THE TRAJECTORY OF DISTRESS TOLERANCE FOLLOWING SUBSTANCE USE TREATMENT

Elizabeth Danielle Reese

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Approved by:

Stacey B. Daughters

Jonathan S. Abramowitz

Daniel J. Bauer

ABSTRACT

Elizabeth Danielle Reese: The Trajectory of Distress Tolerance Following Substance Use Treatment
(Under the direction of Stacey B. Daughters)

Distress tolerance (DT), defined separately as the actual or perceived ability to withstand aversive affective states, has been linked to problematic substance use behavior within nonclinical samples and treatment outcome among those with substance use disorders. Thus, DT may represent an important risk factor for substance use relapse, and has been evaluated as a target of substance use treatment. However, the longitudinal trajectory of DT among treatment seeking substance users remains unknown. The aims of the current study were to (a) characterize trajectories of perceived DT, assessed via self-report, and behavioral DT, assessed using a behavioral task, and (b) evaluate the influence of abstinence duration and frequency of use as predictors of DT change in a sample of residential treatment seeking substance users. Results of latent curve model analyses revealed that both perceived and behavioral DT improved nonlinearly over time. Additionally, abstinence duration was associated with greater improvement in both perceived and behavioral DT, and greater frequency of use post-treatment was associated with attenuated behavioral, but not perceived, DT. The current study provides evidence for naturally occurring improvement in both perceived and behavioral DT over 12 months following completion of residential substance use treatment. Such findings provide support for the conceptualization of DT as a malleable treatment target and emphasize the importance of abstinence in DT improvement and substance use recovery.

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CFI	Comparative fit index
DSM-IV	Diagnostic and statistical manual - fourth edition
DT	Distress tolerance
DTS	Distress tolerance scale
KS	Kolmogorov-Smirnov test of normality
LCM	Latent curve model
MTPT-C	Mirror tracing persistence task - computerized version
PASAT	Paced auditory serial addition task
RMSEA	Root-mean square error of approximation
SCID-NP	Structured clinical interview for DSM disorders - non-patient edition
SRMR	Standardized root-mean-square residual
SUD	Substance use disorder
TLFB	Timeline follow-back
TLI	Tucker-Lewis index

CHAPTER 1: INTRODUCTION

The negative reinforcement theory of addiction maintains that substance use functions to alleviate the aversive physiological and affective symptoms associated with withdrawal from substance use (Baker, Piper, McCarthy, Majeskie, & Fiore, 2004; Koob & Le Moal, 1997), thereby providing increased motivation for repeated use (Koob & LeMoal, 2001). To test this theory, researchers have quantified an individual's distress tolerance (DT), operationalized both as behavioral capacity to persist towards a goal despite psychological or physical discomfort (behavioral DT; e.g., completing a difficult task in order to obtain reward), or as an individual's perceived capacity to withstand aversive physical or psychological states (perceived DT). In doing so, substance use researchers can use DT as the conceptual approximation of a substance user's ability to remain abstinent, a difficult undertaking that treatment-seeking substance users are highly motivated to pursue despite aversive physical or psychological states present in the early stages of abstinence (i.e., during withdrawal from substances). In support of this conceptualization, low DT has been linked to problematic substance use among non-clinical samples (Ali, Ryan, Beck, & Daughters, 2013; Buckner, Keough, & Schmidt, 2007; Hasan, Babson, Banducci, & Bonn-Miller, 2015; Simons & Gaher, 2005), and both early relapse (Brown, Lejuez, Kahler, & Strong, 2002; Cameron, Reed, & Ninnemann, 2013; Daughters, Lejuez, Kahler, Strong, & Brown, 2005; Strong et al., 2012), and treatment dropout (Brandon et al., 2003; Daughters et al., 2005; Tull, Gratz, Coffey, Weiss, & McDermott, 2013) among those with substance use disorders (SUD). Such findings support the notion that DT may represent an important risk factor for substance use relapse and treatment outcomes (Trafton & Gifford, 2010) and as such, DT-specific interventions have been developed and evaluated for SUD and show promising results (e.g., Bornovalova, Gratz, Daughters, Hunt, & Lejuez, 2012; Brown et al., 2008; Brown et al., 2013). Despite such promising work, methodologically relevant concerns prohibit a comprehensive understanding of DT within this population. Specifically, research investigating the associations of DT and substance use originates from both self-report (e.g., Distress Tolerance Scale; Simons & Gaher, 2005 ; Discomfort Intolerance Scale; Schmidt, Richey, & Fitzpatrick, 2006) and behavioral measures (e.g., Paced Auditory Serial Addition Task- PASAT; Lejuez, Kahler, & Brown, 2003; Mirror Tracing Persistence Task-Computerized Version MTPT-C; Daughters et al., 2005), which are thought to represent fundamentally separable constructs as they are repeatedly weakly correlated with one another across studies (Glassman et al., 2015; Kiselica, Rojas, Bornovalova, & Dube, 2015; McHugh et al., 2011). In addition, there is not clear consensus among researchers if an individual's perceived and actual ability to tolerate distress (hereafter referred to respectively as perceived and behavioral DT) represent temporally stable constructs versus malleable mechanisms of change leading to improvement in SUD treatment outcome (Leyro, Zvolensky, & Bernstein, 2010; Zvolensky, Vujanovic, Bernstein, & Leyro, 2010).

DT change in substance users

DT treatment studies provide some evidence for the malleability of DT, both perceived and behavioral, among substance users. In line with the negative reinforcement theory of addiction, DT treatments work to provide individuals with skills to tolerate aversive psychological and physical symptoms during the recovery process. Specifically, increases in behavioral DT were observed as a function of treatment among polysubstance users in residential treatment (Bornovalova et al., 2012), and analyses of pilot data from five opiate dependent individuals suggested an increase in perceived DT with DT-targeted treatment (Brown et al., 2014). Such evidence is preliminary and focused on change specifically related to DT-targeted treatment. However, the extent to which DT naturally changes over time among substance users remains unknown. Relatedly, the dearth of information within DT treatment studies on DT change as a result of targeted treatment and the relationship between this change and substance use is notable. In particular, it’s unclear how both perceived and behavioral DT change may relate to important aspects of substance use, specifically abstinence duration and severity of continued substance use within this population.

Fortunately, related work can inform theoretically based, data driven hypotheses concerning these processes. For example, research suggests multiple cognitive and neurobiologically based processes such as executive control and inhibition of emotion-driven responses contribute to one’s ability to successfully tolerate distress in pursuit of a larger goal (Trafton & Gifford, 2010). Such conceptualizations are supported by recent work showing aberrant activity in neural regions associated with these processes, including less activation in prefrontal cortical regions associated with cognitive control and emotion regulation and less de-activation in emotion related regions such as the amygdala, in substance users performing a behavioral DT task as compared to healthy controls (Daughters et al., 2016). Relatedly, higher frequency of substance use has been shown to predict increased anxiety is response to stress (Fox, Axelrod, Paliwal, Sleeper, & Sinha, 2005), greater deficits in perceived DT (Buckner, Jeffries, Terlecki, & Ecker, 2016), and impairment in processes related to behavioral DT (Dahlgren, Sagar, Racine, Dreman, & Gruber, 2016; Wang et al., 2017). Alternatively, during periods of abstinence, substance users show significant improvements in neural structure and function across studies in regions associated with cognitive processes including behavioral monitoring and response inhibition (for review, see Garavan, Brennan, Hester, & Whelan, 2013). Taken together research suggests that substance use influences both cognitive and neurobiological processes underlying DT, while abstinence allows for the recovery of such processes. Thus, it is likely that the trajectory of DT change among substance users may be influenced by multiple factors, including abstinence and severity of use.

Current Study

As such, the aims of the current study were twofold. First, we sought to examine the natural temporal trajectory of perceived and behavioral DT among residential treatment seeking substance users at five assessment time points from pretreatment to 12-months post treatment. We hypothesized that both perceived and behavioral DT would increase over time. Second, we wanted to examine the influence of both abstinence and severity of substance use on the trajectory of behavioral and perceived DT. Consistent with previous work, we hypothesized that greater improvements in both behavioral and perceived DT would be associated with a longer abstinence duration and lower frequency of substance use.

CHAPTER 2: METHODS

Participants

The study sample consisted of 263 individuals receiving residential substance use treatment in a large urban area. Of these, 70.7% (n = 186) were male, 94.73% were African American (n = 249), 3% Caucasian (n = 8), 1.9% Native American/American Indian (n = 5) and 0.4% Asian (n = 1). Additionally, 192 (73%) individuals had at least a high school education or GED, and 213 (80.99%) were unemployed. The mean age of the sample was 42.68 years (SD = 11.76). Current DSM-IV substance dependence diagnoses included cocaine (n = 86; 32.70%) alcohol (n = 81; 30.80%), hallucinogen (n = 37, 14.07%), opioid (n = 31; 11.79%), marijuana (n = 28; 10.65%), and sedative (n = 2; 0.8%) with 25.1% (n = 66) meeting dependence criteria for more than one substance.

Procedure

Data for this study was part of a larger project assessing the efficacy of a behavioral activation treatment for substance use as compared to a contact time matched control condition (Daughters et al., 2017). Adults between the ages of 18 and 65 years of age were approached by research staff and assessed for study eligibility within one week of treatment entry. Participants were excluded if they (1) endorsed current psychotic symptoms, (2) evidenced impaired cognitive ability or (3) had less than 30 days remaining in the residential facility indicating insufficient time to complete the study treatment before discharge. Eligible and interested participants provided informed consent and were subsequently randomized to a treatment condition (i.e., behavioral activation versus supportive counseling). Detailed study recruitment, flow, screening, and randomization procedures are published elsewhere (Daughters et al., 2017).

Study assessments occurred at pretreatment (T_1), discharge from treatment (T_2), 3-months post-treatment (T_3), 6-months post-treatment (T_4), and 12-months post-treatment (T_5). Assessments consisted of interview, self-report, and computerized behavioral tasks. Upon completion of each assessment, participants were debriefed and compensated for study participation. All study-related procedures were approved by the University Institutional Review Board.

Measures

Sample Characteristics

During the pre-treatment assessment, all participants completed a self-report demographic questionnaire to assess age, sex, ethnicity, education, and employment status. In addition, DSM-IV substance dependence was assessed at pre-treatment using the SCID-NP (First, Spitzer, Gibbon & Williams, 1995).

Mirror Tracing Persistence Test -- Computerized version (MTPT-C; Daughters et al., 2005)

Behavioral DT was assessed using the MTPT-C, a computer-adapted version of the original Mirror-tracing Persistence Task (MTPT; Quinn, Brandon, & Copeland, 1996). During this task, participants are instructed to trace a red dot along the outline of star shape using a computer mouse that is programmed to move the dot in the opposite direction. To increase distress, aversive auditory feedback (i.e., buzzer sound) is presented through headphones each time the participant moves the red dot outside of the star or stalls for longer than 2 seconds, and in such cases, the participant has to once again trace the star shape from the beginning. Four phases of the task are administered, which increase in difficulty as the participant progresses through the four rounds. In the initial, easy phase, participants are asked to move the red dot along a star with a wide border until the tracing is complete. This level lasts for two minutes and difficulty level is titrated such that once the participant completes a star tracing, the border of the next star decreases in width until the allotted two minutes have elapsed. The next level of the task lasts for two minutes, and skill level during this phase of the task is dependent on participant performance in the first phase of the task. The same general procedure is used in the third phase of the task; however, the star's line width is calibrated to a difficulty level that exceeds the participant's performance on the previous round. This level lasts for one minute and is intended to induce distress. In the final phase, participants are shown a star identical to the one presented in the third phase, but unlike the previous phases, participants are given the option to end the task at any time by pressing a key on the computer keyboard. At the same time, participants are reminded that performance on this final phase dictates how much money they receive for study participation. All participants work independently on the task until voluntary task termination during the final phase or until the task self-terminates at the maximum 7-minute time limit. Behavioral DT was calculated as the latency (in minutes) to task termination on the final phase of this task.

Distress Tolerance Scale (DTS; Simons & Gaher, 2005)

The DTS, a 15-item self-report measure assessing beliefs about feelings of distress, was administered to assess perceived DT in the proposed study. Individuals rated their degree of agreement with a series of statements using a 1-5 Likert scale with 1 indicating strong agreement and 5 indicating strong disagreement with each statement. The DTS consists of several subscales including perceived ability to tolerate distress (Tolerance subscale; e.g., "Feeling distress or upset is unbearable to me"), the individual's subjective appraisal of distress (Appraisal subscale;

e.g., “My feelings of distress or being upset are not acceptable”), how much attention is absorbed by the distress (Absorption subscale, e.g., “My feelings of distress are so intense that they completely take over”), and effort expended to alleviate distress (Regulation subscale, e.g., “I’ll do anything to avoid feeling distressed or upset”). Scores on items in each subscale were meaned to create each subscale score. Subscale scores were then averaged to yield a DTS mean item score. The DTS demonstrated good internal consistency in the current study (α > .88 across all assessment time points), which is in line with previous studies (e.g., Hasan et al, 2015; Leyro, Bernstein, Vujanovic, McLeish, & Zvolensky, 2011; Vujanovic et al., 2017).

Timeline Follow-Back (TLFB; Sobell, Maisto, Sobell, & Cooper, 1979)

The TLFB is an interviewer-administered measure assessing substance use in calendar format. An interviewer guides participants through recollection of day-by-day substance use in reverse order, beginning with the current assessment date and working backwards until the time of last assessment. The interviewer prompts participant’s recollection of use with meaningful events such as birthdays, payday, weekend festivities and holidays that may have occurred over the time interval in question**.** This measure demonstrates high test-retest reliability, convergent and discriminant validity, and agreement with collateral reports of substance use and urinalyses (Fals-Stewart, O'farrell, Freitas, McFarlin, & Rutigliano, 2000). Data acquired from the TLFB was used in the current study to determine 1) abstinence duration, defined as the number of weeks from pre-treatment assessment until first substance use and 2) frequency of substance use, defined as the percent of substance use days in the total days occurring between assessment time points, specifically between pre-treatment and residential discharge (T_{1-2}), residential discharge and 3-months post-treatment (T_{2-3}), 3-months and 6-months post-treatment (T_{3-4}), and 6-months and 12-months post-treatment (T_{4-5}). Participants who attrited prior to first use were conservatively considered relapsed, and in those cases abstinence was coded as the time elapsed between pre-treatment and the last attended assessment. For individuals who remained abstinent throughout the study period, abstinence was coded as the time elapsed between pre-treatment (T_1) and 12-month post-treatment (T_5) assessments.

Statistical Analysis

Perceived and behavioral DT trajectories from pre-treatment (T_1) to 12-months post-treatment (T_5) were assessed separately using latent curve models (LCMs). LCM is a particularly useful analytic tool for large data sets with partially missing data that provides higher levels of statistical power than are available with traditional longitudinal analytic methods (e.g., repeated measures analysis of variance). In addition, LCM can accommodate unequal spacing between time points and allow for the inclusion of both time-invariant and time-varying predictors (Bollen & Curran, 2006). The LCM framework typically includes intercept and slope factors (collectively called growth factors), whose means define the estimated average trajectory of a sample outcome. Variability in these growth factors can also be examined to understand individual differences in the shape of change over time.

The analysis proceeded in several stages. First, we performed preliminary analyses to characterize the sample, identify violations of normality, and visualize patterns of change in the data. Next, given the sample size of the current study, we assessed statistical power of LCM to detect effects using a Monte Carlo simulation study. Additionally, because the DTS is a multi-item measure consisting of multiple subscales, longitudinal measurement invariance was evaluated specifically for this measure to verify that subscales of the DTS represent the same latent constructs across all time points (Horn & McArdle, 1992). However, it was not necessary to evaluate measurement invariance for behavioral DT, as the measure used was persistence time, a “one-item” behavioral variable.

To determine the functional form of change in DT, a series of nested LCMs were fit to the data for both perceived and behavioral DT. First, we tested an intercept-only model that implied no change in DT in the sample over the study timeframe. Second, a linear slope factor was added to the model to allow for linear change in the outcome over follow-up. This linear slope model was compared to the intercept-only model using a likelihood ratio test (i.e., chi-square difference), and the slope factor was retained significant improvement was observed in model fit. Finally, a freed loading slope factor was tested, which allows for non-linear growth in the outcome across study waves (Bollen & Curran, 2006). Specifically, the loadings of the observed indicators on this slope factor are fixed to 0 and 1 for the first and last waves (i.e., T_1 and T_5 respectively), and freely estimated for all other measurement occasions (i.e., T_2, T_3, and T_4). The freed loading model provides a flexible way to test for non-linear growth while conserving parsimony by estimating fewer parameters than more traditional non-linear models (e.g., quadratic latent curve models; Bollen & Curran, 2006). As above, the freed loading slope factor was retained if results of a chi-square difference test indicated that including such a factor significantly improved model fit when compared to the linear slope model. Once the functional form of change was ascertained for perceived and behavioral DT, a final model was tested constraining time-specific residual variances of the DT indicators to equality over time in an effort to maximize model parsimony. If this restricted model did not result in significant decrement in model fit, it was retained and interpreted as the final model of DT change. However, if equality constraints resulted in significantly poorer fit, residual variance terms were freely estimated at all time points. All models were compared with respect to chi-square goodness of fit, the comparative fit index (CFI; Bentler, 1990), the Tucker-Lewis Index (TLI; Tucker & Lewis, 1973), the root-mean square error of approximation (RMSEA; Browne & Cudeck, 1993), and standardized root-mean-square residual (SRMR; Bentler, 1995). Acceptable fit was determined based on recommended guidelines (Hu & Bentler, 1999).

Finally, we examined the effect of substance use on the DT trajectory using two separate conditional LCMs based on the best-fitting unconditional models of perceived and behavioral DT. The conditional first model assessed the association between DT growth factors and abstinence duration, which served as a time-invariant covariate in the analysis This allowed us to preliminarily test the hypothesis that DT would continually improve over time without the influence of substances. However, as relatively few individuals maintain abstinence post-treatment (McLellan, Lewis, O'Brien, & Kleber, 2000; National Institute on Drug Abuse, 2012), it is useful to consider alternative indices, such as substance use severity. Thus, a second model was used to investigate the impact of a time-varying covariate, frequency of use between each assessment time point, on time-specific fluctuations in DT. Utilizing this conceptualization not only allowed us to quantify amount of substance use but also aided in conserving statistical power when compared to binary measurement approaches of use historically used in treatment outcome research (Fitzmaurice, Lipsitz, & Weiss, 2017). Specifically, we regressed the observed DT variables at each post-treatment wave (i.e., T_2-T_5) on a time-specific covariate that represented the percentage of days within the interval since the last assessment during which participants had used substances (i.e., percent days used from T_{1-2}, T_{2-3}, T_{3-4}, and T_{4-5}). Thus, for instance, the observed DT indicator at 3-months post-treatment (T_3) was regressed on a covariate reflecting the percentage of substance use days for the period between residential discharge (i.e., T_2) and 3-months post-treatment (T_3). In addition, we included lagged paths between frequency of use and subsequent observed DT indicators to assess the impact of prior use on future DT. All paths were freely estimated for the time-varying covariate at contiguous and subsequent assessment waves to account for the continuity in drug use over the study timeframe. A final model constraining regressions of observed indicators on the time-varying covariates was tested to maximize parsimony. If model fit was significantly degraded by this imposed constraint, a model with freely estimated regression paths was retained and interpreted.

CHAPTER 3: RESULTS

Preliminary Analyses

Associations between sample characteristics and DT at pre-treatment are reported in **Table 1.**

Table 1. Associations of participant characteristics and DT at pre-treatment.

	DTS_{T1}	$MTPT\text{-}C_{T1}$
Age	r = -0.07	r = 0.03
Sex	t(260) = 3.50**	t(254) = 3.41**
Education	t(260) = -2.46*	t(254) = -1.27
Employment	t(260) = -1.51	t(254) = -0.43
Treatment Condition	t(260) = -1.00	t(254) = 0.24
Alcohol Dependence	t(250) = 2.02*	t(244) = -0.04
Cannabis Dependence	t(249) = -0.34	t(243) = 0.20
Cocaine Dependence	t(250) = 2.27*	t(244) = 2.04*
Opioid Dependence	t(249) = -0.72	t(243) = -0.61
Hallucinogen Dependence	t(248) = -0.94	t(242) = 0.44
Sedative Dependence	t(249) = 0.15	t(243) = -0.02
Note: r = Pearson correlation; t = independent samples t-test statistic; $p < .05$ = *, $p < .01$ = **, $p < .001$ = ***		

Both gender and cocaine dependence were significantly associated with pre-treatment perceived and behavioral DT, while education and alcohol dependence were associated with pre-treatment perceived, but not behavioral, DT. Means, standard deviations, and bivariate correlations between repeated measures of behavioral and perceived DT are presented in **Table 2**.

Table 2. Means, Standard Deviations, and Bivariate Correlations Among Repeated Measures of DT.

	Mean	SD	DTS$_{T1}$	DTS$_{T2}$	DTS$_{T3}$	DTS$_{T4}$	DTS$_{T5}$	MTPT-C$_{T1}$	MTPT-C$_{T2}$	MTPT-C$_{T3}$	MTPT-C$_{T4}$
DTS$_{T1}$	2.90	.89	--								
DTS$_{T2}$	3.09	.87	.54***	--							
DTS$_{T3}$	3.12	.87	.39***	.38***	--						
DTS$_{T4}$	3.08	.94	.43***	.60***	.35***	--					
DTS$_{T5}$	3.22	.86	.38***	.48***	.33**	.46***	--				
MTPT-C$_{T1}$	3.75	2.82	.10	.02	.05	.14*	.004	--			
MTPT-C$_{T2}$	4.51	2.80	.13*	.17*	.11	.07	-.03	.45***	--		
MTPT-C$_{T3}$	4.23	2.81	.16*	.11	.06	.02	-.04	.36***	.57***	--	
MTPT-C$_{T4}$	4.66	2.79	.20**	.12	-.01	.12	.06	.32***	.44***	.65***	--
MTPT-C$_{T5}$	4.67	2.77	.22**	.13	.11	.04	.10	.31***	.46***	.63***	.69***

Note: DTS = Distress Tolerance Scale; MTPT-C = Mirror Tracing Persistence Task- Computerized Version (persistence time in minutes); SD = Standard Deviation; T1 = pre-treatment assessment; T2 = residential discharge assessment; T3 = 3-month follow-up assessment; T4 = 6-month follow-up assessment; T5 = 12-month follow-up assessment; $p < .05$ = *, $p < .01$ = **, $p < .001$ = ***

Significant positive correlations were observed within both perceived (*r* range: .33 to .60) and behavioral DT (*r* range: .31 to .69) over time. In contrast, concurrent measures of perceived and behavioral DT were generally small and not statistically significantly different from 0 (absolute values of *r* range from .004 to .22). In addition, inspection of descriptive statistics and normality plots revealed a ceiling effect for behavioral, but not perceived, DT indicating that a high percentage of participants persisted without quitting on the final phase of the MTPT-C at each time point (T_1=33.1%, T_2 = 42.2%, T_3 = 30.4%, T_4 = 39.5%, T_5 = 37.3%). The Kolmogorov-Smirnov (KS) test of normality was used to investigate distributions of all repeated measures of MTPT-C. Results of this test indicate significant deviation from normality at each time point (KS_{t1} = .19, KS_{t2} = .30, KS_{t3} = .25, KS_{t4} = .31, KS_{t5} = .31). Thus, a robust maximum likelihood estimator was used to estimate the change trajectory of behavioral DT to account for non-normality observed in the data (Muthen & Muthen, 2010).

Power analysis

Data were generated for this *a priori* simulation study using suggested values for intercept and slope factor variances, intercept and slope factor covariance, and residual variances of continuous outcomes (Muthen & Muthen, 2002). For the perceived DT simulation, a population estimate of 3.00 was used as the intercept growth factor mean based on previous work examining single time point DTS scores among treatment seeking substance users (Allan et al., 2015; Hsu, Collins, & Marlatt, 2013, Magidson et al., 2013). The behavioral DT population estimate for the intercept growth factor mean was based on average persistence time of 3.50 minutes on the MTPT-C in prior studies of substance users (Daughters et al., 2005; Daughters, Sargeant, Bornovalova, Gratz, & Lejuez, 2008; Daughters et al., 2009). In both perceived and behavioral DT simulations, the population estimate for the slope factor mean was tested at both

0.20 (small standardized effect) and 0.50 (medium standardized effect). In addition, both models were generated assuming missing data. Because this study uses previously collected data, the probability of missing data was calculated and specified for each measurement occasion. Models were estimated by maximum likelihood for normally distributed data (i.e., DTS) and robust maximum likelihood for non-normally distributed data (i.e., MTPT-C).

Results of the Monte Carlo simulation studies for models where population slope mean estimates were set at 0.20 revealed that a linear latent growth model was adequately powered to detect intercept and slope effects (*power* = 1.00 for both intercept and slope) for both behavioral and perceived DT. A nonlinear model with freed factor estimates was also adequately powered to detect the intercept and slope effects for both behavioral and perceived DT outcomes (intercept: *power* = 1.00; slope: power = .87 and .76 for perceived and behavioral DT respectively). Alternatively, when using a medium effect size (0.5) for population slope mean estimates, both linear and freed factor loading models were well powered to detect mean latent intercept (*power* = 1.00) and slope factors (*power* > .99) for both behavioral and perceived DT.

Longitudinal Measurement Invariance of DTS

We evaluated DTS measurement invariance in a series of three nested models. First, a configural invariance model, in which a unidimensional factor structure for the 15 DTS items was specified at each assessment wave, demonstrated good fit to the data ($\chi^2(120) = 239.74$, $p < .001$; CFI = .96; TLI = .93, RMSEA = .06, SRMR = .05). This result suggested consistency in the latent structure of perceived DT over time. Next, we tested a weak invariance model by constraining DTS factor loadings to equality over time. This model fit the data equally as well as the unrestricted configural invariance model, $\Delta\chi^2(12) = 20.02$, $p = .07$, verifying that DTS indicators had equivalent associations with the latent DT construct over time. Finally, a strong invariance model was tested by restricting both factor loadings and intercepts to be invariant over time. This model produced a significant decrement in fit when compared to the weak invariance model, $\Delta\chi^2(12) = 25.58$, $p = .01$. Inspection of modification indices revealed that constraints associated with strong invariance were particularly problematic for the DTS regulation subscale assessed at the second study wave (T_2). This model was re-specified after freeing the equality constraint on this item. This model fit equally well when compared to the weak invariance model, $\Delta\chi^2(11) = 15.14$, $p = .18$, supporting partial strong invariance for the DTS. Overall, this series of analyses justifies use of a LCM to interpret perceived DT change over time as measured by DTS.

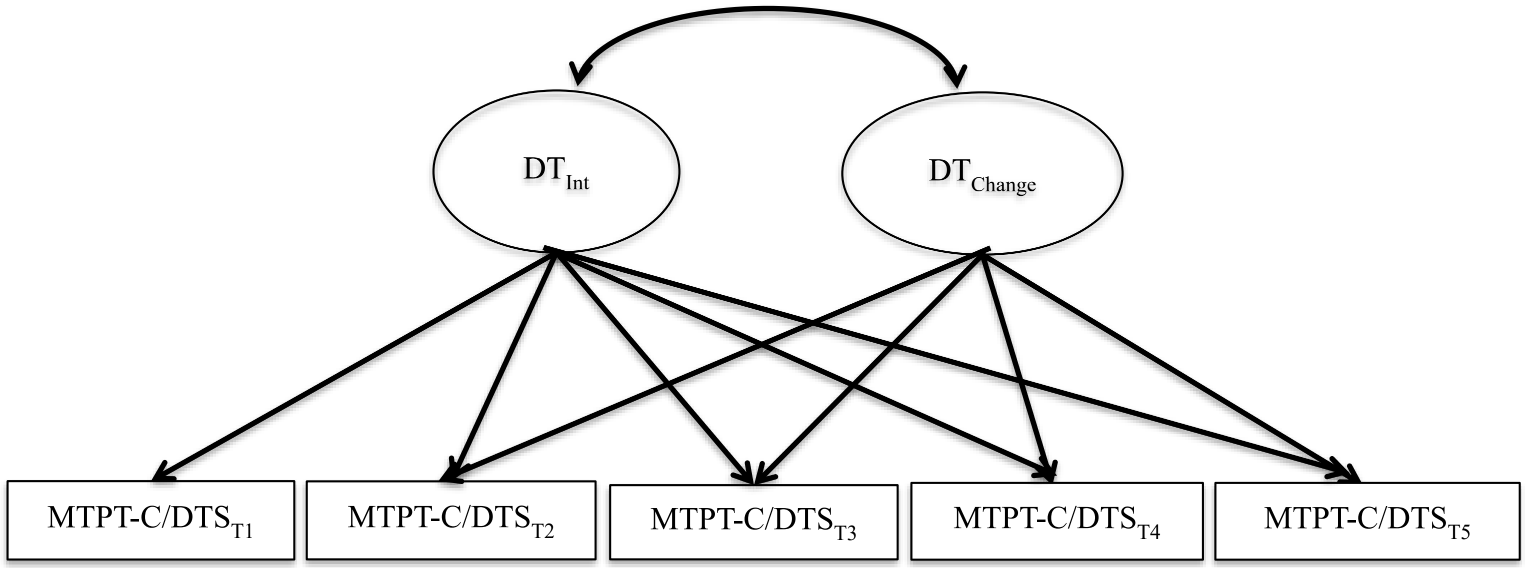
Unconditional Models of Perceived and Behavioral DT

Model comparison

Concerning perceived DT, an intercept-only model was first tested and showed poor fit to the data, $\chi^2(13) = 45.53$, $p < .001$; CFI = .89; TLI = .92; RMSEA = .10; SRMR = .14. Next, a linear growth model was tested and demonstrated significantly improved ($\Delta\chi^2(3) = 18.41$, $p < .001$) but not optimal fit, $\chi^2(10) = 27.12$, $p < .01$; CFI = .94; TLI = .94; RMSEA = .08; SRMR = .10. To test for a non-linear growth trajectory, a freed loading latent growth model was fit to the data, and demonstrated significant improvement over the linear growth model ($\Delta\chi^2(3) = 9.65$, $p < .05$) and good model fit overall, $\chi^2(7) = 17.47$, $p < .01$; CFI = .97; TLI = .95; RMSEA = .08; SRMR = .09. Finally, we tested a freed factor loading model with equality constraints imposed on time specific residuals, but this model produced a significant decrement in fit, $\Delta\chi^2(4) = 9.72$, $p < .05$. Thus we retained the freed loading model with freely estimated residuals as the final perceived DT model.

The same sequence of model comparisons was conducted for behavioral DT using a robust maximum likelihood estimator to account for non-normality in the data. The intercept-only model showed poor fit to the data $\chi^2(13) = 68.53$, $p < .001$; CFI = .77; TLI = .82; RMSEA = .13; SRMR = .12. The linear growth model demonstrated significantly improved (Satorra-Bentler Scaled $\Delta\chi^2(3) = 35.61$, $p < .001$), but not optimal fit to the data, $\chi^2(10) = 32.99$, $p < .001$; CFI = .90; TLI = .90; RMSEA = .09; SRMR = .07. Thus, the freed loading model was tested and led to a significant improvement on the linear LCM (Satorra-Bentler Scaled $\Delta\chi^2(3) = 17.28$, $p < .001$) and good fit to the data overall, $\chi^2(7) = 15.37$, $p = .03$; CFI = .97; TLI = .95; RMSEA = .07; SRMR = .05. Constraining the observed indicator residual variances to equality significantly degraded model fit (Satorra-Bentler Scaled $\Delta\chi^2(4) = 13.25$, $p = .01$) so this restriction was rejected, and the freed loading model with freely estimated residuals was retained as the final behavioral DT model. Final models for both perceived and behavioral DT are displayed in **Figure 1**.

Figure 1. Latent growth curve model examining change trajectory of perceived and behavioral DT.

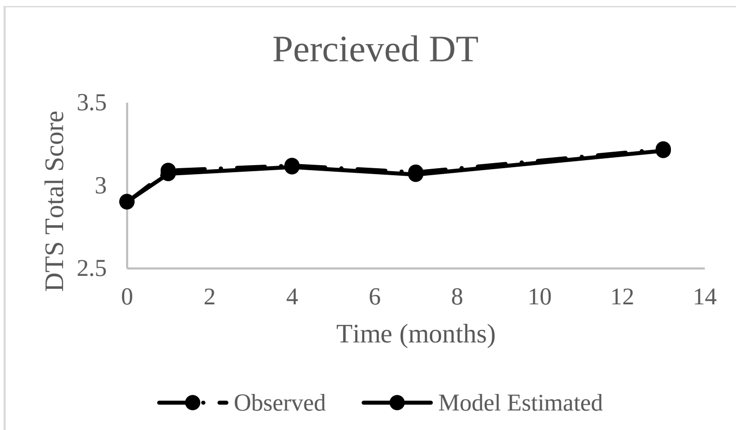


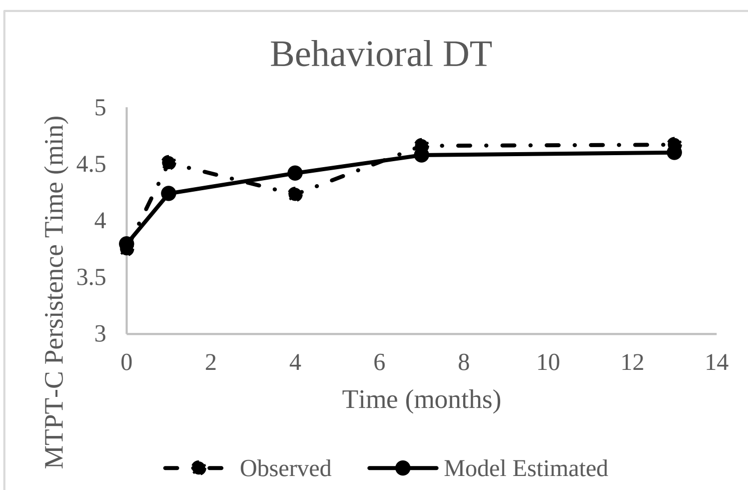
Note: MTPT-C = Mirror Tracing Persistence Test -Computerized Version; DTS = Distress Tolerance Scale; T1 = pre-treatment assessment; T2 = residential discharge assessment; T3 = 3-month follow-up assessment; T4 = 6-month follow-up assessment; T5 = 12-month follow-up assessment

Parameter estimates

Observed and model estimated means of perceived and behavioral DT are displayed in **Figure 2a-b**.

Figure 2a-b. Observed and model estimated sample means for (a) perceived DT estimated using total DTS scores and (b) behavioral DT estimated using task persistence time in minutes on the MTPT-C. Both figures show sample means (observed and model estimated) from DT repeated measures administered at five time points from pre-treatment to 12-months post-treatment.





Note: DT = Distress Tolerance; DTS = Distress Tolerance Scale; MTPT-C = Mirror Tracing Persistence Test- Computerized Version

Additionally, unstandardized factor loadings and parameter estimates from the final unconditional freed loading model of both perceived and behavioral DT are presented in **Table 3**.

Table 3. Unstandardized factor loadings and parameter estimates from unconditional latent curve models of perceived and behavioral DT.

Parameter	Perceived DT (DTS)	Behavioral DT (MTPT-C)
Factor Loadings: Slope		
T_1	0 (0)	0 (0)
T_2	0.51 (0.16)**	0.55 (0.13)***
T_3	0.65 (0.17)***	0.78 (0.12)***
T_4	0.64 (0.20)**	0.97 (0.09)***
T_5	1 (0)	1 (0)
Mean		
Intercept	2.91 (0.06)***	3.79 (0.19)***
Slope	0.31 (0.07)***	0.81 (0.22)***
Variance		
Intercept	0.48 (0.09)***	4.93 (1.09)***
Slope	0.25 (0.16)	5.80 (1.65)***
Intercept-Slope *r*	-0.52 (0.14)***	-0.49 (0.13)***

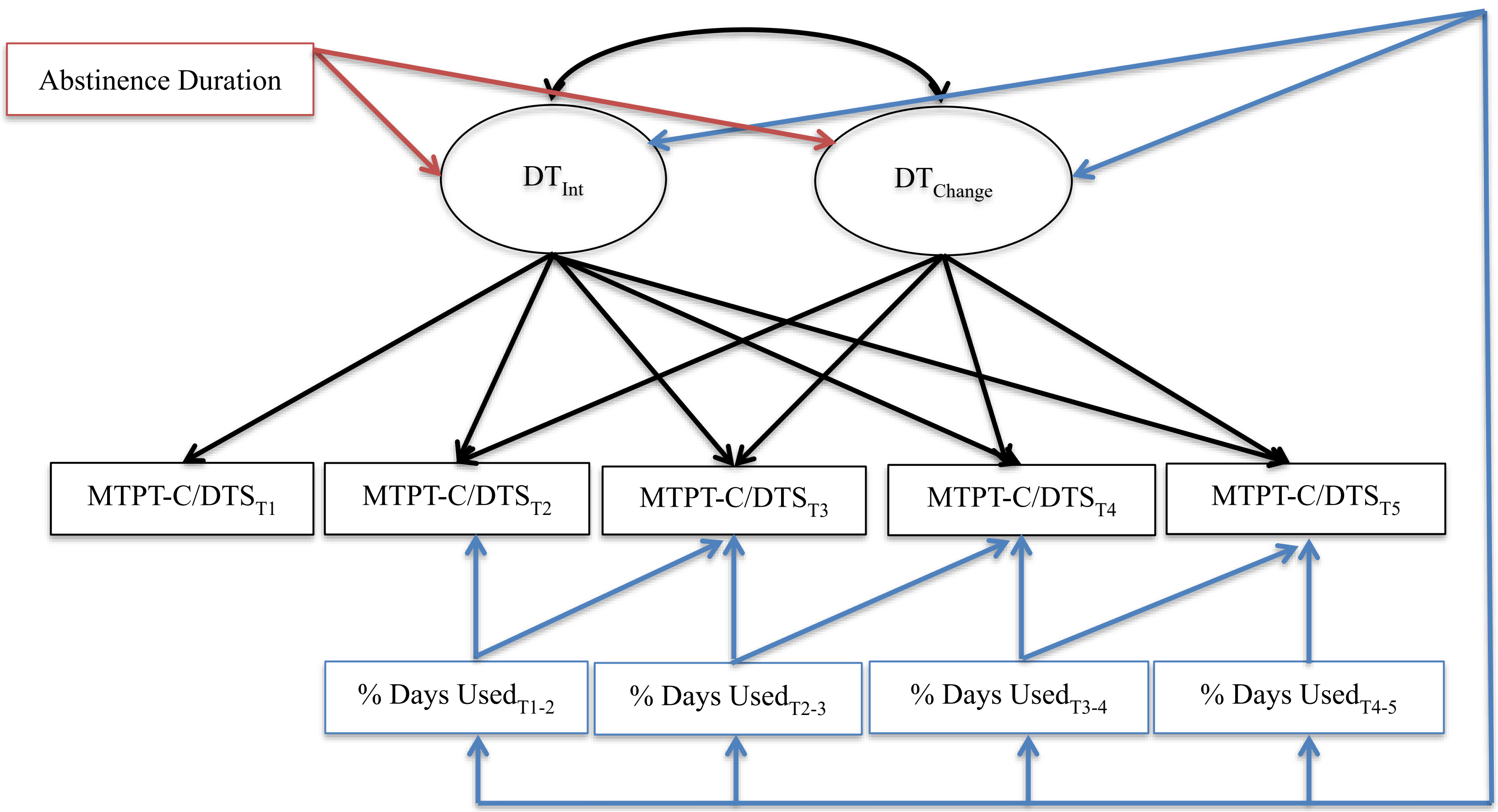
Note: Standard errors are displayed in parentheses; DT = Distress Tolerance; DTS = Distress Tolerance Scale; MTPT-C = Mirror Tracing Persistence Task- Computerized Version; T_1 = pre-treatment assessment; T_2 = residential discharge assessment; T_3 = 3-month follow-up assessment; T_4 = 6-month follow-up assessment; T_5 = 12-month follow-up assessment; $p < .05$ = *, $p < .01$ = **, $p < .001$ = ***

Factor loadings for the first (T_1) and last (T_5) assessment waves were set to 0 and 1 respectively to capture total DT change over the 12-month study period. The unstandardized loadings of the intervening waves (T_{2-4}) can be interpreted as a percentage that represents the proportion of change occurring between two time points relative to total change occurring between first and last time points (McArdle, 1988). As shown, the majority of improvement in both perceived and behavioral DT occurred between pre-treatment (T_1) and residential discharge (T_2) assessments (51% and 55%, respectively). Slope factor means reflecting the expected change in DT from the first to final assessment waves (T_1 to T_5) indicate that both perceived and behavioral DT exhibit a significant propensity to increase nonlinearly over time (*p*s < .001). Furthermore, significant variance in perceived and behavioral DT intercept factors indicate significant individual differences in DT at pre-treatment (T_1), given that the variance of the intercept factor reflects the estimated variability of the outcome at T_1. Significant variance in the behavioral, but not perceived, DT slope factor indicates significant inter-individual variability in behavioral DT change over follow up. Finally, significant negative correlations between both perceived and behavioral DT intercept and slope factors indicate greater DT improvement over time among individuals with low pre-treatment DT. Overall, these models explain 39-59% and 46-70% of the variance in time-specific measurements of perceived and behavioral DT respectively (all *p*s < .001).

Conditional Models of Perceived and Behavioral DT

Figure 3 shows two conditional latent growth models for perceived and behavioral DT. The first examined abstinence duration (red) and the second examined frequency of use (blue) as potential predictors of interest.

Figure 3. Latent growth curve model examining the association of weeks to first use (red) and the influence of time-specific percentage of days used (blue) on the change trajectory of perceived and behavioral DT.

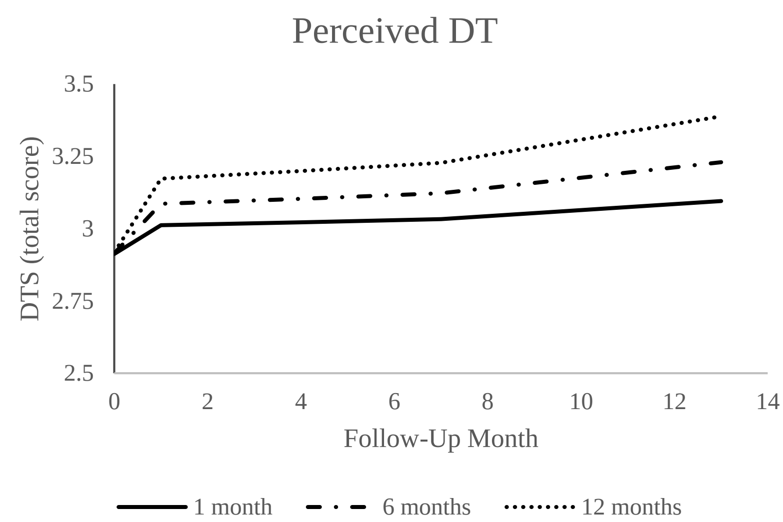


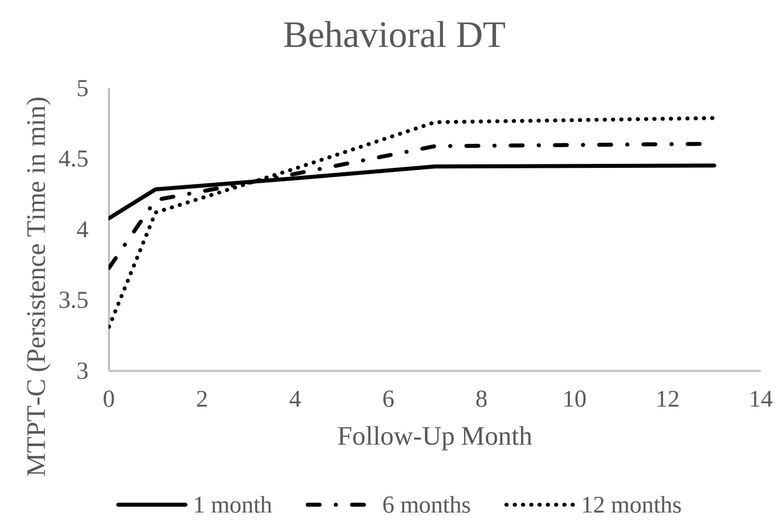
Note: DT = Distress Tolerance; MTPT-C = Mirror Tracing Persistence Test -Computerized Version; DTS = Distress Tolerance Scale; T1 = pre-treatment assessment; T2 = residential discharge assessment; T3 = 3-month follow-up assessment; T4 = 6-month follow-up assessment; T5 = 12-month follow-up assessment

Time-Invariant Covariate: Abstinence Duration

The conditional model estimating the association between abstinence duration and perceived DT trajectory demonstrated adequate fit to the data, $\chi^2(10) = 20.65$, $p = .02$; CFI = .97; TLI = .95; RMSEA = .06; SRMR = .09. Abstinence duration was significantly associated with the perceived DT slope factor ($\beta = .24$; $b = 0.006$, $SE = 0.003$, $p < .05$), but not intercept factor ($\beta = -.01$; $b = 0.001$, $SE = 0.003$, $p = .91$). Similarly, the conditional model estimating the association between abstinence duration and the trajectory of behavioral DT fit the data well, $\chi^2(10) = 19.95$, $p = .03$; CFI = .96; TLI = .95; RMSEA = .06; SRMR = .05. Abstinence duration was significantly associated with the behavioral DT slope factor ($\beta = .20$, $b = .02$, $SE = .01$, $p = .02$) but not intercept ($\beta = -.15$, $b = -.02$, $SE = .01$, $p = .06$). Results of both models are graphically displayed in **Figure 4a-b**, with abstinence duration broken down into 4 weeks (1 month), 26 weeks (6 months), and 52 weeks (12 months) for ease of interpretation. As demonstrated, abstinence duration is positively associated with the perceived (**Figure 4a**) and behavioral (**Figure 4b**) DT trajectory, such that longer periods of abstinence are associated with greater increases in DT over time.

Figure 4a-b. Model estimated trajectory of (a) perceived DT and (b) behavioral DT at specified levels of abstinence duration, a time-invariant predictor. Specifically, the figure shows both perceived and behavioral DT latent trajectory when abstinence duration is equal to 4 weeks (1 month), 26 weeks (6 months), and 52 weeks (12 months).





Time-varying Covariate: Frequency of use

Finally, we tested a LCM with the percentage of days (over follow-up) on which participants used substances serving as a time-varying covariate in the perceived DT model. The initial model fit approached adequate fit, $\chi^2(12) = 26.61$, $p < .01$; CFI = .95; TLI = .88; RMSEA = .07; SRMR = .06. To conserve parsimony, regressions of observed indicators on the time-varying covariates were constrained to equality and did not result in significant degradation of model fit, $\Delta\chi^2(5) = 4.91$, $p = .43$. This model fit the data well, $\chi^2(17) = 31.52$, $p < .02$; CFI = .95; TLI = .92; RMSEA = .06; SRMR = .06, and revealed that frequency of use was not significantly related to DTS scores (i.e. perceived DT) at concurrent (*b* = .03, *SE* = .22, *p* = .89) nor subsequent (*b* = -.01, *SE* = .16, *p* = .97) measurement occasions.

Analysis steps were next replicated using the behavioral DT model. The conditional LCM with percent days used as a time-varying covariate approached adequate fit to the data $\chi^2(12) = 31.30$, $p < .01$; CFI = .95; TLI = .86; RMSEA = .08; SRMR = .04. Regressions of observed indicators on the time-varying covariates were constrained to equality to conserve model parsimony and did not result in significant degradation of model fit, Satorra-Bentler Scaled $\Delta\chi^2(5) = 9.14$, $p = .10$. This model was thus retained, and results revealed that higher percent days used significantly predicted lower MTPT-C scores (i.e. lower behavioral DT) at concurrent (*b* = -1.12, *SE* = .47, *p* < .02) but not subsequent assessment occasions (*b* = .24, *SE* = .53, *p* = .65).

CHAPTER 4: DISCUSSION

The current study examined the trajectory of distress tolerance among substance users receiving residential treatment over a series of five assessment waves occurring intermittently from pre-treatment to 12-months post-treatment and investigated the relationship between DT change over time and both abstinence duration and severity of substance use post-treatment. As predicted, both behavioral and perceived DT improved over time, such that substance users evidenced increased persistence time on a distressing behavioral task, and rated self-reported ability to tolerate distress as generally increasing, from pre-treatment to 12-months post-treatment. In addition, abstinence duration post-treatment was positively associated with both perceived and behavioral DT such that individuals who were able to maintain longer periods of abstinence post-treatment evidenced greater improvements in perceived and behavioral DT. Moreover, greater frequency of use between post-treatment assessment waves was associated with attenuated improvement in post-treatment behavioral DT. Contrary to expectation, this association was not observed for perceived DT change.

This study is the first to provide evidence for naturally occurring DT change over time. Though initial evidence supports the efficacy of DT-targeted treatment in improving DT among varying substance using populations (e.g., Bornovalova et al., 2012; Brown et al., 2014), this study suggests that DT may improve organically over time specifically within this population, as the participants in this trial did not receive treatment targeting distress tolerance (Daughters et al., 2017). The rate of DT change was best characterized as non-linear, suggesting that the rate of

DT change itself changes over time. One explanation may be the influence of environmental factors on an individual's perceived and actual ability to improve DT over time. For example, as demonstrated in this study more than half of the total increase in both perceived and behavioral DT occurred while participants were in the restricted environment of residential treatment, between T_1 (treatment entry) and T_2 (residential treatment discharge). We observe fluctuations in the rate of DT improvement among substance users after treatment discharge, between T_2 and T_5, when environmental factors between participants were no longer held constant. In particular, housing and financial stability, employment, social networks, and acute stressors, that are known to influence the course of recovery for substance users (Davies, Elison, Ward, & Laudet, 2015; Sinha, 2007; Walton, Blow, Bingham, & Chermack, 2003; Worley, Witkiewitz, Brown, Kivlahan, & Longabaugh, 2015) may also have influenced DT trajectories.

Relatedly, we found significant variance in the behavioral DT slope factor specifically, suggesting that not only does the rate of change in DT vary over time, but that differences in overall behavioral DT trajectories exist among substance users. Individual differences in both perceived and behavioral DT at pre-treatment have been investigated in previous studies, revealing relationships between DT and gender (Ali, Seitz-Brown, & Daughters, 2015; Burjarski, Norberg, & Copeland, 2012; Daughters et al., 2009; Tull et al., 2013), and co-occurring psychopathology (Ali, Seitz-Brown, & Daughters, 2015; Gorka, Ali, & Daughters, 2012; Tull et al., 2013). These associations have also been linked to treatment efficacy and outcome among substance users specifically (e.g., Daughters et al., 2009; Gorka, Ali, & Daughters, 2012). However, no study has investigated individual difference factors in relation to behavioral or perceived DT change over time in this population. Though such work is outside the scope of the current study, the association of pre-treatment DT with sample characteristics such as gender and specific substance dependence diagnoses reported here (**Table 1**) provide additional evidence supporting the importance of future studies identifying additional predictors of DT trajectories to further elucidate nuanced variation in DT change.

In the current study, we were specifically interested in examining the influence of substance-related predictors of DT change, namely abstinence and severity of use post-treatment. As predicted, sustained abstinence was associated with greater improvements in both perceived and behavioral DT. This is consistent with findings showing that sustained abstinence allows for recovery of cognitive and affective processes as well as changes in underlying neurobiological structure and function related to DT (Fox, Hong, & Sinha, 2008; Fox et al., 2007; Garavan, Brennan, Hester, & Whelan, 2013; Schmidt, Pennington, Cardoos, Durazzo, & Meyerhoff, 2017; Tull, Schulzinger, Schmidt, Zvolensky, & Lejuez, 2007; Wang et al., 2012). In addition, we found that greater post-treatment frequency of use was associated with attenuated behavioral DT such that participants who used more frequently between assessment waves were unable to persist on a distressing task for as long as those who used less frequently, if at all, during the study period. Research indicates that impairment in cognitive function is associated with acute and chronic substance use (Broyd, van Hell, Beale, Yucel, & Solowij, 2016; Everitt & Robbins, 2016; Volkow et al., 2016), and may be exacerbated by increased rates of use (Grant & Chamberlain, 2014; Vonmoos et al., 2014**).** In addition, evidence suggests that prior heavy use predicts future avoidance behavior and decreased problem solving (Weiss, Bold, Sullivan, Armeli, & Tennen, 2016). Contrary to hypotheses, we did not find a relationship between frequency of substance use and perceived DT change. Theoretical perspectives posit that substance users in particular not only evidence impaired cognitive and behavioral functioning, but additionally lack insight and self-awareness as a by-product of substance use (Goldstein et al., 2009). Thus it may be that individuals who used substances post-treatment were unable to realize the impact of use on current functioning, particularly when evaluating DT. Additional research is needed to understand discrepancies between perceived and behavioral DT within this population more specifically and the implications of this disconnect on future functioning. Nonetheless, findings from the current study lend support to this work and suggest that abstinence allows for recovery of DT while substance use has acute and temporally-specific effects on behavioral DT in particular, providing preliminary evidence for the malleability and sensitivity of DT to proximal psychological and biological events.

Though findings from this study are both novel and important, there are several limitations to consider. First, sample size limits our ability to test for the effects of predictors of DT change over time using a LCM approach. For example, simulation studies conducted by Muthen and Muthen (2002) indicate that the addition of a covariate in a latent growth model significantly increases the sample size necessary to detect effects. As such, we selectively included only two covariates—substance use frequency and abstinence duration—as predictors of DT change in the present study due to their theoretical relevance, and did not evaluate additional potential covariates in relation to current study aims. Additionally, though we examined the relationship between substance use variables and DT change, we were unable to establish definite temporal precedence of abstinence duration and frequency of use in the current study. First, abstinence duration was included in the LCM as a time-invariant covariate, and as such, we were limited to interpreting the association between abstinence and DT change, but could not evaluate the predictive utility of abstinence on such change. Additionally, frequency of use was associated with behavioral DT measured at concurrent, but not subsequent, assessment occasions. For example, we found that substance use occurring between treatment discharge and three months post-treatment was associated with attenuated behavioral DT at three-months post-treatment but was not related to DT at six months post-treatment. One explanation for the null findings of lagged effects may be the large and variable temporal spacing between assessment waves. It may be that substance use behavior has a more immediate effect on DT than could be determined in the current study. Thus, future studies assessing DT and substance use behavior at more frequent intervals post-treatment may be needed to disentangle temporal relationships between substance use and DT change. Finally, the results of the current study reflect the impact of substance use on DT change among a primarily African American sample of residential treatment seeking substance users, limiting the generalizability of study findings. One future direction may be to replicate the current study in other populations, including those from varying racial and ethnic backgrounds, and even non-treatment-seeking substance users or individuals in alternative treatment settings.

Nevertheless, findings from the current study provide important information currently lacking in the DT literature. First, we demonstrated that both perceived and behavioral DT exhibit organic, temporal fluctuations even in the absence of targeted treatment. In general, the temporal stability of the DT construct has been discussed extensively among DT researchers (Leyro, Zvolensky, & Bernstein, 2010) and this study is the first to provide evidence for natural change in both perceived and behavioral conceptualizations of DT among substance users. In addition, by identifying important predictors of this change, we demonstrated both perceived and behavioral DT are sensitive to proximal biological and psychological events. Such situational factors are important to consider in the context of substance use treatment. For example, as higher DT serves as a protective factor against poor treatment outcomes among substance users (Brown, Lejuez, Kahler, & Strong, 2002; Cameron, Reed, & Ninnemann, 2013; Daughters, Lejuez, Kahler, Strong, & Brown, 2005; Strong et al., 2012), prioritizing abstinence duration in current treatment models may allow for natural improvements in DT to occur, and thus improve rates of substance use recovery. Finally, study findings, which support the conceptualization of DT as a malleable treatment target, lend support for continued investigation into the efficacy and implementation of DT-targeted treatment, and emphasize the potential utility of DT-focused treatment among substance users. In conclusion, this study provides the foundation for future research to evaluate DT change as a protective factor among treatment seeking substance users, which may lead to improved outcomes among those suffering from a substance use disorder.

REFERENCES

Ali, B., Ryan, J. S., Beck, K. H., & Daughters, S. B. (2013). Trait aggression and problematic alcohol use among college students: the moderating effect of distress tolerance. *Alcoholism, Clinical and Experimental Research, 37*(12), 2138-2144. doi:10.1111/acer.12198

Ali, B., Seitz-Brown, C. J., & Daughters, S. B. (2015). The interacting effect of depressive symptoms, gender, and distress tolerance on substance use problems among residential treatment-seeking substance users. *Drug and alcohol dependence*, *148*, 21-26.

Allan, N. P., Macatee, R. J., Norr, A. M., Raines, A. M., & Schmidt, N. B. (2015). Relations between common and specific factors of anxiety sensitivity and distress tolerance and fear, distress, and alcohol and substance use disorders. *Journal of anxiety disorders*, *33*, 81-89.

Baker, T. B., Piper, M. E., McCarthy, D. E., Majeskie, M. R., & Fiore, M. C. (2004). Addiction Motivation Reformulated: An affective processing model of negative reinforcement. *Psychological Review, 111*(1), 33-51.

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological bulletin*, *107*(2), 238.

Bollen, K. A., & Curran, P. J. (2006). *Latent curve models: A structural equation perspective* (Vol. 467). John Wiley & Sons.

Bornovalova, M. A., Gratz, K. L., Daughters, S. B., Hunt, E. D., & Lejuez, C. W. (2012). Initial RCT of a distress tolerance treatment for individuals with substance use disorders. *Drug and Alcohol Dependence*, *122*(1-2), 70-76. doi:10.1016/j.drugalcdep.2011.09.012

Brandon, T. H., Herzog, T. A., Juliano, L. M., Irvin, J. E., Lazev, A. B., & Simmons, V. N. (2003). Pretreatment task persistence predicts smoking cessation outcome. *Journal of Abnormal Psychology, 112*(3), 448-456.

Brown, R. A., Bloom, E. L., Hecht, J., Moitra, E., Herman, D. S., & Stein, M. D. (2014). A pilot study of a distress tolerance treatment for opiate-dependent patients initiating buprenorphine: rationale, methodology, and outcomes. *Behavior Modification, 38*(5), 730-759.

Brown, R. A., Lejuez, C. W., Kahler, C. W., & Strong, D. R. (2002). Distress tolerance and duration of past smoking cessation attempts. *Journal of Abnormal Psychology, 111*(1), 180-185.

Brown, R. A., Palm, K. M., Strong, D. R., Lejuez, C. W., Kahler, C. W., Zvolensky, M. J., . . . Gifford, E. V. (2008). Distress tolerance treatment for early-lapse smokers rationale, program description, and preliminary findings. *Behavior Modification, 32*(3), 302-332.

Brown, R. A., Reed, K. M. P., Bloom, E. L., Minami, H., Strong, D. R., Lejuez, C. W., . . . Hayes, S. C. (2013). Development and preliminary randomized controlled trial of a distress tolerance treatment for smokers with a history of early lapse. *Nicotine & Tobacco Research*, *15*(12), 2005-2015.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. *Sage focus editions*, *154*, 136-136.

Broyd, S. J., van Hell, H. H., Beale, C., Yücel, M., & Solowij, N. (2016). Acute and chronic effects of cannabinoids on human cognition—a systematic review. *Biological psychiatry*, *79*(7), 557-567.

Buckner, J. D., Keough, M. E., & Schmidt, N. B. (2007). Problematic alcohol and cannabis use among young adults: The roles of depression and discomfort and distress tolerance. *Addictive Behaviors*, *32*(9), 1957-1963.

Buckner, J. D., Jeffries, E. R., Terlecki, M. A., & Ecker, A. H. (2016). Distress tolerance among students referred for treatment following violation of campus cannabis use policy: Relations to use, problems, and motivation. *Behavior modification*, *40*(5), 663-677.

Bujarski, S. J., Norberg, M. M., & Copeland, J. (2012). The association between distress tolerance and cannabis use-related problems: the mediating and moderating roles of coping motives and gender. *Addictive behaviors*, *37*(10), 1181-1184.

Cameron, A., Reed, K. P., & Ninnemann, A. (2013). Reactivity to negative affect in smokers: The role of implicit associations and distress tolerance in smoking cessation. *Addictive Behaviors*, *38*(12), 2905-2912.

Dahlgren, M. K., Sagar, K. A., Racine, M. T., Dreman, M. W., & Gruber, S. A. (2016). Marijuana use predicts cognitive performance on tasks of executive function. *Journal of studies on alcohol and drugs*, *77*(2), 298-308.

Daughters, S. B., Lejuez, C., Kahler, C. W., Strong, D. R., & Brown, R. A. (2005). Psychological distress tolerance and duration of most recent abstinence attempt among residential treatment-seeking substance abusers. *Psychology of Addictive Behaviors*, *19*(2), 208.

Daughters, S. B., Lejuez, C. W., Bornovalova, M. A., Kahler, C. W., Strong, D. R., & Brown, R. A. (2005). Distress Tolerance as a Predictor of Early Treatment Dropout in a Residential Substance Abuse Treatment Facility. *Journal of Abnormal Psychology*, *114*(4), 729-734.

Daughters, S. B., Ross, T. J., Bell, R. P., Yi, J. Y., Ryan, J., & Stein, E. A. (2016). Distress tolerance among substance users is associated with functional connectivity between prefrontal regions during a distress tolerance task. *Addiction Biology*.

Daughters, S. B., Magidson, J. F., Anand, D., Seitz-Brown, C. J., Chen, Y., & Baker, S. (2017). The Effect of a Behavioral Activation Treatment for Substance Use on Post-treatment Abstinence: A Randomized Controlled Trial. *Addiction*.

Daughters, S. B., Sargeant, M. N., Bornovalova, M. A., Gratz, K. L., & Lejuez, C. W. (2008). The relationship between distress tolerance and antisocial personality disorder among male inner-city treatment seeking substance users. *Journal of personality disorders*, *22*(5), 509-524.

Daughters, S. B., Reynolds, E. K., MacPherson, L., Kahler, C. W., Danielson, C. K., Zvolensky, M., & Lejuez, C. W. (2009). Distress tolerance and early adolescent externalizing and internalizing symptoms: The moderating role of gender and ethnicity. *Behaviour research and therapy*, *47*(3), 198-205.

Davies, G., Elison, S., Ward, J., & Laudet, A. (2015). The role of lifestyle in perpetuating substance use disorder: the Lifestyle Balance Model. *Substance abuse treatment, prevention, and policy*, *10*(1), 2.

Everitt, B. J., & Robbins, T. W. (2016). Drug addiction: updating actions to habits to compulsions ten years on. *Annual review of psychology*, *67*, 23-50.

Fals-Stewart, W., O'farrell, T. J., Freitas, T. T., McFarlin, S. K., & Rutigliano, P. (2000). The timeline followback reports of psychoactive substance use by drug-abusing patients: psychometric properties. *Journal of Consulting and Clinical Psychology*, *68*(1), 134.

First MB, Spitzer RL, Gibbon M, Williams JBW. (1994). Structured clinical interview for DSM-IV patient edition (SCID-NP, Version 2.0) New York, NY: Biometrics Research Department.

Fitzmaurice, G. M., Lipsitz, S. R., & Weiss, R. D. (2017). Statistical considerations in the choice of endpoint for drug use disorder trials. *Drug & Alcohol Dependence*.

Fox, H., Axelrod, S., Paliwal, P., Sleeper, J., & Sinha, R. (2007). Difficulties in emotion regulation and impulse control during cocaine abstinence. *Drug and Alcohol Dependence*, *89*(2), 298-301.

Fox, H., Hong, K., & Sinha, R. (2008). Difficulties in emotion regulation and impulse control in recently abstinent alcoholics compared with social drinkers. *Addictive Behaviors*, *33*(2), 388-394.

Garavan, H., Brennan, K., Hester, R., & Whelan, R. (2013). The neurobiology of successful abstinence. *Current Opinion in Neurobiology*, *23*(4), 668-674.

Glassman, L. H., Martin, L. M., Bradley, L. E., Ibrahim, A., Goldstein, S. P., Forman, E. M., & Herbert, J. D. (2015). A Brief Report on the Assessment of Distress Tolerance: Are We

Measuring the Same Construct?. *Journal Of Rational-Emotive & Cognitive-Behavior Therapy, 34*(2), 87-99.

Goldstein, R. Z., Bechara, A., Garavan, H., Childress, A. R., Paulus, M. P., & Volkow, N. D. (2009). The neurocircuitry of impaired insight in drug addiction. Trends in cognitive sciences, 13(9), 372-380.

Gorka, S. M., Ali, B., & Daughters, S. B. (2012). The role of distress tolerance in the relationship between depressive symptoms and problematic alcohol use. *Psychology of Addictfoxive Behaviors*, *26*(3), 621.

Grant, J. E., & Chamberlain, S. R. (2014). Impulsive action and impulsive choice across substance and behavioral addictions: cause or consequence?. *Addictive behaviors*, *39*(11), 1632-1639.

Hasan, N. S., Babson, K. A., Banducci, A. N., & Bonn-Miller, M. O. (2015). The prospective effects of perceived and laboratory indices of distress tolerance on cannabis use following a self-guided quit attempt. *Psychology of Addictive Behaviors, 29*(4), 933.

Horn, J. L., & McArdle, J. J. (1992). A practical and theoretical guide to measurement invariance in aging research. *Experimental Aging Research*, *18,* 117-144.

Hsu, S. H., Collins, S. E., & Marlatt, G. A. (2013). Examining psychometric properties of distress tolerance and its moderation of mindfulness-based relapse prevention effects on alcohol and other drug use outcomes. *Addictive behaviors*, *38*(3), 1852-1858.

Hu, L. T., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural equation modeling: a multidisciplinary journal*, *6*(1), 1-55.

Kiselica, A. M., Rojas, E., Bornovalova, M. A., & Dube, C. (2015). The nomological network of self-reported distress tolerance. *Assessment*, *22*(6), 715-729.

Koob, G. F., & Le Moal, M. (1997). Drug abuse: hedonic homeostatic dysregulation. *Science, 278*(5335), 52-58.

Koob, G. F., & Le Moal, M. (2001). Drug addiction, dysregulation of reward, and allostasis. *Neuropsychopharmacology, 24*(2), 97-129.

Lejuez, C., Kahler, C. W., & Brown, R. A. (2003). A modified computer version of the Paced Auditory Serial Addition Task (PASAT) as a laboratory-based stressor. *The Behavior Therapist, 26*(4), 290-293.

Leyro, T. M., Zvolensky, M. J., & Bernstein, A. (2010). Distress tolerance and psychopathological symptoms and disorders: A review of the empirical literature among adults. *Psychological Bulletin, 136*(4), 576-600. doi:10.1037/a0019712

Leyro, T. M., Bernstein, A., Vujanovic, A. A., McLeish, A. C., & Zvolensky, M. J. (2011). Distress Tolerance Scale: A confirmatory factor analysis among daily cigarette smokers. *Journal of psychopathology and behavioral assessment*, *33*(1), 47-57.

Magidson, J. F., Listhaus, A. R., Seitz-Brown, C. J., Anderson, K. E., Lindberg, B., Wilson, A., & Daughters, S. B. (2013). Rumination mediates the relationship between distress tolerance and depressive symptoms among substance users. *Cognitive therapy and research*, *37*(3), 456-465.

McArdle, J. J. (1988). Dynamic but structural equation modeling of repeated measures data. In *Handbook of multivariate experimental psychology* (pp. 561-614). Springer US.

McHugh, R. K., Daughters, S. B., Lejuez, C. W., Murray, H. W., Hearon, B. A., Gorka, S. M., & Otto, M. W. (2011). Shared variance among self-report and behavioral measures of distress intolerance. *Cognitive Therapy and Research*, *35*(3), 266-275.

McLellan, A. T., Lewis, D. C., O'brien, C. P., & Kleber, H. D. (2000). Drug dependence, a chronic medical illness: implications for treatment, insurance, and outcomes evaluation. *Jama*, *284*(13), 1689-1695.

Muthén, L. K., & Muthén, B. O. (2002). How to use a Monte Carlo study to decide on sample size and determine power. *Structural equation modeling*, *9*(4), 599-620.

Muthen, L. K., & Muthén, B. O. (2010). Mplus user’s guide, v. 6.1. *Los Angeles, CA: Muthen and Muthen, UCLA.*

National Institute on Drug Abuse, (2012). *Prinicples of drug addition treatment: A Research-based guide* (3rd ed.). NIH Publication No. 12-4180. Rockville, MD: National Institute on Drug Abuse.

Perkins, K. A., Giedgowd, G. E., Karelitz, J. L., Conklin, C. A., & Lerman, C. (2012). Smoking in response to negative mood in men versus women as a function of distress tolerance. *Nicotine & Tobacco Research*, *14*(12), 1418-1425.

Quinn, E. P., Brandon, T. H., & Copeland, A. L. (1996). Is task persistence related to smoking and substance abuse? The application of learned industriousness theory to addictive behaviors. *Experimental and Clinical Psychopharmacology*, *4*(2), 186.

Schmidt, N. B., Richey, J. A., & Fitzpatrick, K. K. (2006). Discomfort intolerance: Development of a construct and measure relevant to panic disorder. *Journal of Anxiety Disorders, 20*(3), 263-280.

Schmidt, T. P., Pennington, D. L., Cardoos, S. L., Durazzo, T. C., & Meyerhoff, D. J. (2017). Neurocognition and inhibitory control in polysubstance use disorders: Comparison with alcohol use disorders and changes with abstinence. *Journal of clinical and experimental neuropsychology*, *39*(1), 22-34.

Simons, J. S., & Gaher, R. M. (2005). The Distress Tolerance Scale: Development and validation of a self-report measure. *Motivation and Emotion, 29*(2), 83-102.

Sinha, R. (2007). The role of stress in addiction relapse. *Current psychiatry reports*, *9*(5), 388-395.

Sobell, L. C., Maisto, S. A., Sobell, M. B., & Cooper, A. M. (1979). Reliability of alcohol abusers' self reports of drinking behavior.

Strong, D. R., Brown, R. A., Sims, M., Herman, D. S., Anderson, B. J., & Stein, M. D. (2012). Persistence on a Stress-challenge Task Before Initiating Buprenorphine Treatment Was Associated With Successful Transition From Opioid Use to Early Abstinence. *Journal of Addiction Medicine, 6*(3), 219-225. doi:10.1097/ADM.0b013e31825d927f

Trafton, J., & Gifford, E. (2010). Biological bases of distress tolerance. Zvolensky, MJ, Bernstein A, Vujanovic AA (Eds). Distress Tolerance: Theory, Research and Clinical Applications: New York: The Guilford Press.

Tucker, L. R., & Lewis, C. (1973). A reliability coefficient for maximum likelihood factor analysis. *Psychometrika*, *38*(1), 1-10.

Tull, M. T., Gratz, K. L., Coffey, S. F., Weiss, N. H., & McDermott, M. J. (2013). Examining the interactive effect of posttraumatic stress disorder, distress tolerance, and gender on residential substance use disorder treatment retention. *Psychology of Addictive Behaviors, 27*(3), 763-773. doi:10.1037/a0029911

Tull, M. T., Schulzinger, D., Schmidt, N. B., Zvolensky, M. J., & Lejuez, C. (2007). Development and initial examination of a brief intervention for heightened anxiety sensitivity among heroin users. *Behavior Modification, 31*(2), 220-242.

Volkow, N. D., Swanson, J. M., Evins, A. E., DeLisi, L. E., Meier, M. H., Gonzalez, R., ... & Baler, R. (2016). Effects of cannabis use on human behavior, including cognition, motivation, and psychosis: a review. *JAMA psychiatry*, *73*(3), 292-297.

Vonmoos, M., Hulka, L. M., Preller, K. H., Minder, F., Baumgartner, M. R., & Quednow, B. B. (2014). Cognitive impairment in cocaine users is drug-induced but partially reversible: evidence from a longitudinal study. *Neuropsychopharmacology, 39*(9), 2200-2210.

Vujanovic, A. A., Meyer, T. D., Heads, A. M., Stotts, A. L., Villarreal, Y. R., & Schmitz, J. M. (2017). Cognitive-behavioral therapies for depression and substance use disorders: an overview of traditional, third-wave, and transdiagnostic approaches. *The American journal of drug and alcohol abuse*, *43*(4), 402-415.

Wang, T. Y., Fan, T. T., Bao, Y. P., Li, X. D., Liang, C. M., Wang, R. J., ... & Shi, J. (2017). Pattern and related factors of cognitive impairment among chronic methamphetamine users. *The American journal on addictions*, *26*(2), 145-151.

Wang, X., Li, B., Zhou, X., Liao, Y., Tang, J., Liu, T., ... & Hao, W. (2012). Changes in brain gray matter in abstinent heroin addicts. *Drug and alcohol dependence*, *126*(3), 304-308.

Walton, M. A., Blow, F. C., Bingham, C. R., & Chermack, S. T. (2003). Individual and social/environmental predictors of alcohol and drug use 2 years following substance abuse treatment. *Addictive behaviors*, *28*(4), 627-642.

Weiss, N. H., Bold, K. W., Sullivan, T. P., Armeli, S., & Tennen, H. (2017). Testing bidirectional associations among emotion regulation strategies and substance use: a daily diary study. *Addiction*, *112*(4), 695-704.

Worley, M. J., Witkiewitz, K., Brown, S. A., Kivlahan, D. R., & Longabaugh, R. (2015). Social network moderators of naltrexone and behavioral treatment effects on heavy drinking in the COMBINE study. *Alcoholism: Clinical and Experimental Research*, *39*(1), 93-100.

Zvolensky, M. J., Vujanovic, A. A., Bernstein, A., & Leyro, T. (2010). Distress tolerance: Theory, measurement, and relations to psychopathology. *Current Directions in Psychological Science, 19*(6), 406-410. doi:10.1177/0963721410388642