*Research Article*

# Acute Stress Effect on Delay Discounting and Cannabis Demand among Individuals Endorsing High-frequency Cannabis Use

*Cannabis*
2024
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researchmj.org
10.26828/cannabis/2024/000275

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## ABSTRACT

**Objective:** Limited research examines the effect of stress on behavioral economic constructs among individuals using cannabis. This study examined whether the effects of acute stress on delay discounting differed in terms of cannabis use status and whether cannabis demand changed after stress induction. **Method:** Participants were two groups ($n$ = 39 endorsing high-frequency cannabis use and $n$ = 48 not endorsing cannabis use) of young adults (75.86% female, 67.82% White, $M_{age}$ = 21.64 years). During an online Zoom session, participants completed a prestress assessment, the Trier Mental Challenge Test (TMCT) stress induction, and then a poststress assessment. **Results:** Subjective stress increased significantly across groups after stress induction ($p$ < .001, $\eta_p^2$ = .23); no group X time interaction was observed. There were no differences in delay discounting across time or groups. For the use group only, cannabis demand intensity ($p$ = .006, $d$ = .50), but not other demand indices, significantly increased following the acute stress induction. Coping motives did not moderate the association between the change in subjective stress and the change in delay discounting or the change in any cannabis demand indices among the use group. **Conclusions:** Cannabis demand might exert a more influential role than delay discounting in shaping decisions related to cannabis use while experiencing acute stress. However, the practical implications of this finding warrant further research due to the relatively small difference in hypothetical cannabis use observed. Study design limitations that could impact the findings or lead to null results are discussed to inform future research.

**Key words**: = acute stress; delay discounting; cannabis demand; cannabis use; marijuana use

Cannabis is the most widely used federally illegal substance in the United States, with approximately 52.5 million people using cannabis and 16.3 million people meeting cannabis use disorder (CUD) criteria in the past year. Across age groups, young adults report the highest prevalence rates of use and CUD, such that more than one-third of young adults used cannabis and 4.8 million young adults met CUD criteria in the past year (Substance Abuse and Mental Health Services Administration, 2022). Although curiosity, availability, and peer pressure are commonly reported reasons for initial cannabis use, stress relief is one of the most frequently reported benefits or reasons for sustaining cannabis use (Copeland et al., 2001; Glodosky et al., 2021; Green et al., 2003; Hyman & Sinha, 2009). In addition, using cannabis to cope not only has a direct link to both cannabis use (Bonn-Miller et al., 2007; Simons et al., 2005) and cannabis-related problems (Lee et al., 2007; Simons et al., 2005), it also serves as a mediator in the relationship between chronic stress and cannabis use and its associated problems (Spradlin & Cuttler, 2019). Therefore, understanding how young adults use cannabis to deal with stress and how they make decisions under stress is critical to help interrupt the

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connection between stress and problematic cannabis use, which in turn may serve to identify potential intervention targets to reduce the prevalence of CUD among young adults.

Behavioral economics proposes a reinforcer pathology model to explain addiction as a behavioral pattern with two mechanisms jointly underlying decisions around initiating and maintaining substance use: delay discounting (i.e., the preference for the immediate acquisition of a commodity despite long-term adverse outcomes) and substance demand (i.e., the relative value of a reinforcer) (Bickel et al., 2014; Bickel & Athamneh, 2020). Several meta-analyses have demonstrated the association between addiction severity and substance use quantity/frequency with delay discounting (Amlung et al., 2017; MacKillop et al., 2011) as well as substance demand (Kiselica et al., 2016; Strickland et al., 2020).

Interestingly, the association between delay discounting and substance use outcomes seems more complex for cannabis specifically than for other substances. For example, unlike other substances, individuals with CUD (Johnson et al., 2010) or those using cannabis (Jarmolowicz et al., 2020; Strickland et al., 2017) did not significantly differ in monetary delay discounting compared to controls, even though individuals using cannabis demonstrated higher delay discounting rate in cannabis rewards than monetary rewards (Foxx et al., 2023; Johnson et al., 2010; Patel et al., 2020). Moreover, delay discounting was positively associated with cannabis problems but not consumption (Aston et al., 2016; Lopez-Vergara et al., 2019; Patel et al., 2020; Strickland et al., 2017). Although a recent meta-analysis showed a significant association between overall delay discounting across commodities and cannabis-related outcomes, the authors noted that the effect was relatively smaller than other substances and called for future research exploring the theoretical rationales underlying this difference (Strickland et al., 2021).

Thus, more research is required to determine the relationship between delay discounting and cannabis use outcomes. To our knowledge, those previous studies examining the relationship between delay discounting and cannabis-related outcomes utilized standard assessment conditions. As research suggests that individuals under stress might shift to a more short-sighted mindset to engage in health risk behaviors as coping behaviors to relieve stress immediately (Fields et al., 2014, 2015) and that individuals tend to choose immediate rewards while experiencing undesired emotions (Tice et al., 2001), one could expect that individuals who tend to use cannabis to cope with stress might increase the preference to choose immediate rewards when experiencing stress. Therefore, examining how delay discounting changes among individuals who use cannabis under stress-induced experimental conditions could further understanding of delay discounting among individuals using cannabis.

Although several reviews demonstrated the association between cannabis demand and cannabis-related outcomes (Aston & Berey, 2022; Aston & Meshesha, 2020; González-Roz et al., 2023; Strickland et al., 2020), most of them assessed trait demand while only a few examined state-dependent demand (Hindocha et al., 2017; Metrik et al., 2016) and none of them examined the effect of stress on state demand. A recent meta-analysis demonstrated state demand increased during stress/negative affect manipulations (Acuff, Amlung, et al., 2020), but this result was based on a limited number of studies on alcohol and cigarettes; none examined cannabis. Thus, little is known about whether cannabis demand changes under stress manipulations. Furthermore, cannabis demand is often indicated through five indices from a hypothetical marijuana purchase task: (a) intensity (i.e., the amount of cannabis consumed when the price is zero); (b) $O_{\max}$ (i.e., maximum expenditure on cannabis across all prices); (c) $P_{\max}$ (i.e., the price at maximum expenditure); (d) breakpoint (i.e., the price at which no cannabis will be purchased); and (e) elasticity (i.e., the sensitivity of cannabis consumption to increases in cost) (Aston et al., 2015; Collins et al., 2014). Across all indices, intensity and $O_{\max}$ of substance demand demonstrate the most consistent and robust relations with substance use and problems (see meta-analyses González-Roz et al., 2023; Martínez-Loredo et al., 2021; Zvorsky et al., 2019). It is integral to investigate how these two cannabis demand indices change under acute stress among individuals using cannabis so that we can better understand how cannabis demand might affect motivations around cannabis use when individuals experience heightened momentary stress in daily life.

### *The Present Study*

The present study planned to answer the question of how acute stress affects delay discounting and cannabis demand among young adults who use cannabis frequently. First, we aimed to compare delay discounting under acute stress among individuals who use and do not use cannabis. We hypothesized that individuals who use cannabis would have greater increases in delay discounting in response to acute stress, given previous research suggesting individuals tend to engage in health risk behaviors to acquire immediate stress relief when experiencing stress (Fields et al., 2014, 2015; Tice et al., 2001). Secondly, we aimed to examine the effect of acute stress on cannabis demand among individuals who use cannabis. We hypothesized that cannabis demand indices intensity and $O_{\max}$ would increase in response to acute stress based on the results from previous research examining alcohol demand (Acuff, Amlung, et al., 2020; Amlung & MacKillop, 2014; Owens et al., 2015). Lastly, we aimed to examine if coping motives serve as a moderator of acute stress effect on delay discounting and cannabis demand. We hypothesized stress would have a greater effect on increasing delay discounting and cannabis demand among individuals endorsing higher coping motives, based on previous research suggesting individuals reporting higher coping motives tended to show greater increases in alcohol demand during negative affect induction (Rousseau et al., 2011).

## METHODS

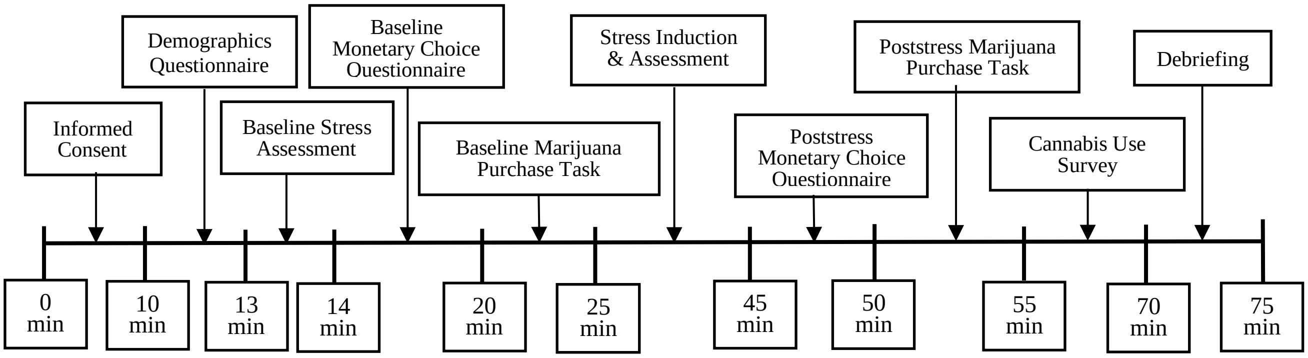
### *Participants*

Participants ($M_{age}$ = 21.64 years; 75.86% female; 67.82% White) were 87 young adults, with 39 endorsing cannabis use (i.e., cannabis use group) and 48 reporting not using cannabis (i.e., non-use group), recruited from advertisements posted in community and online social media sites as well as a psychology subject pool from a large public university in the Pacific Northwest United States. The recruited sample size was established based on a previous study examining the effect of stress on alcohol demand (Owens et al., 2015). Eligibility criteria included: 1) English speaking, 2) 18-29 years of age, and 3) able to participate in the study via Zoom. Further, eligible participants for the cannabis use group needed to endorse cannabis use at least five days per week in the past month and at least weekly use in the past six months, with no intent to quit or receive treatment; eligible participants for the non-cannabis use group needed to report no cannabis use in the past six months. Exclusion criteria for all participants included illicit drug use other than cannabis in the past six months, using any tobacco products (including cigarettes and e-cigarettes) daily, and drinking more than four alcoholic beverages on more than four days of the week. The original recruited sample was 89, but two participants from the use group (one reporting age 39 and one reporting using cannabis once every 3-6 months and not using cannabis in the past month) were removed from the analyses due to ineligibility, resulting in the final sample size of 87. Participants received a $30 gift card or research credit (college students could choose either) for their participation. This study was certified as exempt by the University Institutional Review Board.

### *Procedure*

Eligible participants were scheduled for an online Zoom appointment with a trained research assistant due to COVID-19 social distancing protocols (data collected from March 2021 to July 2022). Participants were requested not to use alcohol, cigarettes, or cannabis 12 hours before the appointment to prevent acute intoxication. However, no biological verification was conducted, though all participants in the use group reported not currently feeling high. During the appointment, research assistants first obtained informed consent. Then, participants were instructed to complete the demographics questionnaires, baseline assessments of subjective stress, and delay discounting. The cannabis use group also completed the baseline assessment of cannabis demand. Then, all participants completed a stress induction task, after which they completed the poststress subjective stress and delay discounting assessments. The cannabis use group also completed the assessment of poststress cannabis demand as well as a cannabis use survey. Participants were debriefed at the end of the study (Figure 1).

Figure 1. *Study Procedure Timeline*




*Note.* Only the use group completed the Marijuana Purchase Task and Cannabis Use Survey.

*Stress Induction.* This study utilized the computerized Trier Mental Challenge Test (TMCT), which resulted in significantly increased cortisol levels in previous research (Kirschbaum et al., 1991; Pruessner et al., 1999), as a stress induction task. During the task, participants were first instructed to share their screen with the researcher and told that the researcher would see their performance in this section. Then, participants were asked to work on three trials of arithmetic problems for three minutes for each trial and told to solve as many problems as they could. When participants answered a problem incorrectly or did not answer it in time, the word "WRONG" appeared on the screen in large font, and the computer would play a buzzing sound. At the end of each trial, participants were asked to report how many points they earned from each trial to indicate how many problems they solved correctly.

## *Measures*

*Demographic Questionnaire.* All participants were required to complete a demographic assessment, including age, gender, race, ethnicity, and income.

*Perceived Stress in Daily Life.* As the data collection was conducted during the COVID-19 pandemic, during which people were experiencing unprecedented stress, we used the 10-item Perceived Stress Scale (PSS; Cohen & Williamson, 1988) to measure participants' overall perception of stress in their life during the last month to ensure that both non-use and use groups did not differ significantly. Participants responded how often they experienced any stressful situations in their life from 0 (never) to 4 (very often) in the last month ($\alpha = .86$ for the non-use group and $\alpha = .91$ for the cannabis use group; $\alpha = .88$ for the whole sample).

*Subjective Stress Assessment.* Participants were required to rate how much stress they are currently experiencing using a 0 (no stress) to 10 (extreme stress) rating scale at the baseline and poststress assessments, which has been used in a previous study examining the acute stress effect among individuals using and not using cannabis (Cuttler et al., 2017).

*Delay Discounting.* The Monetary Choice Questionnaire (MCQ; Kirby et al., 1999) was used to assess delay discounting at baseline and after the stress induction. It consisted of 27 hypothetical monetary choices between smaller immediate and larger delayed rewards. We used the approach Kaplan et al. (2016) provided to calculate each participant's rate of discounting ($k$), which is the slope of the hyperbolic equation $V = A/(1 + kD)$, where V is is the subjective value of the reward (A) of a given delay (D) with larger $k$ indicating more likely to discount the values of delayed rewards (Mazur, 1987). The mean overall consistency was 95.88% ($SD$ = 3.99%) at baseline and 96.82% ($SD$ = 3.44%) at poststress; no participants were below 75%, at which researchers suggest the need to examine further individual-level patterns of responding (Kaplan et al., 2016).

*Cannabis Demand.* The 22-item Marijuana Purchase Task (MPT; Aston et al., 2015) was used to assess cannabis demand. Participants were asked how much cannabis they would use if it was of average quality at 22 ascending prices from $0 to $10 per hit when they had their typical amount of money to purchase cannabis. Participants were also told they did not use marijuana or any other drugs before they made these decisions, and they could consume all the cannabis they requested and would not have an opportunity to use cannabis elsewhere. The MPT provides several indices of cannabis demand: intensity (consumption when there is no cost), $O_{max}$ (maximum expenditure), $P_{max}$ (price at maximum expenditure); (d) breakpoint (price at which no consumption); and (e) elasticity (sensitivity of consumption to increase in cost). All indices were generated from the observed MPT responses except for elasticity ($\alpha$). For those purchasing at least one hit across all prices, the breakpoint was set to the highest price (i.e., $10) (baseline: $n = 16$; poststress: $n = 14$) (Yurasek et al., 2023). Elasticity was derived from the demand exponentiated model: $Q = Q_0 \times 10^{k(e^{-\alpha Q_0 C}-1)}$, where $Q$ is observed consumption at each unit price (i.e., $C$), $Q_0$ is consumption at price of zero, $k$ represents the consumption range in logarithmic units, and α is the rate of the demand curve (Koffarnus et al., 2015). In order to make elasticity (i.e., α) comparable across baseline and poststress, we examined three fixed $k$ values (i.e., 2, 3, 4) to determine which constant provided the best model fit of the mean demand curve (MacKillop et al., 2019; McIntyre-Wood et al., 2022). A value of $k = 4$ was used across baseline and poststress to generate derivative elasticity as it provided the best model fit. The exponentiated model provided a good fit for participant-level data (baseline: mean $R^2 = .92$, median $R^2 = .94$; poststress: mean $R^2 = .93$, median $R^2 = .95$), as well as an excellent fit at the aggregate level (baseline: $R^2 = .98$; poststress: $R^2 = .99$).

*Cannabis Use.* The 33-item Daily Sessions, Frequency, Age of Onset, and Quantity of Cannabis Use Inventory (DFAQ-CU; Cuttler & Spradlin, 2017) was used to assess cannabis use patterns for the cannabis use group.

*Cannabis Use Motives.* The 36-item Comprehensive Marijuana Motives Questionnaire (CMMQ; Lee & Grossbard, 2009) was used to assess 12 domains of motivations for cannabis use for the cannabis use group (α = .91). Here, we only utilized the three items from the subscale of coping motives (α = .81).

*Cannabis Problems.* The 19-item Marijuana Problems Scale (MPS; Stephens et al., 2000) was used to assess the negative consequences related to cannabis use for the use group. Participants responded to each problem with a response ranging from 0 (no problem) to 2 (serious problem); higher scores indicate higher problems (α = .85).

## *Analysis*

*Data Preparation.* Before analysis, delay discounting rate $k$ was log-transformed, a common way to process $k$ in previous studies (e.g., Chang & Ladd, 2023; Mellis et al., 2019; Strickland et al., 2017) due to the lack of normality (skewness = 3.73, 3.21, kurtosis = 16.23, 12.02 for baseline and posttest, respectively). As a result, both skewness and kurtosis were reduced to within acceptable limits (skewness = -0.6, -0.69, kurtosis = 0.04, 0.02 for baseline and posttest, respectively). For the MPT, the R package *"beezdemand"* (Kaplan et al., 2019) was used to pre-process cannabis demand data. Participants with unsystematic responses (Stein et al., 2015) were identified. Overall, two participants violating the criterion of reversals from zero (i.e., no non-zero consumption should occur after two consecutive zero consumptions) at baseline and poststress were removed for demand-related analyses. Outliers of demand indices (i.e., greater/less than 3.29 *SD*s) were winsorized one unit higher than the greatest nonoutlying value (Tabachnick & Fidell, 2013) such that one participant was adjusted for intensity at baseline and posttest, and another one was adjusted for $O_{max}$ at poststress. All demand indices demonstrated skewness and kurtosis values within acceptable limits (-2 and 2) used by previous research (e.g., Acuff, Soltis, et al., 2020; Copeland et al., 2023).

*Analytic Plan.* First, a two-way (2 x 2) mixed ANOVA was conducted with group (use vs. non-use) and time (baseline vs. poststress) as IVs and stress as DV to examine if the stress induction led to change in subjective stress, as well as to compare if the stress levels differed between two groups at baseline and poststress, or the change of stress from baseline to poststress differed between two groups. Second, another similar two-way (2 x 2) mixed ANOVA was conducted with delay discounting rate as DV to compare the effects of stress induction on delay discounting rate $k$ between groups as well as examine if the delay discounting of two groups differed at baseline and poststress. Third, paired $t$-tests were conducted to examine if all five cannabis demand indices significantly differed between baseline and poststress among the use group. Fourth, moderation analyses were performed to investigate whether cannabis use motives moderated the relationships between changes in stress and changes in delay discounting, as well as changes in demand indices. The interaction term of change in stress and coping motives was entered into the regression model to predict change in outcomes (i.e., delay discounting, demand indices). Lastly, to address the concern that observed changes might be attributable to repeated measurement, we examined the bivariate relationships between change in stress and change in delay discounting, as well as change in demand indices, from baseline to poststress to see if the increase in stress was correlated with the change in outcomes, which could further support that the stress induction contributed to the observed changes in outcomes. For demand-related analyses, we only had *a priori* hypotheses for intensity and $O_{max}$ as outcomes. However, we also analyzed other demand indices for exploratory purposes, as researchers have called for fully reporting all demand indices under the manipulation condition to better understand how the manipulation influences different aspects of motivation to use substances (Acuff, Amlung, et al., 2020). All analyses were done in R, version 4.3.1 (R Core Team, 2023), with packages *stats* (R Core Team, 2023) and *afex* (Singmann et al., 2023) for the primary analyses. Four participants (2 in the use group and 2 in the non-use group) did not complete the poststress assessment due to technical difficulties; thus, they were dropped from the related analyses.

### *Transparency and Openness*

We reported how we determined our sample size, all data exclusions, manipulations, and measures in this study. This study's design and its analysis were not pre-registered. Materials, data with a codebook, and R codes for this study are available on the Open Science Framework (https://doi.org/10.17605/OSF.IO/6KJ2G).

## RESULTS

### *Descriptive Characteristics*

There were no significant differences in age, gender, racial and ethnic composition, income, or perceived stress in daily life between groups (Table 1). Among the cannabis use group, baseline intensity and $O_{max}$, but not other demand indices or delay discounting, were significantly correlated with cannabis use frequency and days using cannabis in the past month. Cannabis problems were not associated with delay discounting or any demand indices (Table 2). Descriptive statistics of outcomes by time and group are presented in Table 3

Table 1. *Descriptive Characteristics by Group*

| | Group | | |
|---|---|---|---|
| | Use | Non-use | *p* |
| *n* | 39 | 48 | |
| Age | 22.13 (3.2) | 21.25 (2.96) | .19 |
| Gender | | | .51 |
| Man | 7 (17.95%) | 8 (16.67%) | |
| Woman | 28 (71.79%) | 38 (79.17%) | |
| Other | 4 (10.26%) | 2 (4.17%) | |
| Race | | | |
| Asian | 6 (15.38%) | 10 (20.83%) | .71 |
| American Indian or Alaska Native | 1 (2.56%) | 0 (0%) | .92 |
| Black | 2 (5.13%) | 1 (2.08%) | .85 |

| | | | |
|---|---|---|---|
| Native Hawaiian or Other Pacific Islander | 0 (0%) | 1 (2.08%) | 1.0 |
| White | 28 (71.79%) | 31 (64.58%) | .63 |
| Hispanic/Latine | 9 (23.08%) | 8 (16.67%) | .63 |
| Monthly income | 1073.08 (1169.06) | 1098.86 (1663.37) | .93[a] |
| Perceived stress scale | 19.31 (6.84) | 19.08 (6.53) | .88 |
| Cannabis coping motives | 8.19 (3.12) | | |
| Marijuana problems scale | 6.14 (5.16) | | |
| Cannabis use frequency | | | |
| 3 – 4 times a week | 4 (10.26%) | | |
| 5 – 6 times a week | 9 (23.08%) | | |
| once a day | 5 (12.82%) | | |
| more than once a day | 19 (48.72%) | | |
| Age of onset of regular cannabis use | 18.42 (2.18) | | |
| Age of onset of daily cannabis use | 19.31 (2.42) | | |
| # years used cannabis | 4.53 (3.28) | | |
| # days used cannabis last month | 24.92 (5.27) | | |
| # times/typical weekday | 3.12 (2.2) | | |
| # times/typical weekend day | 4.01 (2.35) | | |
| medical cannabis use | 1 (2.56%) | | |

*Note:* *p*-values represent Pearson's Chi-squared test or independent t-test for between-group comparisons. Numbers in the parentheses indicate standard deviation or percentages. [a] Log transformation was conducted due to the lack of normality. Race and ethnicity were assessed within a single item, even though participants could select multiple options; this resulted in a number of participants indicating Hispanic/Latine ethnicity but not providing race.

Table 2. *Correlations among study variables.*

| Variables | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. age | | -.01 | -.16 | | | | | -.07 | -.12 | .01 | .04 | | | | | | | | | |
| 2. gender[a] | -.02 | | .28 | | | | | .13 | .23 | -.32* | -.26 | | | | | | | | | |
| 3. PSS | -.14 | .49** | | | | | | .61** | .43** | -.09 | .06 | | | | | | | | | |
| 4. cannabis use frequency | .42* | .19 | -.04 | | | | | | | | | | | | | | | | | |
| 5. cannabis use days/month | .41* | .29 | -.14 | .73** | | | | | | | | | | | | | | | | |
| 6. MPS | -.30 | -.11 | .30 | -.06 | -.26 | | | | | | | | | | | | | | | |
| 7. coping motives | .14 | .34* | .56** | .17 | .05 | .45** | | | | | | | | | | | | | | |
| 8. baseline stress | -.19 | .39* | .65** | .02 | .03 | .16 | .26 | | .63** | -.20 | -.10 | | | | | | | | | |
| 9. poststress stress | .04 | .18 | .40* | -.02 | -.08 | .15 | .10 | .65** | | -.04 | .04 | | | | | | | | | |
| 10. baseline log *k* | -.23 | .12 | .12 | -.02 | -.11 | .23 | .02 | .24 | .09 | | .91** | | | | | | | | | |
| 11. poststress log *k* | -.28 | .04 | .01 | -.06 | -.11 | .25 | -.06 | .11 | .02 | .87** | | | | | | | | | | |
| 12. baseline intensity | .17 | .25 | .18 | .35* | .34* | -.02 | .24 | .19 | .36* | .19 | .13 | | | | | | | | | |
| 13. poststress intensity | .21 | .21 | .06 | .34* | .33 | .02 | .15 | .17 | .41* | -.01 | .03 | .96** | | | | | | | | |
| 14. baseline $O_{max}$ | .08 | .12 | .05 | .38* | .36* | .17 | .28 | -.13 | -.21 | -.10 | -.25 | .18 | .16 | | | | | | | |
| 15. poststress $O_{max}$ | .16 | .04 | .04 | .29 | .21 | .21 | .23 | -.10 | .04 | -.31 | -.37* | .16 | .27 | .80** | | | | | | |
| 16. baseline $P_{max}$ | .33* | -.10 | .03 | .19 | .03 | .30 | .31 | -.18 | -.12 | -.26 | -.41* | -.10 | -.06 | .60** | .71** | | | | | |
| 17. poststress $P_{max}$ | .22 | -.14 | .09 | .10 | .01 | .47** | .46** | -.16 | -.18 | -.24 | -.30 | -.11 | -.09 | .56** | .56** | .84** | | | | |
| 18. baseline breakpoint | .20 | -.10 | .12 | .19 | .10 | .28 | .20 | -.04 | -.07 | -.17 | -.31 | .02 | .01 | .68** | .67** | .78** | .77** | | | |
| 19. poststress breakpoint | .23 | -.10 | .01 | .22 | .14 | .29 | .20 | -.05 | -.06 | -.19 | -.26 | -.01 | .04 | .70** | .70** | .77** | .78** | .98** | | |
| 20. baseline elasticity | -.07 | -.12 | -.16 | -.29 | -.28 | -.22 | -.27 | .04 | .16 | .04 | .08 | -.28 | -.28 | -.76** | -.68** | -.45** | -.46** | -.66** | -.69** | |
| 21. poststress elasticity | -.10 | .005 | .002 | -.28 | -.25 | -.29 | -.19 | .08 | .10 | .07 | .07 | -.25 | -.30 | -.76** | -.75** | -.52** | -.51** | -.67** | -.73** | .93** |

*Note*. Correlations above and below the diagonal are non-use group ($n$ = 48) and use group ($n$ = 39), respectively. PSS = perceived stress scale; MPS = marijuana problems scale; log k = logarithmic-transformed delay discounting rate. [a]Gender coded as 1 = men, 2 = women, 3 = non-binary/other. * $p < .05$. ** $p < .01$.

Table 3. Descriptive Statistics of Outcomes by Time and Group

| Time | Baseline | | Poststress | |
|---|---|---|---|---|
| Group | Use Group | Non-use Group | Use Group | Non-use Group |
| *n* | 39 | 48 | 37 | 46 |
| stress | 5.41 (2.42)[a] | 6.17 (2.15)[a] | 6.16 (2.4)[ab] | 7.39 (1.98)[ab] |
| delay discounting (*k*)[1] | -1.98 (.61) | -2.14 (.83) | -1.96 (.65) | -2.02 (.83) |
| intensity | 21.08 (15.37)[a] | | 22.66 (16.54)[a] | |
| $O_{max}$ | 17.41 (12.6) | | 19.56 (16.17) | |
| $P_{max}$ | 4.29 (3.59) | | 3.81 (3.65) | |
| breakpoint | 6.14 (3.68) | | 5.71 (3.84) | |
| elasticity | .0060 (.005) | | .0057 (.0048) | |

*Note.* Values presented as M (SD). Two participants in the use group and two participants in the non-use group did not complete the poststress assessmnts due to technical issues. Elasticity is reported to four decimal places to show the distinction in values. [1]Logarithmic-transformed. [a]Significant within-group differences were observed between baseline and poststress. [b]Significant between-group difference was observed at poststress.

*Effect of Stress Induction on Subjective Stress (Manipulation Check)*

The TMCT resulted in increased subjective stress, as results of the two-way mixed ANOVA showed a significant main effect of time on stress in the overall sample, $F(1, 81) = 23.90$, $p < .001$, $\eta_p^2 = .23$. Both groups significantly increased subjective stress after the stress induction (use group: $t(36) = 2.42$, $p = .02$, $d = .40$; non-use group: $t(45) = 4.72$, $p < .001$, $d = .70$). Group also had a significant main effect on stress, $F(1, 81) = 5.17$, $p = .026$, $\eta_p^2 = .06$. Subjective stress between groups were not significant differently at baseline, $t(85) = -1.54$, $p = .13$, $d = .33$, but significant differently at poststress, $t(69.64)$[1] = -2.50, $p = .01$, $d = .56$, such that the use group had significantly lower stress than the non-use group at poststress. However, the interaction effect of time and group was not significant, $F(1, 81) = 1.04$, $p = .31$, $\eta_p^2 = .01$.

*Effect of Stress Induction on Delay Discounting*

Results of the two-way mixed ANOVA showed a nonsignificant main effect of time on delay discounting, $F(1, 80) = 3.42$, $p = .068$, $\eta_p^2 = .04$. Delay discounting did not change from baseline to poststress among either group (use group: $t(36) = .89$, $p = .38$, $d = .15$; non-use group: $t(44) = 1.75$, $p = .087$, $d = .26$). Group also had a nonsignificant main effect on delay discounting, $F(1, 80) = .37$, $p = .54$, $\eta_p^2 = .005$. Delay discounting between groups was not significantly different at either baseline, $t(84) = 1.03$, $p = .31$, $d = .22$, or poststress, $t(81) = .35$, $p = .73$, $d = .08$. Also, the interaction effect of time and group was nonsignificant, $F(1, 80) = .35$, $p = .56$, $\eta_p^2 = .004$.

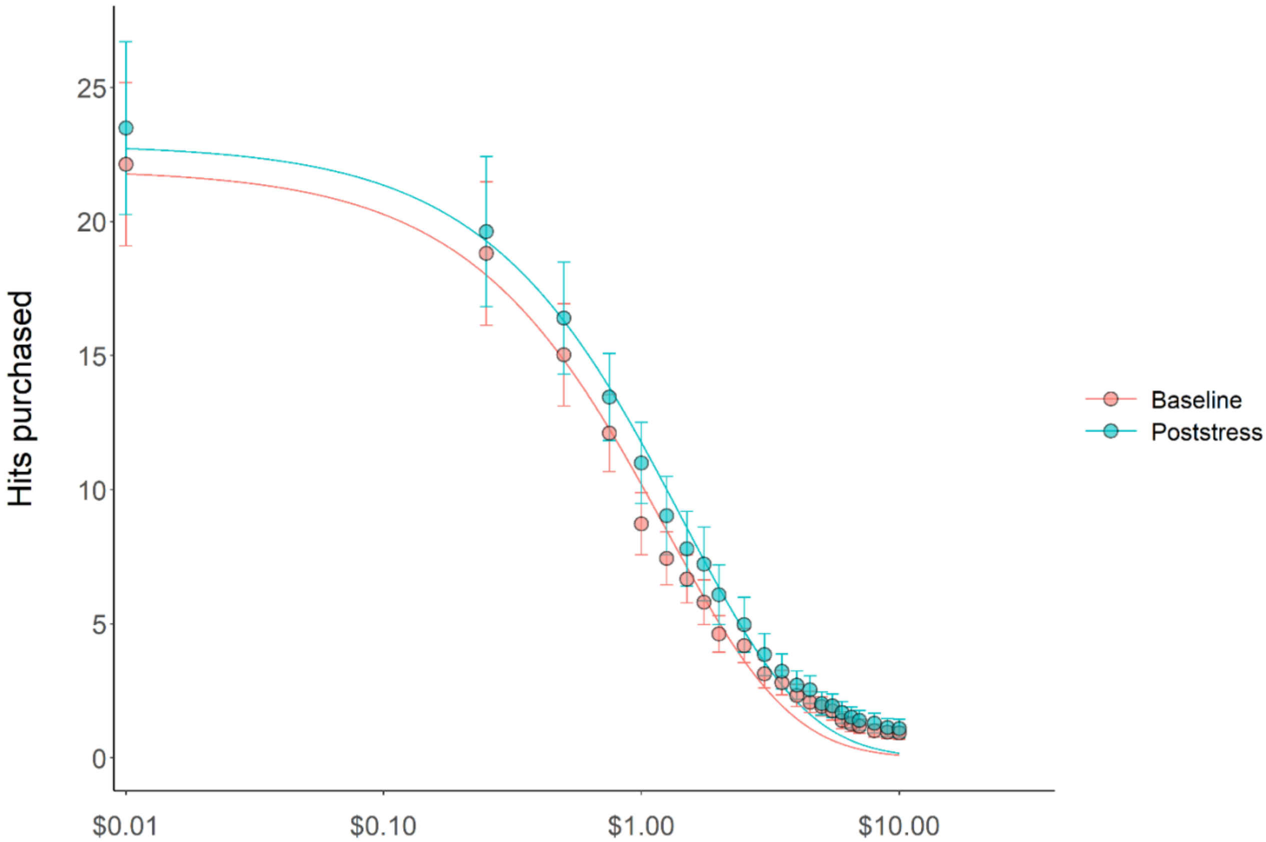
*Effect of Stress Induction on Cannabis Demand*

A paired *t*-test showed cannabis demand intensity significantly increased from baseline to after stress induction, $t(34) = 2.96$, $p = .006$, $d = .50$. However, other demand indices did not significantly change from baseline to poststress, $O_{max}$: $t(34) = 2.02$, $p = .051$, $d = .34$; $P_{max}$: $t(34) = -.97$, $p = .34$, $d = .16$; breakpoint: $t(34) = -1.73$, $p = .09$, $d = .29$; elasticity: $t(34) = -1.76$, $p = .09$, $d = .29$ (see Figure 2 for demand curves at baseline and poststress).

*Moderation Analyses*

Moderation analyses showed coping motives did not significantly moderate the association between the change in stress and the change in any outcomes (delay discounting: $b = .001$, $p = .25$; intensity: $b = -.06$, $p = .62$; $O_{max}$: $b = .04$, $p = .87$; $P_{max}$: $b = .02$, $p = .67$; breakpoint: $b = .02$, $p = .22$; elasticity: $b = -.001$, $p = .20$) among the use group.

*Figure 2.* Cannabis Demand Curves by Baseline and Poststress




*Note.* Each data point represents average hypothetical consumption at a particular price on the marijuana purchase task. The x-axis is log-transformed, and zero values are replaced by trivial nonzero values (0.01) to permit logarithmic units. Error bars represent the standard error of the mean (SEM).

*Relationship between Change in Stress and Changes in Delay Discounting and Cannabis Demand*

We examined bivariate relationships between the change in stress and change in delay discounting from baseline to poststress for the control and cannabis use groups separately. The change in stress and change in delay discounting was not significantly correlated in either group (no-use group: $r$ = .20, $p$ = .19; use group: $r$ = .05, $p$ = .79). Additionally, we explored the bivariate relationship between the change in stress and the changes in cannabis demand indices from baseline to poststress specifically within the use group. The change in stress was not significantly correlated with changes in intensity ($r$ = .29, $p$ = .09), $O_{max}$ ($r$ = .31, $p$ = .07), $P_{max}$ ($r$ = -.21, $p$ = .23), breakpoint ($r$ = -.11, $p$ = .54), or elasticity ($r$ = -.32, $p$ = .06).

## DISCUSSION

This study experimentally examined the effect of acute stress on delay discounting among individuals who use cannabis frequently compared to those who do not use cannabis, as well as cannabis demand among individuals who use cannabis. As expected, subjective stress increased after the acute stress induction in both groups. However, delay discounting did not significantly change from baseline to poststress in either group. Moreover, neither groups differed significantly in delay discounting at baseline, poststress, or change from baseline to poststress. Nevertheless, cannabis demand intensity, but not other demand indices, significantly increased after stress induction within the use group.

[1] $t$-test was adjusted due to unequal variances based on significant Levene's tests.

Finally, we did not see the moderating effect of coping motives on the associations between the change in stress and change in delay discounting as well as cannabis demand.

In terms of our first aim to examine the effect of acute stress on delay discounting, contrary to our hypothesis, we did not see any differences across groups in change scores from baseline to poststress, nor did we observe differences at baseline or poststress. The observation that there was no significant difference in delay discounting between the groups at baseline is consistent with prior studies, which reported no distinct difference in delay discounting of monetary rewards between the cannabis use group and the non-use group under general conditions (Johnson et al., 2010; Strickland et al., 2017). Interestingly, the effect size for the baseline group difference in delay discounting ($d = .22$) closely aligns with the omnibus effect size for the relationship between cannabis use and delay discounting in the recent meta-analysis ($r$ = .08) (Strickland et al., 2021). This raises the question of whether delay discounting serves the same function in reinforcer pathology for cannabis use as it does for other substance use. Given that cannabis is frequently viewed in a positive light and is often considered less detrimental to health compared to other substances like cigarettes (Berg et al., 2015; Nguyen et al., 2023), this perception may result in a diminished trade-off between immediate and future rewards. Consequently, this could explain the absence of any notable difference in delay discounting between individuals who use cannabis and those who do not. On the other hand, the lack of difference in delay discounting across groups at baseline might be due to the cannabis use group in this study being a sample of lower problem severity sample (i.e., average score of 6 on the MPS out of potential range 0-38) despite engaging in relatively heavy cannabis use (i.e., 5+ days/week). As previous research has found that delay discounting was positively associated with the severity of cannabis problems but not cannabis use frequency or quantity (Aston et al., 2016; Lopez-Vergara et al., 2019; Patel et al., 2020; Strickland et al., 2017), it is possible that the use group did not exhibit higher delay discounting than the non-use group under the standard assessment condition due to relatively lower severity of the cannabis use group in this study.

Surprisingly, neither groups significantly changed delay discounting in response to acute stress. This finding was contrary to the observed significant positive association between stress and delay discounting that a review found in the general population (Fields et al., 2014). However, that review was primarily based on cross-sectional data. Several experimental studies further demonstrated the complexity of the effect of acute stress on delay discounting in general. For example, acute stress increased delay discounting only among cortisol responders, not in non-responders (Kimura et al., 2013). A blunted cortisol response to stress has been observed among individuals using cannabis regularly (Cuttler et al., 2017). Although there was a significant change in subjective stress in the current study, perhaps the stress task/format was not strong enough to elicit a more pervasive stress response (e.g., cortisol) regardless of cannabis use status. An alternative explanation for why no significant increase in delay discounting was observed in either group could be the potential blunted stress response acquired due to COVID-19. Data collection during COVID-19 was likely influenced by prolonged stress exposure (Goldfarb, 2020). We did not know if their reactivity to the acute stress was changed due to exposure to the prolonged multi-dimensional stressors (e.g., social, family, economic, employment, and education) that the COVID-19 pandemic brought. Under acute stress, individuals with higher perceived daily life stress tended to choose larger but delayed rewards (i.e., lower delay discounting); individuals with lower perceived daily life stress tended to choose smaller but immediate rewards (i.e., higher delay discounting) (Lempert et al., 2012). Since greater lifetime stress exposure was associated with blunted cortisol response to acute stress (Lam et al., 2019) and acute stress did not alter delay discounting among those with blunted cortisol response (Kimura et al., 2013), it is possible that both groups in this study experienced some levels of blunted stress response from the prolonging stress exposure during COVID-19. This interpretation was also supported by the fact that the mean PSS score in our sample was relatively higher than what was reported in a similar age group in the general population (Cohen & Janicki-Deverts, 2012). On the other hand, the lack of differences in delay discounting in response to acute stress across groups might be attributed to the MCQ's design, which features identical items. Unlike tasks that adjust reward amounts based on responses (e.g., Du et al., 2002), the MCQ's identical items could lead to a lack of sensitivity to change. Given researchers have suggested utilizing alternative MCQ in repeated measure design (Kuang et al., 2018), futher research employing alternative MCQ or other types tasks that adjust reward amounts is recommended.

Likely as a function of the lack of change in delay discounting in response to acute stress, no significant differences were observed in the cannabis use group's response compared to the non-use group. However, this does suggest individuals using cannabis frequently do not prefer more immediate rewards than those who do not use cannabis when experiencing acute stress. This further reinforces the abovementioned question regarding the role of delay discounting in reinforcer pathology regarding cannabis use. Perhaps delay discounting is not a critical mechanism in cannabis use choices while experiencing acute stress. In fact, while there is a lack of research examining the effect of acute stress on delay discounting in individuals using substances, the only other study we are aware of found delay discounting was not affected by acute stress in individuals endorsing heavy drinking either (Amlung & MacKillop, 2014). More studies are needed, but the current study contributes to this limited literature, suggesting that delay discounting may not be an important target to consider under conditions of acute stress despite being proposed as one of the joint mechanisms underlying substance use decision-making generally.

Regarding our second aim to examine the effect of acute stress on cannabis demand, results were partially consistent with our hypotheses, such that we found that demand intensity significantly increased after stress induction. However, $O_{max}$ did not significantly change as a function of stress induction, even though the statistical difference approached significance ($p =$ .051). Notably, the small to medium effect sizes of the changes in cannabis demand indices (intensity: $d = .50$; $O_{max}$: $d = 34$; breakpoint: $d =$ .29; elasticity: $d = .29$) observed in this study were larger than the effect sizes reported in the recent meta-analysis (intensity: $d = .17$; $O_{max}$: $d = 18$; breakpoint: $d = .14$; elasticity: $d = .16$) by Acuff and colleagues (2020). While our findings align in some aspects and diverge in others with the meta-analysis, which found that $O_{max}$ (but not other indices of demand indices) across substances significantly increased in response to stress/negative affect manipulations, it is important to note that the authors also highlighted the possibility of publication bias with a relatively small number of studies and predominantly with samples using alcohol or cigarette (Acuff, Amlung, et al., 2020). To our knowledge, this study is the first to examine the acute stress effect on cannabis demand. Thus, while caution is warranted, demand intensity may play a more important role than $O_{max}$ in cannabis use than other substance use (e.g., alcohol or cigarette) under conditions of acute stress. As recent research found higher momentary alcohol demand intensity was associated with a higher likelihood of drinking and greater total alcohol consumption in the real world (Motschman et al., 2022), one might expect that the observed effects could be applied to cannabis demand such that individuals might be more likely to use cannabis and use more when cannabis demand increases. Accordingly, interventions targeting how to reduce cannabis demand intensity while experiencing momentary stress might be an avenue to reduce the frequency or quantity of cannabis use and to disconnect the relationship between stress and problematic cannabis use in the real world. However, despite observing a medium effect size related to increased intensity, it remains uncertain whether the magnitude of this increase (i.e., consuming an additional 1.5 hits in a typical day when cannabis is free) during acute stress holds any significant meaning or practical implications. It is also important to acknowledge that certain limitations in our study design (detailed in the following section) might impact the interpretation of our findings.

As for the third aim of examining the moderating effect of coping motives on the association between the change in stress and change in delay discounting and cannabis demand, we did not see the expected moderating effect of coping motives. This finding diverges from previous research on alcohol demand, during which individuals reporting higher coping motives tended to increase the reinforcing value of alcohol under a negative mood induction (Rousseau et al., 2011). The discrepancy might stem from the different methods of stress/negative mood induction employed. This study used a standardized math task to induce acute stress, whereas Rousseau et al. (2011) utilized a personalized negative mood induction (i.e., utilizing participants' personal life adverse events). Furthermore, this result should be interpreted cautiously due to the small sample size of the cannabis use group in the current study.

*Limitations and Strengths*

The results of this study should be interpreted cautiously with the following limitations. First, the generalizability may be limited due to the fact that the current sample consisted of individuals identifying primarily as female and White. Relatedly, we did not assess participants' cigarette use status or frequency, except for screening out individuals endorsing daily cigarette or e-cigarette use. Given the strong association between delay discounting and cigarette and e-cigarette use (Amlung et al., 2017; MacKillop et al., 2011; Stein et al., 2018), the absence of this information hinders our ability to fully understand how tobacco use in our sample might confound the results. In addition, our results for the nonsignificant moderating effect might be an issue of a small sample size; future research utilizing a larger sample size to examine the moderating effect of coping motives on the association between stress and delay discounting as well as cannabis demand is recommended. Moreover, this study's experiment was not done in a laboratory. Instead, participants completed the tasks online from their homes. Therefore, we could not control participants' home environments, which might potentially have affected the effect of stress induction. However, this might have increased some ecological validity as the experiment was done in the natural environment.

In terms of research design specifically, we identified several limitations that warrant consideration for future similar studies. First, this study relied solely on the subjective stress assessment at the end of the stress induction task, without incorporating biological measures. It is possible that the effect of stress induction on subjective stress response might have begun to dissipate by the time behavioral measures were conducted. To address this concern, future research could assess stress at different time points during the stress induction task. Additionally, the effects or the lack of effects we observed following stress induction might be confounded by repeated testing on the measures within a short timeframe. Notably, this study lacked a neutral control condition (i.e., no stress condition), which makes it challenging to rule out the impact of repeated testing, nor could we rule out random error. However, the detection of small to medium effect sizes in the correlations between changes in stress and cannabis demand indices among the use group and between changes in stress and delay discounting among the non-use group might alleviate this concern, as it suggests the change in stress contributed to the changes in outcomes observed. Nevertheless, we recommend similar future research consider implementing a neutral control condition to further address these factors. Third, our use of MCQ to assess monetary delay discounting may have limitations. The identical items in MCQ might render it insensitive to detecting changes. The lack of sensitivity could be one reason why we did not observe significant differences. Therefore, future research is recommended to explore tasks that dynamically adjust reward amounts based on responses (e.g., Du et al., 2002). Furthermore, given individuals using cannabis demonstrated higher delay discounting rates in cannabis rewards than monetary rewards, recent research calls for attention to non-monetary delay discounting as well as cross-commodity (i.e., money vs. cannabis) delay discounting in cannabis use (Foxx et al., 2023; Patel et al., 2020; Strickland et al., 2017). Future research using cannabis or cross-commodity discounting tasks is suggested to examine if results might differ due to the task reward type. Lastly, our use of MPT with a trait vignette to assess cannabis demand might not fully capture state-level variations in cannabis demand, despite observing small differences in cannabis demand curves between baseline and poststress assessments. Future research using state-specific vignettes to assess state demand is recommended. In summary, addressing these limitations could enhance the interpretability of study findings and help rule out confounding factors related to study design.

Despite the above mentioned limitations, this study has several strengths. First, to our knowledge, this is the first study to examine the effect of acute stress on delay discounting and demand among individuals endorsing cannabis use. Our findings regarding heightened cannabis demand intensity observed under acute stress could inform researchers and practitioners that cannabis demand could be used as an intervention target for preventing using cannabis to cope. Second, to our knowledge, this study is the first to administer TMCT online as a stress induction. This study demonstrated that the TMCT could be administered online with a significant increase in subjective stress ratings. This effective online TMCT administration provides an alternative approach for future research when facing barriers to administering in-person stress induction tasks. Lastly, as we mentioned before, this study might have higher ecological validity, compared to the traditional experimental research, because the experiment was done in participants' home environments. As people do not exist in a controlled laboratory, we believe our online experiment has a certain value in understanding how stress affects the tendency to choose immediate rewards and perceived cannabis value in the real-world context.

*Conclusion*

The overall findings of this study highlight the importance of cannabis demand while experiencing acute stress among young adults endorsing high-frequency cannabis use. However, we approach these findings with some caution due to the limitations inherent in our study design. Cannabis demand, especially intensity, may play a more influential role than delay discounting in choices around cannabis use decision-making while experiencing acute stress, although the relatively small difference raises questions regarding practical implications. Furthermore, we acknowledge the importance of recognizing the study design limitations that could contribute to the study's observed findings or null results. We recommend that future research explore alternative approaches and methodologies to address these limitations while examining similar research questions, as such knowledge may have great potential to prevent using cannabis to cope with stress and further disconnect the association between stress and problematic cannabis use.

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**Funding and Acknowledgements:** This research was supported in part by funds provided for medical and biological research by the State of Washington Initiative Measure No. 171. The funding source had no role other than financial support. All authors contributed to and were significantly involved in developing and writing this manuscript and have approved the final version of this manuscript. All authors declare no conflict of interest. We sincerely acknowledge and appreciate Dr. James G. Murphy's input on the initial research design/measure and the contributions of Ashlin King, Alexander McAllister, Joseph Box, and Zacheria Krocka to data collection. Portions of this article were presented at the 2022 Annual Meeting of the Research Society on Marijuana. This study was not preregistered. Materials, data with a codebook, and R codes required to replicate the results of this study are available at: https://doi.org/10.17605/OSF.IO/6KJ2G.

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