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DOI: 10.1007/s00213-012-2787-9 · Source: PubMed

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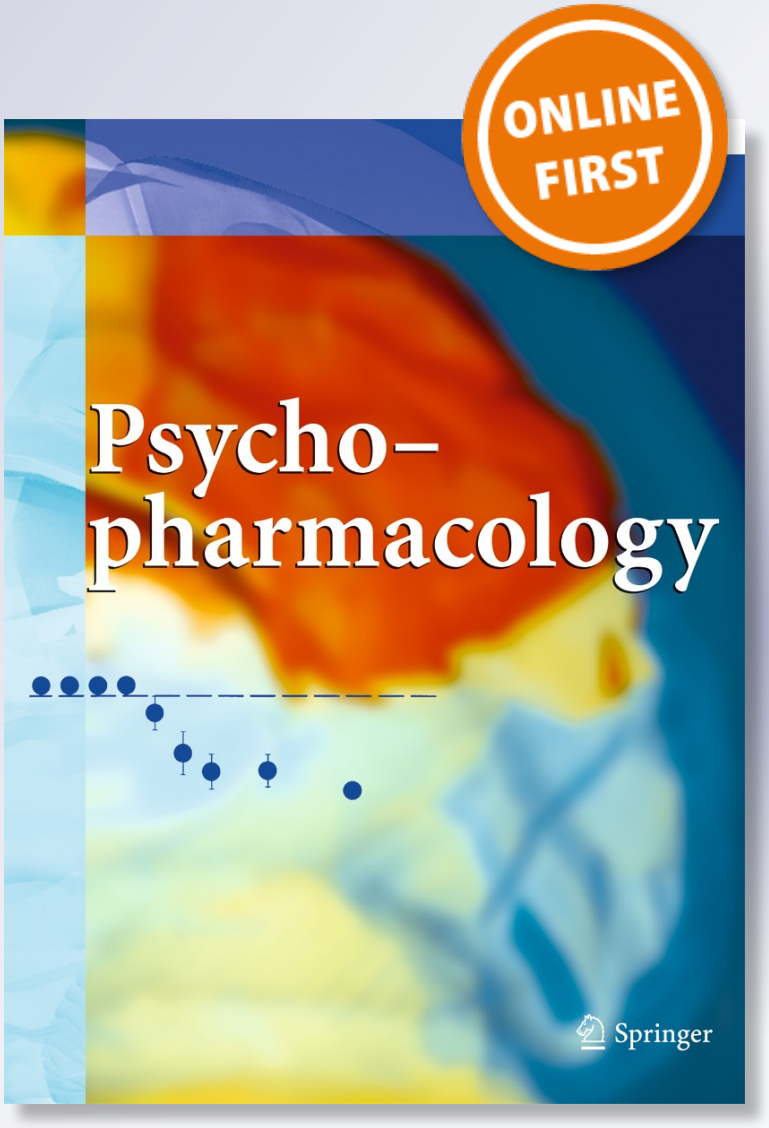
Psychopharmacology
DOI 10.1007/s00213-012-2787-9



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Psychopharmacology
DOI 10.1007/s00213-012-2787-9

ORIGINAL INVESTIGATION

Detecting impairment associated with cannabis with and without alcohol on the Standardized Field Sobriety Tests

Luke A. Downey · Rebecca King · Katherine Papafotiou · Phillip Swann · Edward Ogden · Martin Boorman · Con Stough

Received: 14 December 2011 / Accepted: 18 June 2012

Abstract
Rationale Cannabis and alcohol are the most popular drugs amongst recreational users and most prevalent in injured and deceased drivers. The Standardized Field Sobriety Tests (SFST) are commonly used to establish impairment due to drugs and alcohol, but limited empirical evidence exists concerning the combined effects of these drugs on SFST performance.
Methods The sample comprised 80 individuals (31 females; 49 males). Age ranged between 21 and 35 years (M=26.5, SD=5). Forty participants (15 females; 25 males) took part in the low alcohol condition (BAC, <0.05 %), and 40 participants (16 females; 24 males), took part in the high alcohol condition (BAC, >0.05 %). For each part of the study, two levels of Δ9-tetrahydrocannabinol (THC) were administered (1.8 and 3 % THC) or a matching placebo cigarette (0 % THC) in combination with alcohol. Performance on the SFST was assessed 30 min post-dosing.
Results A number of significant differences in SFST performance were identified with 28 % of the sample failing the test (when the head movement and jerks sign was included) when low alcohol and low THC were administered together. When a higher dose of alcohol was administered with a low dose of THC, 38 % of the sample failed the test, and 35 % also failed when the high dose of alcohol was combined with a higher dose of THC.
Conclusions The current results highlight the limited ability of the SFST to identify drug consumption in the absence of any evidence of driving impairment or physiological indicators.

Keywords Cannabis · Alcohol · Driving · SFST · RCT · Illicit · THC · Δ9-tetrahydrocannabinol

Introduction

The Standardized Field Sobriety Tests (SFST) are utilised to assess driver impairment in relation to alcohol and illicit drug intoxication. These tests are designed to assess aspects of divided attention, cognitive functioning and psychomotor performance and take the form of specific performance tests, principally the Horizontal Gaze Nystagmus (HGN), the Walk and Turn (WAT) and the One-Leg Stand (OLS) tests (Burns and Moskowitz 1977). The SFST have been found to be reliable and accurate predictors of blood alcohol concentration (BAC) above and below 0.08 % BAC (Stuster 2006) and moderately predictive of simulated driving impairment in low dose (65.8 % correct) Δ9-tetrahydrocannabinol (THC) and high-dose (76.3 % correct) THC conditions (Papafotiou et al. 2005). Only recently has a controlled study assessed the combined effects of alcohol and THC intoxication upon the tests utilised to determine impairment associated with drugs and alcohol in drivers. This study in heavy THC users indicated that OLS performance was related to THC consumption, and performance upon the HGN test was significantly related to the alcohol and THC combined conditions (Bosker et al. 2012). Given the SFST are commonly used to inform law enforcement of a driver's intoxication (Silber et al. 2005; Stuster 2006), and the rising incidence of injured and deceased drivers testing positive to alcohol and THC in their blood system (Drummer

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Published online: 05 July 2012

et al. 2004), an understanding of the interactive effects of THC and alcohol upon SFST performance is necessary.

Whilst the SFST are used to identify driving impairment associated with consumption of drugs other than alcohol, only limited empirical evidence exists for the efficiency of the SFST to identify impairment associated with drug consumption. In double-blind placebo-controlled studies, the SFST have been observed to be relatively insensitive to low doses (0.42 mg/kg) of D,L-dexamphetamine, D,L-methamphetamine, D-methamphetamine (Silber et al. 2005) and somewhat more efficient in detecting the presence of D,L-3,4-methylenedioxymethamphetamine (Downey et al. 2012) with the most notable impairment occurring in the OLS (34 % impaired) and WAT (26 % impaired) tests. In the field, use of various SFST such as the Performance Impairment Tests (PIT; Australia) are highly successful (89 % correctly identified) in identifying drivers impaired by drugs other than alcohol (Boorman and Papafotiou 2007). Despite these tests being successful in identifying impairment in drivers suspected of driving under the influence of drugs and alcohol (Compton 1986), controlled studies of specific drugs and drug combinations are necessary to elucidate what aspects of SFST performance are the best indicators of drug intoxication.

Performance on the SFST can be dissociated into a number of 'signs' that can be compromised in the completion of each discrete test. The occurrence of a prescribed amount of these signs during a single test infers that the participant is impaired, and failure of two or all of the three tests that make up the SFST results in the participant failing the SFST, and being regarded as impaired as per the administration procedures used by the Victoria Police (Victorian Government Gazette 2000). Some of these tests have been previously observed to be more sensitive to particular drugs, ostensibly due to their physiological effects. For example, in the HGN test, the appearance of nystagmus is an involuntary physiological reaction to alcohol consumption that cannot be compensated for even by experienced drinkers and has been found to be the most reliable discriminator between drivers below the prescribed BAC and those exceeding the statutory limit (Stuster 2006). Whether this test or specific 'signs' on the other SFST are more affected by illicit drugs when they are consumed in conjunction with alcohol has yet to be empirically investigated. When THC was administered in controlled laboratory conditions, performance on the OLS test have been observed to be the best indicator of impairment associated with THC consumption (Papafotiou et al. 2005). Overall performance on this test was observed to be compromised at 5 (χ^2=25.0; *df*=2; p<0.001), 55 (χ^2=18.2; *df*=2; p<0.001) and 105 min (χ^2=19.0; *df*=2; p<0.001) after smoking low (1.74 %) or high (2.94 %) THC cigarettes and on the following discreet signs: swaying while balancing on one leg, using arms to maintain balance and putting the raised foot down (hopping during test to maintain balance was only 'impaired' at the first two testing time-points) (Papafotiou et al. 2005). Whether this effect is mediated or exacerbated by alcohol consumption warrants further investigation.

Given that alcohol and THC are the most prevalent drugs in injured and deceased drivers (Drummer et al. 2004) and that driving under the influence of alcohol and marijuana alone and in combination has been found to impair driving performance in controlled studies (Bramness et al. 2010), further understanding of the interactive effects of these drugs upon the tests used to assess intoxication of drivers, namely the SFST, is necessary. In light of previous studies concerning the individual effects of alcohol and THC upon SFST performance, the current study aimed to assess the effect of THC and alcohol on SFST performance at two doses of both alcohol and THC and examine individual test performance with respect to the differences in impairment exhibited by participants in the individual treatments and combined treatment conditions. It was expected that THC consumption would impair overall SFST performance and that when consumed in conjunction with alcohol, greater decrements in performance would be observed and that an increase in dose of either alcohol or THC would produce significantly greater impairment in overall SFST performance.

Method

Participants

The sample comprised 80 individuals (31 females and 49 males). Age varied between 21 and 35 years (M=26.45, SD=5). Part one comprised 40 participants (15 females and 25 males) who took part in the low alcohol (BAC, <0.05 %) condition. In part two, 40 participants included 16 females and 24 males; these participants took part in the high alcohol (BAC, >0.05 %) condition. All participants had smoked cannabis previously and consumed alcohol. Of these participants, 48 were regular cannabis users and 32 non-regular cannabis users as identified through a Frequency of Cannabis Use questionnaire. Participants' reported frequency of cannabis use varied from once a week to once every 2–6 months. They underwent a medical examination prior to participation to ensure that they had no history of cardiac disorders, current or past substance abuse, mental health problems, allergies to drugs and other medical illness. All participants had a valid full driver's license (no probationary or learner drivers) to ensure that they had at least 3 years of driving experience. All participants provided informed consent, and the Institutional Research Ethics Committee approved the research, which was conducted in accordance to the declaration of Helsinki, 1964 (amended in Seoul, 2008).

Materials

Alcohol was administered according to a weight-related dose. The target blood alcohol concentration for participants was

either 0.05 or 0.08 % BAC. The placebo session was masked as the theoretically equivalent number of drinks to obtain a 0.04 % BAC, when it actually contained no alcohol (the nurse administered the breath alcohol test but did not administer any performance tests). By the time the SFST were performed, BAC had dropped to 0.04 or 0.07 % BAC, as the level of alcohol in blood drops approximately 0.01 % every 40 min. The cannabis cigarettes used in the study were provided by the National Institute on Drug Abuse in the USA. Each THC cigarette was administered using a controlled smoking procedure (Papafotiou et al. 2005). Participants were instructed to inhale marijuana smoke for 2 s, hold the smoke in their lungs for 10 s (or for as long as they could if they could not hold for 10 s) and exhale and rest for 35 s. This procedure was repeated a maximum of eight times and was terminated if the cannabis cigarette had been fully consumed. The two levels of THC administered were 1.8 % (0.81 g) THC for the low dose and 3 % (1.78 g) THC for the high dose. A matching placebo cigarette (0 % THC) was also utilised. The treatment order was counter-balanced, double-blind and used a within-subject design to reduce the possibility of practise effects.

The standardised field sobriety tests

All three tests that comprise the SFST battery were administered, as per the administration procedures used by the Victoria Police for the Performance Impairment Tests (Boorman and Papafotiou 2007; Downey et al. 2012). This selection of tests has been highly successful in identifying drivers as impaired in the field with the PIT being successful in 89 % of cases (Boorman and Papafotiou 2007). Participants were also familiarised with the SFST battery in a training session conducted by a trained researcher prior to the testing days to eliminate any possible learning effects on the tests that may affect the relative failure rate upon the individual tests. The SFST comprise three tests: the HGN and Vertical Gaze Nystagmus (VGN), the WAT and the OLS. Overall performance on the SFST is calculated by summing the performance on the three tests (HGN, WAT and OLS). In accordance with Victoria Police implementation training procedures, if the participant was identified as impaired on two or more of the tests, the participant was subsequently classified as impaired on the SFST.

For the HGN and VGN, participants are required to focus on a pen located 30 to 36 cm in front of their nose as the experimenter moves the pen horizontally and vertically. Participants were classified as impaired on the test if they exhibited four or more (out of eight) of the following signs (four possible per eye): (1) lack of smooth pursuit, (2) distinct Nystagmus at maximum deviation, (3) Nystagmus onset before 45°; (4) VGN. An additional sign, head movements and/or jerks (HMJ), was also recorded, as previous research has observed HMJ in participants affected by THC (Papafotiou et al. 2005). HMJ was recorded if the participant was unable to keep their head stationary two or more times while following the moving stimulus. The WAT test requires participants to take nine heel-to-toe steps along a straight line, turn in a prescribed manner, and take nine heel-to-toe steps back along the line. Participants are classified as impaired if they show two or more of the following signs: not keeping balance while listening to the test instructions, starting the test before the instructions are completed, stopping walking during the test, not touching heel-to-toe while walking, stepping off line, using arms to maintain balance, turning incorrectly or taking an incorrect number of steps. The OLS task requires the subject to stand on one leg, with the other leg extended to the front held approximately 15 cm above the ground. The participant is required to maintain this stance while counting out loud for 30 s by thousands. If two or more of the following signs or clues are observed, the participant is deemed to be impaired, swaying while balancing on one leg, using arms to maintain balance, hopping during test to maintain balance and putting raised foot down.

Blood sampling

Blood samples were taken before the experimental sessions proceeded to ensure that participants had no drugs in their system. Samples were analysed for the seven major drug classes (opiates, amphetamines, benzodiazepines, cannabinoids, barbiturates, cocaine and methadone). Two blood samples were taken during the 1-h testing period. One blood sample was taken at 20 min after completion of cannabis smoking (Time 1; pre-performance tests) and a second sample was taken at approximately 60 min after completion of cannabis smoking (Time 2; post-performance testing). A medical doctor was on call throughout the testing sessions. Each 10-ml blood sample was transported to a toxicology laboratory and analysed immediately. Blood samples were screened for the seven major drug classes (opiates, amphetamines, benzodiazepines, cannabinoid, barbiturates, cocaine and methadone) using ELISA/EMIT screens. Subsequently, all three blood samples were analysed for active THC levels using the gas chromatography mass spectroscopy method (Moeller and Kraemer 2002). This method has been documented to be the most accurate technique for testing specific drug levels in blood. Thus, all participants were screened for recent use of drugs, and additionally for presence of the levels of the study drug.

Procedure

At each session, participants' would consume the required amount of alcoholic (or placebo) drinks, wait 20 min and provide a breath sample to confirm the required BAC had been reached. Participants would then smoke the cannabis cigarette, again wait 20 min before providing a blood sample, then complete a driving simulation task (presented elsewhere),

then complete the SFST 50 min after smoking the cannabis. The blood sample was taken 20 min after THC smoking, as past research indicates that, although THC plasma levels peak immediately after smoking, behavioural impairment occurs once plasma levels have dropped (Berghaus et al. 1995).

Data analysis

In order to determine the frequency of errors in each cannabis (placebo, low THC or high THC) condition (with and without alcohol), for both the low alcohol study (<0.05 % BAC) and the high alcohol study (>0.05 % BAC) the Cochrane Q statistic was calculated to determine whether a significantly different percentage of participants displayed a particular error between each of the six drug/alcohol conditions. Pair-wise comparisons (Cochrane Q) were conducted on each possible pair to identify which conditions were significantly different with the significance corrected for multiple comparisons (significance level/15). Only the errors that were displayed in a significantly different percentage across the drug conditions are reported.

Results

Levels of THC in blood and BAC's

Blood samples were collected to assess the level of THC and a breath analysis device was employed to assess BAC before and after the performance of the SFST. As can be seen in Table 1, average levels of BAC were marginally below 0.04 % for the low alcohol condition (reflecting an average level of BAC in the legal range), and above 0.05 % for the high alcohol condition (reflecting an average level of BAC in the illegal range) for the pre- and post-SFST performance assessments. With regard to the levels of THC in the blood, the recorded levels of THC pre- and post-SFST performance were very similar in both low and high alcohol conditions, and the high (3 % THC) condition produced noticeably higher levels of THC in the blood than the low THC condition (1.8 % THC).

The percentage of individuals who were classified as impaired based on each test in the SFST battery for every THC/alcohol condition are displayed in Fig. 1 for the Low Alcohol study and Fig. 2 for the High Alcohol study. Cochrane Q statistics for any significant differences between conditions are displayed in the notes below each figure. Differences between conditions were observed for HGN, HMJ, OLS, overall SFST and when HMJ was included with the overall SFST score in the low alcohol study. Further examination of these findings using pair-wise comparisons on the significantly different tests (and the signs they comprise) are presented in Table 2 for the low alcohol study and Table 3 for the high alcohol study. In the low alcohol study, pair-wise comparisons (with adjusted significance, $p/15$) indicated that the high THC/alcohol (43 %) produced significantly more errors on the HGN test than high THC/placebo alcohol (18 %), placebo THC/alcohol (8 %), low THC/placebo alcohol (6 %), and placebo THC/placebo alcohol (3 %). With regard to the particular 'signs' that comprise the HGN test that were affected by condition,

Table 1 Blood alcohol and THC concentrations for pre- and post-SFST assessments for each THC and alcohol condition

Condition		THC pre-SFST		THC post-SFST		BAC pre-SFST		BAC post-SFST	
		Mean (ng/ml)	SD (ng/ml)	Mean (ng/ml)	SD (ng/ml)	Mean	SD	Mean	SD
Low alcohol condition	Placebo Alc/low THC	73	37	38	16	–	–	–	–
	Placebo Alc/high THC	90	39	45	18	–	–	–	–
	<0.05/placebo THC	–	–	–	–	0.04	0.01	0.04	0.01
	<0.05/how THC	77	32	47	53	0.04	0.01	0.04	0.01
	<0.05/high THC	119	70	54	23	0.04	0.01	0.04	0.02
High alcohol condition	Placebo Alc/low THC	69	30	38	17	–	–	–	–
	Placebo Alc/high THC	92	51	48	23	–	–	–	–
	>0.05/placebo THC	–	–	–	–	0.08	0.02	0.07	0.02
	>0.05/low THC	76	39	40	15	0.07	0.02	0.07	0.02
	>0.05/high THC	102	56	56	26	0.07	0.02	0.07	0.02

In the low alcohol condition, the concentration of THC pre-SFST was significantly different between high and low THC doses when combined with alcohol t (74)=3.47, $p<0.01$ but did not reach significance t (77)=1.94, $p=0.06$ when consumed with placebo alcohol. Concentration of THC was also not significantly different post-SFST between the high and low THC doses. In the high alcohol condition, the concentration of THC pre-SFST was significantly different between high and low THC doses when combined with alcohol t (72)=2.29, $p<0.05$ and when consumed with placebo alcohol t (73)=2.38, $p<0.05$. Concentration of THC was significantly different post-SFST between the high and low THC when combined with alcohol t (61)=3.00, $p<0.01$. BAC pre-SFST readings were significantly different in the high alcohol condition between the >0.05/placebo THC and >0.05/low THC conditions t (77)=2.44, $p<0.05$

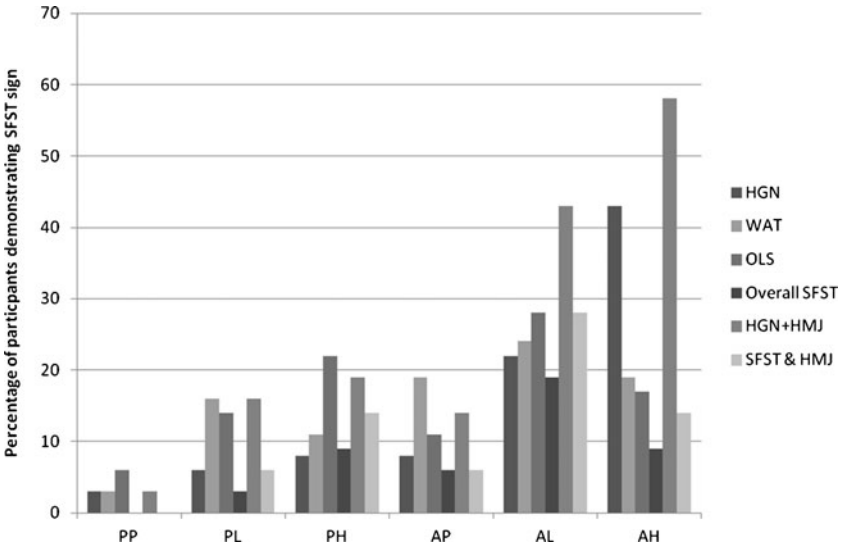

Fig. 1 Percentage of participants demonstrating signs of intoxication in the six experimental conditions in the low (BAC, <0.05) alcohol study. *HGN* horizontal gaze nystagmus, *LSP* lack of smooth pursuit, *NMax* nystagmus at maximum deviation, *HMJ* head movement and jerks, *OLS* one leg stand, *FD* foot down, *SFST* Standardized Field Sobriety Tests, *HA* high THC/alcohol, *HP* high THC/placebo alcohol, *LA* low THC/alcohol, *LP* low THC/placebo alcohol, *PA* placebo THC/alcohol, *PP* placebo THC/placebo alcohol. Differences were observed in the percentage of participants who displayed the signs of intoxication across conditions in the low alcohol condition for HGN (Q=39.39; df=5; p<0.001), HGN+HMJ (Q=16.88; df=5; p<0.01), OLS (Q=12.63; df=5; p<0.05), overall SFST (Q=12.22; df=5; p<0.05) and SFST and HMJ (Q=16.91; df=5; p<0.01)

the lack of smooth pursuit sign was produced significantly more often in the high THC/alcohol condition (56 %) than in the low THC/placebo alcohol (22 %), placebo THC/alcohol (22 %), high THC/placebo alcohol (19 %), and placebo THC/placebo alcohol (6 %) conditions. The low THC/alcohol (37 %) also produced significantly more errors than the placebo THC/placebo alcohol condition (6 %). For Nystagmus at maximum deviation, again the high THC/alcohol condition (58 %) produced significantly more errors than the low THC/placebo alcohol (22 %), placebo THC/

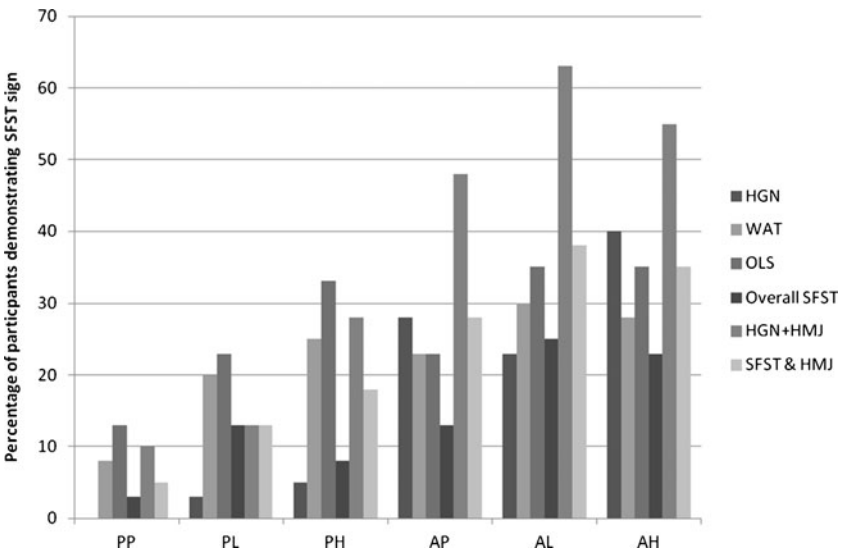

Fig. 2 Percentage of participants demonstrating signs of intoxication in the six experimental conditions in the high (BAC, >0.05) alcohol study. *HGN* horizontal gaze nystagmus, *LSP* lack of smooth pursuit, *NMax* nystagmus at maximum deviation, *HMJ* head movement and jerks, *OLS* one-leg stand, *FD* foot down, *SFST* Standardized Field Sobriety Tests, *HA* high THC/alcohol, *HP* high THC/placebo alcohol, *LA* low THC/alcohol, *LP* low THC/placebo alcohol, *PA* placebo THC/alcohol, *PP* placebo THC/placebo alcohol. Differences were observed in the percentage of participants who displayed the signs of intoxication across conditions in high alcohol condition for HMJ (Q=22.09; df=5; p<0.05), HGN (Q=41.08; df=5; p<0.001), OLS (Q=11.53; df=5; p<0.05), overall SFST (Q=15.00; df=5; p<0.05) and SFST and HMJ (Q=26.10; df=5; p<0.001)

Table 2 Pair-wise comparisons between conditions in the low (BAC<0.05) alcohol study

Test/sign	Cochran's Q (*df* 5)	Contrast (*Q*)	Contrast (*Q*)
HGN	39.39*	HA>HP (4.54)*, PA (4.54)*, LP (4.89)* and PP (5.24)*	
HGN-LSP	35.93*	HA>LP (3.73)***, PA (3.73)***, HP (4.02)*** and PP (5.46)*	LA>PP (3.45)***
HGN-NMax	42.24*	HA>LP (3.71)***, PA (4.24)* and PP (5.30)*	LA>PA (3.44)*** and PP (4.50)*
HGN+HMJ	39.39*	HA>HP (4.14)***, LP (4.41)*, PA (4.69)* and PP (5.80)*	LA>PA (3.04)** and PP (4.14)***
OLS	12.63**	LA>PP (3.14)**	
OLS-FD	12.84**	LA>PP (3.15)**	
SFST	12.22**	LA>PP (3.20)**	
SFST-HMJ	16.91***	LA>LP (2.95)**, PA (2.95)** and PP (3.69)***	

Q test statistics for each pair-wise comparison are presented in parentheses, and all *p* values have been presented as adjusted significance (*p*/15)

HGN horizontal gaze nystagmus, *LSP* lack of smooth pursuit, *NMax* nystagmus at maximum deviation, *HMJ* head movement and jerks, *OLS* one leg stand, *FD* foot down, *SFST* Standardized Field Sobriety Tests, *HA* high THC/alcohol, *HP* high THC/placebo alcohol, *LA* low THC/alcohol, *LP* low THC/placebo alcohol, *PA* placebo THC/alcohol, *PP* placebo THC/placebo alcohol

*p<0.001; **p<0.05; ***p<0.01

alcohol (16 %) and placebo THC/placebo alcohol (6 %) conditions. The low THC/alcohol (50 %) also produced more errors than both the placebo THC/alcohol (16 %) and placebo THC/placebo alcohol (6 %) conditions.

The additional recording of the HMJ sign also produced significant differences in its observation, with the high THC/alcohol (58 %) producing significantly more HMJ than the low THC/placebo alcohol (16 %), placebo THC/alcohol (14 %), high THC/placebo alcohol (19 %) and placebo THC/placebo alcohol (3 %) conditions. The low THC/alcohol condition (43 %) also produced significantly more HMJ than the placebo THC/alcohol (14 %) and placebo THC/placebo alcohol (3 %) conditions. For the remaining pair-wise comparisons, significant differences were observed between the low THC/alcohol condition and placebo THC/placebo alcohol, with more errors occurring in the OLS (28 and 6 %), OLS foot down sign (25 and 3 %), total SFST (19 and 0 %), and when the HMJ sign was included in the total SFST score (28 %, 0 %). The addition of the HMJ sign to the SFST score also produced significant differences between the low THC/alcohol (28 %) condition and the placebo THC/alcohol (6 %).

In the high alcohol study, differences were observed across conditions for HMJ, HGN, OLS, SFST total score and again when HMJ was included within the total SFST score (Fig. 2). Examination of these differences using pair-wise comparisons on the significantly different tests/signs is presented in Table 3. They indicated that the high THC/

Table 3 Pair-wise comparisons between conditions in the High (BAC>0.05) alcohol study

Test/sign	Cochran's Q (*df* 5)	Contrast (*Q*)	Contrast (*Q*)	Contrast (*Q*)
HGN		HA>HP (4.38)*, LP (4.70)* and PP (5.01)*	PA>LP (3.13)** and PP (3.44)*	
HGN-LSP	59.93*	PA>HP (4.04)***, LP (4.27)* and PP (4.99)*	LA>HP (4.04)***, LP (4.27)* and PP (4.99)*	HA>HP (4.04)***, LP (4.27)* and PP (4.99)*
HGN-NMax	54.55*	HA>HP (3.82)***, LP (4.91)* and PP (6.27)*	PA>LP (3.54)*** and PP (4.91)*	LA>PP (4.09)***
HGN+HMJ	49.50*	LA>HP (3.49)***, LP (4.98)* and PP (5.23)*	HA>LP (4.23)* and PP (4.48)*	PA>LP (3.49)*** and PP (3.73)***
WAT-SOL	12.62**	LA>PP (3.38)**		
OLS-AB	13.64**	LA>PP (3.08)**		
OLS-FD	20.00***	HA>LP (3.45)*** and PP (3.73)***		
SFST	15.00**	LA>PP (3.19)**		
SFST-HMJ	26.10*	LA>LP (3.12)** and PP (4.06)***	HA>P (3.75)***	

Q test statistics for each pair-wise comparison are presented in parentheses, and all *p* values have been presented as adjusted significance (*p*/15)

HGN horizontal gaze nystagmus, *LSP* lack of smooth pursuit, *NMax* nystagmus at maximum deviation, *HMJ* head movement and jerks, *OLS* one leg stand, *FD* foot down, *SFST* Standardized Field Sobriety Tests, *HA* high THC/alcohol, *HP* high THC/placebo alcohol, *LA* low THC/alcohol, *LP* low THC/placebo alcohol, *PA* placebo THC/alcohol, *PP* placebo THC/placebo alcohol

*p<0.001; **p<0.05; ***p<0.01

alcohol (40 %) and placebo THC/alcohol (28 %) produced significantly more HGN than the low THC/placebo alcohol (3 %) and placebo THC/placebo alcohol (0 %) conditions. The three active alcohol conditions also produced significantly more HGN lack of smooth pursuit errors (63 % failure in each condition), than in the placebo THC/placebo alcohol (10 %), low THC/placebo alcohol (18 %) and high THC/placebo alcohol (20 %) conditions. For the Nystagmus at maximum deviation sign, the high THC/alcohol condition (58 %) produced significantly more errors than the three non-alcohol conditions (0, 13 and 23 %), the low THC/alcohol (38 %) produced more errors than the placebo THC/placebo alcohol (0 %) condition, as did the placebo THC/alcohol condition (45 %) which was additionally different to the low THC/placebo alcohol condition (13 %).

The HMJ sign was significantly more evident in the three alcohol conditions (with placebo THC, 48 %; low THC, 63 %; and with high THC, 55 %) than in the low THC/placebo alcohol (13 %) and placebo THC/placebo alcohol (10 %) conditions. For the remaining pair-wise comparisons, the low THC/alcohol condition adversely affected performance on the WAT steps off line (20 % versus 0 %), OLS arms balance (43 % versus 15 %), total SFST score (25 % versus 3 %), and SFST total score including HMJ (38 % versus 5 %) in comparison to the placebo THC/placebo alcohol condition. The sign foot down appeared more often in the high THC/alcohol condition (43 %) than in both the placebo THC/placebo alcohol (10 %) and low THC/placebo alcohol (13 %) conditions. Finally, the addition of HMJ to the total SFST score also produced a significant difference between the high THC/alcohol condition (35 %) and placebo THC/placebo alcohol condition (5 %).

Discussion

The present study compared performance on the SFST after the administration of THC (at two levels), alcohol (at two levels) and both THC and alcohol at each level. A number of significant differences in SFST performance were identified, with performance on the entire SFST battery (the total of HGN, WAT and OLS test scores) being significantly impaired in both the alcohol conditions alone, in the low alcohol and low THC condition and in the low and high THC conditions when combined with the higher dose of alcohol. When THC was consumed together with alcohol, the percentage of individuals classified as impaired more than doubled compared with when THC was consumed alone. These results further highlight the sensitivity of SFST to test for the presence of alcohol and underscore their appropriateness for administration as evidence of DUID cases in addition to specimen collection. When scoring of the SFST included HMJ, the percentage of individuals classified as impaired also increased. This finding is consistent with our previous research that suggests that including HMJ in the scoring procedure increases the likelihood of classifying an individual who has consumed THC as impaired (Papafotiou et al. 2005). Administrators of the SFST battery should, therefore, consider scoring, or at least recording, the presence of HMJ as it is a good indicator of drug consumption, especially in cases where THC and alcohol are suspected of being consumed together. The blood results of the present study are consistent with past research showing that the level of THC detected in the blood is higher after the consumption of THC in combination with alcohol, than THC without alcohol (Lukas and Orozco 2001).

In the HGN test, the percentage of participants exhibiting errors was higher in the low THC and high THC condition than in the placebo condition. When THC and alcohol were administered, the percentage of participants exhibiting errors in the HGN test increased. In the two active THC conditions, when THC was administered together with alcohol, the number of participants exhibiting the sign LSP, NMax and N45 more than doubled compared with when THC was administered without alcohol. When the dose of alcohol administered with THC was greater than 0.05 % BAC, the number of participants displaying LSP and NMax signs tripled. These results are consistent with studies that report that alcohol induces nystagmus (Stuster 2006), and performance on the HGN test is most strongly correlated with BAC. Interestingly, the current study observed nystagmus at lower BAC than expected, possibly due to an interaction between the physiological effects of THC and alcohol in the low alcohol condition where the consumption of alcohol alone increased HGN presence from 3 % (when placebo THC and alcohol were consumed) to only 8 % (alcohol and placebo THC); whereas the addition of THC in low (22 %) and high (43 %) doses increased the detection of HGN markedly. In addition, the number of participants who were scored as impaired on overall HGN was higher when THC was consumed together with alcohol, than in the THC only condition. This is somewhat consistent to the findings of Bosker et al. (2012), who observed an increase in HGN when THC was administered with 0.7 mg/ml alcohol (28 % positive) than when consumed alone (15 %). However, when THC was combined with 0.5 mg/ml alcohol, the presence of HGN was lowered (11 %) in their sample of heavy THC users who attended the study already under the influence of THC at each baseline (average baseline THC level was 7.1 ng/ml), and displayed no HGN at baseline.

Another obvious effect of THC and alcohol was that neither THC, nor THC together with alcohol, resulted in the presence of VGN. It appears that this error is not related to the consumption of THC, or to the consumption of alcohol. Previously it has been reported that the HMJ error is observed in a high percentage of individuals who have

consumed THC (Papafotiou et al. 2005). The present study re-examined the relationship between the error HMJ and the administration of THC with and without alcohol. The data showed that the sign HMJ was observed in a higher percentage of individuals when compared with traditionally scored errors during the HGN test. Furthermore, when scoring performance on the SFST included HMJ, the highest percentage of participants was classified as impaired in the high THC with alcohol condition. In the placebo condition, scoring HMJ did not substantially change the percentage of individuals classified as impaired. These results suggest that scoring HMJ increases the likelihood of identifying an individual who has consumed THC alone and THC together with alcohol.

Unlike the results from the HGN test, only one sign from the WAT test—steps off line—was related to drug condition. For the remaining WAT signs, an equal number of participants displayed the errors across all drug conditions (including placebo). While there were no statistically significant differences for these WAT signs (Swaying, Misses Heel to Toe and Improper Turn), they were observed more often when THC was consumed alone, rather than in conjunction with alcohol. It was expected that the addition of alcohol would produce greater impairment because the SFST battery was designed to test for the presence of alcohol (Burns and Moskowitz 1977). However, the results are consistent with our previous research reports in which some individual WAT signs were not accurate indicators of the recent consumption of THC or driving impairment associated with THC usage (Papafotiou et al. 2005). In this previous study, the Improper Turn error was observed more often in placebo conditions and is suggested to not be related to drug consumption. This information is important because these errors may be observed during the administration of the WAT test even when no drug has been consumed. Overall WAT impairment (where all errors are taken into consideration) was observed significantly more often in the THC condition than in the placebo condition, and a greater number of participants failed the WAT test when THC was consumed with alcohol.

Results from the OLS test suggest there was a significant relationship between the presence of all the signs scored during the OLS test and the THC only condition and the THC with alcohol conditions. More errors were observed as the dose of THC consumed increased. OLS test scores, however, did not appear to have a consistent relationship with the presence of alcohol. Interestingly, in the low alcohol condition, the addition of alcohol to the respective doses of THC produced opposing effects, with the addition producing more OLS errors in the low THC condition, and fewer errors in the high THC condition. In the high alcohol condition, the addition of alcohol produced more errors in the low THC condition, but did not increase the errors observed in the high THC condition. This is an interesting finding given previous research suggests that the OLS test score is the best predictor of the consumption of THC (compared with the HGN test and the WAT test) (Papafotiou et al. 2005) and that alcohol and THC may have an additive or synergistic effect (Bramness et al. 2010). In this case, the addition of relatively low doses of alcohol (0.04/0.08 BAC) seemed to attenuate the negative effect of THC upon OLS performance. Whether this effect was due to participants compensating for their increased intoxication (given the low THC/alcohol combination affected performance more so than the high THC/alcohol condition) or a less than additive effect (Ballard and De Wit 2011) on the required cognitive processes or coordination needed to complete the OLS requires further investigation. The results, however, suggest that the OLS test score is the most reliable indicator of impairment associated with the consumption of THC. The relative sensitivity of this test to THC intoxication is ostensibly related to the established impairments in concentration, problems with memory and learning, distorted perception, difficulty in thinking and problem-solving and loss of coordination in complex or divided attention tasks associated with cannabis consumption (Kirk and De Wit 1999; Ramaekers et al. 2000, 2006; Ronen et al. 2008). It is these same decrements in performance that negatively impact car handling performance, reduce the ability to maintain car headway and stay in the correct lane of travel when people drive under the influence of both alcohol and THC (Ramaekers et al. 2000, 2004; Ronen et al. 2008).

In conclusion, under double-blind, within-subject, and placebo-controlled conditions, the combination of THC and alcohol was found to significantly impair SFST performance in comparison to placebo with 28 % of the sample failing the test (when HMJ was included) when low alcohol and low THC were administered together. When a higher dose of alcohol was administered with a low dose of THC, 38 % of the sample failed the test, and 35 % also failed when the high dose of alcohol was combined with a higher dose of THC. That a consistent additive or synergistic effect was not identified with the consumption of THC and alcohol together between the two alcohol conditions suggests that at the doses employed, alcohol may have attenuated the negative effects on some SFST, or individual signs, reducing its efficiency in detecting intoxication. A second possibility would be that experienced users may be aware of greater intoxication in the higher alcohol and THC conditions and attempt to compensate for this by devoting extra effort or attention when completing the SFST. In the absence of any evidence of driving impairment or confirmation of alcohol or cannabis usage, the relative sensitivity of the SFST in detecting drug usage is limited. Whether this sensitivity is modulated by heavier past usage of either cannabis or alcohol is also worthy of future research. With the combination of alcohol and THC being detected in an increasing number of injured and

deceased drivers in Australia (Drummer et al. 2004, 2007), an understanding of the utility of field measures such as the SFST to predict drug and alcohol consumption in the absence of random roadside saliva testing for the presence of illegal drugs or breath analysis tests for alcohol consumption is necessary. The current results highlight the utility of the HGN test for detecting the presence of alcohol, and the OLS test to accurately identify the consumption of THC. That these tests can identify drug consumption in the absence of any evidence of driving impairment or physiological indicators (blood, saliva or breathalyser tests), even at the relatively low levels observed in the current studies, supports their continued use to identify driver's whose driving under the influence of drugs is endangering theirs and other driver's lives.

Acknowledgements This study was funded by a National Drug and Law Enforcement Fund grant to Professor Con Stough, Martin Boorman, Dr. Edward Ogden and Dr. Katherine Papafotiou.

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Victorian Government Gazette No. G 46 Thursday 16 November (2000) 2723(G 46)-2725 (G 46), Traffic Alcohol Section, Victoria Police, Victoria, Australia