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Publication Date

2024

DOI

10.1037/abn0000948

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Moriarity, D.P.; Case, J.; Kautz, M.M.; Ghias, K.; Pennypacker, K.; Angus, D.; Harmon-Jones, E.; & Alloy, L.B. (*in press*). Toward diversification of acute stressors and precision stress research: Validation of a reward-salient stress task in emerging adults. *Journal of Psychopathology and Clinical Science*.

Toward Diversification of Acute Stressors and Precision Stress Research: Validation of a Reward-Salient Stress Task in Emerging Adults

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Author Note: The registered report, code, and materials can be found at https://osf.io/8y6gh/. The study was approved by Temple University's IRB (#26290). CRediT specifications: DPM contributed to all parts of this study's execution. All other authors contributed to reviewing and editing the writing. More specifically, JC contributed to the resources and software; MK contributed to funding acquisition, investigation, project administration, and supervision; KG and KP contributed to the investigation; DA contributed to conceptualization, resources, and software; EHJ contributed to conceptualization, funding acquisition, and resources; and LBA contributed to conceptualization, funding acquisition, project administration, resources, and supervision. Daniel P. Moriarity was supported by National Research Service Award F31 MH122116 (the primary grant supporting Daniel Moriarity's salary and the execution of Project MIME) and an APF Visionary Grant (which provided supplemental funds for Project MIME). Daniel is presently funded by National Research Service Award F32 MH130149 and grant #OPR21101 from the California Governor's Office of Planning and Research/California Initiative to Advance Precision Medicine. Lauren B. Alloy was supported by National Institute of Mental Health R01 MH101168 and R01 MH123473 (both of which paid for lab infrastructure and study staff that supported Project MIME). The authors report no conflicts of interest.

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Abstract

Stress is one of, if not the, most ubiquitously studied risk factor across the health sciences. This unlikely to change given that the primary drivers of mortality and disability are chronic, stress-mediated illnesses (often highly comorbid with psychopathology). We argue that an important limitation of stress research is the consistency with which the Trier Social Stress Test is used when the research questions are not specific to social stress. We advocate for precision stress research using qualitatively different stressors to facilitate exploration of how different types of stressors might differentially impact health outcomes, including psychopathology. This registered report validates a reward-salient stress task (a modified Anger Incentive Delay Task; AIDT) in a sample of 101 emerging adults, over half of whom reported clinically relevant anxiety, hypo/mania, depression, and/or suicidal ideation, who participated in a study between 2020 and 2022. This task involves teaching participants a game where they can win money. Part way through, the "goal frustration" condition changes the rules such that correct responses to trials with anticipatory stimuli indicating the possibility to win money actually lose money on 56% of trials despite visual feedback indicating that responses were successful. Results consistently indicated that the AIDT successfully reduced positive emotions and motivation and increased negative emotions. The magnitude of these responses were predicted by individual differences in reward and punishment sensitivity. Given the breadth of psychopathologies that share both stress and reward and punishment sensitivity as risk factors, a reward-salient acute stress task is an important tool for precision psychopathology research.

Keywords: Reward sensitivity; Reward processing; Punishment sensitivity; Anger Incentive Delay Task; Stress

General Scientific Summary

High and low reward processing are key risk factors for many mental health problems, as is elevated stress reactivity; however, the vast majority of studies using acute lab-based stressors rely on social stress tasks. To facilitate stress research focused on reward processing, this study validates a modified version of the Anger Incentive Delay Task—demonstrating its ability to induce emotional and motivational changes and that these changes are greater in individuals with elevated reward and punishment sensitivity.

Introduction

Stress is arguably one of, if not the, most ubiquitously studied risk factors across the health sciences. This is not likely to change given that the primary drivers of modern mortality and disability are chronic, stress-mediated illnesses such as heart disease (Case & Deaton, 2017) and depression (LeMoult et al., 2020). Given the transdiagnostic importance of stress research, improving public health is contingent on methodologically rigorous studies that capture the nuance of human psychosocial and physiological responses to stress.

The vital importance of comprehensive stress research inspired the recent NIMH director's call to diversify and refine stress research methodology to "understand the heterogeneity across stressors and their associated outcomes" (Simmons et al., 2021). Acute stressor paradigms are key to studying stress responses and the most popular psychosocial stressor for humans in many (if not all) subfields is the Trier Social Stress Test (TSST; Kirschbaum et al., 1993) due to its demonstrated ability to consistently evoke psychological and biological stress responses (Man et al., 2023; Seddon et al., 2020; Shields et al., 2016; Szabo et al., 2020). The TSST challenges participants to a public speaking assignment and a surprise mathematics test. Although the utility of this task is proven, the dearth of published studies using non-TSST acute lab stressors is a field-wide limitation due to the inability to test whether stressor—outcome associations depend on the type of stressor used (Shields et al., 2016).

The lack of acute laboratory stressor diversity further entrenches noted issues within stress science methodology, referred to as "stressnology" (Slavich, 2019). Specifically, the TSST's monopoly on psychosocial stress paradigms precludes scientists from challenging implicit assumptions that stressors possessing different psychosocial characteristics are equivalent and interchangeable with respect to their consequences (Slavich, 2019). In other words, it is difficult to evaluate the extent to which two stressors' qualitative differences (e.g., social vs. goal-oriented) differentially impact outcomes of interest (e.g., depression risk, likelihood to engage in problematic substance use, biological stress reactivity). Further, without psychosocially distinct stressor paradigms, it is impossible to identify characteristics that predict which type of stressor an individual will find most stressful. This lack of information is in stark contrast to the understanding that there are individual differences in which types of events are most stressful (Brown et al., 2020; Roth et al., 2015) and person-specific stressor prioritization in many therapeutic techniques (e.g., establishment of a personalized fear hierarchy in exposure therapy or identifying person-specific themes behind prompting events using chain analysis; Katerelos et al., 2008; Linehan, 2014; Rizvi & Ritschel, 2014).

Consistent with the tenets of precision medicine to identify treatments that are ideally beneficial for an individual, we advocate for precision stress research that evaluates the extent to which qualitatively different stressors differentially impact individuals and how psychosocial profiles may explain these differences. Given the different psychosocial risk and maintenance factors associated with separate diagnoses/dimensions of psychopathology, we believe precision stress studies using stressors that are complementary to the theories under study (e.g., reward-salient stressors for mood psychopathologies; Alloy et al., 2016; Alloy & Abramson, 2010; Moriarity, Ng, Titone, et al., 2020) have the potential to identify critical psychosocial stressors and/or skills to target in treatment for individuals with specific diagnoses, symptom profiles, and/or risk factors. Further, precision stress research would allow the exploration of stressor-specific, multi-level mechanisms and maintenance factors of psychopathology.

The adoption of precision stress research (in clinical psychology and beyond) is contingent on validating a variety of stressors that complement key psychosocial characteristics.

Originally designed as an anger induction task for neuroscience research, the Anger Incentive Delay Task (AIDT; Angus & Harmon-Jones, 2019) is a reward-salient stressor that induces goal frustration. Goal frustration refers to when a goal, reward, or desired state is blocked, disrupted, or does not occur when it “ought to” based on expectations regarding goal contingencies (Carver & Harmon-Jones, 2009a, 2009b; Frijda, 1986). Goal frustration has been associated with greater subjective frustration (Rich et al., 2007) and neural reactivity (i.e., changes in event-related potentials) compared to non-frustrating goal outcomes (Gatzke-Kopp et al., 2015; Rich et al., 2007, p. 200) and is key to the concept of BAS (Behavioral Activation System) de-activating states in the BAS theory of mood psychopathology (Alloy et al., 2008).

Critically, “frustrative nonreward” is one of the six constructs in the negative valence systems domain of the National Institutes of Mental Health Research Domain Criteria (RDoC; Insel et al., 2010). In a recent expert consensus report (NIMH, 2016), two existing lab-based methods were recommended to assess frustrative nonreward: the Points Subtraction Aggression Paradigm (PSAP; Cherek, 1981; Geniole et al., 2017) and the Laboratory Temperament Assessment Battery (Lab-TAB; Gagne et al., 2011). The PSAP focuses on inducing aggression and competitive interaction via a computer game, with participants competing against a fictitious opponent to earn points that can be exchanged for money. Points are earned by pressing a specific key a set number of times. They are warned that the opponent can steal a point from them, which is indicated by a red flashing light and a score decrease. Should this happen, participants can either (a) continue to earn points by pressing the button, (b) press a second key that protects their points for a duration, or (c) press a third key to steal points from the opponent. Participants are instructed that they have been randomized into a condition where they cannot use any of their stolen points—so stealing points only hurts the other player but does not benefit the participant's score. The Lab-TAB is a task designed to assess child temperament using 12 standardized behavioral episodes to elicit specific behavioral and emotional reactions. Specifically, the NIMH report suggests two episodes as tasks pertinent to frustrative nonreward: Box Empty (in which a child opens a wrapped box to build the expectation it is a "present," but the box is empty) and Transparent Box (in which a desirable object is locked in a transparent box, visible but inaccessible to the child).

Although beneficial in certain contexts, each of these tasks have limitations that do not apply to the AIDT. Specifically, the PSAP combines frustrative nonreward with social stressors (i.e., competition), making it difficult to isolate stress responses to a particular stress dimension/context. It also lacks a true baseline in which the participant plays the game outside of a stress-inducing scenario. Alternatively, the Lab-TAB is developmentally limited to toddlers—a critical limitation for research on psychopathologies that often develop later in life. It also lacks the ability (or at least, the illusion of the ability) for the participant to influence the outcome, which could plausibly increase the magnitude of the stress response as the participant invests more energy without earning a reward. As such, there is a need for complementary, alternative frustrative nonreward tasks to support RDoC-inspired (and other) research.

Before describing the AIDT itself, and in line with a precision stress approach, it is critical to delineate between several common terms found in stress research. For this task, we distinguish between the stressor itself (i.e., the task that aims to induce stress), stress (i.e., a latent state resulting from a perceived inability to reach a desired and/or anticipated outcome (Epel et al., 2018)), and frustration (a specific affective stress response). Specifically, frustration is part of the larger emotional construct of "anger" (Ekma, 1992)—supported by factor analytic work featuring items about "frustration" loading onto the same factor as other anger-related terms (e.g., irritated, furious, angry; C. Harmon-Jones et al., 2016) and studies finding that anger and frustration manipulations typically induce similar affective and EEG responses (Angus et al., 2016; E. Harmon-Jones, 2003, 2007) .

The AIDT builds off the monetary incentive delay task (MID; Knutson et al., 2000) in that each participant is instructed to win money (during “gain trials”) while avoiding losing money on other trials (“breakeven trials”) by responding to an onscreen target stimulus by pressing the spacebar before the end of the trial. As part of the MID (and AIDT), participants received feedback regarding the success of each trial and whether they had won money (responded in time for “gain trials”), broke even (responded in time for “breakeven trials”), or lost money (failed to respond in time). The primary difference between the MID and AIDT was the structure of the trials. In the original AIDT task (Angus & Harmon-Jones, 2019), 56% of the trials featured rewards consistent with what the participant was informed prior to the trial and what the feedback stimulus indicated; 22% were designed to ensure that the participant was unsuccessful and received corresponding feedback and lost money; and 22% of trials had “inconsistent” outcomes (novel to the AIDT). Half of these trials (11% total) provided feedback that participants would win money, but then participants were informed they lost money (referred to as “goal frustration trials”). In the other half of the inconsistent trials, participants won money when informed that they could only breakeven (“surprise trials”). These trials were interspersed across twelve 19-trial blocks. In the original validation study, the AIDT successfully induced negative state affect and physiological responses (P3b amplitudes) to the goal frustration trials (Angus & Harmon-Jones, 2019).

Although the AIDT represents a critical step toward acute stressor diversification, several features of the original AIDT that hinder its suitability to a wide variety of stress science subfields (including many subfields of clinical psychology). First, whereas this dispersion of goal frustration trials complements neural and behavioral assessments that can track trial-level responses and performance, it is not ideal for outcome measures with less temporal resolution (e.g., pre-/post-block, pre-/post-stressor) that seek to compare affective or biological differences between responses to goal frustration vs. non-frustration conditions. Second, some studies that want to strictly use this task as a stressor may not benefit from including “surprise” trials where participants unexpectedly earn money—which could dilute the stress experienced. Third, many potential outcomes of interest (hopelessness, peripheral stress biology) might lack sensitivity to goal frustration trials interspersed with non-frustration trials (which might induce confusion rather than frustration). It is plausible that some clinically meaningful effects instead might require concentrated exposure to consistent goal frustration trials to observe effects. Fourth, affective or physiological reactions to frustration trials might carry-over to other, positively- or neutrally-valenced trials (potentially confounding dependent variables and/or task performance). Fifth, it also is plausible that goal frustration might be enhanced after a concentrated exposure to the non-frustration trials during which a participant can develop feelings of mastery and confidence. Given reward processing’s role as a transdiagnostic factor in a variety of psychopathological outcomes such as bipolar spectrum disorders (Alloy et al., 2016; Alloy & Abramson, 2010), depression (Alloy et al., 2016; Foti & Hajcak, 2009), substance use (Bart et al., 2021; Baskin-Sommers & Foti, 2015), and psychosis (Leroy et al., 2020), it is critical to validate modified AIDT protocols that complement outcomes and methods of interest to maximize the utility of this tool across psychology and psychiatry. In pursuit of this goal, this registered report validated a modified AIDT that separates the task into two subsections of “non-frustration” and “goal frustration” blocks.

Hypotheses

The accepted-in-principle registered report for this manuscript can be found at https://osf.io/8y6gh/ (Moriarity et al., 2024). We hypothesized that there would be differences in average affective and motivational self-reports between the non-frustration and goal frustration conditions and that this finding would be consistent across t-tests and phase-temporal multilevel models. Regarding the t-tests, we hypothesized that feelings of (a) happiness, satisfaction, accomplishment, and motivation would be lower and (b) anxiety, sadness, emptiness, anger, frustration, and self-criticism would be higher during goal frustration vs. non-frustration blocks. Regarding the phase-temporal multilevel models, we hypothesized significant phase-shifts in item endorsement after the change between conditions such that (a) happiness, satisfaction, accomplishment, and motivation would be lower and (b) anxiety, sadness, emptiness, anger, frustration, and self-criticism would be higher during goal frustration vs. non-frustration blocks. We made no hypotheses regarding change in slope after the frustration condition began.

We also hypothesized that trait reward sensitivity and punishment sensitivity would predict psychological reactivity to the AIDT. This was first tested using regressions which regressed the average goal frustration block value of each affective and motivational response onto (a) the average non-frustration block value of the same item (to assess change) and (b) reward variables (one model with total reward sensitivity and punishment sensitivity, a second model with reward sensitivity subscales and punishment sensitivity). We hypothesized that higher reward and punishment sensitivity would be associated with greater (a) decreases in happiness, satisfaction, accomplishment, and motivation and (b) increases in anxiety, sadness, emptiness, anger, frustration, and self-criticism between the non-frustration and goal frustration blocks. We expected a similar pattern of results with the phase-temporal models, with higher reward and punishment sensitivity predicting more extreme phase-shifts in item endorsement such that (a) happiness, satisfaction, accomplishment, and motivation decreased more steeply and (b) anxiety, sadness, emptiness, anger, frustration, and self-criticism increased more steeply at the transition between non-frustration to goal frustration blocks.

As a supplemental analysis, models with demographic variables but without the reward predictors were estimated to explore potential demographic differences in stress reactivity. Significant demographic predictors were included as covariates in sensitivity analyses for the reward/punishment predictors of self-report outcomes.

Methods

Participants

This study used data from 101 emerging adult participants collected as part of Project MIME (Moriarity et al., 2022). See Table 1 for descriptives. This sample size was determined by power analysis of anticipated effect sizes for longitudinal associations between reward processing, rumination, and mood symptoms for aims of the grant not reported in this manuscript. Participants were recruited from a large, public university in the Northeast region of the United States of America between 2020 and 2022. The study protocol was approved by the university IRB. Informed consent was collected from all participants prior to data collection. No data from this study have been analyzed before this project. Participants were recruited using an online screener that assessed inclusion/exclusion criteria including: 18-22 years old, fluency in English, and absence of medical history or current medications that would substantially impact the immune system (e.g., recent cancer, HIV/AIDs, currently taking corticosteroids). To the extent possible given recruitment difficulties during the COVID-19 pandemic, participants were oversampled for high and low reward sensitivity (defined as the top and bottom 33% of

Behavioral Activation System Total Score (BAS-T, described below), as quantified in the first 428 participants to complete the screener) to increase the probability of clinically relevant levels of psychopathology and extreme reactions to the reward-salient stressor. Of the 101 participants in this sample, 32 (32%) reported some level of suicidal ideation or behavior on the Beck Suicidal Ideation Scale, 43 (43%) reported levels of hypo/mania above empirically supported cut-offs on the Altman Self-Rating Mania Scale (Altman et al., 1997), between 42-50 (42%-50%) reported levels of depression above empirically supported clinical cutoffs on the PROMIS-Depression v. 1.0 scale (Cheng et al., 2023; Pilkonis et al., 2014), and 54 (54%) reported levels of anxiety above empirically supported clinical cutoffs on the PROMIS-Anxiety v. 1.0 scale (Cheng et al., 2023). Participants were excluded if they incorrectly answered more than one out of three attention checks (items that instruct the participant how to respond to ensure they are carefully reading items) during the screener.

Table 1. Sample Characteristics

	Mean (SD) or %
Age	20.09 (1.11) years
Biological Sex	
Female	82.5%
Male	17.5%
Gender Identity	
Woman	78.6%
Man	17.5%
Nonbinary	3.9%
Sexual Orientation*	
Heterosexual	45.7%
Bisexual	34.8%
Lesbian, gay, or homosexual	13.0%
Don't Know/Prefer not to answer	6.5%
Ethnicity	
Native American	1.0%
Asian or Pacific Islander	15.5%
Black	14.6%
White	71.8%
Hispanic or Latino/a	12.6%
Other	1.0%
Parental Income	
<$10,000	4.9 %
$10,000–$24,999	6.8%
$25,000–$49,999	12.6%
$50,000–$74,999	19.4%
$75,000–$99,999	20.4%
>$100,000	35.9%
Subjective Socioeconomic Status	
0	0.0%
1	0.0%
2	1.0%
3	3.9%
4	12.6%
5	12.6%
6	24.3%
7	29.1%
8	11.7%
9	4.9%
10	0.0%
Nativity/Immigration History	Unmeasured

Note: *Percentages for orientation are based off available responses, this question was only assessed in 46% of participants as it was added halfway through data collection. Summed ethnicity percentiles are greater than 100% because participants were allowed to select multiple identities. Subjective socioeconomic status was reported as where the participant identified on the ladder from worst to best off on the continuum of combined financial wealth, education, and employment.

Procedure

Eligible participants were invited to an in-person study visit to complete the modified AIDT and self-report measures. The AIDT was always completed before the self-report measures. Self-report measures completed in Project MIME can be found in Supplemental Table

1.

Measures

Anger Incentive Delay Task (AIDT; Angus & Harmon-Jones, 2019)

The AIDT is a Monetary Incentive Delay Task (MID; Knutson et al., 2000) modified to induce acute stress and is completed on a computer. Table 2 characterizes the features of this stressor and the outcome measures using characteristics outlined in The Stress Measurement Network taxonomy (Epel et al., 2018). During this study, the task was completed in E-prime version 2.0.10.356 on computers with screens that were 20.4 inches x 12.7 inches. Participants were instructed to "win as much money as possible and avoid losing money" and that they could win money on some trials ("gain trials") or avoid losing money on others ("breakeven trials") by responding to a target stimulus (four white asterisks) by pressing the spacebar before the end of the trial. Participants were instructed they could earn a $15 gift card if they ended the task with positive money. Participants start with $1 and could win $.40, lose $.20, or breakeven on each trial.

Table 2. Stressor Features of the Modified Anger Incentive Delay Task

Stressor Exposure Characteristics	
Timescale	Acute stressor
Life Period	Emerging adulthood
Assessment window	
Measurement timeframe	Current ratings
Proximity of assessment to stressor exposure	Immediately after stressor
Stressor attributes	
Duration	27 minutes total (9 minutes stress trials)
Severity	To be evaluated
Controllability	Uncontrollable
Life domain	Financial, Performance
Target of stressor	Self
Potential of the stressor to elicit potentially harmful emotional responses	Yes

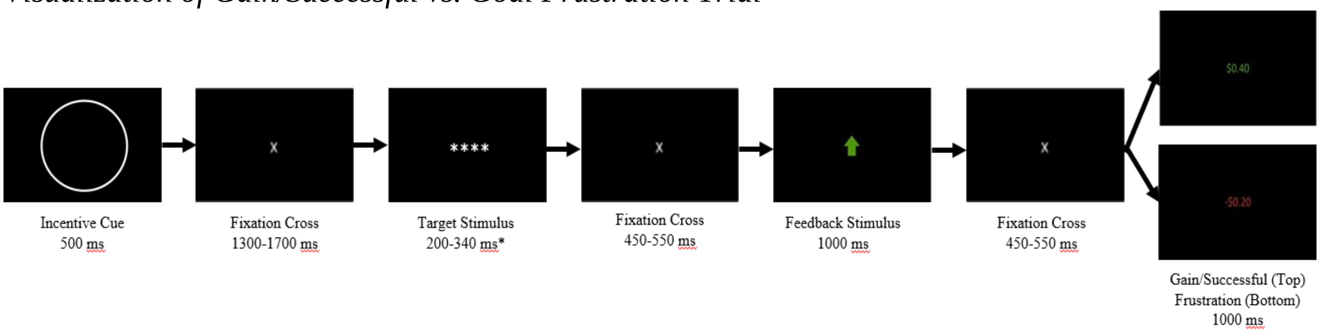
At the beginning of each trial, a fixation cross was presented in the center of the screen for 900-1100 ms (Figure 1). Next, an incentive cue was presented for 500 ms. Incentive cues could be either circles (indicating that the participant can win money during a successful trial) or triangles (indicating that the participant can breakeven during a successful trial). Unsuccessful trials always lost money. After the incentive cue, another fixation cross was presented for 1300-1700 ms. The target stimulus duration was adaptive to performance, increasing or decreasing by 20 ms to a minimum of 200 ms or a maximum of 340 ms if participant accuracy increased or decreased from 90%. Success probability was manipulated further by increasing target stimulus duration by 40-80 ms on trials designed for success and decreasing by 40-80 ms on trials designed for failure. Targets remained on screen for the entire duration regardless of reaction time. After the target stimulus disappeared, another fixation cross was presented for 450-550 ms, followed by a feedback stimulus presented for 1000 ms to indicate success or failure. Failures are signaled with a downward arrow; trials in which the participant wins money are signaled with an upward arrow; and trials in which the participant breaks even are signaled with an = sign. Following the feedback stimulus, another fixation cross is displayed for 450-550 ms, followed by the amount of money won or lost on that trial, displayed for 1000 ms.

Out of twelve blocks (each block lasting 2 minutes and fifteen seconds), the first eight had the above-listed rules (18 minutes total). Each block was 18 trials long (216 trials in total). The ordering of “gain” vs. “breakeven” trials was pseudorandomized, so the trial structure was identical across participants.

During the final four blocks (approximate duration is 9 minutes), correct responses to trials with anticipatory stimuli indicating the possibility to win money begin to actually lose money on 56% of trials even if the participant reacts in time (10/18 trials). Critically, if they reacted in time, they were still presented successful feedback stimuli to induce goal frustration. This resulted in 40 frustration trials compared to the original AIDT's 25. This change was not communicated to participants ahead of time to surprise participants and induce frustrative nonreward. See Figure 1 for a visualization of a gain/successful vs. a goal frustration trial and Table 3 for a breakdown of the trial structure.

Figure 1.

Visualization of Gain/Successful vs. Goal Frustration Trial



Note:* Success probability was manipulated further by increasing target stimulus duration by 40-80 ms on trials designed for success and decreasing by 40-80 ms on trials designed for failure.

Table 3. Anger Incentive Delay Task Trial Structure

Condition Label	Incentive cue	Outcome	Total # (% of total trials)	Total # (% of non-frustration trials)	Total # (% of goal frustration trials)
Gain/consistent outcome	Gain	Consistent Outcome (i.e., winning = gain money)	56 (26%)	49 (34%)	7 (10%)
Breakeven/consistent outcome	Breakeven	Consistent Outcome (i.e., winning = breakeven)	59 (27%)	50 (35%)	9 (13%)
Gain/dedicated failure	Gain	Consistent Outcome (i.e., failure = lose money)	24 (11%)	21 (15%)	3 (4%)
Breakeven/dedicated failure	Breakeven	Consistent Outcome (i.e., failure = lose money)	37 (17%)	24 (16%)	13 (18%)
Goal frustration	Gain	Inconsistent outcome (i.e., winning = lose money)	40 (19%)	0 (0%)	40 (56%)

Note. Dedicated failure = a trial with shorter stimulus presentation to ensure failure; incentive cue = incentive cue at the beginning of a given trial (i.e., gain or breakeven); outcome refers to whether the outcome was consistent with the incentive cue (wording of descriptions chosen to match the designed outcome of each type of trial). As noted above, durations of trials designed for participant success were extended by 40-80 ms and durations of trials designed for participant failure were decreased by 40-80 ms.

The degree to which each participant experienced various state affects (happy, satisfied, accomplished, anxious, sad, empty, angry, frustrated, self-critical) and motivation to perform well were measured immediately after each block using items with 7-point scales (“Not at all”, “Slightly”, “Somewhat”, “Moderately”, “Quite a bit”, “Very much”, and “An extreme amount”). Immediately following the task, participants completed questions about their reactions to specific scenarios in the task (e.g., when the game informed them they answered correctly but they then lost money) using similar item responses. Participants were debriefed at the end of the study.

Behavioral Inhibition/Behavioral Activation Scales (BIS/BAS Scales; Carver & White, 1994)

The BIS/BAS Scales assess sensitivity to punishment and rewards; the scales consist of 20 items using a 4-point response scale ranging from *strongly disagree* to *strongly agree*. This study used BIS/BAS assessments completed during the study visit. There are 4 original subscales: BIS (Ω=.79) assesses behavioral inhibition/avoidance to adverse outcomes, BAS Reward Responsiveness (Ω=.78) assesses positive responses to rewards, BAS Drive (Ω=.85) assesses vigor and persistence in reward pursuit, and BAS Fun Seeking (not tested individually) assesses willingness to approach rewards and novel stimuli on impulse. The items of the three BAS subscales were averaged to create BAS-Total (Ω=.89). An additional BIS/BAS subscale specific to frustrative nonreward was developed (Wright et al., 2009) and is an NIMH-recommended self-report measure to study frustrative nonreward (NIMH, 2016). Although this measure was not collected as part of this study, the validation of this subscale found that all but one of the new items loaded onto the BIS subscale (which we did collect)—further strengthening the relevance of the BIS/BAS Scales to the development of this stressor.

Analytic Strategy

Manipulation Check

The significance threshold for all analyses was $p < .05$. Analyses were conducted in R Version 4.3.3 (R Core Team, 2024). We first determined whether or not the transition between non-frustration and goal frustration blocks successfully influenced affective and motivational states. First, the mean response across all non-frustration blocks was compared to the mean response across all goal frustration blocks using Pearson correlation coefficients and paired samples t-tests/Wilcoxon signed-rank tests (when assumption of normality was violated). These analyses used the "stats" package (R Core Team, 2024) except for the Wilcoxon signed-rank tests, which used the "coin" package (Hothorn et al., 2008).

Second, "phase-temporal" multilevel models (described in more technical detail below) featuring random intercepts and estimated in both "lme4" (Bates et al., 2015) and "glmmTMB" (specifics described in the diagnostics section below; Brooks et al., 2017) tested the effects of the manipulation in a multilevel modeling framework with greater temporal resolution. "Phase-temporal" models are named as such because of their ability to distinguish effects that happen as a shift in response to an event (i.e., "phase") and those that occur continuously over time (i.e., "temporal"). These phase-temporal models are particularly relevant for stress reactivity research due to their ability to provide separate information about instantaneous affect/motivational phase-shifts in response to stressors as well as more gradual increases and/or recovery.

The phase-temporal models evaluated (i) trajectories of affective/motivational responses across the entire task, (ii) whether the transition between non-frustration and goal frustration conditions predicted change in average endorsement (i.e., a phase-shift up or down) and/or (iii) trajectories of affective/motivational responses strictly after the condition change. This was accomplished by modeling "π_1" as a dichotomous variable indicating whether the block was pre- (coded as "0") or post-condition change (coded as "1"), "π_2" as the specific block number, and

"π_3" as the number of blocks post-condition change (see Formula 1 for the base formula and Table 4 for sample interpretation of significant effects). In this model "π_1" and "π_3" corresponded to the post-condition change in intercept and trajectory, respectively.

Formula 1: $Response_{ij} = \pi_{0j} + \pi_1(ConditionChange_{ij}) + \pi_2(Block_{ij}) + \pi_3(PostChangeBlock_{ij}) + R_{ij}$

Note: $Response_{ij}$= self-report response after block *i* for participant *j*, π_{oj} = intercept participant I, R_{ij} = residual after block *i* for participant *j*

Table 4. Interpretive Guide to Phase-Temporal Models

Parameter	Interpretation
π_1	Condition change induces immediate shift in affect/motivation
π_2	Across the entire task, there is a linear trend across blocks for affect/motivation
π_3	After the condition change, there is a change in linear trend across blocks for affect/motivation

Reward/Punishment Predictors of AIDT Reactivity

To evaluate whether changes in self-report were greater for individuals at high levels of reward/punishment sensitivity, we again used a two-pronged modeling strategy. All reward predictors were z-standardized. First, regressions were run with (a) BAS Total and BIS and (b) BAS Drive, BAS Reward Responsiveness, and BIS predicting the mean response of each affective/motivational state across all goal frustration blocks controlling for the mean response across all non-frustration blocks. Models were estimated as both linear regressions and generalized linear models (specifics described in the diagnostics section below) in the base "stats" package (R Core Team, 2024) and model performances were compared (described below). Second, identical "phase-temporal" multilevel models as described above were estimated, with the inclusion of interaction terms between a given reward predictor and (a) a dichotomous variable indicating whether the block was pre- (coded as "0") or post-condition change (coded as "1"), (b) the block number, and (c) the number of blocks post-condition change. Relevant to hypotheses— significant, positive BAS or BIS x (a) interactions supported that the condition change in self-report endorsement was greater for individuals with higher reward or punishment sensitivity scores. Significant, positive BAS or BIS x (b) interactions supported that the self-report trajectory across blocks after the condition change was steeper for individuals with higher reward or punishment sensitivity scores. Multilevel models were estimated in a similar structure as the linear regression (i.e., first BAS Total and BIS, then BAS Drive, BAS Reward Responsiveness, and BIS). These models also included main effects for each reward or punishment predictor.

To make this validation as comprehensive as possible while maximizing this report's ability to generate important new lines of inquiry, similar regression and phase-temporal models replaced the reward variables with (a) gender, (b) race, (c) subjective socioeconomic status, and (d) parental income to test potential demographic differences in affective and motivational reactivity. As sensitivity analyses, models including all reward predictors and significant demographic predictors also were estimated.

Diagnostics

The assumption of normality for paired samples t-tests was tested using visual inspection of density plots of the condition change scores using the "ggplot2" package (Wickham, 2016). All assumptions for regressions and multilevel models were checked using the R package, "performance" (Lüdecke et al., 2021), and appropriate adjustments were made. Specifically, due to the right-skew of many of the outcome variables, generalized linear models were estimated that complemented right-skewed outcomes and compared to the standard linear regressions (i.e., gamma regression with a log link) and multilevel models (i.e., lognormal models with a log link). The modeling strategy with the highest model performance was selected, unless it also resulted in a meaningful worsening of one or more statistical assumptions. The selection between linear model and generalized linear model was determined during the first level of the model building process for both regressions and multilevel models to ensure comparability between models with the same outcomes.

Influential observations were identified via default cut-offs in the “performance” package using Cook’s Distance, removed, and models re-estimated. If non-normality was observed in both standard and generalized linear models after removing influential observations, the above evaluative steps were repeated comparing the standard linear model and the generalized linear model to a third linear model with a log-transformed outcome variable (and a log-transformed version of the outcome variable taken from the pre-condition change blocks as a covariate to model change). If heteroskedasticity was present, corrected standard errors were estimated using *parameters* function from the “parameters” package (Lüdecke et al., 2020).

Deviations from Pre-registration

Throughout the development of this project, minor deviations from the pre-registered plan occurred. First, Pearson correlations were used instead of Spearman because the variables were continuous. Second, the plan specified that supplemental analyses would covary for all listed covariates; however, it was deemed more appropriate to use an iterative model building procedure where first significant demographic predictors were identified and only those were included in the models with reward predictors to avoid the “garbage can” approach of covarying for variables without sufficient empirical evidence (Achen, 2005). Third, the registered report did not include the comparison between linear models and generalized linear models; however, given the distributions that were observed in the data, this was determined to be an important expansion to maximize rigor.

Transparency and Openness

We reported how we determined our sample size, all data exclusions, all task details, and all measures in the study, and followed Journal Article Reporting Standards (Appelbaum et al., 2018). The registered report, analysis code, and research materials are available at https://osf.io/8y6gh/. Data are available upon request. Data were analyzed using R Version 4.3.3 (R Core Team, 2024). This study's design was not pre-registered; however, the current hypotheses and analytic strategy were pre-registered as a registered report in the *Journal of Psychopathology and Clinical Science*.

Results

Manipulation Checks

Correlations

All correlations (Supplemental Figure 1) between the average affective/motivational self-report pre and post-condition change for the same response were correlated $p<.001$. Pre-post condition change correlations ranged from .609 (Satisfied) to .865 (Emptiness).

T-tests/Wilcoxon Paired Signed-Rank Tests

Paired samples t-tests were used for all but two of the self-report responses (Sadness and Emptiness), due to very severe deviations from normality in their change scores between conditions. Consequently, these two responses were tested using Wilcoxon Paired Signed-Rank tests. The condition change between regular blocks and goal frustration blocks were successful in inducing change in all measured affective/motivational responses ($p < .05$, Table 5).

Table 5. Pre- vs. Post-Condition Change Paired Samples T-tests/Wilcoxon Paired Signed-Rank Tests

Response	***t/Z***	**Mean Regular Blocks**	**Mean Goal Frustration Blocks**	**Cohen's D/ Wilcoxon *r***	**95% CI Mean Difference/ Wilcoxon *r***	***p***
Happy	-13.30	2.95	1.86	-1.32	-1.26 – -0.93	<.001
Anxious	-2.80	3.10	2.84	-0.28	-0.44 – -0.08	.006
Accomplished	-10.84	2.61	1.65	-1.08	-1.14 – -0.79	<.001
Sad*	4.20	1.56	2.01	0.42	0.25 – 0.57	<.001
Empty*	3.09	1.52	1.75	0.31	0.13 – 0.48	.002
Satisfied	-11.74	2.64	1.60	-1.17	-1.21 – -0.86	<.001
Angry	9.06	2.26	3.40	0.90	0.89 – 1.39	<.001
Frustrated	9.53	3.20	4.24	0.95	0.82 – 1.26	<.001
Self-Critical	-2.67	3.14	2.86	-0.27	-0.49 – -0.07	.009
Motivated	-10.81	5.28	3.75	-1.08	-1.81 – -1.25	<.001

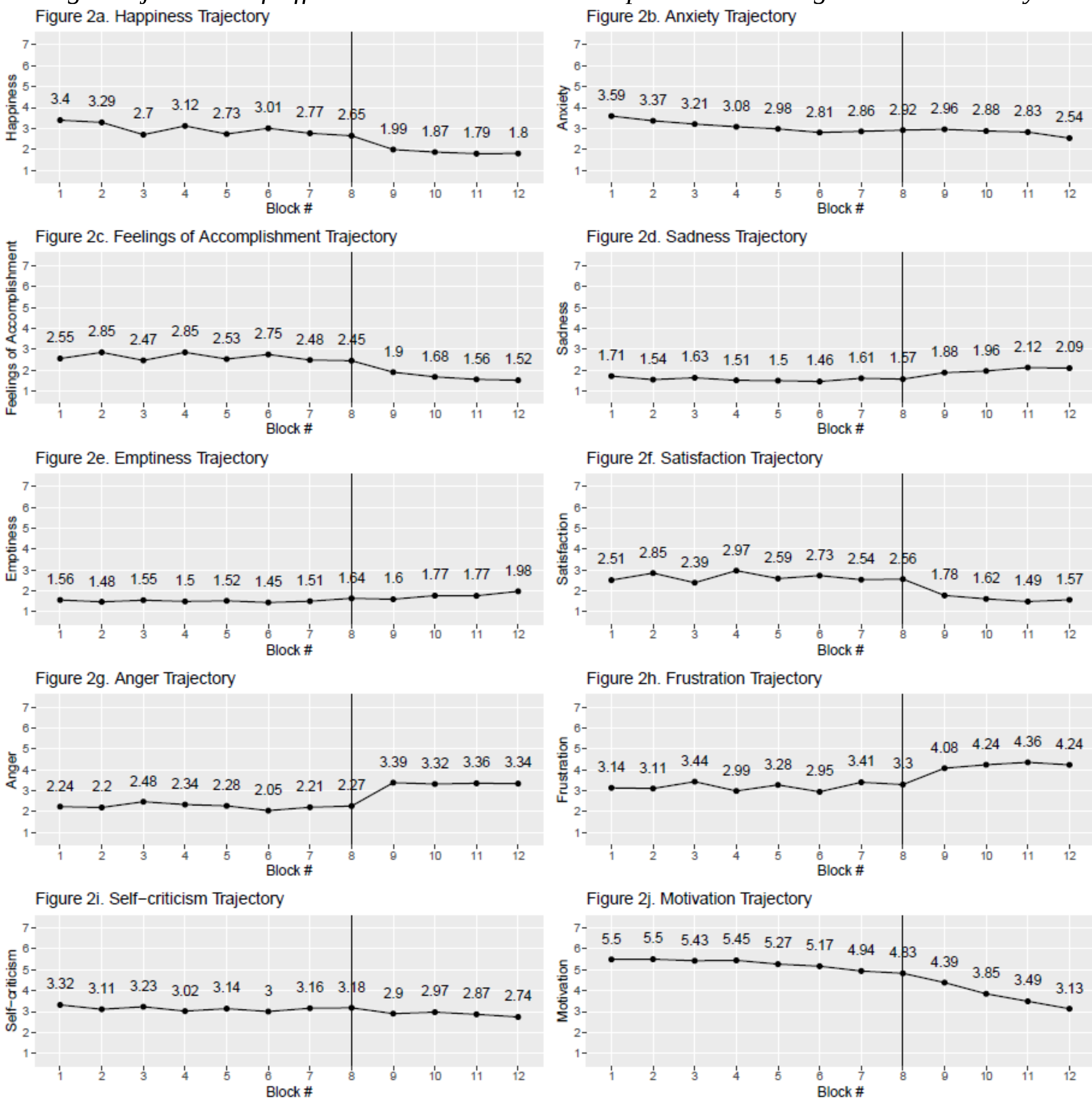
Note. N=101, * = tested using Wilcoxon paired signed rank test. Wilcoxon paired signed rank tests have different test statistics and effect size estimates (i.e., Z and *r*) than paired samples *t*-tests.

Phase-Temporal Models

See Supplemental Tables 2a-2j for full results; only significant results pertaining to the hypotheses will be reported here. Change in condition (from pre to post) predicted increased anxiety (B=.38, $p<.001$), sadness (B=.39, $p<.001$), anger (B=1.14, $p<.001$), and frustration (B=.89, $p<.001$); however, it also predicted decreased happiness (B=-.60, $p<.001$), sense of accomplishment (B=-.66, $p<.001$), satisfaction (B=-.86, $p<.001$), and motivation (B=-.50, $p<.001$). Advancement through the goal frustration portion of the AIDT (indexed by the # of blocks past condition change) predicted increases in sadness (B=.08, $p=.015$) and emptiness (B=.11, $p<.001$); however, advancement through the goal frustration portion also predicted decreases in sense of accomplishment (B=-.10, $p=.016$), satisfaction (B=-.09, $p=.029$), and motivation (B=-.33, $p<.001$). No temporal components predicted self-critical responses (all *p*s>.05). Plots of the trajectories of each response can be found in Figures 2a-2j.

Figure 2.

Average Trajectories of Affective and Motivational Responses to the Anger Incentive Delay Task



Note: Vertical black line extending from the "8" on the x-axis indicates final block before goal frustration condition began.

Reward Predictors of AIDT Reactivity

Regressions

See Supplemental Tables 3a-3j for full results. β_x indicates that the reward predictor was z-standardized. Neither BAS-Total nor BAS-Drive predicted change in affect/motivation in any of the models. Given that BAS-Total didn't predict any outcomes ($p > .05$) and the BIS model inferences were identical between models with BAS-Total vs. BAS subscales, only BIS results from BAS subscale models are reported in-text. Higher BAS-Reward Responsiveness predicted post-condition change decreases in happiness (β_x=-.12, p=.008), decreases in accomplishment (β_x=-.09, p=.035), increases in anger (β_x=.35, p=.034), and increases in frustration (β_x=.32, p=.023). Higher BIS predicted post-condition change decreases in accomplishment (β_x=-.10, p=.014), increases in sadness (β_x=.09, p=.047), and decreases in satisfaction (β_x=-.08, p=.030). Results largely were robust to inclusion of demographic covariates (see Supplemental Tables 4a-4j for covariate identification and 4a-4f for models with reward predictors and covariates).

Phase-Temporal Models

See Supplemental Tables 6a-6j for full results; only significant results pertaining to the stress manipulation (i.e., condition effects and trajectories after the change in condition) are presented here. β_x indicates that the reward predictor was z-standardized. The pattern of significant results was identical when controlling for demographic covariates (see Supplemental Tables 7a-7j for covariate identification and 8a-8e for models with reward predictors and covariates). Higher BAS-Total was associated with greater condition change-induced decreases in satisfaction (β_x=-.20, p=.046), increased trajectories of anger during goal frustration blocks

(β_x=.04, *p*=.043), and decreasing trajectories of motivation during goal frustration blocks (β_x=-.12, *p*=.015). Higher reward responsiveness predicted greater condition change-induced decreases in subjective accomplishment (β_x=-.33, *p*=.009), greater condition change-induced decreases in satisfaction (β_x=-.42, *p*=.001), and greater condition change-induced increases in anger (β_x=.15, *p*=.008). Higher reward drive was associated with increasing trajectories of emptiness (β_x=.07, *p*=.035) and anger (β_x=.06, *p*=.018) during goal frustration blocks. Higher punishment sensitivity (BIS) was associated with greater condition change-induced decreases in subjective accomplishment (BAS total model: β_x=-.25, *p*=.012; BAS subscales model: β_x=-.20, *p*=.042), increased trajectories of emptiness during goal frustration blocks (BAS total model: β_x=.07, *p*=.007; BAS subscales model: β_x=.08, *p*=.003), and decreasing trajectories of satisfaction during goal frustration blocks (BAS total model: β_x=-.13, *p*=.002; BAS subscales model: β_x=-.11, *p*=.006).

Discussion

Across different modeling strategies, this version of the AIDT was successful in manipulating positive and negative affect and motivation—supporting its utility as a laboratory-based stressor in affective psychopathology research. Further, consistent with hypotheses, facets of reward and punishment sensitivity were predictive of affective responses to the AIDT—positioning this task as a synergistic stressor paradigm for research on reward processing and reward system associated psychiatric disorders such as bipolar spectrum disorders (Alloy et al., 2016; Alloy & Abramson, 2010), depression (Alloy et al., 2016), and substance use (Bart et al., 2021). These results suggest that the AIDT will make a useful tool in precision stress and precision psychopathology research focused on reward and/or punishment sensitivity and a variety of affective responses.

Both *t*-tests and phase-temporal models largely supported hypotheses about the AIDT's ability to dampen positive affect/motivation and increase negative affect, with two exceptions. First, the *t*-tests found that average anxiety was lower in the goal frustration blocks than the non-frustration blocks. Importantly, this helps differentiate the negative affective response profiles of the AIDT from the TSST, which is primarily characterized by anxiety. Specifically, the AIDT was the most effective at inducing anger and frustration, both of which had a Cohen's D over 2x the size of the other negatively valenced responses. However, the phase-temporal models of anxiety help contextualize this result—the greater temporal resolution of these models demonstrated a) that the change in conditions was associated with an increase in anxiety and b) that anxiety tended to decrease in general as the task continued. Thus, it is likely that most participants were initially more anxious at the start of the task, their anxiety tended to decrease as they acclimated (explaining the *t*-test result), and the condition switch was effective at initiating an initial anxiety spike. Both analytic strategies found results counter to the hypothesis that the task would increase self-criticism (it decreased in the *t*-tests and was unrelated to the temporal predictors in the phase-temporal models). It is plausible that participants realized that the stress of the goal frustration trials was outside their control (as indicated to them by the feedback images during goal frustration blocks) and, thus, self-criticism was not a relevant response. Relatedly, self-criticism is one of only two responses (the other being anxiety) that were not associated with reward or punishment sensitivity in any of the reward-predictor models tested.

Trait reward and punishment sensitivities were consistent predictors of affective/motivational responses in both analytic paradigms; however, support was not equally observed for all responses. In both analytic paradigms, these traits predicted decreasing satisfaction and sense of accomplishment while increasing anger. Regression models, but not phase-temporal models, found these traits predictive of decreased happiness and increased sadness and frustration during goal frustration blocks (consistent with theories of BAS-deactivation inducing depressive mood changes following goal frustration in people with elevated reward/punishment sensitivity; Alloy et al., 2008). Conversely, only the phase-temporal models found high levels of these traits predictive of decreased motivation and increased emptiness during the goal frustration blocks. It cannot be ruled out that some of the discrepancies between these models could come from computational differences or chance. However, as we described above with respect to the discrepancy between the two models of self-criticism change, it is important to consider how the increased temporal specificity of the phase-temporal models might substantively influence results. Specifically, they could simultaneously a) facilitate discovery of some effects by separating temporally distinctive facets of the different emotional responses and b) potentially obscure some results that may have otherwise been found by over partitioning variance of certain emotions that don't require this level of temporal granularity. As such, we believe that both modeling approaches can be employed for similar designs to more comprehensively probe results and build theory.

With respect to specific reward/punishment predictors, only reward responsiveness and punishment sensitivity predicted change in responses in the regression models. Specifically, reward responsiveness predicted decreased happiness and sense of accomplishment but increased anger and frustration, whereas punishment sensitivity predicted increased sadness and lower positive reactions (accomplishment and satisfaction). All of these results replicated in the phase-temporal models, except the reward responsiveness—happiness, reward responsiveness—frustration, and punishment sensitivity—sadness associations. With the greater temporal specificity of these models, both of these reward responsiveness findings were specifically associated with phase-shifts rather than trajectories (i.e., instantaneous shifts in average endorsement vs. changes that grow over time). This pattern was also true for the reward responsiveness finding unique to the phase-temporal models, with higher reward responsiveness predicting a lowering phase-shift in satisfaction. Conversely, punishment sensitivity was associated with a phase-shift decrease in accomplishment but steeper decreases in satisfaction trajectories and increases in emptiness trajectories across the goal frustration blocks. In contrast to the regression models, both BAS-Total and reward drive were associated with responses to the stressor in the phase-temporal models. BAS-Total predicted phase-shift decreases in satisfaction as well as steeper decreases in motivation and steeper increases in anger across the goal frustration blocks. Finally, reward drive exclusively predicted increased trajectories in negative responses (anger and emptiness) during the goal frustration blocks. The dynamic specificity of the phase-temporal findings is interesting to consider clinically with respect to which emotion regulation tools might be most useful to employ in response to reward-activating stressors with individuals with elevated reward or punishment sensitivity. For example, for reward-response dynamics associated with an immediate phase-shift, distress tolerance skills that are quick to act and de-escalate might be ideal. Conversely, for associations characterized by trajectories that build over time, more involved multi-step emotion regulation techniques (Linehan, 2014; Rizvi & Ritschel, 2014) might be suitable.

Limitations/Constraints on Generality

These results should be considered in the context of their limitations. First, it is imperative that new measures be broadly validated across diverse samples to evaluate potential differences in reactivity across racial/ethnic groups, socioeconomic backgrounds, and developmental stages to ensure an equitable and valid stress science. In particular, having <20 participants in each ethnicity category other than “White” reduces confidence in both our ability to detect differences by ethnicity as well as confidence in the generalizability of the differences that were observed. We encourage future researchers using the AIDT to consider the appropriateness of expanding/modifying characteristics of the task and recruitment protocol consistent with the characteristics outlined in The Stress Measurement Network taxonomy (Epel et al., 2018). Second, this study did not collect EEG measures that were the focus of the original AIDT, resulting in a missed opportunity to compare ERP signatures across the two versions of this task. Third, given that this study was conducted during the beginning of the COVID-19 pandemic, it is worth considering whether some participants’ stress response systems might have been sensitized or dampened by ongoing global events.

Conclusion

Given the transdiagnostic role of stress in many psychiatric and somatic pathologies, it is imperative to develop tools that facilitate precision stress research that can develop parallel to precision medicine. This study demonstrates the utility of the AIDT as a reward-salient stressor synergistic with studying many reward-salient psychopathologies—positioning it as a useful tool in precision stress and precision psychopathology research. We encourage other stress researchers to extend this work to more diverse samples and validate additional modifications in service of generating a highly flexible paradigm with maximal utility.

Acknowledgements

The authors would like to thank Drs. Alexander Puhala, Solomon Kurz, and John Flournoy for contributing as consultants at various stages of this project.

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