Research Article

A Latent Variable Analysis of Psychomotor and Neurocognitive Performance After Acute Cannabis Smoking

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ABSTRACT

Objective. This paper evaluated a novel, tablet-based neurocognitive and psychomotor test battery for detecting impairment from acute cannabis smoking using advanced quantitative methods. The study was conducted in a state with legal, recreational cannabis use and included participants who use cannabis occasionally or daily, and a no use comparison group. **Methods**. Participants completed a tablet-based test assessing reaction time, decision making, working memory and spatial-motor performance. The test was completed before and after participants smoked cannabis (or after a rest period in the case of controls). An Exploratory Factor Analysis approach was implemented to reduce dimensionality and evaluate correlations across the four assessed domains. Linear regression models were utilized to quantify associations between factor scores and cannabis use groups (daily vs. occasional vs. no use). **Results**. Seven factors were identified explaining 56.7% of the variance among the 18 measures. Regression models of the change in factors after cannabis smoking indicated those who use cannabis daily demonstrated poorer performance on a latent factor termed *Displaced and Delayed* (standardized coefficient 0.567, 95% CI: 0.178, 0.955; $P = 0.005$) compared to those with no use. Those who use cannabis occasionally exhibited a decline in performance on a latent factor termed *Recall and Reaction* (standardized coefficient 0.714, 95% CI: 0.092, 1.336; $P = 0.025$) compared to no use. **Conclusions**. This analysis demonstrates an innovative, quantitative approach to study how cannabis consumption affects neurocognitive and psychomotor performance. Results demonstrated that acute cannabis use is associated with changes in neurocognitive and psychomotor performance, with differences based on the pattern of occasional or daily use.

Key words: = factor analysis; cannabis use; drug tolerance; reaction time; neurocognitive and psychomotor performance; cannabis impaired driving

With 38 U.S. states having legalized recreational and/or medicinal cannabis use, public policy related to cannabis impaired driving is of increasing significance. Several desktop computer tests of psychomotor or neurocognitive performance have been utilized to assess the acute effects of cannabis on psychomotor and neurocognitive performance (McCartney et al.,

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2021). Tablet or cellphone-based applications suitable for application field investigations of workplace accidents or transportation crashes are attempting to objectively measure and assess impairment (Chung et al., 2020; Karoly et al., 2020; Pal et al., 2016). (Chung et al., 2020; Karoly et al., 2022; Pal et al., 2016). While these technologies are relatively widely used for general cognitive testing, applying these technologies to scenarios of assessing driving performance is a new application of these devices. These devices typically include multiple tasks measuring several neurocognitive and/or psychomotor domains such as reaction time, processing speed, working memory (visual or auditory), executive function, judgement, and spatial-motor control.

These are areas of performance in which there is a history of research demonstrating relationships with drug impairment, and with cannabis use in particular (McCartney et al., 2021). This research has found that cannabis use history and the development of drug tolerance mitigate the impact of acute cannabis use on certain measures of psychomotor and neurocognitive performance (Colizzi & Bhattacharyya, 2018; McCartney et al., 2021).

Our team recently applied a within-subject, cross-over design to assess the effects of acute cannabis smoking on multiple aspects of human performance in subjects with a history of occasional use and daily use. A non-using control group was included to assess for learning (i.e., practice) effects. Our findings on the impact of acute cannabis use on performance in a driving simulator have recently been reported (Brooks-Russell et al., 2021). In this same study population, we also conducted neuropsychological testing before and after acute cannabis smoking using a prototype computer tablet test battery (Impirica®, Edmonton, Canada). The tasks in that battery included measures of simple and choice reaction time, decision making, working memory and spatial-motor performance. Our findings concerning the impact of acute cannabis use on each task separately is the subject of a separate report (Brooks-Russell et al, in submission).

We herein present the application of exploratory factor analysis to the results of all the tasks and subtasks included in the Impirica human performance test battery. By including multiple tasks and measures, these test batteries are operationalizing multiple indicators for a hypothesized latent construct that is acute drug-induced impairment. However, rarely are latent variable methods applied in these analyses. Exploratory factor analysis is a statistical technique postulating the existence of underlying latent factors derived from the correlation among observed outcome variables. This dimension reduction technique is an important tool for the analysis of multivariate data and explores the underlying structure of the data to observe groupings or relationships among the observed variables, often referred to as latent constructs or "factors". These "factors" are estimated as weighted combinations of subsets of the observed data. Typically, a smaller number of latent factors are selected relative to the total number of observed variables resulting in dimension reduction. Testing associations between the latent factors and covariates of interest reduces the total number of statistical tests employed thereby reducing Type I error and the burden of adjusting for multiple comparisons. In other words, if the information contained in the full set of variables can be conveyed in a much smaller set, our summary of the results can be drastically simplified. The challenge is to condense the many variables that we begin with into a much smaller set with minimal loss of information (Bartholomew et al., 2011).

METHODS

Participants

Eighty-six healthy adults (43 men, 43 women, ages 25 to 45; 31 with daily use, 23 with occasional use defined as 1 to 2 days per week over the past 30 days, and 32 with no cannabis use in at least the prior 30 days) completed the tablet-based test battery at two timepoints, referred to as the "pre" and "post" timepoints; see Supplemental Table 1 for additional participant demographics. Before data collection was initiated for the pre-timepoint (baseline) session, participants were requested to abstain from smoked cannabis for at least 8 hours and edible cannabis for at least 12 hours (i.e., at least overnight) as verified by completion of a cannabis use diary. Recent use of alcohol and other recreational drugs were among the study's exclusion criteria. This was verified by each subject providing a negative alcohol breath test and

negative urine drug screen (30 mL Alere brand 13-panel iCup®) prior to data collection. Additional details regarding inclusion and exclusion criteria, subject recruitment, the logistics of cannabis administration and the time-frame of data collection are reported elsewhere (Brooks-Russell et al., 2021).

Participants in the occasional and daily use groups were observed to smoke or vaporize cannabis flower while seated in a ventilated room. Participants self-supplied cannabis flower containing 15% to 30% total THC (less than 2% cannabidiol (CBD)), which was brought in its original packaging from a state-licensed Colorado dispensary. Participants were instructed to smoke or vape "the amount you most commonly use for the effect you most commonly desire" for up to 15-minutes. Participants in the non-use group were invited to relax for the same amount of time. The "post" timepoint occurred approximately one hour after the smoking session. The test battery was administered on an iPad (Apple iPad 9.7" 5th Gen Wi-Fi Only (Model A1822) Installed iOS version 11.4.1) mounted on a portable stand and required approximately 12 minutes to complete. The assessment consisted of four tasks: decision-making, spatial-motor control, reaction time, and working memory, and was part of a larger study assessing multiple aspects of cannabis use and driving performance (Brooks-Russell et al., 2021).

Measures

Decision Making. The decision-making task consisted of two trial stages with increasing difficulty. For this task, participants were presented with a rectangular object on the far-left screen of their tablet and a series of barriers placed to the right of their object. The first stage consisted of one row of barriers, and the second stage consisted of two rows of barriers. The participant was instructed to use the "GO" and "STOP" buttons to navigate the rectangular object across the screen without colliding with the barriers (see Supplemental Figure 1). Participants had to wait to press the "GO" button until the indicator light at the top of the screen turned green. Failure to wait for this indicator resulted in an unsuccessful start, and a minimum of 10 successful starts were needed to complete each stage of this task. The priority emphasized for completing this task was to successfully navigate across the screen without colliding with the barriers, whereas the speed at which this was accomplished was not prioritized in the instructions.

Spatial-motor Control. This task measured a participant's ability to avoid objects, while still maintaining a desired location on the screen. On the screen, participants could see a ball inside a circular object called the reticle. As the task progressed, the ball inside the reticle seemed to be moving forward towards oncoming obstacles. Participants were instructed to maneuver the iPad in a way that the ball would shift and move outside the reticle to avoid oncoming objects, and then maneuver back to the reticle after the object was avoided (see Supplemental Figure 2). A total of three laps were completed, each with increasing velocity. The priority emphasized for completing this task was success at object avoidance, while attempting to maximize time spent inside the reticle.

Reaction Time. This task consisted of two stages respectively measuring simple and choice reaction time in milliseconds. In the first stage, participants were presented with an object in the middle of the screen, with start and stop buttons at the bottom of the screen, and a light indicator at the top of the screen. Once the light turns green, participants were instructed to hit the start button, causing the object in the middle of the screen to begin to move. Participants then needed to hit the stop button as quickly as possible to stop the object before it moved off the screen. A successful start for this task was indicated by not hitting the start button prior to the light turning green, and a minimum of 10 successful starts were needed to complete this task stage. The second stage of the reaction task measured not only reaction time, but reaction in the correct direction. Like the first stage, participants were presented with a rectangular object in the middle of the screen, and a series of light indicators at the top of the screen. The bottom of the screen now had a start button with a stop button on either side. Once the light turned green, participants were instructed to hit start, and the object would begin to move either to the right or the left. Participants then needed to hit the stop button that corresponded with the direction in which the object moved. The top of the screen has green lights that could present in either direction, independent of the direction in which the object would move (see Supplemental Figure 3). A successful start for this task was indicated by not

hitting the start button prior to the light turning green, and a minimum of 15 successful starts were needed to complete this task stage. Trials in which the participant pressed the button corresponding to the incorrect direction were not counted.

Working Memory. The memory task consisted of four trial stages. Participants were shown a shape created from a set of 8 dots in a circle (see Supplemental Figure 4). A distracting screen was presented, followed by the participant being asked to replicate the shape they had been shown. In the first two stages of this task, participants are shown and asked to replicate one shape at a time. In the third and fourth stages of this task, participants are shown two shapes, and then asked to replicate both shapes shown. The priority for completing this task was placed on correctness of shape replication, rather than the time it took to replicate the shapes.

Driving Performance. A car-based driving simulator (miniSim™) was used to measured standard deviation of lateral placement (SDLP) before and after acute cannabis use in simulated urban, straight-segmented driving scenarios. Additional details about the driving simulator portion of the study have been previously published (Brooks-Russell et al., 2021).

Statistical Approach

All statistical analyses were carried out in RStudio version 1.3.1073. As described in the measures and presented in Supplemental Table 2, 18 outcome variables were aggregated from the information collected throughout the test battery. The assessment was administered, and data recorded, at two time points for each participant, referred to as "pre" and "post" smoking. We applied normality transformations and any variables which could not be suitably transformed were included in the analysis without transformation. To ensure the consistent interpretation of higher scores indicating increased impairment, the total replicated shapes variables in the memory task, and the proportion of correct reactions in the reaction time task were reverse coded to match the direction of the other variables in the analysis.

We fit exploratory factor analysis (EFA) models using the R function 'factanal' from the 'stats' package with an oblique, promax rotation which allows for correlated factors (Taherdoost et al., 2022). The number of factors was chosen using a combination of the "scree test" (Bartholomew et al., 2011) and Kaiser's 'eigenvalue > 1' criteria. Using these criteria, we applied EFA to the 18 transformed variables in the pre-smoking/baseline data after standardization and normality transformations. Factor loadings for variables with loadings > ±0.30 were retained, and loadings < ±0.30 were coerced to 0. The revised factor loading matrix was used to estimate factor scores. The variables that contributed most strongly to each factor were used to define relevant titles for that factor. It is hypothesized that impairment cannot be directly measured by one observable outcome. For the current analysis we are also hypothesizing that there could be multiple latent factors which are functions of the observed variables measured by the 4 tasks. These multiple latent factors or constructs are designed to capture *latent impairment*, as opposed to *measured impairment.*

Construct validity of each estimated factor was evaluated by estimating the association of our "pre" factor scores with covariates of interest. These covariates included age, gender, frequency of video game use and SDLP (driving performance outcome from the miniSim™). In addition to analyzing the association between our obtained factors and the driving performance metrics from the miniSim, we evaluated if our factors are related to characteristics of driving similar to those taken from a scenario simulating driving, justifying the effectiveness of our iPad battery to capture driving performance.

After assessing associations, the factor loading matrix was then applied to the "post" timepoint to obtain scores after a smoking period for those in the occasional and daily use group, or after a rest period (for the no use group). The differences in factors scores (post minus pre) were examined, and the changes among the three use groups were compared. We hypothesized the no use group would demonstrate stable scores over time, while the groups that smoked cannabis may demonstrate a change in scores which would reflect increased impairment. The no use group, serving as our controls, allowed us to account for "learning (or practice) effects" given that participants repeated the same tasks twice. Fitting a linear regression model with user type as our primary explanatory variable, while controlling for age, gender, and video game use, we identified differences in the change in factor scores from pre to post assessment across use-groups. For each factor, comparisons were made between the daily use group and the no

use group, and between the occasional use group and the no use group. Where necessary, a Bonferroni correction for multiple comparisons will be applied and discussed. In the context of comparing factors scores for the three use groups, a new significance threshold of 0.025 will be implemented to account for each group being compared twice. The decision to implement a Bonferroni correction was based on this being the most conservative approach to handling the case of multiple comparisons.

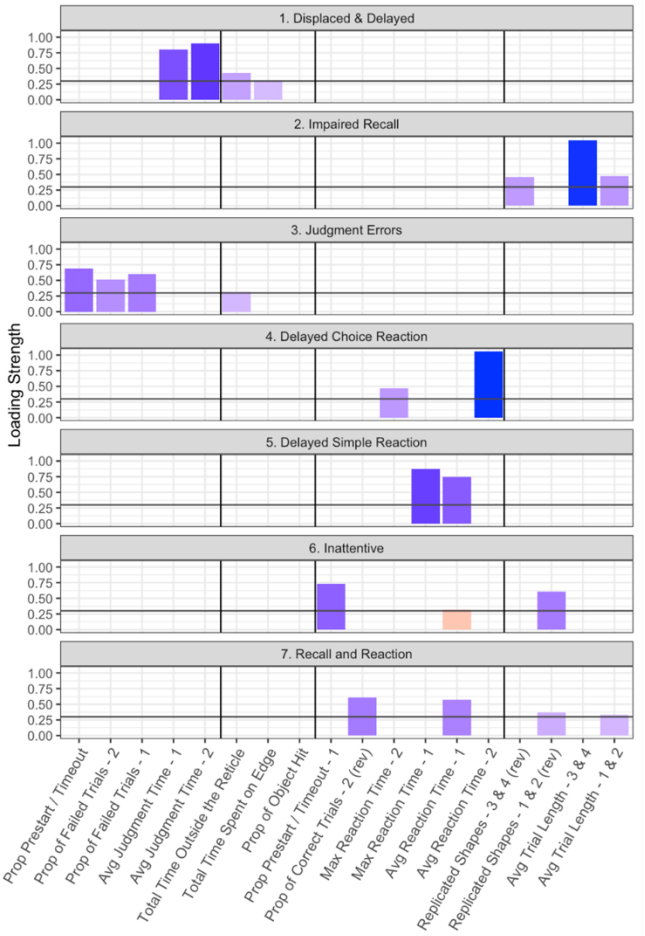
RESULTS

Exploratory Factor Analysis

We applied exploratory factor analysis to the 18 measured variables from the four tasks described above and chose to implement seven factors. The results for this model fit indicated that seven factors explained 56.7% of the total variability in our 18 measured variables (χ^2 = 39.74, p = 0.796). A scree plot along with eigenvalues and variance contribution for each factor have been included as Supplemental Figure 5. Four of the seven factors had loadings from outcomes across two tasks (Figure 1). Higher scores for each factor indicate increased impairment.

Participants that scored high on Factor 1 (*Displaced & Delayed*) spent more time outside the reticle and on the edge of the iPad screen in the spatial-motor control task and, on average, took longer to make decisions in the decision-making task.

Figure 1. *Factor Loadings for Each of the 18 Outcome Variables onto the 7 Obtained Factors*



Note. The vertical dividers delineate each of the four tasks. From left to right the tasks are: decision making, spatial-motor control, reaction time, and working memory. The magnitude of the bars indicates the loading strength of the measured variable onto the factor. The blue toned bars indicate positive loadings, while the orange toned bars indicates negative loadings of that variable onto the respective factor. The variables that end in "-1" and "-2" denote the trial stage with which that variable is describing.

Table 1. *Associations Between Use Group and Covariates with Final Latent Factors at Baseline*

Displaced & Delayed Factor				
Term	**Estimate**	**Std. Error**	**Test Statistic**	**P-Value**
(Intercept)	0.549	0.768	0.715	0.477
Occasional Use	0.085	0.261	0.326	0.745
Daily Use	-0.175	0.241	-0.726	0.470
Age	-0.009	0.020	-0.438	0.663
Gender (Female)	**0.437**	**0.210**	**2.081**	**0.041**
Sometimes Video Games	-0.415	0.309	-1.343	0.183
Occasional Video Games	-0.423	0.300	-1.410	0.162
Daily Video Games	**-0.867**	**0.262**	**-3.304**	**0.001**
Impaired Recall Factor				
Term	**Estimate**	**Std. Error**	**Test Statistic**	**P-Value**
(Intercept)	-1.496	0.908	-1.648	0.103
Occasional Use	-0.119	0.309	-0.384	0.702
Daily Use	-0.308	0.284	-1.084	0.282
Age	**0.054**	**0.024**	**2.272**	**0.026**
Gender (Female)	-0.098	0.248	-0.393	0.695
Sometimes Video Games	-0.305	0.365	-0.835	0.407
Occasional Video Games	0.303	0.355	0.855	0.395
Daily Video Games	-0.340	0.310	-1.097	0.276

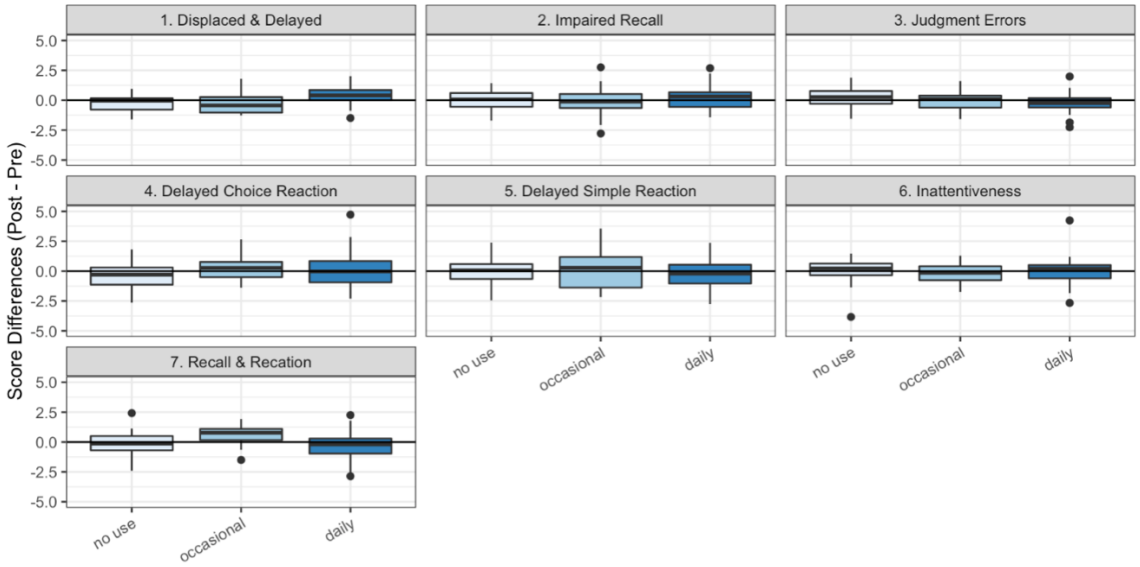
Note. Bolding indicates significance, p<.05

Participants that scored high on Factor 2 (*Impaired Recall*) demonstrated longer average time to complete memory tasks and replicated fewer shapes when presented with multiple shapes to replicate. Participants that scored high on Factor 3 (*Judgement Errors*) demonstrated overall less success in the decision-making task with fewer correct judgment decisions, in addition to a higher proportion of timeout trials and false starts. Participants that scored high on Factor 4 (*Delayed Choice Reaction*) showed slower reactions, indicated by longer average and maximum reaction times, in the choice reaction task where reaction time and the correctness of their reaction direction are both assessed. Participants that scored high on Factor 5 (*Delayed Simple Reaction*) showed slower reactions, indicated by longer average and maximum reaction times, in the simple reaction task where the participant simply had to react to a "GO" stimulus. Participants that scored high on Factor 6 (*Inattentiveness*) replicated fewer shapes in the memory task when presented with multiple shapes to replicate and suffered higher proportions of false starts or timeout trials in the simple reaction task, suggesting a degree of inattentiveness of the participant. Participants that scored high on Factor 7 (*Recall and Reaction*) demonstrated slower memory recall, and fewer replicated shapes when asked to replicate one shape at a time. Higher scores in this factor indicated longer simple reaction times and fewer correct reactions in the choice reaction task.

Covariate Associations at Baseline

Before evaluating associations between each of the seven factors and use groups, we assessed if additional covariates of interest (age, gender and video game usage) were associated with each of these factors at the pre timepoint. As shown in Table 1, there were two factors that demonstrated associations with our covariates of interest. For *Displaced & Delayed,* female participants demonstrated higher (poorer) scores on average as compared to males, and individuals that played video games daily scored significantly lower (better) on average. For *Impaired Recall,* older age was associated with higher scores. Given these associations, we controlled for age, gender, and video game use in subsequent analyses for all factors.

Figure 2. *Differences in Factor Scores by Cannabis Use Group*



Note. The horizonal line at 0 suggests no change from pre to post, and the colors of the boxplots coordinate with the use group designated on the x-axis. Distributions above the 0.0 line represent a decline in performance, those below the 0.0 line represent an improvement in performance.

Table 2. *Unadjusted and Adjusted Regression Models for Use Group on Difference in Factor Score (Post – Pre) [Adjusted for age, gender, and video game use]*

Unadjusted Regression Models for Use Group on Difference in Factor Score				
	Estimate*	**95% CI**	**P-Value**	**Adjusted R2**
Factor 1: Incorrect Positioning & Delayed Decision Making				0.149
Occasional Use	-0.080	(-0.494, 0.335)	0.704	
Daily Use	**0.667**	**(0.284, 1.049)**	**0.001****	
Factor 3: Decision Making Failure				0.0278
Occasional Use	-0.236	(-0.675, 0.203)	0.289	
Daily Use	**-0.427**	**(-0.832, -0.022)**	**0.039**	
Factor 7: React & Recall Failure				0.0946
Occasional Use	**0.721**	**(0.144, 1.298)**	**0.015****	
Daily Use	-0.215	(-0.747, 0.317)	0.424	
Adjusted Regression Models for Use Group on Difference in Factor Score				
	Estimate*	**95% CI**	**P-Value**	**Adjusted R2**
Factor 1: Incorrect Positioning & Delayed Decision Making				0.227
Occasional Use	-0.131	(-0.550, 0.289)	0.537	
Daily Use	**0.567**	**(0.178, 0.955)**	**0.005****	
Factor 3: Decision Making Failure				-0.0178
Occasional Use	-0.220	(-0.697, 0.257)	0.362	
Daily Use	-0.399	(-0.840, 0.043)	0.076	
Factor 7: React & Recall Failure				0.0651
Occasional Use	**0.714**	**(0.092, 1.336)**	**0.025****	
Daily Use	-0.250	(-0.825, 0.326)	0.390	

* standardized difference from no use group
** significant after Bonferonni correction

Performance on Latent Factors by Cannabis Use History

The mean, standard deviation, and range of scores on each factor at the "pre" (baseline) and "post" timepoints are presented in Supplemental Tables 4 and 5. The difference in individual factor scores (post – pre) represented the acute change in performance associated with cannabis smoking.

Figure 2 plots the distributions of post minus pre score by cannabis use group for each factor unadjusted for covariates. The horizontal line at 0 indicates no change, so distributions that lie above this line indicate worse performance after smoking, and distributions that lie below this line indicate improved performance after smoking. Descriptively, the daily use group exhibited worse mean performance in *Factor 1- Displaced & Delayed* and the occasional use group exhibited worse mean performance on *Factor 7- Recall & Reaction*.

In the unadjusted models, a statistically significant improvement in performance was observed for the daily use group on *Factor 3 - Judgment Errors*. However, this result was not significant after adjustment for covariates of age, gender, and frequency of video game use.

The results from the covariate-adjusted linear models regressing use group on the difference in factor score further quantified differences in performance after acute cannabis smoking by use group. The coefficients from these models, reported in Table 2 represent the standardized difference comparing occasional use to no use, and daily use to no use. Because all measured variables were standardized prior to analysis, the coefficients directly comparable. Positive estimates indicate participants scored higher, or were more impaired, after smoking as compared to baseline. Those in the daily use group performed worse after cannabis smoking in *Factor 1 - Displaced & Delayed* (standardized coefficient 0.567, 95% CI: (0.178, 0.955), p = 0.005) compared to the change that occurred between the pre and post time points in

the no use group, and participants in the occasional use group performed worse after cannabis smoking on *Factor 7 - Recall & Reaction* (standardized coefficient 0.714, 95% CI: (0.092, 1.336), p = 0.025) compared to the change in the no use group. After applying a Bonferroni correction for multiple comparisons, both results reported above would still be statistically significant.

Factor Association with Simulated Driving Performance

For analyses including SDLP, we had complete data for 83 of our 86 primary study participants. Prior to analyzing the associations between SDLP and our obtained factors, we assessed correlation among these two types of measures of impairment in all participants considered together. Pearson correlation matrices demonstrated significant correlations between SDLP and *Factor 1- Displaced & Delayed* at the pre (r = 0.296, p = 0.007) and post timepoint (r = 0.290, p =0.008). We also observed marginally significant correlations between the change in SDLP and the change in *Factor 4- Delayed Choice Reaction* (r = 0.203, p = 0.065). After identifying the correlations between these measures of impairment, a linear model was fit to determine if baseline SDLP varied by use group. These models demonstrated a significant difference in the SDLP of those in the occasional use group at baseline (-4.103, 95% CI: (-7.101, -1.105), p = 0.009), indicating differences in baseline driving performance between groups; thus, we controlled for SDLP at baseline (See Supplemental Material).

Fitting linear models to the relationship between the change in factor scores and the change in SDLP, controlling for baseline SDLP, change in the factor scores by any user group was not a significant predictor of change in SDLP.

DISCUSSION

This study utilized latent variable methods to evaluate performance on a neurocognitive and psychomotor assessment, allowing correlations across multiple tasks to utilize the information available from the measured outcomes in a smaller number of composite outcomes for detecting impairment from acute cannabis use. The finding of four factors with significant loadings across tasks supports the hypothesis that there are correlations among the outcome variables of this test battery. For example, *Factor 1- Displaced & Delayed* a combination of variables from the decision-making task (time to complete tasks) and spatial-motor tasks (object placement), accounted for the largest amount of variability in the data. In turn, this factor was correlated with the driving simulator measure of SDLP in the combined study population. Prior research of psychomotor or neurocognitive performance using computer or tablet-based tests have typically examined outcome domains such as memory or reaction time independently (Desrosiers et al., 2015; Karoly et al., 2022). Our findings suggest the combined analysis across domains or tasks may provide additional information. This methodological approach of EFA could be useful in similar studies using multiple measures to identify a latent construct of impairment.

Other factors that revealed significant differences between group from pre to post included *Factor 3 - Judgement Errors* and *Factor 7 - Recall and Reaction.* Similar to *Factor 1,* these two factors included loadings of variables from across two tasks. We found the occasional use group had decrements in performance on *Factor 7 - Recall and Reaction* from pre to post, compared to the no use group and those in the daily use group had improvements in their performance on *Factor 3 - Judgment Errors* from pre to post use as compared to the no use group. From pre to post, the factor loadings indicated that the daily use group took longer to complete the decision-making task but did so with fewer errors. It is important to note that the decision-making task instructions prioritized accuracy over speed, and this interplay of variables and trade-offs is reflected in the factor. The occasional use group demonstrated slower reaction time in the reaction time tasks (in which speed was prioritized in the instructions) and less accuracy in the memory task. By using correlations among test battery outcomes in this analysis, we harness the ability to potentially identify different types of impairment not captured by strictly evaluating individual measured outcomes.

Despite the strengths of our approach, and significant findings, it is important to note the relatively small magnitude of the significant findings. A goal of this field of research is to identify impairment due to acute cannabis use with post-only measures. Currently, the within-

person variability in performance across the groups overwhelms the between-group changes in performance related to cannabis use. Although it may be possible to account for baseline performance in an occupational context, this would not be possible in a road-side application. Furthermore, the lack of a significant relationship between change in factor scores by use group with SDLP indicates that the factors identified in this analysis, using this particular test battery, may not be mediators of the relationship between acute cannabis smoking and SDLP.

The cannabis dosing aspect of this study, in which subjects smoked self-supplied cannabis *ad libitum* over a 15-minute interval, constitutes a limitation to the extent that the internalized (i.e., absorbed) dose of THC may vary considerably among the cannabis using subjects. As reported in our prior publication on this study population, on average those in the daily use group combusted a greater mass of THC present in their cannabis, and achieved higher blood THC concentrations, than those in the occasional use group (Brooks-Russell et al, 2021, Tables 2 and 3). Our study therefore represents a naturalistic observational design that compared performance changes pre and post acute cannabis use among occasional cannabis users and daily cannabis users where the latter group, as expected, received a higher dose of THC.

Our study design required all subjects to complete similar psychomotor tasks at the pre and post smoking time points. The inclusion of a control group that did not use cannabis but completed the tasks with the same timing allowed us to assess and adjust for a potential learning (or practice) effect. This analytical approach, in which pre- versus post-period least squared mean differences for each user group were contrasted with each other (occasional user versus non-user, daily user versus non-user) has been commonly used to account for possible learning or practice effects in repeated measures, within-subject designs. However, the existence of a differential impact of practice on performance in users versus nonusers independent of drug effect cannot be ruled out and may constitute a limitation.

Factor analysis performs best in scenarios with a sample size greater than 200 participants. So while our sample size is acceptable, it is smaller than the optimum for a factor analysis approach. Finally, if future iterations of this study wished to include Race and Ethnicity as potential covariates, as more diverse participant enrollment would be needed in order to analyze these.

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