2015a, 2015b). The 12 steps include: (1) breath alcohol test, (2) DRE interview of the arresting officer, (3) preliminary examination and first pulse, (4) eye examination (including HGN, vertical gaze nystagmus [VGN], and lack of convergence [LOC] tests), (5) divided attention psychophysical tests (including Modified Romberg Balance [MRB], WAT, OLS, and finger to nose [FTN]), (6) vital signs (including blood pressure, body temperature, and second pulse reading), (7) dark room examinations (pupil examination under three different lighting conditions: room light, near-total darkness, and direct light), (8) muscle tone examination, (9) check for injection sites and third pulse, (10) interview of the suspect, (11) analysis and opinions of the evaluator, and (12) toxicological examination. Detailed descriptions of each step are presented in Supplemental Text and previous publications (Richman et al., 2004; Smith et al., 2002).

The psychophysical tests challenge suspects' coordination and ability to divide attention and follow directions. In each exam, the DRE provides instructions and asks whether the suspect understands the instructions. The MRB test consists of standing with feet together, head tilted backward with eyes closed, and estimating the passage of 30 s. This modified version of the Romberg Test (Richman, 2010) detects the inability to maintain a steady standing posture with eyes closed, as well as divided attention and time sense impairment. Documented observations include body sway and direction, actual time elapsed over the suspect's estimated 30 s, and eyelid and body tremors. The WAT requires the suspect to take nine heel-to-toe steps along a straight line, counting steps aloud, followed by turning in a prescribed manner [turning on the planted foot using a series of small steps with the opposite foot] and returning in the opposite direction in the same fashion. The eight possible impairment clues are: losing balance during instructions, starting too soon (prior to instruction to start), stopping while walking, missing heel-to-toe, stepping off the line, using arms to balance, incorrect number of steps, and improper/incorrect turn. The "impairment" criterion is ≥2 WAT clues. Other observations such as tremors also are recorded. The OLS involves standing with one foot ~6″ off the floor, and counting aloud by thousands ("one thousand one. . ." etc.) until told to put the foot down (30 s timed). Clues are body sway, using arms to balance, hopping, or putting foot down (≥2 clues is "impairment" criterion). Additional observations (tremors and the count reached in 30 s) also are recorded. In the FTN test, the suspect attempts to touch the tip of his/her nose with the tip of the index finger 6 times (3 per hand); number of misses (missed fingertip-to-nose tip or incorrect part of finger utilized) were recorded (6 maximum).

The eye examination consists of oculomotor control and eye convergence assessment. HGN comprises three measures of eye movement function integrity: lack of smooth pursuit (eyes' ability to fixate and track a moving target smoothly); nystagmus at maximum deviation (ability to hold eyes steady in fixed position on a non-moving target without nystagmus [involuntary jerking of the eye]); and nystagmus onset prior to 45° (ability to fixate and track a slow-moving target without nystagmus). A maximum of six clues may be recorded (3/eye). VGN assesses presence/absence of nystagmus at maximum deviation in upward vertical gaze. LOC assesses the eyes' inability to converge ("cross") while attempting to focus on a stimulus pushed slowly toward the bridge of the nose. LOC was present if the subject could not converge the eyes to a minimum of 2 inches from the bridge of the nose. The

examiner applied the standardized methods (Citek et al., 2003; International Association of Chiefs of Police, 2013b, 2015a, 2015b) for the HGN, VGN, and LOC exams, scoring the presence or absence of the requisite signs or clues. The dark room examination (Step #7) requires the examiner to estimate and evaluate pupil size with a card pupillometer. This type of pupillometer has a series of circles or semi-circles with diameters ranging from 1.0–10.5 mm in half-millimeter increments. The pupillary responses and size are measured under three lighting conditions: room light (RL), near-total darkness (NTD), and direct light (DL). The pupils' reaction and response to light are observed and recorded. During DL testing, the eye is observed for 15 s with a pupillometer in position before recording the observed pupil size. The examiner checks for rebound dilation (brief pupillary constriction during the first seconds of DL, followed by pupillary dilation wherein pupil size steadily increases and does not return to its original constricted size) and records its presence or absence. Rebound dilation is differentiated from normal pupillary unrest (continuous, irregular change in pupil size that may be observed under room or steady light conditions). Rebound dilation may occur in persons impaired by drugs that cause pupillary dilation. Of the seven drug categories that are evaluated in the DECP protocols, cannabis most frequently exhibits rebound dilation (International Association of Chiefs of Police, 2015b).

The DRE utilizes the combined results from all observations in the 12-step DECP to formulate an overall opinion on whether the driver is impaired and if so, which (if any) of the drug categories is/are the source(s) of the impairment. Because the DECP is designed to assess for impairment from multiple different drug classes, not every measurement taken during the DECP 12-step program is expected to be cannabis-sensitive and specific. Additionally, as it would be inappropriate to base an opinion of impairment solely on one or two outcome measures, the DRE utilizes combined results from all of the various tests and observations throughout the 12-step program to formulate an opinion.

2.4. Blood analysis

Blood THC was quantified by local forensic laboratories' standard analytical procedures. For study consistency, a quantifiable 1 μg/L blood THC cutoff was established for all laboratories.

2.5. Data analysis

Statistical analyses were performed with GraphPad Prism 6 (La Jolla, CA). To determine how blood collection timing in the DRE process affected measured THC concentrations, cases were categorized according to whether blood collection occurred before, during, or after the evaluation. A Kruskal-Wallis test with Dunn's test (post-hoc multiple comparisons) evaluated THC concentrations according to these categories (before, during, after DRE evaluation). Spearman's r correlation was utilized to assess the effect of post-arrest time on measured blood THC concentration. Fisher's exact test was utilized to compare frequency of crash and/or moving violations as the cause of traffic stop when blood THC <5.0 μg/L versus when blood THC ≥5.0 μg/L.

Overall comparisons between cannabis cases and controls were performed by Mann-Whitney *U* analyses. Within-subject left-vs.-right comparisons were performed by Wilcoxon matched-pairs tests. Performance at blood THC concentrations relative to proposed 5 μg/L THC per se cutoffs were compared via Kruskal-Wallis one-way ANOVA (groups: controls, THC <5 μg/L [n = 114], THC ≥5 μg/L [n = 188]) with all three post-hoc comparisons (Dunn's multiple comparisons correction).

To evaluate which tests and combinations best predicted cannabis impairment, we evaluated diagnostic test characteristics (sensitivity, specificity for impairment identification, positive and negative predictive value [PPV/NPV], and efficiency) for psychophysical tests and other frequently detected signs. Because the study's premise was that cases were successfully-identified cannabis impairment confirmed by cannabis-only toxicology and controls were self-reported drug-negative individuals called "non-impaired" by DREs, true positives (TP) were defined as DRE cases (impaired) that exhibited a given attribute; true negatives (TN), controls (non-impaired) who did not exhibit the attribute; false negatives (FN), cases which did not display the sign; and false positives (FP), controls who displayed the sign. Sensitivity is defined as TP/(TP + FN); specificity, TN/(TN + FP); PPV, TP/(TP + FP); NPV, TN/(TN + FN); efficiency, (TP + TN)/(TP + TN + FP + FN). As FTN and MRB are not yet validated, we evaluated various outcome measures for diagnostic efficacy. "Impairment" criteria (validated for 0.08% blood alcohol concentration (Stuster, 2006)) utilized by DREs on the WAT and OLS are ≥2 distinct clues; we based our evaluation upon those metrics. Because the DECP evaluates multiple drug classes and takes into account several types of impairment indicators, we also evaluated diagnostic characteristics combining multiple impairment indicators.

3. Results

Three hundred two cannabis DRE cases collected from 2009 to 2014 were included in this investigation, and 302 controls obtained over the same time period for comparison (Table 1). Cases were significantly younger than controls ($p < 0.001$), but sex distribution did not significantly differ. Drivers (cases) originated from nine US states: Arizona, (101), California (3), Colorado (14), Montana (19), New Mexico (11), Pennsylvania (20), Texas (3), Washington (119) and Wisconsin (12); controls were obtained from California, Texas, Oklahoma, New Mexico, and Kansas. Twenty-six cases (8.6%) from four states (Washington, 14; Arizona, 5; Colorado, 5; Montana, 2) were from drivers with medical marijuana cards. Mean pulse (over three repetitions throughout the exam) was significantly higher in cases (median [range] 91 [49–166] bpm) than controls (71 [39–107]), $p < 0.001$ (Table 1). Mean pulse was ≥90 bpm in 53.6% of cases, but only 5.6% of controls. Systolic blood pressure also was significantly higher in cases (138 [82–205] vs. 130 [90–170] mmHg, $p < 0.001$), but diastolic blood pressure was not ($p = 0.570$).

Case distributions of arrest time, driver age, time between arrest and start of evaluation, time between arrest and blood collection, blood THC concentration, and reasons for traffic stops are presented in Fig. 1. Most (54.6%) arrests occurred between 9:00 PM-3:00 AM, and most (70.9%) drivers were 18–25 years old. In 72.3% of cases, one or more moving violations were listed as reasons for the traffic stop. Moving violations included improper speed (27.7%), weaving (19.0%); crash (9.3%), improper turn (7.7%), disobeying traffic control devices (7.0%), and failure to yield (3.3%). Other cited reasons included equipment failure such as headlight or taillight defects (10.3%), expired vehicle license (3.7%), criminal activity such as observable cannabis smoking or driving in prohibited areas (2.7%), and other (11.3%). In all but one of the improper speed cases, the suspect was reported driving faster than the posted limit. The one case reported driving slower than the limit also was drifting within the lane. In 72.3% of cases, the officer detected a cannabis odor; 35.3% of drivers had cannabis in their possession. In 23.3% of cases, neither cannabis odor nor possession was reported. For the 97 cases where the officer reported the suspect's demeanor, the most common were "relaxed" (34.0%), "lethargic" (21.6%), "slow" (17.5%), and "carefree" (6.2%). Other adjectives (≤3 cases) reported included "sluggish", "laughing", "restless", "emotional", "dazed", "shaking", "rigid", "disoriented", "sleepy", "anxi[ous]" or "withdrawn". The most common adjectives reported for controls were

Table 1
Median [range] or prevalence of demographic characteristics, pulse, body temperature, and blood pressure for 302 cannabis-only Drug Recognition Expert (DRE) cases and 302 controls (police officers and police academy students, volunteers) evaluated.

		Cases	N	Controls	N	p-value	DRE Non-Impaired "Average" and/or "Average Range"[a]
Age (years)		21 [15–59]	302	34 [15–59]	282	**<0.001**	–
Sex		87.4% M, 12.6% F	302	89.2% M, 10.8% F	295	0.5272	–
Race/Ethnicity	A/PI	2.3%	7	3.3%	9		–
	B	10.6%	32	3.5%	10		–
	H	19.2%	58	17.8%	52		–
	I	2.0%	6	0.3%	1		–
	W	65.6%	198	74.9%	218		–
	O	0.3%	1	0.6%	2		–
Body Temperature (°F/°C)		98.3[93.8–100.6]/36.8 [34.3–38.1]	295	98.3 [94.0–99.3]/36.8 [34.4–37.4]	300	0.0749	98.6(97.6–99.6)/37.0 (36.4–37.6)
Pulse[b] (bpm)		91 [49–166]	302	71 [39–107]	302	**<0.001**	(60–90)
SBP		138 [82–205]	300	130 [90–170]	302	**<0.001**	(120–140)
DBP		80 [42–110]	300	80 [36–120]	302	0.5696	(70–90)

Values are reported for all cases where data were available (N indicates number of cases or controls with data available). Boldface indicates statistical significance at $p < 0.05$.
Abbreviations: A/PI, Asian/Pacific Islander; B, Black or African American; H, Hispanic; I, Indian; W, White; O, Other; SBP, systolic blood pressure; DBP, diastolic blood pressure.
[a] Language utilized in DRE program.
[b] Pulse is mean pulse for each individual, across three measurements.

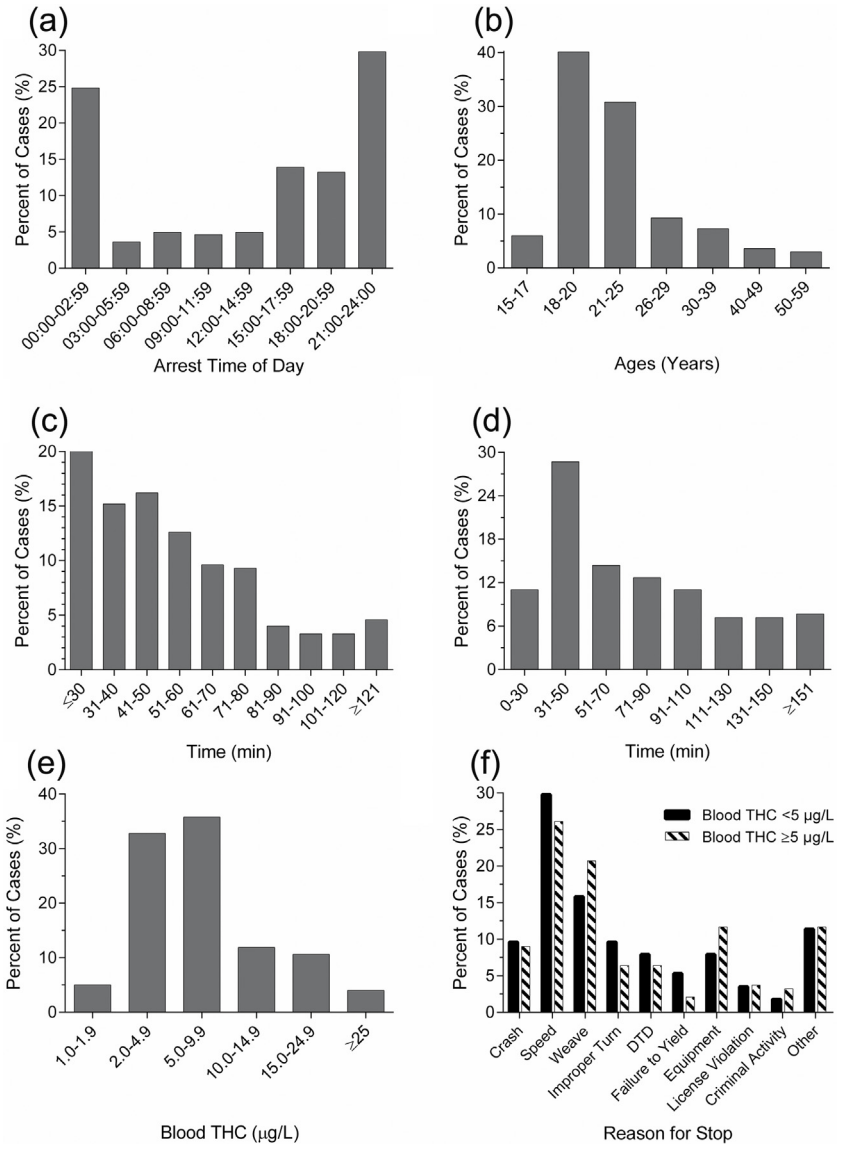

Fig. 1. Case distribution of (a) arrest time of day, (b) ages, (c) time from arrest to start of drug recognition expert (DRE) evaluation, (d) time from arrest to blood collection, (e) blood Δ^9-tetrahydrocannabinol [THC] concentration, and (f) reasons for the traffic stop, for 302 suspected drugged drivers who underwent DRE evaluation and tested positive for cannabis only. Abbreviation: DTD, disobeyed traffic device (e.g., stop sign, traffic signal).

"cooperative" (70.0%), "calm" (14.8%), "good" (9.1%), "normal" (5.7%), and "relaxed" (3.7%).

Median [range] elapsed time between arrest and evaluation start was 47.5 [2–189] min, with 21.9% of case evaluations commencing within a half hour and 67.7% within an hour post-arrest (Fig. 1c). Evaluation duration was 43 [20–150] min, with 58.6% of evaluations lasting 31–50 min. Median [range] measured blood THC concentration was 6.0 [1.0–47.0] μg/L. Most drivers' blood THC was 5.0–9.9 μg/L (35.8%), with 32.8% between 2.0–4.9 μg/L. Only 5.0% had blood THC <2 μg/L. There was information about blood collection time for 180 cases; median [range] time from arrest to blood collection was 61 [0–225] min. Blood collection time relative to the DRE evaluation (before/during/after) significantly affected measured THC concentrations ($p = 0.034$) overall (Fig. 2), with blood collected before the evaluation showing significantly greater ($p = 0.030$) concentrations (median [range] 7.1 [1.1–35.0] μg/L, n = 91) than blood collected after the evaluation (5.0 [1.1–47] μg/L, n = 72). Increasing blood collection time (relative to arrest) was significantly correlated with decreasing measured blood THC (Spearman r, −0.2317; $p = 0.0017$). No significant differences were detected in incidence of moving violations or any specific type of moving violation between drivers with blood THC quantified ≥5 μg/L and those with THC <5 μg/L.

MRB, WAT, and OLS results are presented in Fig. 3. In the MRB, drivers' estimation of 30 s was variable with wide distribution (median [range] 29 [4–90] s), whereas controls' estimations were more normally distributed (30 [20–53] s). Overall, a significant difference in time estimation was detected ($p = 0.002$), with only 4.0% of cases' estimations coinciding with exactly 30 s on the clock, compared to 29.9% of controls. However, cases' over- and under-estimation prevalences were approximately equal (31.1% over and 36.1% under 30 s by >10%), and 50.7% of cases (controls, 83.1%) estimated 30 s within ±5 s. In 78.5% of cases' MRB tests, sway (front-to-back, side-to-side, or both) was documented, compared with only 11% of controls. In 28.8% of cases, both side-to-side and front-to-back sway were noted; circular sway was recorded for 22.8% of cases. Eyelid tremors were observed in 57.9% of cases during the MRB, and an additional 28.1% displayed eyelid and body tremors. On the WAT, median [range] number of clues (8 possible) were 3 [0-8] for cases and 0 [0–2] for controls ($p < 0.001$). The most distinctive clue for the WAT was improper turn, detected in 57.3% of cases and 0% of controls. Other common cannabis WAT clues included using arms to balance (43.7% cases/2.3% controls), stopping (41.4%/2.0%), and missing heel-to-toe (41.1%/3.0%). WAT tremors were observed in 17.5% of cases and 0% of controls. Similar patterns emerged for the OLS. Of 4 possible OLS clues, the median number of observed clues (on either left or right leg) for cases was 1 versus 0 for controls ($p < 0.001$), with a broader distribution. No significant differences in reported clues were noted between left and right legs; however, some *individuals* had a higher number of clues for one leg than the other. Thus, although the medians for each leg [n(R) = 302, n(L) = 302] and all trials collectively [n = 604] were 1, 55.0% of drivers (cases) demonstrated ≥2 clues on at least one leg. Fewer than 20% of cases had 0 observed clues, compared to >90% of controls. Sway was the most common OLS clue detected, followed by using arms to balance (Fig. 3). Cases counted significantly faster on the second attempt (right leg) than on the first (left). Median [range] count reached in 30 s were: cases, 24 [10–40] left/24 [13–56] right, $p = 0.027$. Although controls' left versus right counts also significantly differed ($p = 0.040$), distributions tightened on the second attempt: 29 [16–36] left/30 [17–35] right. Cases' versus controls' counts significantly differed ($p < 0.0001$) for left and right legs. Although tremors are not considered a "clue" in any DRE test, they were a recorded observation in 63.4% of cases' OLS tests. Cases and controls displayed opposing patterns for number of "misses" (unsuccessful attempts [including missing the tip of the nose and using the pad, rather than tip, of the finger], out of 6 possible misses) on the FTN (Fig. 4). Cases missed substantially more than controls (median [range] 5 [0–6], 0 [0–6] respectively, $p < 0.0001$). Both eyelid and body tremors were documented for 23.8% of cases (0 controls), and eyelid tremors only in 39.7% of cases (0.7% controls). There was no correlation between THC concentration and tremors observations (eyelid, body, or both) in the OLS, WAT, MRB, or FTN tests (Spearman r = −0.0421–0.0744, $p \geq 0.198$). No significant differences were detected in test results between cases with blood THC measured ≥5.0 μg/L and those with <5 μg/L (Supplemental Figs. 1 and 2).

Cases' mean (SD) pupil size was significantly more dilated than controls ($p < 0.001$) in RL, NTD, and DL (Fig. 5a). Mean values for controls were, in effect, the same as those for DRE pupil size average [unimpaired] ranges (International Association of Chiefs of Police, 2015b), whereas mean values for cases exceeded them. HGN occurrence did not significantly differ between cases and controls (2.65% vs. 0.33%, respectively, $p > 0.05$ [Fig. 5b]). VGN was not detected in controls or cases. LOC and rebound dilation occurred significantly more ($p < 0.001$) in cases (78.8% and 70.9%, respectively) than controls (10.9% and 1.0%).

Results of our evaluation of metrics and combinations to predict cannabis impairment are presented in Table 2. At least 3 FTN misses produced the overall best diagnostic performance characteristics on that test, and the observation of MRB eyelid tremors showed good sensitivity (86.1%), specificity (94.0%), and PPV (93.5%). Overall, the best single impairment indicators (efficiency ≥89.1%) were ≥3 FTN misses, MRB eyelid tremors, sway during the OLS, and ≥2 clues on the WAT. All demonstrated sensitivity ≥80.5%, ≥92.4% specificity, and PPV ≥91.8%. Rebound dilation occurred in 70.9% of cases and no controls; LOC had higher sensitivity (78.8%) than rebound dilation, but specificity was 89.1% and PPV 87.8%. In the evaluation of combined metrics, rebound dilation *or* LOC produced high performance characteristics (all ≥89.1%). The best overall result (all performance characteristics ≥96.7%) arose from requiring ≥2/4 of the following: ≥3 FTN misses, MRB eyelid tremors, ≥2 OLS clues, and/or ≥2 WAT clues.

4. Discussion

For approximately thirty years, the DRE program has applied a comprehensive, systematic, and standardized 12-step evaluation consisting of physical, mental and medical components for determining presence of possible drug-related driving impairment (International Drug Evaluation and Classification Program, 2016). Since the expansion of the DECP in the US and Canada, other countries, such as the United Kingdom, China, and Germany incorporated many aspects of the DECP. The United Kingdom uses two drug recognition systems, the field impairment testing (FIT) and drug recognition training (DRT) protocols (Jackson et al., 2000; Department for Transport, 2004) to identify the signs and symptoms associated with drug effects and the driver's possible drug impairment. A number of FIT and DRT procedures were adapted from the DRE protocol in the United States (Jackson et al., 2000; Department for Transport, 2004). Some differences between the US DECP and other countries' protocols include: (1) Training: In the US, the three-phase training process to assess physical, mental and medical components requires approximately 100 h, including extensive written and practical field testing for the officer to be certified as a DRE. In addition, recertification is required every two years (International Drug Evaluation and Classification Program, 2016). In other drug impairment training programs such as FIT and DRT in the UK, the training is much less time-intensive but also requires that portions of the drug-impairment assessment be conducted by a forensic medical examiner or physician (Sancus

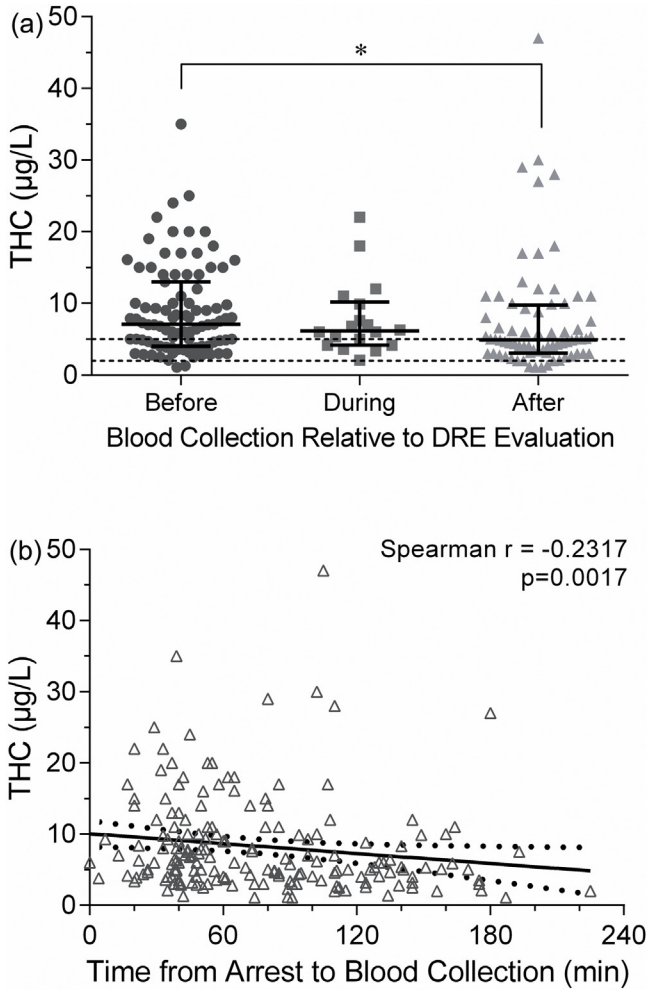

Fig. 2. Distribution of blood Δ^9-tetrahydrocannabinol [THC] concentrations a) collected before, during, or after Drug Recognition Expert (DRE) evaluation with median [interquartile range] indicated; and b) correlation with time between arrest and blood collection. *THC concentrations measured in blood collected before DRE evaluations were significantly greater than THC measured in blood collected afterward ($p = 0.030$). Dotted lines in (a) represent 2 and 5 µg/L THC, commonly debated per se cutoffs. Dotted lines in (b) represent 95% confidence interval in correlation line displayed.

Solutions, 2016). (2) Assessment: In the US, a police officer uses the SFSTs at roadside to identify impairment. Based on the results of the SFSTs, the officer may decide to arrest and charge the suspect for DUI, not always knowing the cause of the impairment. Once a breath test is obtained and if alcohol is not involved, a DRE is often summoned to conduct a drug evaluation under controlled conditions in the police station. In other countries, the police officer applies the information from the stop and field impairment tests. If impairment is suspected, the officer makes the arrest. What follows varies per country (Hughes, 2007). An outside resource is consulted and requested to continue the assessment, to assist in determining if the driver's condition may be due to alcohol or drugs. If determined due to drugs, a toxicological sample is acquired for drug analysis and the suspect is charged accordingly (Hughes, 2007). (3) Decision process: DREs use an extensive systematic and standardized process that is recognized in many courts in the United States to determine the possible presence of impairment and its likely cause. In other countries, the testing and decision protocols used to determine possible drug impaired driving vary and are designed, organized, and applied according to their respective laws (Hughes, 2007; International Police Association-IAC, 2012; Oliver et al., 2006).

Our data are among the most comprehensive cannabis-impaired DRE evaluation results ever established, and will help inform drug impairment identification techniques worldwide. We successfully collected 302 full DRE evaluations from cannabis-only cases to establish a population profile of driver impairment due to cannabis. In DUI cases, although cannabis is the most common illicit drug identified (Berning et al., 2015; Legrand et al., 2013; Pilkinton et al., 2013), it is difficult to obtain cannabis-only cases. This requirement historically restricted n in cannabis-impaired driving studies (Drummer et al., 2004). For the first time to our knowledge, >300 cannabis-only DRE cases (in which the DRE's opinion correctly [toxicologically confirmed] identified cannabis) were amassed for evaluation, with a size-matched control population providing normative data. With this study population, we were able to observe statistically significant differences between cases and controls. Our controls were consistent with DRE-established "average ranges" (International Association of Chiefs of Police, 2015a), while the cases significantly differed in several characteristics including pulse, SBP, and pupil size. Another unique aspect of this research is our evaluation of FTN and MRB results best indicating cannabis impairment, as these psychophysical tests are not yet validated.

Cannabis-driving legislation is increasingly debated as medical and recreational cannabis use expand (ProCon.org, 2014; Salomonsen-Sautel et al., 2014; Urfer et al., 2014). Blood THC zero-tolerance or per se thresholds are under consideration in several jurisdictions and already adopted in 14 states (Armentano, 2013). Blood THC ≥5 µg/L is a commonly considered per se threshold.

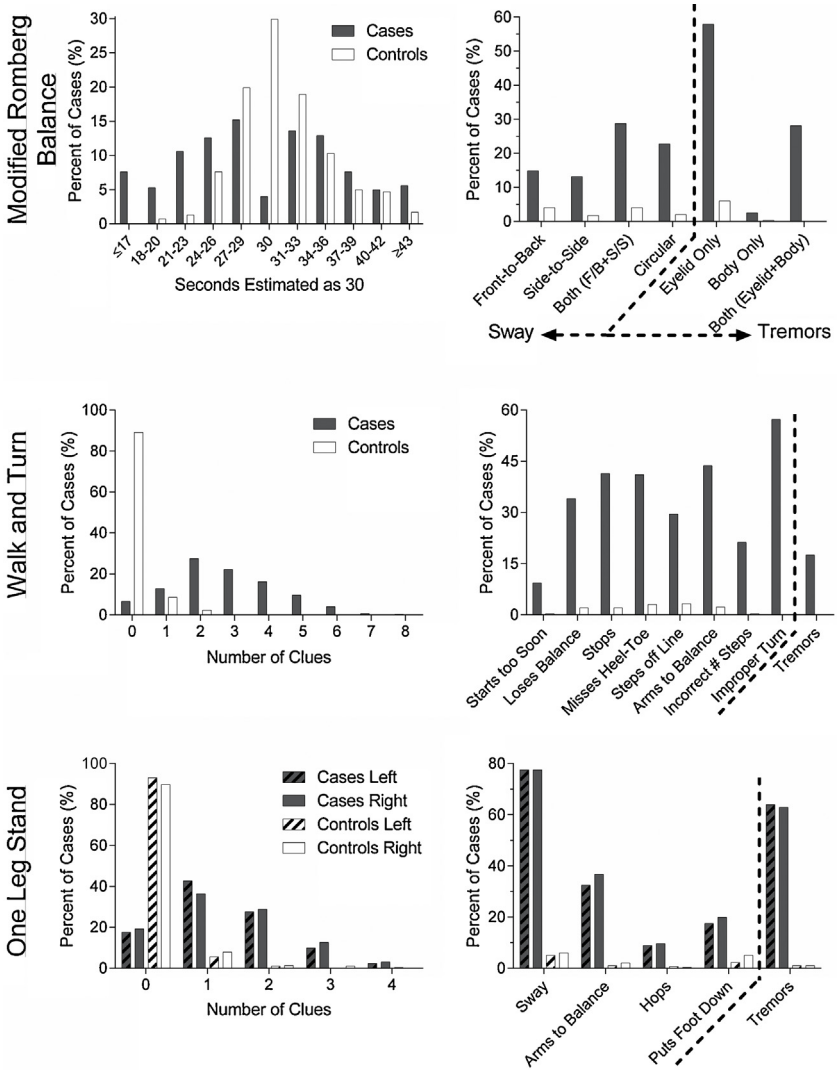

Fig. 3. Case (N = 302) and control (N = 302) frequency distribution of performance measures on Modified Romberg Balance (MRB), Walk and Turn (WAT), and One Leg Stand (OLS) psychophysical tests. For MRB, observations include number of seconds estimated as 30 s, front-to-back (F/B) and side-to-side (S/S) sway, and tremors. For the WAT and OLS, number of distinct "clues" detected are provided on the left graph, with specific clues on the right. Dotted lines separate tremors; WAT and OLS tremors are recorded observations, *not* clues. For the OLS, results from left and right legs are presented.

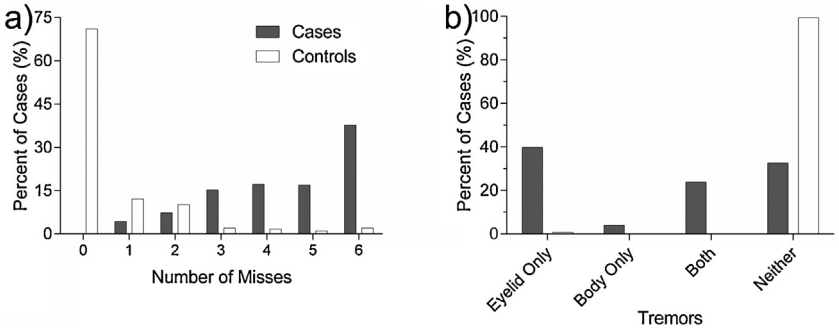

Fig. 4. Case (N = 302) and control (N = 302) frequency distribution of (a) misses (of 6 attempts), and (b) tremors observations on the Finger to Nose (FTN) test.

Of states where recreational cannabis is currently legal, Washington adopted a 5 μg/L per se cutoff (Armentano, 2013), and Colorado adopted a 5 μg/L "permissible inference" law (Colorado Revised Statutes, 2014; Urfer et al., 2014). We compared DRE results from cases with blood THC ≥5 μg/L to those with <5 μg/L. It was unsurprising that no significant differences were detected, due to the range of post-arrest blood collection times. Due to THC's pharmacokinetic profile, delaying blood collection may result in substantially lower concentrations than those present at the time of the traffic stop or crash (Biecheler et al., 2008; Desrosiers et al., 2014; Huestis, 2005; Huestis et al., 1992). Our DRE data illustrate this pattern: blood THC concentration was significantly and inversely correlated with blood collection time after arrest. To obtain the most accurate and reliable results, blood should be

Table 2
Evaluation of frequently detected signs or observations from the Drug Recognition Expert (DRE) evaluation in 302 cannabis-only driving cases and 302 non-impaired controls.

Sign/Condition/Observation	Percent of Cases (%)	Percent of Controls (%)	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Efficiency (%)
≥2 Misses, FTN	94.4	16.6	94.4	83.4	85.1	93.7	88.9
≥3 Misses, FTN	87.1	6.6	87.1	93.4	92.9	87.9	90.2
≥4 Misses, FTN	71.9	4.6	71.9	95.4	93.9	77.2	83.6
Eyelid Tremors, MRB	86.1	6.0	86.1	94.0	93.5	87.1	90.0
Any Sway[a], MRB	78.5	11.0	78.5	89.0	87.8	80.5	83.7
Any Sway[b], OLS	85.8	7.6	85.8	92.4	91.8	86.6	89.1
≥2 Clues, OLS[c]	55.0	3.0	55.0	97.0	94.9	68.3	76.0
≥2 Clues, WAT	80.5	2.3	80.5	97.7	97.2	83.3	89.1
LOC	78.8	10.9	78.8	89.1	87.8	80.8	83.9
Bloodshot Eyes	77.5	3.1	77.5	96.9	96.3	80.7	87.1
Rebound Dilation	70.9	0	70.9	100	100	77.4	85.4
≥2 Clues, OLS[c] *and* ≥2 Clues, WAT	48.7	0	48.7	100	100	66.1	74.3
≥2 Clues, OLS[c] *or* ≥2 Clues, WAT	87.1	3.0	87.1	97.0	96.7	88.3	92.1
2/3 of: ≥3 Misses, FTN ≥2 Clues, OLS[c] ≥2 Clues, WAT	81.1	1.3	81.1	98.7	98.4	83.9	89.9
≥3 Misses, FTN *and* (≥2 Clues, OLS[c] *or* ≥2 Clues, WAT)	76.2	0.7	76.2	99.3	99.1	80.6	87.7
2/4 of: ≥3 Misses, FTN Eyelid Tremors, MRB ≥2 Clues, OLS[c] ≥2 Clues, WAT	97.0	3.3	**97.0**	**96.7**	**96.7**	**97.0**	**96.9**
3/4 of: ≥3 Misses, FTN Eyelid Tremors, MRB ≥2 Clues, OLS[c] ≥2 Clues, WAT	74.2	0	74.2	100	100	79.5	87.1
Rebound Dilation *or* LOC	92.7	10.9	92.7	89.1	89.5	92.4	90.9

Boldface indicates optimized combination of measures (best overall results, ≥96.7% on all diagnostic performance characteristics).
Abbreviations: Sensitivity (true positives [TP]/(TP + false negatives [FN])); Specificity (true negatives [TN]/(TN + false positives [FP])); PPV, positive predictive value (TP/(TP + FP)); NPV, negative predictive value (TN/(TN + FN)); Efficiency (TP + TN)/(TP + TN + FP + FN); MRB, Modified Romberg Balance test; LOC, lack of convergence; WAT, Walk and Turn test; OLS, One Leg Stand test; FTN, Finger to Nose test.
[a] Note: The MRB test does not have designated "clues"; sway represents a recorded observation.
[b] Note: Sway constitutes one of the four possible "clues" on the OLS test.
[c] ≥2 Clues on the OLS was considered true if ≥2 clues presented on at least one leg.

obtained as early as possible in the process of evaluating suspected impaired drivers. Although currently listed as the 12th step in the DRE evaluation procedure (International Association of Chiefs of Police, 2013a, 2015a, 2015b), it behooves officers to ensure blood is collected expediently, and the DECP training now allows for early collection of blood (International Association of Chiefs of Police, 2013a). The number of collections that occurred before the DRE examination in our study suggests that this message is disseminating, but still not yet ubiquitous. Early blood collection is challenging due to the requirement for a phlebotomist and/or a warrant to collect the blood, complicating the issue.

Eye examinations provided valuable data. HGN assessments are a regular part of clinical examinations by health care clinicians, evaluating integrity of the oculomotor system for irregularity or abnormality as signs of CNS impairment (Carlson and Kurtz, 2012 Ciuffreda and Tannen, 1995; Leigh and Zee, 2015; Rett, 2007). HGN in DRE evaluations likewise indicates impairment associated with select categories of drugs, e.g. alcohol, CNS depressants, dissociative anesthetics, inhalants, and/or medical conditions affecting driving ability, but is not typically associated with cannabis in these protocols (Couper and Logan, 2014; Kosnoski et al., 1998; McLane and Carroll, 1986; Richman and Jakobowski, 1994). Thus, the lack of significant HGN differences in our study was expected. VGN is associated with the same drugs that produce HGN [at higher doses] (Couper and Logan, 2014), but not cannabis. Our data suggest normal incidence of LOC in controls, consistent with overall ranges for convergence insufficiency (CI) in the general population (Scheiman et al., 2003), although no specific prevalence is known. However, LOC incidence in cases was 7-fold higher than controls. An underlying cause of CI is a connection between accommodative insufficiency (focusing) and convergence (Cooper et al., 2011). Focusing and adequate sustained attention to a task are essential components for absence of LOC. Cannabis produces dilated pupils, reduced focusing ability, and diminished attending abilities (Böcker et al., 2010), likely accounting for the increased LOC documented. Cases' pupils were consistently larger than controls' in all lighting conditions, indicating an overall cannabis dilation effect. Controls' pupil sizes in this study replicated an earlier study of unimpaired pupil sizes utilizing the DRE protocol (Richman et al., 2004), with no statistical difference in mean pupil sizes for any light condition between these studies. Besides acting as a marker for cannabis intake, pupil dilation influences safe driving. Dilated pupils can interfere with certain aspects of driving and vision performance (e.g., trouble seeing in light that is too bright), resulting in impaired daytime driving even without the presence of an impairing drug such as cannabis (Battistella et al., 2013; Wood et al., 2003). These negative effects would be further compounded by the psychomotor and cognitive effects of cannabis (Hartman and Huestis, 2013). Pupil responses to light such as rebound dilation ("pupillary escape") are influenced by initial pupil size (Sun and Stark, 1983). While small pupils are better regulators of light, dilated pupils more likely exhibit rebound dilation. This is consistent with our findings of overall pupil dilation and increased rebound dilation incidence in cases. Rebound dilation also was observed in a previous cannabis study (Fant et al., 1998), wherein final pupil diameter (diameter at the end of bright stimulus presentation) was significantly affected by cannabis.

This study has several limitations. Although the control population was negative by self-report for impairing drugs, were under observation of other police officers, and were participants in training/practice sessions, no toxicology results were available. Thus, controls may not have been 100% free of impairing substances; however, if this did occur, it would make it more difficult to identify differences between cases and controls. Additionally, the controls' demographic characteristics (age/race) were notably different from cases'—with median case age significantly younger (21 years) than that of controls (34 years)—and control evaluations only occurred during normal business hours (whereas case evaluations occurred at all hours). While cases had narratives available in addition to face sheets, controls did not, preventing certainty in FTN scoring. Another limitation to consider is that many (albeit not all) of the controls were police officers participating in DRE training sessions;

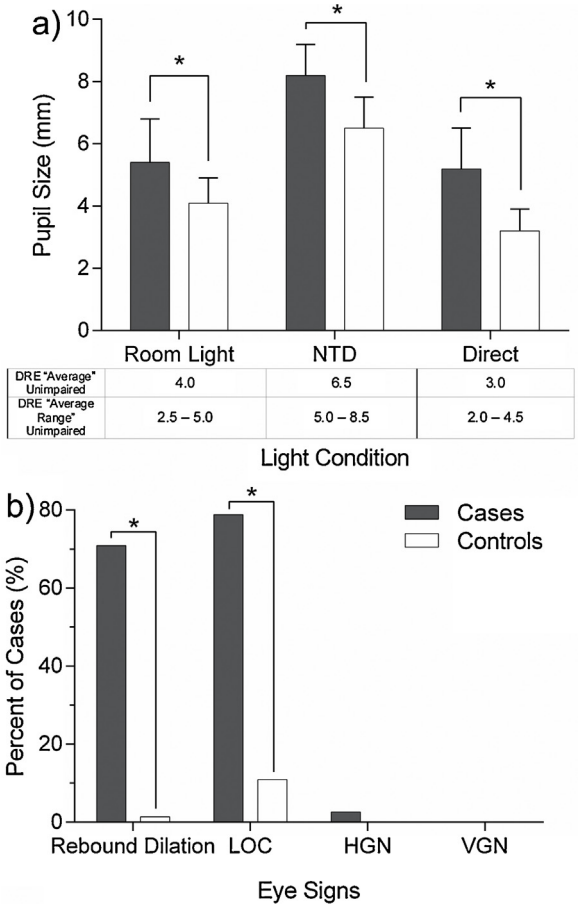

Fig. 5. Drug Recognition Expert (DRE) recorded eye signs for cannabis cases (N = 302) and controls (N = 302). (a) Mean (SD) pupil size measured in room light, near-total darkness (NTD), and direct light, with DRE-established "average ranges" for comparison. (b) Prevalence of rebound dilation, lack of convergence (LOC), horizontal gaze nystagmus (HGN), and vertical gaze nystagmus (VGN) detected. *$p < 0.001$, unpaired *t*-test.

thus, they were more knowledgeable and experienced with the divided attention tasks. Differences between the cases and the control group may have been greater than if a less experienced control group was included. It also is necessary to consider that cannabis represents only one of 7 drug categories evaluated by DREs. To fully elucidate a profile *specific* to cannabis, cases positive for other drug classes must also be evaluated and directly compared with cannabis-only cases, because several signs are exhibited in multiple drug classes. Finally, in this study all cases constituted correctly identified cannabis impairment by DREs in real-world evaluations. Our study design included only cases where the DRE identified cannabis impairment and toxicology supported cannabis intake. Thus, the diagnostic parameters (sensitivity, specificity, PPV, NPV, and efficiency) represent only those terms within the context of our study structure. Because there was selection bias in the positive "cases" (e.g., THC-positive cases where the DRE did not opine cannabis, and other erroneous DRE findings were not included), these parameters' results may be greater than if all cases were included. Additionally, evaluation of the *scientific* validity of the examinations is limited in this study design because DREs communicate with arresting officers and with suspects, thus knowing arrest conditions/observations (e.g., whether cannabis was present in vehicle or suspect was observed smoking) (Schechtman and Shinar, 2005). Thus, not all cases were identified purely by signs exhibited on psychomotor examinations, limiting our ability to identify psychomotor examinations that could definitively indicate cannabis impairment in the absence of other observations.

However, this also represents the greatest strength of the DECP. Psychophysical tests indicate impairment; other observations help distinguish cannabis as the causative agent. Certain signs and impairment characteristics may be observed for multiple drug classes (Cochems et al., 2007; International Association of Chiefs of Police, 2013a, 2015a, 2015b; Logan, 2009; Smith et al., 2002), and not all signs are detected in every case. The DECP is effective because it relies upon combined results from several examinations and observations, rather than any in isolation. Limiting DREs' observational information and interaction ability decreases effectiveness. When DREs evaluated 20 real cannabis-only cases (correctly identified by the original DRE) by relying solely upon recorded data, only 80.7% produced correct cannabis identifications (Smith et al., 2002). In an evaluation of DRE performance in a controlled-administration setting with multiple drug classes available, combining pulse rate, direct light pupil diameter, and reaction to light variables (without considering psychophysical results) produced 49% sensitivity and 77% specificity for cannabis impairment detection (Schechtman and Shinar, 2005). More elaborate combinations of 5 and 28 DRE variables resulted in 90.6% and 100% sensitivity, 92.6% and 98.1% specificity, and 91.9% and 98.8% efficiency for cannabis detection, respectively (Heishman et al., 1996). Our study corroborates previous evaluations (Heishman et al., 1996; Schechtman and Shinar, 2005) indicating that pupil size, rebound dilation, LOC, bloodshot eyes and elevated pulse may strengthen cannabis identification.

DECP impairment detection in cannabis cases was optimized by requiring impairment evidence in ≥2/4 of the psychophysical tests, further illustrating the value of considering aggregate results from multiple sources. Papafotiou et al. (2005a) evaluated the sensitivity of the SFSTs to cannabis after placebo, 14 and 52 mg smoked THC, defined as "impaired" classification on at least 2 of the 3 SFSTs. Sensitivities were 23.1% and 41.0–46.2% (respectively) after the active doses within an hour post-intake, decreasing to 15.4% and 28.2% 1.75 h post-dose. Because HGN incidence after cannabis is negligible (International Association of Chiefs of Police, 2015a, 2015b; Porath-Waller and Beirness, 2014), it is more meaningful to compare the incidence of ≥2 clues on *both* OLS and WAT. This metric in our study compared favorably to previous data (Papafotiou et al., 2005a), occurring in 48.7% of cases and 0 controls. Importantly, the SFSTs differ from their respective DECP techniques; e.g., the OLS is only performed on one leg. Furthermore, although our study lacks controlled dosing and a within-subjects design, it retains real-world validity as these were actual cases involved in traffic stops (albeit not all moving violations) and determined to be impaired.

5. Conclusion

In 302 correctly identified cannabis-only DRE cases, the most reliable impairment indicators included elevated pulse, dilated pupils, LOC, rebound dilation, and documented impairment in 2 of 4 psychophysical tasks. Blood specimens for toxicology should be collected as early as possible, as measured concentrations are significantly related to collection time. No significant differences were detected in outcome measure prevalences between cases with <5 μg/L and ≥5 μg/L blood THC. Combined observations on psychophysical and eye exams produced the best indicators of cannabis impairment. The results of this research support the cannabis impairment training taught in the DECP.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.aap.2016.04.012.

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