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I Don't Want to Come Back Down: Undoing Versus Maintaining of Reward Recovery in Older Adolescents

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Adolescence is characterized by heightened and sometimes impairing reward sensitivity, yet less is known about how adolescents recover from highly arousing positive states. This is particularly important given high onset rates of psychopathology associated with reward sensitivity during late adolescence and early adulthood. The current study thus utilized a novel reward sensitivity task in order to examine potential ways in which older adolescent females (ages 18–21; $N = 83$) might recover from high arousal positive reward sensitive states. Participants underwent a fixed incentive reward sensitivity task and subsequently watched a neutral, sad, or a low approach-motivated positive emotional film clip during which subjective and physiological recovery was assessed. Results indicated that the positive and negative film conditions were associated with maintained physiological arousal while the neutral condition facilitated faster physiological recovery from the reward sensitivity task. It is interesting to note that individual differences in self-reported positive emotion during the reward task were associated with faster recovery in the neutral condition. Findings suggest elicited emotion (regardless of valence) may serve to maintain reward sensitivity whereas self-reported positive emotional experience may be a key ingredient facilitating physiological recovery or undoing. Understanding the nuances of reward recovery provides a critical step in understanding the etiology and persistence of reward dysregulation more generally.

Keywords: reward, adolescents, emotional recovery, positive emotion, undoing hypothesis

Adolescence is characterized by heightened reward sensitivity compared with younger children and adults (e.g., Galván, 2013; Steinberg, 2010). This elevated reward sensitivity has often been linked to seeking out increased independence and more social interactions, but is also associated with increased sensation-seeking and risk-taking behaviors (e.g., drug use, sexual promiscuity; Dahl & Gunnar, 2009; Galván, 2013; Steinberg, 2008). Moreover, many forms of psychopathology that onset during adolescence and emerging adulthood are characterized by problematic reward sensitivity, including anxiety, depression, bipolar disorder, alcohol and substance abuse, eating disorders, and psychosis (Häfner et al., 1989; Kessler, Chiu, Demler, & Walters, 2005). However, it not well understood what potential processes older adolescents can use to effectively down-regulate these high arousal positive states. Gaining a better understanding of how adolescents and emerging adults recover from reward sensitive states is thus a critical research priority (e.g., Davidson, 2015).

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Reward sensitivity is intricately tied with positive emotional experience, as positive emotion is commonly elicited by the anticipation or receipt of rewarding stimuli (Rolls, 1999). Specifically, reward sensitivity can be characterized as a high-arousal positive emotional state associated with increased energy mobilization and expenditure as individuals are more sensitive to pursuing and obtaining goals or rewards in their environment (Gable & Harmon-Jones, 2011; Russell, 2003; Tsai, 2007). Adolescence is characterized by increases in reward sensitivity as brain systems associated with emotion and motivation develop earlier than those regions implicated in cognitive control and regulation (Casey & Caudle, 2013; Luna, Paulsen, Padmanabhan, & Geier, 2013; Nelson, Leibenluft, McClure, & Pine, 2005). This imbalance in brain development leads to greater reliance on emotional systems compared with underdeveloped regulatory abilities (e.g., Casey & Caudle, 2013). Difficulty cognitively regulating heightened reward sensitivity peaks in mid-adolescence but continues to a lesser degree into emerging adulthood as cognitive control regions develop well into the mid-20s (Giedd, 2004).

Difficulty with reward regulation has been provided as one potential explanation for increased risk-taking behaviors (Eaton et al., 2008; Galván, 2013) and the high onset rates of a range of psychopathology (Dahl & Gunnar, 2009; Ernst, Pine, & Hardin, 2006; Paus, Keshavan, & Giedd, 2008) in adolescence and young adulthood. In particular, adolescent females exhibit especially high rates of psychopathology compared with adolescent males, including depression (Galambos, Leadbeater, & Barker, 2004), anxiety (Lewinsohn, Gotlib, Lewinsohn, Seeley, & Allen, 1998), and eating disorders (Lewinsohn, Seeley, Moerk, & Striegel-Moore, 2002) and these rates remain high through older adolescence and emerging adulthood. During the older adolescent period, many of these vulnerable females are also faced with new stressors such as increasing responsibilities and independence (e.g., moving away for college, a first apartment, and increasing job responsibilities) and new rewards become relevant (e.g., fraternity parties, binge drinking, and less parental control) while cognitive control regions are still “catching up” developmentally. Thus, it is imperative to isolate potential processes, such as reward sensitivity, that may contribute to an increased risk for psychopathology in this population. Given difficulty with traditional forms of cognitive regulation, identifying additional pathways for older adolescent females to recover from high arousal positive states may aid in the development of targeted intervention foci. The aim of the current study was to understand how older adolescent females may adaptively recover from heightened reward sensitive states in ways other than utilizing underdeveloped regulation or cognitive control.

Exploring Positive Emotion Recovery

Emotion recovery is defined as the rate, or degree, to which an emotional or physiological response returns to a pre-stress baseline level following a stressor (Davidson, 2015; Haynes, Gannon, Orimoto, O’Brien, & Brandt, 1991). One well-studied strategy that facilitates emotion recovery is by means of experiencing positive emotion, which has demonstrated to aid emotional and physiological recovery via the “undoing hypothesis” (Fredrickson & Levenson, 1998). The *undoing hypothesis* suggests that positive emotions aid in recovering from, or “undoing” heightened emotional and physiological arousal often associated with negative emotion states (Fredrickson & Levenson, 1998; Fredrickson, Mancuso, Branigan, & Tugade, 2000). Supportive evidence for this perspective has demonstrated that following a negative (i.e., sad, fearful, or anxious) affective state, subsequently eliciting and experiencing a positive (i.e., amusing or content) state leads to a faster return to preinduction cardiovascular baseline as compared with a neutral or negative emotion state (Fredrickson & Levenson, 1998; Fredrickson, Mancuso, et al., 2000; Tugade & Fredrickson, 2004).

The undoing hypothesis has provided a useful perspective on the benefits and functions of positive emotions as facilitating negative emotional recovery. Recent work has demonstrated nuances such that the undoing hypothesis is most strongly supported in the context of specific types of positive emotion, namely, low approach-motivated positive emotions such as amusement and contentment (Gable & Harmon-Jones, 2011; Harmon-Jones & Gable, 2008). Low approach-motivated positive emotions are experienced when a goal or reward is not relevant or after a reward is obtained, so the action urge may not be to approach, whereas high approach-motivated positive emotions are pregoal, reward-sensitive emotions that are associated with an urge to act or approach (Harmon-Jones & Gable, 2008). Thus, positive emotion low on approach-motivation (i.e., positive emotions experienced when a goal is not relevant) are purported to facilitate recovery and aid in undoing heightened arousal. However, positive emotions high on approach-motivation, such as excitement or enthusiasm, which may occur in the context of approaching a goal or reward and which may be high arousal, may not facilitate physiological recovery.

The majority of work on the undoing hypothesis to date has focused on how positive emotions facilitate recovery from *negative* emotions. To our knowledge it has not yet been directly tested whether low approach-motivated states might also facilitate emotion recovery from high approach-motivated rewarding stimuli as well. Given the distinctive role of low approach-motivated positive states in the undoing hypothesis, the undoing hypothesis might also apply to adaptively undoing highly physiologically activating, approach-motivated, reward sensitive emotions. Because adolescents experience heightened positive emotional arousal in the form of elevated reward sensitivity, and this heightened reactivity is also difficult to regulate (Casey & Caudle, 2013; Galván, 2013), the undoing hypothesis may provide one adaptive way for adolescents to recover from reward sensitive states. Stated otherwise, increasing low approach-motivated positive emotion might actually serve as a candidate way to help older adolescents recover from heightened reward sensitivity.

We also examined an alternative perspective to the undoing hypothesis, which we refer to as the “maintenance hypothesis.” The *maintenance hypothesis* posits that any positive emotion, no matter the motivational intensity or valence, might lead to maintaining emotional and physiological reactivity in adolescents. Given aforementioned difficulties managing negative and positive emotional states due to ongoing neurobiological development (e.g., Casey & Caudle, 2013), it may be the case that adolescents are unable to reap the benefits of emotional recovery using low-approach positive emotions, but instead, any emotion may *maintain* or perpetuate reward-related emotional and physiological reactivity compared with experiencing no emotion. It might be, that in fact, a neutral, or low-emotional state, may lead to more undoing and faster recovery.

The Present Investigation

The present investigation examined the role of positive emotion in facilitating emotion recovery from a heightened reward sensitive state. To do so, older adolescent females underwent an experimental manipulation starting with a novel reward sensitivity task. They were then randomized to watch one of three emotional film clips: a sad, neutral, or amusing video. Subjective and physiological reactivity was measured throughout the experimental session and recovery was calculated during the emotional film clips following previously validated guidelines (e.g., Fredrickson & Levenson, 1998). This enabled us to examine the following aims.

The first aim was to validate a novel reward sensitivity task among older female adolescents. We hypothesized that using both monetary and social rewards in a modified and fixed incentive delay task would increase self-reported positive emotion and arousal as well as heightened physiological reactivity. This was based on previous research demonstrating that the monetary incentive delay task that the current paradigm was adapted from been associated with increased positive emotion (Nielsen, Knutson, & Carstensen, 2008) and involves motivation to accrue monetary and social reward (Knutson, Westdorp, Kaiser, & Hommer, 2000). Moreover, adolescents respond to social evaluation with heightened positive emotional reactivity (Somerville, 2013), and when accepted by a peer, adolescent females report a boost in positive emotions and increased activation in reward-related brain regions (Guyer, Choate, Pine, & Nelson, 2012). Adolescents also demonstrate increased physiological reactivity to reward (Brenner, Beauchaine, & Sylvers, 2005; Richter & Gendolla, 2009) and heightened reward sensitivity in social contexts (Brenner et al., 2005).

The second aim was to explore the undoing hypothesis in a novel context by examining it in response to a positively valenced reward sensitivity induction in an older adolescent female population. Given that adults can effectively use low-approach positive emotional states to "undo" physiological stress and arousal (Fredrickson, Mancuso, et al., 2000), the first *undoing* hypothesis predicted that low approach-motivated positive emotion would facilitate effective emotion recovery (i.e., decrease in emotional and physiological intensity via return to baseline) following a reward sensitivity task as compared with a neutral or negative emotion. The second hypothesis, the *maintenance* hypothesis, predicted that positive emotion (and negative emotion) would not facilitate effective emotion recovery (i.e., no decrease in emotional and physiological intensity and longer or no return to baseline) following a reward sensitivity task. We predicted any emotion to maintain reward sensitive physiological arousal, we hypothesized that the neutral, non-emotional condition would facilitate recovery.

The third aim was to examine the influence of self-reported positive emotion on reward recovery processes. Previous work suggests that increased self-reported positive emotion during stress is associated with shorter physiological recovery and better habituation to physiological stress in adolescent girls at high risk for depression (Waugh, Muhtadie, Thompson, Joormann, & Gotlib, 2012). Moreover, self-reported positive emotion during a stressor mediates the relationship between resilience and faster physiological recovery in adults (Folkman & Moskowitz, 2000; Waugh et al., 2012). We thus extended this work to examine the role of self-reported positive emotion during a reward induction on physiological recovery across the neutral and positive conditions. We hypothesized that higher self-reported positive emotion would be associated with a faster physiological return to baseline across conditions.

Method

Participants

Participants were recruited from online postings and flyers posted in the general New Haven, Connecticut, region ($N = 83$). Inclusion criteria included community sample females between the ages of 18 and 21 ($M = 19.68$, $SD = 1.13$). Only females were recruited because male and female adolescents differ in both behavioral and self-reported sensation seeking and risk taking behaviors, with males displaying higher sensation seeking compared with females (Steinberg et al., 2008). Participants ($N = 83$) were Caucasian (44.6%), Asian (19.3%), African American (15.7%), Hispanic (9.6%), and other (10.8%) ethnicities. Participants in each condition did not differ on age, $F(2, 80) = 0.84$, $p = .44$, or ethnicity $\chi^2(8, N = 83) = 1.94$, $p = .98$.

Measures

Reward sensitivity task. Participants completed a novel "money winning task" to elicit elevated reward sensitivity. The task was a modified monetary incentive delay (MID) task (Knutson, Fong, Bennett, Adams, & Hommer, 2003), a reaction time (RT) task during which participants have to respond quickly to cued targets in order to gain money. The current task was modified from the original MID task to exclude a "loss" condition to isolate anticipatory and consummatory reward winning. Instructions stated, "If you are fast enough to hit a target, you can win different amounts of money." During the task, each trial presented a cue on the screen indicating an amount of money ($0.00, $0.50, or $1.00) that could be gained on that trial (anticipatory phase). Following a short delay (2 s), a target appeared on the screen and the participant responded as quickly as possible by pressing a computer key. The screen then flashed whether or not the participant responded fast enough to win the previously cued amount of money and also listed the total amount of money won from previous trials. Participants completed two predetermined and standardized blocks of trials where more money was won than lost at two thirds win to lose ratio (for a total of 21 trials across the two blocks, $n = 14$ or 66% resulted in wins). The blocks were predetermined so that the same amount of money was won by all participants. The current MID task also used a lengthened delay between cue and target to increase anticipatory gain of reward, similar to a behavioral version of this task that effectively increased subjective positive arousal during anticipation of winning in adults (Nielsen et al., 2008).

In order to further increase reward sensitivity, a social evaluative component was included and predetermined positive feedback was provided, given that social evaluation is heightened during adolescence and it increases positive emotion and reward-related reactivity, especially in female adolescents (Brenner et al., 2005; Guyer et al., 2012; Somerville, 2013). Prior to task start, adolescents were instructed that if they perform better than 75% of their peers on the first block of trials, they could complete a second round of the game and have a chance to win more money. Following the first block of trials, a screen appeared stating that the computer was tabulating scores to compare the adolescent's score with those of her peers. After 15 s to allow for social-evaluative reward anticipation, all adolescents read, "Congratulations, you have performed in the top 25% and you can now complete a second round to earn more money! Good luck!" A second block of predetermined trials then commenced, and across both blocks all adolescents won $5.00.

Self-reported emotion. Participants assessed their emotion and arousal over the course of the experimental session using the Self-Assessment Manikin (SAM; Bradley & Lang, 1994) and individual emotion items. The SAM is a quick, nonverbal 9-point rating of emotion that consists of graphic pictures of valence and arousal (a third item assessing dominance was not used). The valence figures start at a frowning (negative face), include a neutral face and end in a smiling (positive face). The arousal figures consist of a sleeping figure (not-aroused) to a figure that appears to be moving uncontrollably (highly aroused). Prior to experimental procedure starting, participants were provided a verbal explanation from the experimenter about how to use the SAM and were given a chance to ask questions. The SAM was assessed at baseline, during the reward induction and following the film clip. Additionally, because the negative film clip has been validated to induce sadness and because the positive emotion film clip being used has been validated to increase amusement (Rottenberg, Ray, & Gross, 2007), participants completed ratings of written items of *sad* and *amused* using a Likert scale from 1 (*very slightly or not at all*) to 5 (*extremely*). These emotion word items were not pictoral and were only included at baseline and following the film clip.

Psychophysiological response. Continuous recordings of physiological activity were measured at a sampling rate of 1,000 Hz, recorded using a Biopac MP150 system and analyzed with ACQKnowledge 4.1 (Biopac Systems Inc, Santa Barbara, CA). A transistor-transistor logic (TTL) digital signal enabled the synchronization of physiological data with the onset and offset of the different experimental periods. Artifacts and recording errors were corrected offline and values more or less than 3.0 standard deviations were deemed outliers and Winsorized (i.e., reassigned a value at the next highest or lowest value that is not an outlier).

Heart rate (HR). An EKG signal was recorded by applying two pregelled Ag-AgCl disposable snap electrodes in a modified Lead II configuration. A Biopac ECG100C amplifier with a high-pass filter of 0.5 Hz measured HR by importing the EKG signal into QRSTool (Allen, Chambers, & Towers, 2007) and an IBI series was created by applying an automatic R-peak detector. This series was then corrected manually and imported into CmetX (Allen et al., 2007) for calculation of mean HR, in beats per minute, for the individual experimental periods.

Respiratory sinus arrhythmia (RSA). RSA is the rhythm created by the oscillation in HR as a result of respiration (Bernardi, Porta, Gabutti, Spicuzza, & Sleight, 2001; Berntson, Cacioppo, & Quigley, 1993). It was obtained using the Biopac ECG100C amplifier and a respiration signal using Biopac's RSP100C respiration module with a high-pass filter of .05 Hz and a low-pass filter of 1 Hz. Using AcqKnowledge 4.1, RSA was calculated using the Grossman peak-valley method, which calculates the distance between the shortest and longest R-R interval for each breath. Higher RSA values are associated with higher parasympathetic influence.

Pre-ejection period (PEP). PEP is a measure of sympathetic arousal that has been implicated in reward (Brenner et al., 2005; Sherwood et al., 1990). PEP is the systolic time interval starting from the Q in the QRS complex to the cardiac ejection when the aortic valve is opened and it measures myocardial contractility. Impedance cardiography (Z) was measured using the Biopac NICO 100C module set at 50 kHz frequency with a low-pass filter of 10 Hz and with four Biopac strip-electrodes: two parallel electrodes on the neck and two on the lower back. PEP was calculated using the derivative of Z, dz/dt in conjunction with the EKG signal and cleaned using motion artifact removal, the adaptive matching function, and interpolation of out-of-range values in AcqKnowledge 4.1. PEP is measured in seconds and smaller values of PEP indicate higher ventricular contractibility and increased sympathetic innervation on the heart.

Finger pulse amplitude (FPA). Finger pulse amplitude measures the amount of blood pumped in the tip of the finger by measuring from the trough to the peak of the finger pulse. FPA is an index of peripheral vasoconstriction, and increased vasoconstriction in the fingertip (i.e., less blood flow to the fingertips) is a result of cardiovascular sympathetic activation. A plethysmograph was applied to the distal phalanges of the first finger of the nondominant hand to measure finger pulse and was calculated using a 100C PPG amplifier set to AC coupling and with a low pass of 3.0 Hz and a high pass of 0.5 Hz. Using AcqKnowledge 4.1, data were resampled offline to 250 Hz and the trough-to-peak amplitude was calculated for each finger pulse, which was measured in millivolts (mv).

Procedure

All participants first completed informed consent and self-report measures. Next, an experimenter explained and attached noninvasive physiological sensors to the participant for the experimental part of the study and explained how to use the SAM. Sitting in front of a computer, participants completed a 5-min adaptation period during which the participant remained quiet and still and physiological recordings were obtained. Following the adaptation, physiological recordings were obtained during a 90-s resting baseline during which participants were instructed to remain seated. Immediately following, participants current emotional state was assessed using the SAM valence and arousal measures and the positive (*amused*) and negative (*sad*) emotional words.

Participants then played the "money winning task" in order to induce heightened reward sensitivity. The reward induction took approximately five minutes and physiological recordings were obtained throughout the entire task. During the second block of trials, participants were prompted with the two-item SAM nonverbal mood rating assessment in between trials to assess current emotional state. The emotional word items (*amused* and *sad*) were not included at this second rating as to provide minimal disturbance in emotional and physiological responding during the reward induction (Lieberman et al., 2007; Taylor, Phan, Decker, & Liberzon, 2003). Immediately following completion of the reward induction, all adolescents were randomized to watch either a negative (n = 27), neutral (n = 29) or positive (n = 27) film clip.

Three previously validated film clips were utilized to induce specific emotional states (Rottenberg et al., 2007). A 171-s clip from *The Champ* (Lovell & Zeffirelli, 1979) depicting a boy crying as he watches his father die was used for the sad film, that has been validated to show an increase in sadness (Gross & Levenson, 1995; Rottenberg et al., 2007) and has been used as a comparison to positive and neutral film clips in previous "undoing" studies (Fredrickson, Mancuso, et al., 2000). Sadness is also a low approach-motivated negative emotion (Gable & Harmon-Jones, 2010). The positive film clip was drawn from the TV show "Whose Line Is It Anyway?" (McCarthy, Forrest, Gowers & de Moraes, 2001). This 223-s film clip depicts a stand-up comedian creating an ice cream sundae and it has been validated to elicit high levels of amusement (Rottenberg et al., 2007). Amusement is a low approach-motivated positive emotion that is not associated with motivation toward a goal or reward and has been reliably used to test the undoing hypothesis (Fredrickson, Mancuso, et al., 2000). A neutral emotional state was induced by showing an instructional video on how to apply wallpaper for 200 s (Curby, Johnson, & Tyson, 2012). Physiological recordings were obtained for 171 s, the length of the shortest film clip. Immediately following completion of the clips, a third SAM and individual emotion rating assessed how participants felt during the assigned film clip. Participants then completed other tasks not related to the current study and then watched a 60-s positive film clip of puppies and kittens to effectively bring participants back to a stable emotional baseline (Joormann, Gilbert, & Gotlib, 2010). Finally, participants were debriefed and paid $20 for their time.

Results

Data Analytic Strategy

We tested Aim 1 by validating changes in subjective and cardiovascular functioning from baseline to during the novel reward sensitivity task. Second, we conducted a manipulation check to confirm that each film induced the subjective emotional state intended. To assess Aim 1 and the manipulation checks, we employed repeated measures multivariate analysis of variance (MANOVA) for each domain of change (subjective and physiological; see Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005; Rottenberg, Kasch, Gross, & Gotlib, 2002) with time as the within-subject variable and condition as the between-subjects variable and using Pillai's Trace measures of significance. To Test Aim 2, we performed a priori planned contrasts predicting that the duration of time to recover from the cardiovascular reactivity elicited from the reward induction to baseline during the positive emotional film clip to either be (a) faster than the duration of time to recover from cardiovascular reactivity elicited from the reward induction to baseline during the neutral emotional film clip (undoing) or (b) slower than the duration of time to recover from the cardiovascular reactivity elicited from the reward induction to baseline during the neutral film clip, but not different than the negative film clip (maintenance). For Aim 3, we performed a hierarchal linear regression to examine the role of self-reported positive emotion on emotion recovery. Missing data were deleted listwise and multicollinearity diagnostics showed tolerance statistics below standards. Block 1 included the centered independent factor of subjective emotion during the reward induction, Block 2 included dummy coded condition (neutral vs. positive), and Block 3 included the interaction between subjective emotion and condition. We tested significant interactions using simple slopes analyses. Two separate regressions were run for each of the recovery measures.

For Aim 1, we assessed if there were any condition differences during the adaptation and baseline measurements using a one-way analysis of variance (ANOVA). No differences emerged for any subjective emotion or physiological indices ($ps > .05$), except for RSA at baseline, $F(2, 79) = 3.41$, $p = .04$, $\eta_p^2 = 0.04$. However, follow-up Tukey or Bonferroni post hoc tests revealed no condition differences in RSA at baseline, and given there were also no RSA differences during adaptation, we continued as planned for Aim 1, assessing subjective and physiological responses to the reward induction. The MANOVA conducted on subjective experience included SAM valence and arousal as dependent variables, time (baseline to two thirds of the way through the reward induction) as the within-subject variable, and condition (positive, negative, neutral) as the between-subjects variable (see Table 1). This MANVOA yielded a significant main effect of time, $F(2, 78) = 39.92$, $p = .00$, $\eta_p^2 = 0.51$, but no main effect of condition, $F(4, 158) = 0.12$, $p = .98$, $\eta_p^2 = 0.00$ and no Time × Condition interaction, $F(4, 158) = 1.38$, $p = .25$, $\eta_p^2 = 0.03$. Follow-up univariate repeated measures ANOVAs demonstrated that for the main effect of time, self-reported positive emotion (SAM valence), $F(1, 79) = 4.93$ $p = .03$, $\eta_p^2 = 0.06$ and self-reported arousal (SAM arousal), $F(1, 79) = 80.86$, $p = .00$, $\eta_p^2 = 0.51$, increased from baseline to midreward induction. For physiological variables, we used the same analytic strategy of repeated measures MANOVA to assess physiological dependent variables of HR, FPA, PEP, and RSA from the 90-s baseline to the 90-s reward induction (see Table 1). The MANOVA revealed a main effect of time, $F(4, 60) = 15.32$, $p = .00$, $\eta_p^2 = 0.51$, but no main effect of condition, $F(8, 122) = 1.79$, $p = .09$, $\eta_p^2 = 0.11$, and no Time × Condition interaction, $F(8, 122) = 0.60$, $p = .77$, $\eta_p^2 = 0.04$. Follow-up univariate repeated measures ANOVA revealed that from baseline to the reward induction, HR significantly increased, $F(1, 73) = 10.21$, $p = .00$, $\eta_p^2 = 0.12$, RSA significantly increased, $F(1, 76) = 10.99$, $p = .00$, $\eta_p^2 = 0.13$, PEP significantly decreased, $F(1, 74) = 5.88$, $p = .02$, $\eta_p^2 = 0.07$, FPA significantly decreased, $F(1, 72) = 25.09$, $p = .00$, $\eta_p^2 = 0.26$. When asked following the experiment whether they could tell that the task was predetermined, no participants spontaneously indicated knowledge of the experiment being fixed; however, once the experimenter debriefed participants, four (5%)

Table 1
Means, Standard Deviations, and 95% Confidence Intervals (CIs) of Baseline and Reward Induction Task Across Conditions

Condition	Baseline		Reward induction	
	M (*SD*)	95% CI	*M* (*SD*)	95% CI
SAM valence	3.98 (1.12)	[3.73, 4.22]	3.56 (1.55)*	[3.22, 3.91]
SAM arousal	5.70 (1.84)	[5.29, 6.10]	3.70 (1.46)**	[3.38, 4.02]
HR	75.24 (10.74)	[71.23, 77.31]	77.01 (11.18)**	[72.97, 79.20]
FPA	.09 (.12)	[.06, .14]	.04 (.06)**	[.028, .065]
PEP	.09 (.03)	[.08, .10]	.09 (.03)*	[.07, .89]
RSA	4.31 (0.65)	[4.17, 4.46]	4.45 (0.61)**	[4.31, 4.58]

Note. Self-Assessment Manikin (SAM) valence higher scores indicate lower mood; SAM arousal higher scores indicate less arousal. HR = heart rate in beats per minute; FPA = finger pulse amplitude in mV; PEP = pre-ejection period in seconds; RSA = respiratory sinus arrhythmia as natural log of variance of interbeat interval time series.
* $p < .05$. ** $p < .01$.

endorsed knowing the monetary portion and two (2%) assumed the social comparison were predetermined. When these participants were removed and analyses rerun, subjective and physiological results did not differ and thus these participants were kept in all subsequent analyses. Together, the reward induction increased sympathetic (FPA, PEP) and cardiovascular arousal (HR) arousal and also increased parasympathetic responding (RSA).

To test whether each emotional film clip elicited the subjective emotional experience desired, we completed a repeated measures MANOVA of SAM valence, SAM arousal, and individual emotion ratings of sadness and amusement from baseline to immediately following the film clips. If multivariate effects were detected, we followed up these findings with univariate repeated measures ANOVA. If significant univariate interactions were found (Time × Condition), we completed paired *t* tests as well as a one-way ANOVA of group differences at the second time point. MANOVA results indicated a main effect of time, $F(4, 76) = 8.20$, $p = .00$, $\eta_p^2 = 0.30$, a main effect of condition, $F(8, 154) = 12.25$, $p = .00$, $\eta_p^2 = 0.39$, and a Time × Condition interaction, $F(8, 154) = 18.04$, $p = .00$, $\eta_p^2 = 0.48$. Univariate follow-up tests revealed significant Time × Condition interactions for SAM valence, $F(2, 79) = 54.44$, $p = .00$, $\eta_p^2 = 0.56$, SAM arousal, $F(2, 79) = 16.52$, $p = .00$, $\eta_p^2 = 0.16$, sadness, $F(2, 79) = 12.07$, $p = .00$, $\eta_p^2 = 0.50$, and amusement, $F(2, 79) = 18.84$, $p = .00$, $\eta_p^2 = 0.45$ (see Figure 1).

Follow-up *t* tests for each group separately revealed from baseline to postmovie, SAM valence ratings became more negative in the neutral condition, paired $t(27) = -3.40$, $p = .00$ and the sad condition, paired $t(26) = -6.40$, $p = .00$, and more positive in the amusement condition, paired $t(26) = 6.36$, $p = .00$. Groups significantly differed from each other following the movie, $F(2, 79) = 87.93$, $p = .00$, $\eta_p^2 = 0.69$, and Bonferroni comparisons revealed that all three groups differed from each other with the amusement condition reporting the highest positive emotion ($M = 2.22$, $SD = 1.12$), followed by the neutral condition, ($M = 4.71$, $SD = 0.98$), and then the sad condition ($M = 6.41$, $SD = 1.39$). For SAM arousal, follow-up paired *t* tests revealed that arousal did not change from baseline to following the movie for the neutral condition, paired $t(27) = -1.35$, $p = .19$ or in the sad condition, paired $t(26) = -0.08$, $p = .94$, but arousal subjectively increased in the amusement condition, paired $t(26) = 4.14$, $p = .00$. Examining arousal following the movie, the groups did significantly differ, $F(2, 79) = 8.84$, $p = .00$, $\eta_p^2 = 0.18$ with the amusement condition demonstrating higher subjective arousal ($M = 4.33$, $SD = 1.62$) compared with the neutral condition ($M = 6.19$, $SD =$

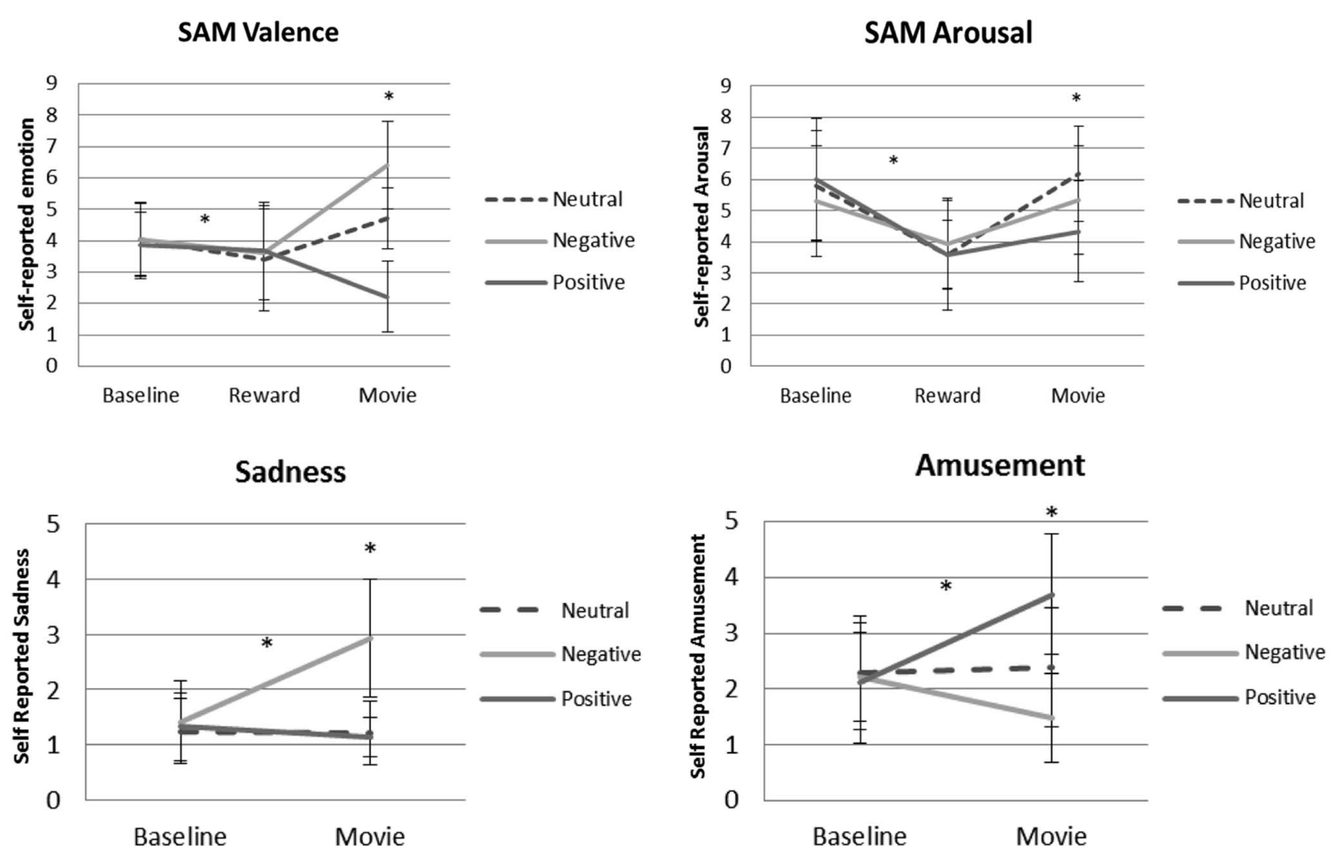

Figure 1. Mean subjective response to reward task and movie clip in the neutral, positive, and negative conditions. Error bars represent standard deviations; higher values for Self-Assessment Manikin (SAM) valence indicate higher negative emotion; higher values for SAM arousal indicate a less aroused (more calm) state; asterisk between conditions denotes significant main effect of time; asterisk over a time point denotes significant interaction demonstrating differences at that time point. * $p < .05$.

1.54) whereas the negative condition did not significantly differ from either group (M = 5.33, SD = 1.73). For individual emotion ratings of sadness, follow-up paired t tests revealed that neither the neutral condition, paired $t(27)$ = 0.37, p = .71 nor the amusement condition, paired $t(26)$ = 1.99, p = .06 changed in self-reported sadness, whereas the sad condition increased, paired $t(26)$ = −6.84, p = .00. Moreover, groups differed in sadness following the movie, $F(2, 79)$ = 52.10, p = .00, η_p^2 = 0.57 as the sad condition (M = 2.93, SD = 1.07) reported significantly higher sadness compared with the neutral (M = 1.21, SD = 0.57) and amusement condition (M = 1.15, SD = 0.36). The neutral and amusement groups did not differ. For emotion ratings of amusement, follow-up paired t tests demonstrated that the neutral condition did not change in amusement, paired $t(27)$ = −0.60, p = .56, but the sad condition decreased in amusement, paired $t(26)$ = 3.92, p = .00, and the amusement condition increased in amusement, paired $t(26)$ = −6.46, p = .00. The groups differed on amusement following the movie, $F(2, 79)$ = 34.62, p = .00, η_p^2 = 0.47, and all three groups significantly differed from each other with the amusement condition endorsing the highest amusement (M = 3.70, SD = 1.07), followed by the neutral, (M = 2.39, SD = 1.07) and then the sad (M = 1.48, SD = 0.80) conditions.

For Aim 2, we quantified physiological recovery as the time, in seconds, taken for the individual physiological response indices to return to the participants' own baseline confidence interval for 5 of 6 consecutive seconds. We created a baseline confidence interval by adding and subtracting one standard deviation from the mean measure of response during the 90-s resting baseline period as has been previously been done to assess physiological recovery and the undoing hypothesis (Fredrickson & Levenson, 1998; Fredrickson, Mancuso, et al., 2000). We utilized second by second data and recovery times three plus or minus standard deviations were deemed outliers and were Winsorized prior to analysis. We also included a second measure of recovery that summed the total number of seconds each participant's physiological score remained in the baseline confidence interval ("baseline CI") during the entire emotional film clip. We included this measure because our first measure did not account for the possibility that once recovery is reached, participants might fluctuate out of the baseline CI recovery zone and thus, were never fully recovered. For both recovery measures, indices of cardiovascular recovery (HR, FPA, and PEP) were assessed by running two planned contrasts, (a) comparing the neutral and positive condition and (b) comparing the neutral condition with the positive and negative conditions combined.

For the first measure of recovery assessing time to recover, contrasts revealed no group differences in recovery in HR between the neutral (M = 15.10, SD = 16.06; 95% confidence interval [CI] [8.88, 21.34]) and positive (M = 20.20, SD = 24.39; 95% CI [10.13, 30.26]) condition, $t(75)$ = 0.82, p = .42, d = .10 nor any group differences in recovery between the neutral and combined negative (M = 22.64, SD = 26.99; 95% CI [11.50, 33.78]) and positive conditions, $t(75)$ = 1.18, p = .24, d = .27. Similar results were found for contrasts of FPA between the neutral and positive condition, $t(48)$ = −1.37, p = .18, d = −.40, and between the neutral and combined negative and positive condition, $t(48)$ = −1.14, p = .26, d = .33, and for PEP, in the neutral versus positive, $t(72)$ = 1.11, p = .27, d = .26, and the neutral versus combined negative and positive $t(72)$ = 0.48, p = .64, d = .11.

For the second recovery measure assessing the total time spent in the baseline confidence interval ("baseline CI"), there was a group difference in HR between the neutral and positive condition, $t(77)$ = −2.83, p = .01, d = .65, and a group difference between the neutral compared with the combined negative and positive condition, $t(77)$ = −2.29, p = .03, d = −.52. The neutral condition (M = 106.79, SD = 29.97; 95% CI [95.17, 118.40]) spent more time in the HR baseline CI compared with the positive (M = 81.50, SD = 31.58; 95% CI [68.74, 94.25]) and positive and negative (M = 96.81, SD = 36.78; 95% CI [81.95, 111.66]) combined group. No significant group differences emerged for PEP when comparing the neutral to the positive condition, $t(75)$ = −0.13, p = .90, d = −.03, or the neutral to the combined positive and negative condition, $t(75)$ = −0.50, p = .62, d = −.12, or for FPA in either contrast: neutral versus positive, $t(65)$ = −0.67, p = .51, d = −.17, or neutral versus combined negative and positive, $t(65)$ = −1.18, p = .24, d = −.29.

For Aim 3, we examined the extent to which self-reported positive emotion experienced during the reward induction influenced our two physiological recovery measures of HR during the positive and neutral conditions. For HR recovery, subjective emotion during the reward induction entered into Model 1 and condition added in Model 2 were not significant predictors of HR recovery (see Table 2). When the interaction between mood and condition were entered in Model 3, the interaction predicted HR recovery, Model 3: $F(3, 49)$ = 3.42, R^2 = 0.17, ΔR^2 = 0.16; Condition × Mood: β = 0.58, p = .004. To interpret this interaction, simple slopes were tested and both the neutral and positive conditions revealed significant associations. In the neutral condition a more positive mood was associated with faster HR recovery (b = 5.16; SE = 2.23, t = 2.27, p = .027), whereas in the positive condition, a more positive mood was associated with slower HR recovery (b = −4.90, SE = 2.40, t = −2.04, p = .047; see Figure 2a). For time in the baseline CI, subjective mood in Model 1 was not a significant predictor, although Model 2 was significant when group was entered, Model 2: $F(2, 51)$ = 4.61, R^2 = 0.15, ΔR^2 = 0.14; condition: β = 0.38, p = .005. When the interaction was entered into Model 3, it was also significant, Model 3: $F(3, 50)$ = 5.72, R^2 = 0.26, ΔR^2 = 0.10; Condition × Mood: β = −0.47, p = .01. Similarly, simple slopes testing the interaction revealed that a more positive mood was associated with longer time spent in

Table 2
Hierarchical Multiple Regression Analyses Predicting Heart Rate Recovery Measures From Subjective Mood and Arousal During the Reward Induction

	Subjective mood predicting measures of recovery			
	Time to recover		Time spent in baseline CI	
Predictor	ΔR^2	β	ΔR^2	β
Step 1	.00		.01	
Mood		.05		−.10
Step 2	.02		.14**	
Condition		−.12		.38
Step 3	.16**		.10*	
Mood × Condition		.58**		−.47*

Note. CI = confidence interval.
* $p < .05$. ** $p < .01$.

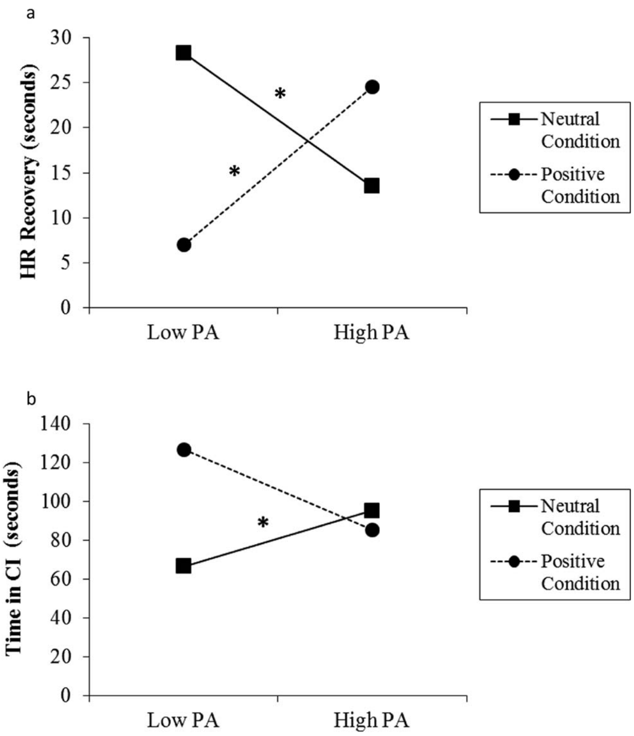

Figure 2. Simple slopes for subjective mood on recovery indices. PA = state positive affect during reward induction; HR recovery = time (in seconds) until heart rate is recovered; time in CI = total time spent in baseline confidence interval. * $p < .05$.

baseline CI for the neutral condition ($b = -7.65$, $SE = 3.49$, $t = -2.19$, $p = .03$); however, no significant association was found in the positive condition ($b = 5.71$, $SE = 3.68$, $t = 1.55$, $p = .13$ (see Figure 2b).

Discussion

The present investigation assessed the validity of a novel reward sensitivity induction in an older adolescent female population and examined recovery from a heightened reward sensitivity state, a common emotional state in adolescence and emerging adulthood that can be difficult to effectively manage and often leads to maladaptive outcomes (e.g., Dahl & Gunnar, 2009; Galván, 2013; Steinberg et al., 2008). Specifically, we examined how low approach-motivated positive emotion might serve as a particularly effective down-regulator of these heightened high approach-motivated reward sensitive states, and tested two competing hypotheses regarding the extent to which positive emotional states may foster recovery (undoing hypothesis) versus maintaining the status quo (maintenance hypothesis). This study is novel insofar as it is the first time that the undoing hypothesis and physiological recovery from a positive emotional reward sensitive states has been tested during older adolescence, a critical developmental time when learning effective strategies to down-regulate reward sensitivity is particularly important.

Results indicated partial support for the maintenance hypothesis insofar as low approach-motivated positive emotions did not lead to faster physiological emotion recovery from reward sensitive states; but by contrast, the positive (and negative) conditions were associated with maintained physiological HR reactivity during the recovery period. Moreover, higher subjective positive emotion during the positive emotion condition was associated with perpetuated physiological reactivity. Older adolescents may exhibit particular difficulty recovering from these reward-related positive emotional states given heightened reward sensitivity and emotional reactivity characteristic of this developmental period (e.g., Galván, 2013). However, it should be noted that some conditional support also emerged for the undoing hypothesis: When *not induced* into an emotional state (i.e., in the neutral low-emotional condition), subjective positive emotion during the reward sensitivity induction led to faster physiological recovery. Critical insights provided for the first time by this research are that induced low-approach positive emotion following the reward induction maintains heightened reward sensitive reactivity, but that individual differences in subjectively reported positive emotion experienced *during* (rather than *following*) the heightened reward sensitivity induction aid in faster recovery.

The first aim of this study was to test the validity of a novel reward sensitivity induction in an older adolescent female population. This was a critical methodological step to ensure that a uniform reward sensitivity state was induced across all participants. Consistent with our hypotheses and a similar to a modified version of this task for adults (Nielsen et al., 2008), the reward sensitivity induction successfully increased subjective positive emotion and arousal in older adolescent females. Physiologically, the reward induction resulted in increased HR, elevations in indicators of sympathetic activity (i.e., FPA and PEP) as well as indicators of parasympathetic activity (i.e., RSA). This suggests that the task elicited both physiological correlates that have been associated with positive emotion (RSA; Kogan, Gruber, Shallcross, Ford, & Mauss, 2013; Kok & Fredrickson, 2010; Oveis et al., 2009), as well as physiological correlates of increased sympathetic arousal associated with reward, behavioral activation, and elevated goal-striving and attainment (Brenner et al., 2005; Kreibig, Gendolla, & Scherer, 2010; Richter & Gendolla, 2009). This heightened sympathetic arousal leads to body mobilization and preparedness to act (Levenson, 1994), which would be required during high approach-motivated reward sensitivity positive emotional states. The current reward induction was also novel in that it is one of the few (for neuroimaging paradigm see Forbes et al., 2009) to operationalize a heightened subjective and physiological reward sensitive state as an independent variable that did not depend on participant performance. Most tasks used to activate reward sensitivity are behavioral tasks that participants "play" to win money or social feedback, such that performance on the task dictates how much reward is obtained (e.g., Cauffman et al., 2010; Galván et al., 2006; Rademacher et al., 2010; Rao et al., 2011; Vaidya, Knutson, O'Leary, Block, & Magnotta, 2013). The current induction enables theoretical disentangling of reward sensitivity that is distinct from performance or success on the task itself.

The second aim of the study sought to test the viability of the undoing hypothesis of positive emotion compared with the maintenance hypothesis when recovering from heightened reward sensitivity. Results indicated some support for the maintenance hypothesis as the neutral condition demonstrated significantly more total time spent in the baseline confidence interval for HR during the recovery film clip compared with the negative or positive emotional conditions. This suggests that positive emotion did not aid in undoing HR, but in fact, may have served to maintain or perpetuate elevated HR during a recovery period. This is in contrast to work suggesting that (low approach-motivated) positive emotion aids in faster physiological recovery from various forms of heightened emotional arousal, including stress-induced anxiety, anger, fear, and sadness (Fredrickson & Levenson, 1998; Fredrickson, Mancuso, et al., 2000; Fredrickson, Maynard, et al., 2000).

Several possible explanations may help understand these findings. First, the present study is the first to focus on recovery from heightened positive reward-sensitive states. Although we did switch motivational intensity (from high to low-approach) to facilitate recovery, the valence remained constant (positive emotion in both cases). Although the current study tested recovery when valence was switched by using a low approach-motivated negative emotion condition to recover from the positive reward sensitivity induction, it may be the case that the necessary ingredients for recovery from reward-focused positive emotional states are fundamentally different than those that facilitate recovery from stress or negative emotional states. It is interesting to note that our findings did suggest that even in the presence of an induced sad mood (a switch in valence from positive to negative during recovery), which is often associated with decreased physiological responding (Kreibig, 2010), heightened physiological reactivity associated with reward reactivity was maintained. Second, although our population was on the older end of adolescence and thus peak reward-reactivity has already passed (e.g., Steinberg, 2010), given the ongoing development of prefrontal regions through the mid-20s (Giedd, 2004), imbalanced neurobiological development may have impeded the ability to capitalize on the adaptive outcomes of low approach-motivated positive emotions. Specifically, the heightened physiological responding to the reward sensitivity task might have been of great enough intensity to carry over into the emotional conditions.

No matter what the mechanism, continually experiencing this perpetuated activated state may lead to increased vulnerability for making risky decisions and onset of psychopathology. This heightened approach-motivated and physiologically activated state might contribute to a form of allostatic load, the notion that the body experiences wear and tear from chronic heightened physiological arousal (McEwen, 1998; Seeman, McEwen, Rowe, & Singer, 2001). The effects of this allostastic load may be a mechanism that puts older adolescents at greater risk for developing psychopathology characterized by heightened approach-motivated reward dysregulation (e.g., Gilbert, 2012). Given that an inability to physiologically recover from heightened reward sensitivity may lead to increased vulnerability to developing disorders characterized by reward-dysregulation, future work would benefit from investigating the repeated reactivity to, recovery from, and habituation to reward sensitivity in adolescents both experimentally (e.g., Waugh et al., 2012) and longitudinally.

These findings also indicate that distracting with neutral information may help to adaptively regulate heightened reward sensitivity. When reward saliency is high, trying to distract with another positive emotion (e.g., thinking about a funny incident with friends) or even a negative emotion (e.g., thinking about missing out on the last party) as a way to regulate, may perpetuate emotional arousal, while thinking about neutral distracting material (i.e., thinking about tomorrows weather), might help individuals better downregulate reward sensitivity and associated physiological activation. Distraction is an adaptive emotion regulation strategy in certain contexts (e.g., Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Sheppes, Catran, & Meiran, 2009), and when distracting with neutral material, it may also be an adaptive way for older adolescents to downregulate heightened reward sensitivity. It should be noted that we did not include any measure of task engagement while watching the film clips and so another explanation might be that the individuals in the neutral condition were daydreaming or possibly engaging in self-relevant processing or mind-wandering rather than actively distracting. Given mind-wandering is commonly reported (Killingsworth & Gilbert, 2010), this possible passive daydreaming or mind-wandering might have led to disengagement from the positive emotions elicited by the reward and potentially a differential decrease in physiological responding. Studying the mechanisms and specific processes underlying the faster recovery in the neutral condition will be important to assess in future work so as to better understand the various adaptive and maladaptive ways to downregulate heightened reward sensitivity.

The third aim examined how self-reported positive emotion might influence physiological recovery from reward sensitivity. Results differed by condition, such that only in the neutral condition, higher subjective positive emotion during the reward induction was associated with faster HR recovery and more time spent in the baseline HR confidence interval. Higher state positive emotion during a stressor has been shown to lead to better coping, faster physiological recovery from the stressor, and better habituation to stress (Folkman & Moskowitz, 2000; Waugh et al., 2012). Our finding provides conditional support of the undoing hypothesis: When no other emotion is experienced following the reward induction, the ability to experience greater positive emotion *during* the reward induction leads to a faster return to baseline *after* the reward induction is over. This finding may also be an indication of psychological flexibility, or the ability to shift and adapt to situational demands (e.g., Kashdan & Rottenberg, 2010). Specifically, those individuals who were able to most fully experience and possibly savor the positive emotional state during the reward-induction also were best able to flexibly recover and detach from the experience after it was over when no other emotion was induced.

In the positive condition, higher subjective state positive emotion during the reward induction led to slower physiological recovery. Participants in this condition experienced a positive reward-salient induction immediately followed by a second positive mood induction with no need to detach, shift, or recover from the positive emotional experience. It should be considered that it may be adaptive to maintain and coast on the positive emotional and physiologically activated state when experiencing two individual positive emotion inductions. In fact, although reward sensitivity is often characterized as maladaptive given its association with risky behaviors and onset of psychopathology, Casey (2013) reminds us that characterizing something that is part of normative development (heightened reward sensitivity) as maladaptive is ill-informed. Elevated reward sensitivity may help older adolescents engage in goal-directed behaviors such as seeking out new relationships, interests, and academic pursuits. Moreover, increased neurobiological reactivity to prosocial reward is associated with prospective *decreases* in risk-taking behaviors (Telzer, Fuligni, Lieberman, & Galván, 2013). Reward sensitivity may not be something that necessarily always needs to be "regulated," but instead, simply finding ways for older adolescents to channel this heightened reward sensitivity into more adaptive behaviors (such as sports, extracurricular activities, or academic/career pursuits) may be a more useful route. Research examining recovery from heightened reward sensitivity states is understudied, and future work should aim to understand when recovery from reward sensitivity is adaptive or when it might relate to onset of psychopathology.

Findings from the present study should be interpreted with the confines of several limitations. First, although the reward-induction appeared to influence a reward sensitive state, because there is no known subjective way to measure heightened reward sensitivity and we did not specifically assess whether we induced heightened approach-motivation, the induction might simply be capturing elevated positive emotional arousal. Although understanding recovery from positive emotional states is important, the current study aimed to specifically assess recovery from approach-motivated and reward-sensitive positive emotional states that have been linked with sensation-seeking behaviors and negative outcomes in adolescence (Galván, 2013). Related, we used a relatively small monetary reward in addition to a social reward and thus we are unable to disentangle what participants specifically found rewarding about this task. Future studies might employ neuroimaging or electroencephalography (EEG) methodology to assess whether emotional and motivational regions implicated in reward sensitivity and approach-motivation are activated in response to this reward induction. Moreover, future research would benefit by assessing both subjectively and physiologically what aspects of the reward manipulation appear to be most rewarding. Second, the current sample size was relatively small and may have been statistically underpowered to detect observable differences. Future studies replicating these findings in larger samples are warranted. Third, the current study only utilized females. Males exhibit heightened reward and sensation seeking compared with females (Steinberg et al., 2008) and future research would benefit from examining gender differences in recovering from reward sensitivity. Fourth, the current study recruited only late adolescents and emerging adults ages 18–21; however, reward sensitivity peaks during younger adolescence (i.e., age 14–15; Steinberg et al., 2008). Although brain development continues into the 20s as do risky behaviors and onset of psychopathology associated with reward sensitivity, using a younger and more reward-sensitive age might yield a different pattern of results. Future research would benefit from assessing recovery from reward sensitivity in younger ages and across adolescent developmental trajectories into emerging adulthood to understand how recovery from heightened reward sensitive states differs across development. Fifth, the positive emotion used to assess recovery specifically induced amusement. Although this emotion has previously been used to test the undoing hypothesis (Fredrickson, Mancuso, et al., 2000), and can be conceptualized as a low approach-motivated positive emotion (Gilbert, 2012; Harmon-Jones & Gable, 2008) amusement has demonstrated mixed effects on physiological reactivity (Kreibig, 2010). Amusement might not have been the most effective emotion manipulation to aid in recovery especially considering it elevated subjective arousal in the current study, and future research should assess other low-approach motivated positive emotions, such as contentment or gratitude, to assess recovery from heightened reward sensitive positive emotional states. Sixth, the current study assessed recovery in a manner that is dependent on the standard deviation of baseline physiological reactivity. Given that the standard deviation defines the size of the confidence interval, fluctuations in physiological baseline measurements largely influence the calculation of recovery duration. Although this measurement of recovery has previously been used in foundational studies of the undoing hypothesis (Fredrickson & Levenson, 1998; Fredrickson, Mancuso, et al., 2000; Tugade & Fredrickson, 2004) other measures of recovery might lead to different conclusions.

In light of these limitations, the current study successfully induced a heightened positive state of reward sensitivity using a novel induction and also provided the first test of the undoing hypothesis from heightened reward sensitivity in older adolescents. Results found that induced positive emotion maintained physiological arousal while state positive emotion during the reward induction was associated with faster undoing. This study provides a first step at examining ways individuals can "undo" heightened reward sensitivity states. Future research would benefit from prospectively examining the long-term benefits, or dysregulation, that different types of reward reactivity and reward recovery may lead to and how this might relate to onset of risky behaviors and psychopathology.

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