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The acute effects of vaporized cannabis on drivers' hazard perception and risk-taking behaviors in medicinal patients: A within-subjects experiment

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ABSTRACT

Introduction: As the medically prescribed use of cannabis flower continues to increase, there is a need to understand how vaporized cannabis can acutely affect driving-related skills and risk-taking behaviors in medicinal populations. *Method:* Given this, the present study examined the acute effects of vaporized cannabis flower on measures of hazard perception, driving-related risk-taking behaviors, and subjective perceptions of driving skills in a sample of adult medicinal cannabis patients. Participants ($N = 38$, M age = 43) attended both a baseline (no cannabis) and intervention appointment (with cannabis consumption), where they completed video-based tasks and self-report measures of driving ability. *Results:* After vaporizing one dose of their prescribed cannabis flower, participants exhibited no significant changes in performance on any of the video-based tasks (hazard perception skill, gap acceptance, following distance or speed) compared to baseline. However, cannabis consumption resulted in significant reductions in perceived hazard perception task performance and on-road traffic conflict prediction ability. Furthermore, there was a lack of association between objective and subjective hazard perception performance at both time points. *Practical applications:* These results suggest that while acute prescribed cannabis consumption may reduce appraisals of selected skills, overall hazard perception ability and driving-related risk-taking behavior may remain unchanged.

1. Introduction

Medicinal cannabis has undergone a global surge in popularity in the wake of legislation approving its use in a range of jurisdictions (Shulman et al., 2022). A continued rise in applications to the Therapeutic Goods Administration access scheme has occurred in Australia since legalization passed in 2016 (MacPhail et al., 2022). However, concerns have been raised in relation to medicinal cannabis use and road safety regulatory frameworks pertaining to drug driving (Arkell et al., 2020; Perkins et al., 2021). In many Australian jurisdictions (such as Queensland, where the present study took place), there is a zero-tolerance approach towards cannabis and driving, such that drivers are not permitted to drive with delta-9-tetrahydrocannabinol (THC; the primary psychoactive compound of cannabis; Atakan, 2012) in their system, as determined through oral fluid or blood samples (Queensland Government, 2023). When inhaled, THC is known to produce rapid and temporary psychoactive effects that may impair driving-related skills (e.g., cognitive and motor abilities; McCartney et al., 2021). However, as THC is highly lipophilic, it may be detected in oral fluid or blood samples days after use (Karschner et al., 2009; Odell et al., 2015). Patients undergoing treatment with medicinal cannabis have also voiced concern over the potential to provide a positive drug indication if tested roadside, irrespective of recent use (Love et al., 2022). As oral fluid and blood THC concentrations do not reliably correlate with changes in driving performance (McCartney et al., 2022; Wurz & DeGregorio, 2022), it cannot be determined from these test results whether driving ability is affected at a specific time point. Consequently, research is urgently needed to further understand how medicinal cannabis use might influence driving-related skills in medicinal populations.

A large body of work has assessed driving performance following acute cannabis administration, with measures primarily focused on speed maintenance, lane position/weaving and reaction time to hazards

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(Bédard et al., 2007; Hartley et al., 2019; Hartman et al., 2015; Ortiz-Peregrina et al., 2020). When examining smoked/vaporized cannabis, studies have found that while lane deviation and reaction time are significantly affected, compensatory behaviors such as slower speed and greater headway are also often evident (Brooks-Russell et al., 2019; Hartley et al., 2019; Hartman et al., 2016). The noted compensatory adjustments may suggest an influence of the individual's perceptions of impairment when it comes to driving abilities, although there is a notable lack of research on understanding the link between objective and subjective performance following cannabis consumption. Inhaled THC leads to a faster onset of effects, with a detectable impairment window for skills such as lane deviation lasting up to eight hours, depending on factors such as cannabis use history and dose consumed (McCartney et al., 2021). Nonetheless, the impact of cannabis on driving abilities is not straightforward, with differences apparent between occasional and frequent user groups (Hartley et al., 2019). While the present literature provides valuable insights into cannabis-related effects on driving performance, these studies have been primarily conducted in recreational user groups.

The performance detriments seen in recreational users are likely to differ substantially from outcomes in medicinal patients. Consequently, it is difficult to extrapolate current findings when assessing the influence of medically prescribed cannabis flower on driving safety. For example, it has been suggested that the symptom relief provided by cannabis in patient populations may positively impact some aspects of functioning, which could in turn benefit driving capacity (Ramaekers et al., 2021), while also potentially negating the use of some other substances that are known to independently affect driving (e.g., opiates, benzodiazepines; Arkell et al., 2021). It is also likely that the frequent (medically prescribed) usage patterns of this population may mitigate some of the pronounced acute effects of THC on driving abilities (such as are seen in occasional users; Hartley et al., 2019) because of higher tolerance (Ramaekers et al., 2021). Previous studies have demonstrated the role of tolerance, with some skills remaining largely unaffected by the neurocognitive effects of THC in those who use cannabis frequently (Desrosiers et al., 2015; Ramaekers et al., 2009; Schwope et al., 2012; Theunissen et al., 2012). More recently, research in medicinal cannabis patients has observed markedly higher use patterns than those typically reported in studies assessing occasional/recreational users (Almog et al., 2020; Arkell et al., 2023; Colizzi et al., 2018; Mueller et al., 2021; Olla et al., 2021; Ramaekers et al., 2016; Sholler et al., 2021). These studies have also reported attenuated or null effects on cognitive performance measures (e.g., Almog et al., 2020; Arkell et al., 2023; Olla et al., 2021). These outcomes, in conjunction with the potential moderating influence of symptom relief, support the notion that individuals who consume cannabis in line with prescriber recommendations to manage a health condition may respond differently to acute THC administration. Therefore, research utilizing validated measures of safety-related driving skills and behaviors would be of benefit to further elucidate the effects of THC in this population.

Drivers' hazard perception skill, defined as their ability to anticipate potentially dangerous road situations, has been found to be associated with crash risk across multiple studies, both prospectively and retrospectively (Horswill, 2016; Horswill & Hill, 2021). Given that this ability is considered to involve higher-order cognitive processes, such as predicting the future state of traffic situations, it is plausible that it might be acutely affected by medicinal cannabis use, potentially impacting crash risk. A number of aspects of driving-related risk-taking behavior have also been found to be associated with crash risk, including following distance (i.e., the amount of separation that a driver typically allows when following another vehicle), speeding propensity, and gap acceptance behavior (i.e., how small a gap in traffic a driver is willing to merge into; Horswill et al., 2022; Horswill et al., 2020). It is plausible that the judgments involved in these behaviors could also be impacted by medicinal cannabis use via potential effects on cognitive processes.

In light of this, the present study used a within-subjects design to assess the acute effects of vaporized cannabis flower on driving-related skills and behaviors in a sample of adult medicinal cannabis patients. Understanding the effects of vaporized cannabis flower in medicinal populations is important, given that flower is the second most commonly prescribed THC product in Australia (Therapeutic Goods Administration, 2021) and peak effects emerge 15-minutes post inhalation (McCartney et al., 2021). Accordingly, participants completed validated video-based measures of hazard perception skill and driving-related risk-taking behaviors (following distance, speeding propensity, and gap acceptance) both without cannabis (baseline condition) and post-vaporization of their usual cannabis medication (intervention condition). In conjunction with this, a self-report measure of perceived hazard perception skill was used to assess the relationship between participants' subjective perceptions of their hazard perception skill and their objective performance at both time points. Finally, self-report ratings of on-road driving skills and safety (detecting traffic conflicts, overall driving skill, driving safety, and crash risk) were assessed. Specifically, this study was designed to investigate the following research questions:

(1) What is the acute effect of vaporized cannabis flower on hazard perception skill performance?
(2) What are the acute effects of vaporized cannabis flower on driving-related risk-taking behaviors?
(3) What is the acute effect of vaporized cannabis flower on drivers' subjective perceptions of their hazard perception skill performance?
(4) Is there a relationship between cannabis flower users' objectively-measured hazard perception skill performance and self-ratings of their own hazard perception skill (with or without the acute effect of vaporized cannabis flower)?
(5) What are the acute effects of vaporized cannabis flower on drivers' self-ratings of their on-road driving skills and safety?

2. Method

2.1. Participants

Participants for this study were 38 adults (*M* age = 43.39, *SD* = 12.19, range 24–67 years), all of whom held a valid medical prescription for cannabis flower. This sample was recruited as part of a larger study investigating the effects of medically prescribed cannabis flower on cognitive function and driving-related skills. Participants were recruited through targeted paid Facebook advertising in addition to promotional materials provided to medicinal cannabis clinics. Participants were also able to refer others to the study via snowball-sampling. To be included in the study, participants were required to be over the age of 18, hold a current Queensland driver's license (driving at least once per week) and live within 50 km of the testing site. Exclusion criteria included pregnancy, visual or hearing impairments (uncorrected), neurocognitive impairment due to traumatic brain injury or dementia, diagnosed major psychiatric illness (schizophrenia, panic disorder or delusional disorder), respiratory condition (e.g., asthma, bronchitis) or epilepsy. Written consent was provided prior to undertaking study procedures. Approval for this research was provided by the University of the Sunshine Coast Human Research Ethics Committee (approval number A211677), in compliance with the ethical guidelines of the National Health and Medical Research Council of Australia.

3. Materials

3.1. Demographics

Prior to their first appointment, all participants completed an online questionnaire pack (hosted via Qualtrics, https://www.qualtrics.com) covering demographics, health, medication use and drug use history. The short-form version of the Depression Anxiety Stress Scale (DASS-21;

Lovibond & Lovibond, 1995) was also administered as part of the questionnaire pack, to further characterize the sample.

3.2. Hazard perception test

The Hazard Perception Test (HPT) involved participants viewing video footage of real-world traffic scenes (filmed in Southeast Queensland) showing the driver's perspective from a moving vehicle (Hill et al., 2019). Clips were displayed on a 527.04 mm by 296.46 mm computer monitor using custom software. Participants were first shown an instruction video explaining the test. They were then asked to predict any traffic conflicts as early as possible. Traffic conflicts were defined as any event where their vehicle (i.e., the car containing the camera) was on course to hit another road user. Participants were required to indicate their predictions by clicking on any road user likely to become involved in a traffic conflict. Response times to each conflict were standardized and averaged to give a total HPT score in seconds. Two alternate versions of the test (with 30 different clips in each version) were counterbalanced across the two conditions (baseline and intervention) to minimize potential practice effects. The test took approximately 20 min to complete. Validity evidence for scores derived from versions of this test include their ability to discriminate between high risk (young novice) and lower risk (mid-age experienced) driver groups, and correlations with heavy-braking rates measured during everyday driving (Hill et al., 2019). The internal consistency of both test versions was high (*Cronbach's* $\alpha = 0.884$ and 0.867 in the present sample).

3.3. Following distance test

In the Following Distance Test (Horswill et al., 2020), participants viewed 20 video clips of traffic footage filmed from the point of view of a driver following another vehicle, depicting a range of traffic environments and following distances. At the end of each clip, participants were asked to indicate the shortest following distance they would be comfortable to accept (relative to that shown in the video) on a vertical visual analogue scale (Horswill et al., 2020). The scale is anchored at four points, ranging from '50% closer' to 'same,' 'double,' and 'triple' the following distance shown in the video. Responses were converted into an average following separation in seconds. The validity of test scores has previously been evidenced via age-related differences consistent with following distance decisions in real driving. The internal consistency of the test was high (*Cronbach's* $\alpha = 0.933$ (cannabis condition) and 0.959 (no cannabis condition).

3.4. Video speed test

The Video Speed Test is a measure of speeding propensity (i.e., how fast a participant habitually chooses to drive; Horswill et al., 2022). The test involves 16 filmed scenarios depicting a car driving along a road without obstructions, filmed from the driver's perspective. At the end of each clip, participants were required to indicate the extent to which they would drive faster or slower in km/hour (e.g., a response of zero would indicate they would drive at the same speed as the vehicle in the video). The final score is calculated as the mean of responses across all 16 clips, where a higher score would indicate they tend to choose faster speeds. The validity of test scores has been evidenced via their correlations with real everyday speeding behavior, as measured by GPS trackers over a 5-week period (Horswill et al., 2022). The internal consistency of the test was high (*Cronbach's* $\alpha = 0.932$ (cannabis condition) and 0.944 (no cannabis condition).

3.5. Gap acceptance test

The Gap Acceptance Test is a measure of how long a driver is willing to wait for an appropriate gap in a stream of traffic to merge into (Horswill et al., 2020). It can also be conceptualized as a measure of the minimum size gap in traffic they are willing to accept. Participants view a series of 23 video clips of an oncoming stream of traffic on a main road. They were filmed from the perspective of a driver waiting at a side road to merge with the traffic. Each clip depicted a series of gaps in the flow of traffic, which tended to become longer as the clip progressed. Participants were instructed to click on the screen whenever they would consider merging with the stream of traffic (i.e., when they identified a gap in the traffic that they would be willing to pull out into). When they responded, the clip ended and the next clip began (that is, the earlier they responded, the shorter the test duration was). The task took from 1 min 20 secs to 11 min 47 secs to complete, depending on how long participants waited before accepting a gap in the traffic. The test score was participants' mean response time to the video clips (i.e., shorter response times indicated they were willing to pull out into shorter and hence more risky gaps). The validity of test scores has previously been evidenced via age-related differences consistent with gap acceptance behavior in real driving. The internal consistency of the test was high (*Cronbach's* $\alpha = 0.906$ (cannabis condition) and 0.911 (no cannabis condition).

3.6. Self-rated hazard perception skill performance

Upon completing each HPT, participants were asked to rate their own performance using a horizontal Visual Analogue Scale in response to the question "How early did you predict the traffic conflicts compared with other Sunshine Coast drivers?" (range 0 to 100, labelled as follows: 0 = worst, 50 = typical, 100 = best).

3.7. Self-rated on-road driving skills and safety

Participants were also asked to rate several aspects of their on-road driving skills and safety (predicting traffic conflicts, overall driving skill, driving safety, and crash risk) on a Visual Analogue Scale (with the same anchors) in response to the question, "If you were driving **right now**, how would you compare to other Sunshine Coast drivers?" (items adapted from Horswill et al., 2013).

4. Procedure

All participants completed both a baseline and intervention testing session assigned to them in a counterbalanced fashion. These appointments were scheduled for the same time approximately one week apart (where possible) and were completed between July 2022 and June 2023. Upon arriving via a taxi service, participants provided consent (initially obtained via the online screening form) before providing proof of a valid prescription for cannabis flower. After this, an oral drug screening test (Drager DrugCheck 3000) was administered. This provided an indication of the presence of several substances that could potentially influence performance on the tasks (THC, amphetamine, cocaine, benzodiazepine, opiates and methamphetamine). Participants were asked to abstain from using cannabis products containing THC for 11.5 h prior to each testing session (guided by McCartney et al., 2021). Participants who provided a positive reading for THC were asked to confirm they had not consumed any products containing THC on the day of testing. After this, participants completing their intervention appointment were directed to the medicinal laboratory for cannabis consumption. For those completing their baseline appointment, the test battery proceeded immediately after completing the oral drug screening.

Participants completing their intervention session were provided an overview of the vaping procedures, ensuring they understood the research activities to be undertaken and were comfortable to proceed. After this, each participant measured out their typically consumed dose (which was accurately weighed) before it was administered into a polythene valve balloon using the Volcano Medic Vaporiser (Storz & Bickel). The vaporizer was set at a temperature of 210°C (unless otherwise requested by the participant), as recommended for the efficient yield of THC (Hazekamp et al., 2006; Pomahacova et al., 2009). The Volcano Medic has TGA approval in Australia and is well-validated in the literature as a safe method for the administration of cannabis (Hazekamp et al., 2006). Participants had approximately 10 min to consume their cannabis product, during which time the valve balloon could be refilled at their request (from the same dose). After cannabis consumption was complete, there was a 15-minute delay before commencing test procedures to allow for the onset of the peak effects of inhaled cannabis (McCartney et al., 2021). Participants then completed a neurocognitive test battery taking approximately 30 min (results reported elsewhere), before beginning the video-based assessments of hazard perception skill and driving-related risk-taking behaviors. The self-report measures of hazard perception skill performance and on-road driving skills and safety were then completed.

4.1. Statistical analysis

All questionnaire pack and task performance data were analyzed using IBM SPSS Statistics (Version 29; IBM, 2023). Descriptive statistics were used to provide an overview of participant characteristics (provided through the questionnaire pack) and oral drug screening results. Further, a series of paired-samples *t* tests were used to examine differences in performance on the hazard perception test, driving-related risk-taking measures, self-rating of hazard perception skill performance, and self-ratings of on-road driving skills and safety between baseline and intervention. For research questions where multiple comparisons were conducted, the Holm-Bonferroni correction was applied to maintain the familywise error rate at 0.05 (Holm, 1979). Pearson correlations were conducted to examine whether self-ratings of hazard perception performance correlated with objective performance at baseline and following cannabis consumption. Cohen's *d* was utilized to examine the magnitude of change with cut-offs of 0.2, 0.5 and 0.8 representing small, medium and large effects sizes, respectively (Cohen, 1988). One participant was identified as an extreme outlier (IBM, 2021). However, when this outlier was excluded from analyses, the overall results did not differ from that found in the complete sample. Consequently, this outlier was retained in the final analysis.

5. Results

5.1. Participant characteristics

The final sample comprised 38 participants aged 24 to 67, the majority of which were male (n = 32, 84.2%). On average, participants reported driving approximately 318 km per week (SD = 227.12, range = 24–1200), with the majority holding an open driver's license (n = 35, 92.1%). Two participants held a multi-combination truck license (5.2%) and one participant held a P2 provisional license. A number of participants reported having health conditions (presented in Table 1), with DASS-21 scores also indicating that seven (18.42%) participants met mild or greater criteria for all three subscales (i.e., depression, anxiety and stress). An additional five participants met criteria for at least two of the subscales, and five exhibited mild or greater scores for just one scale. This equated to a total of 18 (47.37%) participants with mild or greater scores on the DASS-21.

5.2. Cannabis and substance use history

On average, participants reported that they had been prescribed medicinal cannabis for approximately 11 months (SD = 12.54, range = 0–61), typically using their product five times a day (SD = 5.44, range = 1–30) by either vaping (n = 20) or smoking (n = 13), with two participants reporting a combination of both and three participants reporting 'other.' Note that vaporization is currently the only recommended administration method for medically prescribed cannabis flower in Australia (Therapeutic Goods Administration, 2017).

On average, the sample reported an estimated 22.87 years of total cannabis use (including illegally obtained cannabis), with 26 days of cannabis use in the previous month (prescribed or illegal; range = 1–31). Illegal cannabis use was reported by approximately half of the sample (n = 18, 47.37%). A breakdown of all other reported substance use can be seen in Table 2, and the oral drug screening results are presented in Table 3. A total of 22 participants (57.9%) provided a positive THC oral drug screening indication at both the baseline and intervention appointment.

Table 1
Sample Health Characteristics (N = 38).

Characteristic	*n*	%
Psychiatric disorder/mental illness	17	44.7
Learning condition*	2	5.3
Cancer	2	5.3
Physical injury	6	15.8
DASS-21 (Greater than mild [a])		
Depression	12	31.6
Anxiety	12	31.6
Stress	12	31.6
Prescribed medicinal cannabis for		
Chronic pain	25	65.8
Mental health	19	50.0
Sleep disorder	16	42.1
Gastrointestinal symptoms	4	10.5
Other	7	18.4

*Undiagnosed; DASS-21 = Depression Anxiety and Stress Scale 21.
[a] Cut-off scores (mild or greater): depression = ≥5, Anxiety = ≥4, Stress = ≥8.

5.3. Medicinal cannabis consumption

Medicinal cannabis used in the present study ranged in strength from 17 to 26% THC (M = 21.08%; milligrams of THC per gram of cannabis), with participants weighing out on average, under a quarter of a gram of dried plant material (SD = 0.14 g, range = 0.06–0.76 g). This equated to an average dose of approximately 50 mg of THC (SD = 33.92, range = 10.20–190) or 0.60 mg/kg when accounting for body weight. Doses were consumed in a minimum of 0.5 and a maximum of four polythene balloons, with the vaporizer temperature on average set to 197 °C (range = 173–210 °C). Note that due to great variance in dose, as well as the number of balloons consumed by participants, caution should be taken when interpreting these outcomes. THC delivery can vary as a function of temperature and inhalation technique, making it challenging to accurately depict doses (Hazekamp et al., 2006; Zuurman et al., 2008).

5.4. Objective and subjective driving performance

Results evaluating the acute effects of vaporized cannabis flower on

Table 2
Substance use.

Characteristic	Mean ± SD/ *n* (%)	Range
Alcohol consumption (Standard drinks/week)	13.26 (22.85)	0–110
Illicit drug use[a]	14 (36.8%)	
Current prescription drug use[b]		
Opioid	2 (5.3%)	
Anti-inflammatory	3 (7.9%)	
Anti-convulsant	2 (5.3%)	
Antidepressant	6 (15.8%)	
Gastrointestinal treatment	1 (2.6%)	
Blood-pressure treatment	3 (7.9%)	
Cholesterol treatment	1 (2.6%)	
Diabetes treatment	1 (2.6%)	

[a] cannabis, cocaine, MDMA, LSD, ketamine, ayahuasca and/or psilocybin
[b] data from 11 participants.

Table 3
Oral drug screening results.

Oral drug screening	Baseline *n* (%)	Intervention *n* (%)
THC	26 (68.4%)	25 (65.8%)
Amphetamines	0	1 (2.6%)*
Methamphetamines	0	1 (2.6%)*
Opiates	2 (5.3%)	3 (7.9%)
Benzodiazepines	0	3 (7.9%)
Cocaine	0	0

*This was a single participant who also tested positive for THC.

hazard perception skill performance, driving-related risk-taking behaviors, self-rated hazard perception skill performance, and self-rated on-road driving skills and safety are presented in Table 4. Paired-samples *t* tests revealed no significant changes in performance on the hazard perception test or any of the video-based risk-taking measures from baseline to intervention (after applying the Holm-Bonferroni correction to the risk-taking measures; Holm, 1979). Significant reductions in self-reported hazard perception test performance and on-road traffic conflict prediction ability were observed, with medium magnitude effect sizes. No significant correlation was found between objective and subjective hazard perception performance at baseline or intervention.

Those participants who provided a positive drug indication other than THC ($n = 8$) were removed in order to conduct a sensitivity analysis (as these substances may impart their own influence on performance). Analysis of data from the resulting sample ($n = 30$) yielded the same pattern of results as the full sample, where self-reported hazard perception test performance and on-road traffic conflict prediction remained statistically significant between baseline and intervention ($p = 0.004$ for both).

Table 4
Hazard Perception Skill Performance, Driving-Related Risk-Taking Behaviors, Self-Rated Hazard Perception Skill Performance, and Self-Rated On-Road Driving Skills and Safety at Baseline and Intervention.

Measure	Baseline	Intervention	Bias-corrected bootstrap		Effect size
	M (SD)	*M (SD)*	*P*	*95% CI*	*d*
Hazard Perception Skill Performance (HPT Score)	6.25 (1.76)	5.92 (1.73)	0.196	[-0.14, 0.79]	0.22
Driving-Related Risk-Taking Behaviours					
Following Distance Test	1.59 (0.31)	1.65 (0.29)	0.030	[-0.11, −0.01]	0.37
Video Speed Test	−2.57 (4.18)	−3.02 (4.24)	0.387	[-0.54, 1.38]	0.15
Gap Acceptance Test	14.98 (6.55)	14.16 (6.54)	0.295	[-0.66, 2.26]	0.19
Self-Rated Hazard Perception Skill Performance	72.17 (14.56)	62.42 (14.84)	0.002*	[5.42, 14.32]	0.67
Self-Rated On-Road Driving Skills and Safety					
Predicting traffic conflicts	76.08 (15.20)	66.89 (19.64)	0.011*	[3.26, 15.63]	0.47
Driving skill	74.22 (16.33)	65.76 (23.14)	0.041	[1.04, 16.74]	0.35
Driving safety	74.22 (16.33)	67.16 (20.15)	0.071	[-0.26, 14.28]	0.31
Crash risk	73.19 (21.92)	63.19 (27.81)	0.070	[-0.06, 20.48]	0.31

*Significant at $\alpha = 0.05$ (after Holm-Bonferroni correction, where applicable).
Note: $n = 36$ for self-rated HPT performance, $n = 38$ for Following Distance & Video Speed task, $n = 37$ for all other measures.

6. Discussion

This within-subjects study investigated the acute effects of medicinally prescribed cannabis flower on video-based tasks of driving performance and behavior, as well as self-ratings of driving ability. First, no significant changes in test scores from baseline to intervention were observed for the video-based assessments of hazard perception skill and driving-related risk-taking behaviors. While cannabis consumption did result in significant reductions in perceived hazard perception test performance and perceived on-road traffic conflict prediction ability, there was no association between objective and subjective measures of hazard perception performance (at baseline or intervention). The findings from this study suggest that a dose of vaporized cannabis (consumed in accordance with prescription) may not affect hazard perception ability or driving-related risk-taking behavior among medicinal cannabis patients. However, the findings indicate that cannabis consumption may lead to a reduction in participants' perceptions of their hazard perception performance and ability to predict traffic conflicts during real driving, although it did not change their perceptions of their overall driving skill, safety or crash risk. In addition, the lack of relationship between objective and subjective ratings of hazard perception performance highlights that individuals lack insight into their own abilities, irrespective of whether or not they have consumed cannabis.

The extensive cannabis use history (both medical and illegal) reported in the sample may assist in explaining some of the present outcomes. For example, on average, participants reported an estimated 23 years of cannabis use, and currently used their medication typically five times a day. Frequent and persistent use of cannabis has been shown to lead to a reduction of the common neurocognitive effects, mitigating negative effects associated with THC (Desrosiers et al., 2015; Ramaekers et al., 2020; Schwope et al., 2012). Consequently, it is likely that participants in the current study would have developed a tolerance to their medication, especially when following a consistent schedule of dosing. For example, the doses measured by participants in this study are much greater than typically seen in the literature, with the sample having consumed doses that would normally be directly related to impairment in infrequent user groups (Colizzi et al., 2018; Sholler et al., 2021; Spindle et al., 2018). These findings hence support the role of tolerance in moderating the effects of cannabis (Ramaekers et al., 2021). In addition, recent research has highlighted the role of symptom relief following cannabis consumption in these clinical populations (Arkell et al., 2023; Olla et al., 2021; Ramaekers et al., 2021; Wallace et al., 2015). It has been proposed that cannabis treatment may improve functioning due to the relief of symptoms (e.g., pain, anxiety) that might otherwise impact performance (Eysenck et al., 2007; Keogh et al., 2014). This could be another plausible explanation for the results observed in the present study, although the role of symptom relief requires further investigation.

Whilst participants reported a reduction in hazard perception skill performance, there was no correlation between objective and subjective ratings of performance. This outcome remained the same irrespective of cannabis condition, indicating that this sample generally had a limited ability to assess aspects of their own performance. This is consistent with previous work suggesting that self-assessments of aspects of driving ability are generally uncorrelated with actual driving performance (Amado et al., 2014; Martinussen et al., 2017). Interestingly, participants rated their hazard perception/prediction performance as significantly worse after cannabis consumption, indicating that the sample perceived a negative change in the absence of any measured objective difference. Despite this, some compensatory strategies evidenced in previous research (Brooks-Russell et al., 2019; Hartley et al., 2019; Hartman et al., 2016) were not observed in this study, with following distance, video speed and gap acceptance task performance exhibiting no significant changes as compared to baseline after correction for multiple comparisons. However, since the effect of cannabis consumption on following distance was significant prior to correction, the null result for this outcome measure may be considered somewhat inconclusive and should not be over-interpreted. Together, these findings are interesting considering that participants perceived changes in hazard perception performance but no other variables, with the sample mostly appearing confident of their driving style and propensity for risk-taking while under the acute effects of THC. This latter finding is consistent with previous work in medicinal users, noting that many patients admit to driving shortly after consuming their medication as they believe their driving performance is unaffected by their cannabis medication (Arkell et al., 2020; Bonar et al., 2019; Wickens et al., 2023). Together, these outcomes suggest that objective measures of driver safety are needed when assessing the effects of cannabis.

While the within-subjects design of this study assists in accounting for individual differences, there are important limitations that should be considered. With approximately 70% of the sample testing positive for THC during the baseline appointment, it is possible that task performance may have been influenced by the delayed (or recent) effects of cannabis consumption, leading to no differences in performance between baseline and intervention. However, it should be noted that cannabis may be detected up to 72-hours post consumption in oral fluid samples (Karschner et al., 2009; Odell et al., 2015). Participants were asked to abstain from consuming cannabis products for 11.5 h prior to their appointments. In addition, those who tested positive to THC at the beginning of the testing session were also asked to confirm they had not consumed cannabis on the day of testing. Nevertheless, it cannot be guaranteed that all participants who tested positive to THC on the day of testing had abstained from taking their medication or other cannabis products. Further, as noted previously, it is difficult to determine precise doses of THC consumed in this study. As a result, it is possible that the large range of product consumed across the sample (0.06–0.76 g) may have obscured any potential effects on performance. It should also be noted that 42% of the sample reported they did not typically vaporize their prescribed cannabis product at home and instead reported 'smoking' only or using 'other' methods, which may have affected the amount of THC they consumed and their overall experience. Further, as participants for this study were asked to consume their own medically prescribed cannabis, they were not blinded to the condition they were in, and there was no placebo condition. Therefore, it is possible that perceptions surrounding cannabis consumption may have influenced outcomes on these tasks. It should also be acknowledged that symptoms of depression, anxiety, and stress (as measured through the DASS-21) were only assessed via the questionnaire pack once, and not on the day of the assessments. Consequently, it was not possible to test for their individual effects on performance.

Finally, the above-reported tasks were completed after a neurocognitive task battery, putting the start time for the HPT at approximately 45 min after consumption of cannabis. Since the peak effects of vaporized cannabis are known to emerge within 15 min of consumption (McCartney et al., 2021), it is possible that while these tasks were completed well within the timeframe that THC is known to affect driving-related skills, initial impairment may not have been captured. Alternatively, we cannot rule out the possibility that the tests utilized in the present study were not sufficiently sensitive to detect the impacts of cannabis impairment, despite evidence of their validity as measures of safety-related driving skills and behaviors in other contexts.

Nonetheless, the outcomes of the present study provide important insights into the effects of prescribed cannabis flower on driving-related skills in patients who have consumed cannabis regularly for an extended period. Understanding the effects of vaporized cannabis flower in medicinal populations is important, given that cannabis flower is commonly prescribed in countries such as Australia (MacPhail et al., 2022) and the neurocognitive effects emerge rapidly within 15-minutes of inhalation (McCartney et al., 2021). The onset of effects arising from cannabis flower differ markedly from those of other administration methods such as oral methods, where effects are apparent at approximately 90-minutes and decline at a much slower rate (McCartney et al., 2021; Schlienz et al., 2020). The results from this study suggest that some driving-related skills and behaviors (e.g., hazard perception skill, speeding propensity, and gap acceptance) may not be acutely affected following medicinal cannabis consumption in a sample of tolerant users. It should also be considered that the rapid symptom relief provided by cannabis flower may assist in maintaining performance rather than reducing performance (as seen in studies of recreational or infrequent users), providing an explanation for these results. Furthermore, while it appears that cannabis flower may influence perceived skill in terms of hazard perception/prediction, overall self-assessment of driving ability appears to be unreliable even in the absence of cannabis consumption. Future research is needed to clarify whether these effects are observed in patients who are less tolerant to the substance (e.g., do not have a history of illicit or medicinal cannabis use prior to obtaining their prescription) and at a given dose. Examining a specified dose in samples of those recently prescribed cannabis as well as long-term patients would provide valuable insight into the development of tolerance with continued cannabis use. In addition, the present results highlight the need for continued efforts to identify objective measures of cannabis-related effects. This study highlights the critical role of moderators such as tolerance and symptom relief and adds to the current understanding of the effects of vaporized cannabis flower on driving-related skills in medicinal populations.

CRediT authorship contribution statement

Carla Schiemer: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Mark S. Horswill:** Writing – review & editing, Software, Resources, Methodology, Formal analysis. **Andrew Hill:** Writing – review & editing, Software, Resources, Methodology. **Mathew J. Summers:** Writing – review & editing. **Kayla B. Stefanidis:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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