Cognitive, Affective, & Behavioral Neuroscience
https://doi.org/10.3758/s13415-024-01248-y

SPECIAL ISSUE/INDIVIDUAL DIFFERENCES IN MEMORY MODULATION

Effects of motivated emotion regulation on downstream memory for and affective responses to re-encountered stimuli

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Accepted: 19 November 2024

Abstract

Emotion regulation is integral to well-being and adaptive behavior. Differing regulation strategies have important downstream consequences. Evidence suggests that reappraisal use can improve memory and reduce emotional reactivity to previously regulated stimuli. Reappraisal is cognitively demanding and dependent on prefrontal-based cognitive control processes typically enhanced by motivation. We recently demonstrated that motivational incentives increased reappraisal use and decreased negative affect during emotion regulation. It is currently unknown how incentive manipulations of emotion regulation affect later memory and affective response: some accounts suggest that motivation boosts memory relatively automatically, via dopamine input to hippocampus, whereas others suggest that motivated memory might depend on control allocation at encoding. In a 2-day online study, we examined how motivated emotion regulation relates to downstream memory and affect. Participants completed an emotion regulation task under baseline and incentive conditions, with recognition memory and affect examined ~ 24-hours later. Surprisingly, for stimuli encountered under incentive, memory decreased, challenging the hypothesis that motivational enhancements of memory occur automatically. Additionally, Day 2 affect did not significantly differ for stimuli encountered in baseline and incentive contexts, suggesting that incentive-related affective benefits were short-lived. In contrast, reappraisal predicted increased memory and reduced negative affect upon reencounter. These results suggest that incentive may have promoted global, potentially automatic changes in affect, independent from regulatory control processes that also could lead to affective change. Further characterization of these multiple pathways will be important for advancing a mechanistic understanding of emotion regulation and its consequences across motivational contexts.

Keywords Emotion regulation · Motivation · Memory · Reappraisal · Incentive

Introduction

While emotions are a ubiquitous part of daily life, they can also cause distress, hinder daily function, or be inappropriate to present social and environmental contexts. As such, *emotion regulation*, or the ability to alter or intervene in emotional experience and expression, plays a pivotal role in well-being and everyday adaptive behavior. In recent years, emotion regulation has been increasingly recognized as a form of flexible, goal-oriented behavior dependent on cognitive control mechanisms (Ochsner & Gross, 2005; Pruessner et al., 2020), implemented via differing regulation strategies, towards varying goal outcomes (English et al., 2017; Greenaway et al., 2021). Emotion regulation processes also have consequences for downstream memory: while prioritization of emotional over nonemotional content in memory is a well-established phenomenon (LaBar & Cabeza, 2006), memory for emotional content can also be modulated by emotion regulation strategy and success (Knight & Ponzio, 2013; Richards & Gross, 2000; Sheppes & Meiran, 2008). Extensive research has shown that memories can be shaped by motivational influences (Shohamy & Adcock, 2010) and might guide future adaptive behavior (Schacter, 2012). As such, memory modulation by emotion regulation processes might likewise reflect motivational influences on regulation strategy, as well as memory selectivity for the emotional information encountered. Despite these implications, to our knowledge, the effects of motivation manipulation on emotion regulation and its consequences for downstream memory remain largely uncharacterized.

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Published online: 06 January 2025

Emotion regulation can be implemented via strategies that differ on multiple parameters, including their timing relative to emergence of affect, demands on cognitive resources, and potential benefits in the short- and long-term (Hermann et al., 2017; Sheppes, Catran, & Meiran, 2009; Thiruchselvam et al., 2011). Two emotion regulation strategies that have been well-studied in terms of their potential similarities and differences are *cognitive reappraisal* and *distraction*. *Cognitive reappraisal* refers to reframing of the meaning of an emotional stimulus to alter the associated experience (e.g., "finding the silver lining" in a disappointing outcome to reduce negative emotion), whereas *distraction* refers to allocation of attention away from an emotional stimulus to reduce its impact (Ochsner & Gross, 2005). Evidence suggests that both of these strategies can engage prefrontal brain regions linked to cognitive control and successfully reduce negative affect short-term (McRae et al., 2010; Sheppes & Meiran, 2007), but the longer-term consequences of habitual reappraisal versus distraction might diverge. Habitual use of cognitive reappraisal has been associated with enhanced well-being and reduced risk for psychopathology (Eftekhari et al., 2009; Gross & John, 2003), whereas long-term use of distraction has generally been found to be less adaptive, especially when used in conjunction with avoidance tendencies, reducing the likelihood that an individual will revisit and address the emotion in the future (Wolgast & Lundh, 2017).

These observed differences in long-term adaptiveness between reappraisal and distraction strategy use might relate to differences in their underlying psychological mechanisms and downstream consequences for memory. According to the *process model of emotion regulation* (Gross, 2015), emotions can be understood as unfolding over time, with their progression and magnitude modulated by the type and associated timing of regulation strategy used. Reappraisal is usually implemented later than distraction in the emotion generation process, given that it typically requires initial appraisal of and engagement with the target stimulus before attributing it a new meaning via semantic elaboration. In contrast, distraction is typically used earlier in the emotion generation process, reducing emotion through attention diversion at stimulus onset (Thiruchselvam et al., 2011). Evidence suggests that reappraisal and distraction differ in their cognitive demands. Reappraisal requires more cognitive effort than distraction (Sheppes & Meiran, 2008). Together, these theoretical and empirical accounts suggest that reappraisal- and distraction-based strategies might differ in timing, attentional allocation towards, and semantic elaboration of the eliciting stimulus. Strategy-related differences in memory for stimuli encountered during emotion regulation might be driven by such differences in attention and elaborative processing as well as resultant emotional arousal.

To date, studies examining the effects of regulation strategy on downstream memory for emotional stimuli suggest that reappraisal typically boosts subsequent memory, but that this effect might depend on whether the target emotion is upregulated or downregulated. When reappraisal is used to *upregulate* emotion and arousal, memory is typically enhanced; this has been observed in memory tests immediately after viewing and up to 1 week later (Ahn et al., 2015; Dillon et al., 2007; Knight & Ponzio, 2013; Wang et al., 2017). In work where reappraisal is used to *downregulate* emotion and arousal, some studies indicate a continued benefit of reappraisal to memory (Dillon et al., 2007; Wang et al., 2017; Willroth & Hilimire, 2016; Yeh et al., 2020), although a small number of other studies suggest comparable or worse memory for reappraised versus unregulated stimuli (Ahn et al., 2015; Knight & Ponzio, 2013). It has been argued that reappraisal effects on memory for downregulated stimuli might depend on retrieval test method. Knight and Ponzio (2013) suggested that reappraisal might enhance memory more reliably when tested using recognition versus free recall. Given that recall depends on conscious recollection, whereas recognition can depend on either recollection or familiarity-based memory processes (Yonelinas, 2002), this suggests that reappraisal might specifically benefit familiarity-based memory for emotional stimuli.

Compared with reappraisal, considerably fewer studies have examined how distraction strategies modulate memory. One such study (Sheppes & Meiran, 2008) required participants to watch a sad film clip under instructions to regulate their responses to it by using reappraisal versus distraction, each relative to a nonregulation condition, and tested their memory for film details. In the distraction group, active regulation was associated with lower memory than the nonregulation condition, while memory performance in the reappraisal group did not significantly differ from that in the nonregulation condition. This outcome is consistent with the idea that distraction, by allocating attention away from emotional information, might be associated with reduced subsequent memory for such information. Additional work examining patterns of eye gaze to visual target stimuli during emotion regulation (Strauss et al., 2016) demonstrated that use of distraction was associated with gaze reallocation away from emotionally arousing areas of the stimulus image, whereas reappraisal was associated with increased dwell time on emotionally arousing areas of such images. Together, these findings suggest that distraction may be associated with attentional reallocation away from emotional information and reduced downstream memory for it as a result, whereas the opposite pattern may occur with reappraisal.

Along with diverging effects on memory, different regulation strategies have been associated with varying emotional responses when the emotion-eliciting stimulus is encountered again. Such changes in emotional response over time and upon re-encounter have important clinical implications and might help account for differences in well-being associated with long-term strategy use (Denny et al., 2015). Habituation, characterized by reduced responses to repeatedly encountered stimuli, has been observed upon re-exposure to emotional information (Fischer et al., 2003). However, in addition to habituation effects, differences in responses to previously regulated emotional stimuli can be linked to prior strategy use. In particular, evidence suggests that reappraisal may offer affective benefits upon re-exposure to emotional stimuli. Negative affective responses to previously reappraised stimuli have been shown to be reduced 30 min later (Qi et al., 2017; Zehtner et al., 2023) and up to 1 week later (Denny et al., 2015) compared with responses to previously unregulated stimuli. Importantly, these affective benefits at re-exposure do not appear to emerge when distraction is used as a regulation strategy instead (Hermann et al., 2017). It is possible that strategy-related differences in memory for regulated stimuli and emotional differences upon stimulus re-exposure are linked. Specifically, emotional benefits when re-encountering previously reappraised stimuli might reflect adaptive re-access and use of appraisals from memory. In contrast, emotional responses to previously distracted stimuli might remain similar or be amplified upon re-encounter, given reduced attentional allocation at and reduced memory for initial exposure.

Taken together, the evidence reviewed suggests that emotion regulation can be implemented via differing strategies with varying consequences for subsequent memory and affect. Additionally, recent work suggests that emotion regulation strategy selection in daily life might adaptively vary with situational and motivational context (English et al., 2017). Given these observations, we were interested in investigating whether *experimentally* manipulating motivation would be associated with changes in emotion regulation outcomes, given that such manipulations have been important for characterizing adaptive shifts in controlled performance more generally (Botvinick & Braver, 2015). In the emotion regulation domain, we hypothesized that motivation manipulation might be associated with changes in strategy selection, as well as downstream changes in memory for and subsequent affective responses to re-encountered stimuli. Such relationships are important to delineate, given the importance of emotion regulation, memory, and motivation processes to mental health and their disruption in psychopathology (Samide & Ritchey, 2021; Sheppes et al., 2015).

Along with these clinical implications, examining motivational modulation of emotion regulation performance and downstream memory could advance a broader understanding of motivated memory and adaptive behavior. Extensive research indicates that both emotionally and motivationally salient information is prioritized in memory (reviewed in Bowen, 2020; Clewett & Murty, 2019). Evidence further suggests that rewards can enhance memory encoding both through controlled and automatic mechanisms (Chiew & Bowen, 2022). Rewards can increase controlled attention to motivationally relevant stimuli, improving subsequent memory for such stimuli both when memory performance is directly incentivized (Adcock et al., 2006) and when it is incidental to incentivized performance on an attention task (Poh et al., 2019). Additionally, rewards have been shown to enhance memory even when this is in conflict with control demands. Bowen et al. (2020) used a directed-forgetting paradigm to examine the effects of reward incentives on memory for to-be-forgotten stimuli, and they observed that reward-related stimuli remained privileged in memory. This pattern was argued to reflect automatic enhancement of memory by reward, independent of cognitive control performance at encoding. Additionally, neuroimaging evidence suggests that reward anticipation can enhance memory via mesolimbic dopamine input to hippocampus (Adcock et al., 2006), without involving prefrontal brain regions linked to control. Such a mechanism might be considered relatively automatic in nature.

While these findings suggest that reward can enhance memory through both controlled and automatic pathways, prior work has not examined memory outcomes in situations where the motivation to downregulate emotional responses to stimuli is manipulated. Such manipulations could modulate attention and affective responses to such stimuli and lead to downstream changes in incidental memory. In such a situation, the effects of increased motivation and reduced emotional response on memory might be in opposition to one another, or one influence may be more powerful than the other. If increased motivation to emotionally regulate influences memory primarily through *controlled* processes, memory for stimuli regulated in a motivated context, versus baseline, might be more strongly modulated by regulation strategy (i.e., showing even greater increases in memory for reappraised stimuli and greater decreases in memory for distracted stimuli), as a product of motivationally enhanced attentional control. In contrast, if increased motivation to emotionally regulate influences memory primarily through *automatic* processes, we might anticipate enhanced memory for stimuli encountered in a motivated context more globally, regardless of strategy use. Finally, it is possible that motivation to downregulate emotion might enhance regulation success, reducing emotional arousal and subsequent memory for target stimuli; additionally, such an effect could occur with or without potential effects of regulation strategy on downstream memory.

In the present study, we addressed these diverging hypotheses in an online behavioral experiment where we experimentally manipulated motivation (using monetary incentives, as commonly used in the motivated cognition literature; Braver et al., 2014) to regulate emotion in an experimental emotion regulation paradigm and examined subsequent memory for and affective responses to task stimuli. In this paradigm, participants were cued on a trial-by-trial basis to respond naturally or downregulate their responses to emotionally evocative image stimuli, freely choosing between different regulation strategies and immediately reporting strategy use and experienced affect after each image. Emotion regulation was completed under both a baseline and a motivation condition, wherein successful downregulation of emotion was incentivized using a cover story manipulation. Importantly, incentive was not directly linked to use of any particular regulation strategy. Twenty-four hours later, participants completed a recognition memory test for images presented in the emotion regulation task, as well as reporting experienced affect upon image re-encounter. The effects of our motivation manipulation on momentary emotion regulation in this dataset have been previously reported (Herrera, Ferron, Asmar, & Chiew, 2024) and revealed that the motivation manipulation was associated with significantly higher use of reappraisal versus distraction as a regulation strategy, as well as decreased negative affect, relative to baseline. Furthermore, motivation-related increases in reappraisal use marginally correlated with motivation-related decreases in negative affect on regulation trials. Given that reappraisal has been argued as an effective but effortful emotion regulation strategy (Sheppes et al., 2009), this shift is consistent with broader studies of cognitive control in suggesting that motivation can increase task effort and enhance cognitive performance. In the present paper, we focus on the effects of motivated emotion regulation on subsequent memory and affect 24 hours later. Characterizing such effects might be important for understanding the mechanisms of how emotion regulation influences adaptive behavior and mental health over time.

Finally, we examined on an exploratory basis whether individual differences in trait emotion regulation modulates the effects of motivated emotion regulation on downstream memory and affect. The Emotion Regulation Questionnaire (ERQ; Gross & John, 2003) was developed to index individual differences in habitual tendencies to use reappraisal versus suppression (reducing outward emotional expression) to regulate in everyday life. These differences have been linked to long-term adaptive function, with improved mental health outcomes reported in habitual reappraisers versus habitual suppressors (Aldao & Nolen-Hoeksema, 2012). Given these long-term affective benefits of reappraisal, as well as its documented memory benefits, we hypothesized that habitual reappraisers might show both enhanced memory for and reduced negative affect to previously reappraised stimuli. Additionally, given evidence that habitual reappraisers may display higher reward responsivity (Kelley et al., 2019), we hypothesized that effects of motivational incentive on emotion regulation, as well as downstream effects on memory and affect, might be amplified in such individuals.

Methods

Study overview

This study was conducted online over a 2-day period, with participants recruited from the Prolific online platform (www.prolific.com) and was administered in Qualtrics software. On Day 1, participants provided informed consent, trained on reappraisal and distraction emotion regulation strategies, and then completed a trial-by-trial, picture-based emotion regulation task under baseline and incentive conditions (see *Emotion Regulation Paradigm* below). Critically, on trials with instructions to regulate, participants were free to select a regulation strategy and reported which strategy they used from four listed choices. On Day 2, ~ 24 h after the Day 1 session, participants completed a surprise recognition memory test for stimuli from the Day 1 emotion regulation task, as well as reporting current affective response to each presented stimulus (see *Recognition Memory Test and Affective Rating (Day 2)* below). On Day 2, participants also completed the ERQ (Gross & John, 2003). Effects of motivational incentives on affect and strategy choice during emotion regulation task performance (Day 1) were previously described in Herrera et al. (2024) but are outlined here with relevance to recognition memory and reported affect on Day 2. A supplement is included to allow for full presentation of methods and results information.

Participants

A total of 192 young adult participants, based in the United States or United Kingdom, were recruited from the Prolific online platform. Participants were required to be aged 18 to 35 years and fluent in English. Sixty participants were excluded from the present study for failing to successfully complete the Day 1 session, failing to return for the Day 2 recognition memory session, or for returning more than 24 h late. An additional six participants were excluded for failing to pass a comprehension check of the emotion regulation task on Day 1 (4 participants), responding to 75% or fewer of task trials (1 participant), or completing the study more than once (1 participant). The final participant sample consisted of 126 participants (57 women, 66 men, 3 genderqueer/gender nonconforming; mean age 27.9 years, SD = 4.6; 80.2% White, 9.5% Asian, 5.6% Black, 0.8% Central/South American, 2.4% more than one race, 1.6% self-described or no-response). The study was approved by University of Denver's Institutional Review Board.

Note that the present study sample was a subset of participants previously reported in Herrera et al. (2024), which focused on the Day 1 experimental session only and reported a final sample of 156 participants. This included participants who passed all Day 1 checks but did not return for Day 2 participation.

Sensitivity power analysis

We conducted a power analysis using Westfall and colleagues' calculator (Westfall et al., 2014; https://jakewestfall.shinyapps.io/crossedpower/) for a linear mixed-effects model with stimuli-within-condition, assuming participants and stimulus intercepts and residual variance partitioning coefficients of 0.1, 0.4, and 0.5 respectively, estimated from recent unpublished data. Other variance partitioning coefficients were set to 0, because those effects were not included in our models. The analysis revealed that a sample of 120 participants, with 120 stimuli (the total number presented in the Day 1 emotion regulation task), was large enough to detect a small-to-moderate effect of $d=0.34$ with 80% power. This estimate should be considered highly conservative, as stimuli were counterbalanced across negative stimuli conditions, improving power. A parallel analysis indicated that a fully counterbalanced design with 120 participants and 120 total stimuli should be powered to detect a very small effect, $d=0.03$, with 80% power. An additional, complementary power analysis was conducted in G*Power 3 for a repeated-measures ANOVA with one group, three measurements, and an assumed correlation of 0.75 between repeated measures and revealed that a sample of 82 participants should be powered to detect a small effect ($d=0.2$) with alpha = 0.05 and 80% power. However, note that G*Power and other commonly used power calculators do not support power calculation for general linear models with within-subject interactions, so a power estimate specifically for such potential interactions could not be calculated.

Emotion regulation paradigm (Day 1)

This study used a trial-by-trial, picture-based emotion regulation paradigm adapted from a previous investigation of emotion regulation (McRae et al., 2010; schematic shown in Fig. 1). Negative- and neutrally valenced images from the International Affective Picture System (IAPS; Lang et al., 1997) were used as emotionally evocative task stimuli, with images normed on valence (on a 9-point Likert scale; 1 as most negative and 9 as most positive) and arousal (on a 9-point Likert scale: 1 as least-arousing and 9 as most-arousing). Eighty moderately arousing negative images (normed valence: $M=2.52$, $SD=0.50$, min/max range = 1.57–3.85; normed arousal: $M=5.71$, $SD=0.78$, min/max range = 4.00–7.35) and 40 low-arousal neutral images (normed valence: $M=4.84$, $SD=0.15$, min/max

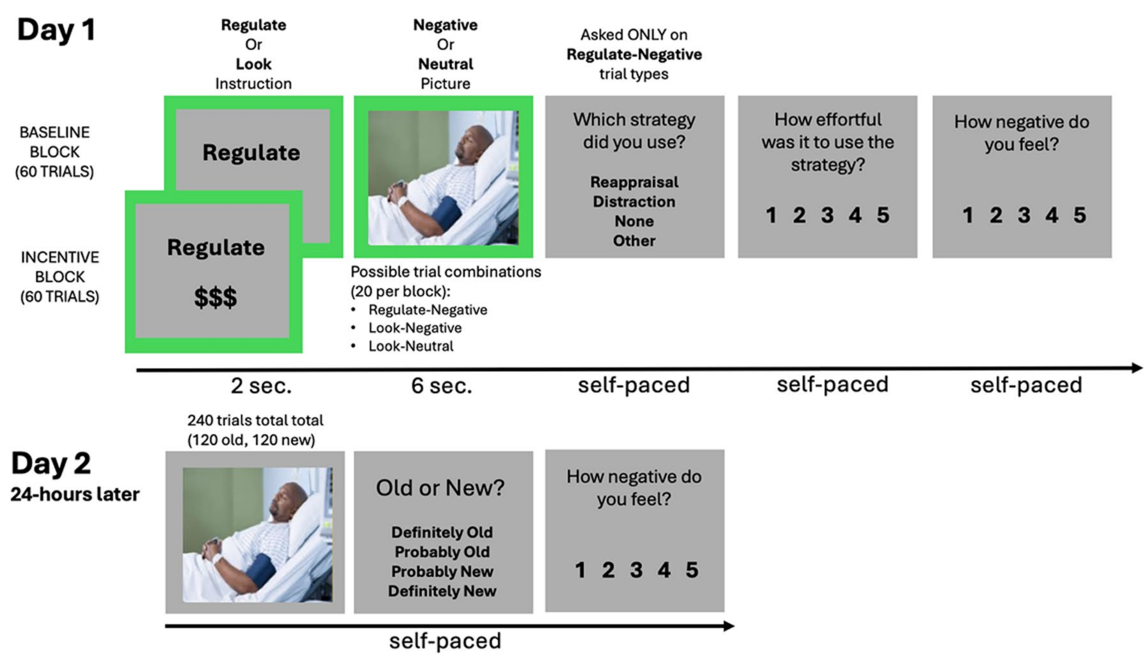

Fig. 1 Example of task trial structure on Day 1 shown for Regulate-Negative trials. Colored borders indicated trial requirements (green for "Regulate" trials, and orange for "Look" trials, or vice versa; counterbalanced across participants). Participants completed two blocks of the task with an equal number of each of the three different trial types. The baseline block was completed first, followed by the incentive block. ~24 hours later, participants made memory judgements for old pictures from Day 1 randomly intermixed with new pictures

range = 4.49–5.35; normed arousal: $M = 2.91$, $SD = 0.56$, min/max range = 1.72–3.97) were used in the experiment. Images used in the baseline and incentive block did not significantly differ on IAPS valence and arousal norms (valence norms: $t(118) = -0.426$, $p = 0.671$, arousal norms: $t(118) = 0.634$, $p = 0.527$). Selected negative and neutral images included both images with and without people depicted in them. Negative stimuli included potentially sadness-inducing images (i.e., grieving or injured individuals), fear-inducing images (i.e., an aimed gun or scenes of violence), and anger-inducing images (i.e., a hate rally). Neutral stimuli included images of people in mundane activities (i.e., looking at the camera) as well as images of inanimate objects and landscapes. Specific image files used are listed in Table S1.1 of the Supplement.

Each trial consisted of an instructional cue ("LOOK" or "REGULATE") presented for 2 s, followed by an emotionally neutral or negative image presented for 6 s. Participants were instructed to respond naturally to images presented with LOOK cues and to downregulate their emotional responses to images presented with REGULATE cues. Cues and images were presented with different colored borders (green and orange, counterbalanced across participants) to remind the participant of task instructions. Following image presentation, participants were asked to report how negative they felt (using a 5-point Likert scale), which regulation strategy was implemented (for REGULATE trials only; selecting between *Reappraisal, Distraction, Other,* and *None* response options) and how much effort they put into implementing the response (using a 5-point Likert scale). Post-image reports were self-paced and presented in a counterbalanced order across trials to promote engagement and deliberate responding. In the Incentive condition only, three dollar signs were presented with the instructional cue on each trial to remind participants of the manipulation (detailed further in the *Motivation Manipulation* section below).

Participants first completed a Baseline block of the task, followed by an Incentive block. Each task block consisted of 60 trials, with equal numbers of Look-Neutral, Look-Negative, and Regulate-Negative trials (determined by the combination of instructional cue and image valence). Trials were presented in a pseudo-random order, with no more than three of the same trial type in a row, across each block. Negative images were counterbalanced across Look-Negative and Regulate-Negative trial conditions between participants.

Emotion regulation paradigm training

Before beginning the Baseline task block, participants were instructed on the emotion regulation task and completed training on the use of reappraisal and distraction emotion regulation strategies via written instructions (adapted from McRae et al., 2012). For *Reappraisal*, participants were instructed to "think of something to tell yourself that helps you feel less negative about the picture," and for *Distraction*, participants were instructed to "focus on a specific part of the picture that doesn't make you feel negative." Participants were told to try to use one of these two strategies but were also told that they would view two additional reporting options on Regulate-Negative trials: *Other* and *None*. Participants were instructed that they should select the *Other* option if they tried to reduce their negative emotions using a strategy other than Reappraisal or Distraction. They were also instructed to select the *None* option on trials where they did not attempt to decrease their negative emotions (i.e., they did not comply with the "REGULATE" cue). Specific examples of how to use the reappraisal and distraction regulation strategies were provided. In the training to use reappraisal, participants were instructed on how to reinterpret the situation and reappraisals were suggested (i.e., participants could tell themselves that the outcome would improve, that help might be on the way, or that the situation may not be as bad as it first seemed). In the training to use distraction, participants were instructed to focus on the background of the image or a particular object in the image that did not make them feel as negative. Task comprehension was assessed by asking participants to provide a written description of what they should do when presented with the "LOOK" and "REGULATE" instructions on each trial; these responses were reviewed to ensure comprehension. Following these examples, participants completed two practice Regulate-Negative trials, where they were explicitly instructed to use the reappraisal strategy on one trial and the distraction strategy on the other. After presentation of the target image on each of the two practice trials, participants were asked to provide written descriptions of what they had done to make themselves feel less negative for each instructed strategy. These written responses were also reviewed to ensure sufficient comprehension of each emotion regulation strategy and appropriate use. Full instructions for our emotion regulation paradigm training are provided in the Supplement (S2).

Motivation (Incentive) manipulation

Following Baseline task performance, the motivation manipulation was introduced. For this manipulation, we employed a cover story informing participants that their mouse movements during performance in the next task block would be monitored through experiment software to index their subjective emotional experience during the task (following recent evidence from Yamauchi & Xiao, 2018 that such measurement of emotional experience from mouse movements is possible). Participants were further told that these measurements of emotional experience specifically on Regulate trials would be used to determine a monetary bonus of up to $10 for effective emotion regulation awarded after the task, whereby decreased levels of negative emotion, relative to reacting naturally, would be awarded a higher bonus. We did not specify the exact amount of monetary bonus awarded on a trial-by-trial basis or the total number of trials that participants would be required to Regulate. Participants then were prompted to write a text response describing the instructions of the motivation manipulation, and these responses were reviewed to ensure comprehension. All participants were awarded a $5 bonus as part of their experiment compensation after the completion of the 2-day experiment, regardless of performance. To remind participants of the motivation manipulation, the instructional cue was accompanied by dollar signs on each trial of the Incentive task block. The Day 1 experimental session ended with an open-ended question asking participants to describe their experience of the study and performance. Text responses were reviewed to screen for evidence of potential demand effects, skepticism regarding the validity of the motivation manipulation, or other concerns that might constitute potential grounds for exclusion. No such comments were identified.

Recognition memory test (Day 2)

Approximately 24 hours after completing the Day 1 session, participants received an invitation link to complete a self-paced recognition memory test for previously seen task images (Fig. 1). The recognition memory test was comprised of all 120 images previously shown in the emotion regulation paradigm on Day 1, randomly intermixed with 120 new distractor images also taken from the IAPS stimulus set. In total, 80 negative and 40 neutral distractor images were employed, following proportions used in the emotion regulation task. These distractor images were matched to previously viewed images on IAPS normed valence and arousal (Negative distractors normed valence: $M = 2.65$, $SD = 0.60$, min/max range = 1.31–3.46 and normed arousal: $M = 5.55$, $SD = 0.89$, min/max range = 3.67–7.26; Neutral distractors normed valence: $M = 4.87$, $SD = 0.35$, min/max range = 4.30–5.34 and normed arousal: $M = 3.04$, $SD = 0.44$, min/max range = 2.27–4.20). Images used in the Day 1 task and distractor images did not significantly differ on IAPS valence and arousal norms (valence norms: $t(238) = 0.618$, $p = 0.537$, arousal norms: $t(238) = -0.323$, $p = 0.747$). Specific image files used are listed in Table S1.2 of the Supplement.

In the recognition memory test, for each image, participants were required to make an old/new recognition judgment at high or low memory confidence, by selecting one of four possible responses ("definitely old"; "probably old"; "probably new"; "definitely new"), as well as reporting how negative they felt upon viewing the stimulus (on a 5-point Likert scale, as in Day 1).

Emotion regulation questionnaire

The 10-item ERQ (Gross & John, 2003) was used to assess habitual use of two emotion regulation strategies: cognitive reappraisal and expressive suppression (inhibiting outward expression of emotion). We used the 6-item Cognitive Reappraisal subscale as an index of habitual reappraisal. This subscale contains items such as "I control my emotions by changing the way I think about the situation I'm in." Participants rated their agreement with questionnaire items using a 7-point Likert scale (ranging from *1 = strongly disagree* to *7 = strongly agree*).

Data analysis plan

Statistical analyses were performed in R (version 4.3.1). The effects of motivation manipulation and emotion regulation condition on trial-by-trial negative affect and memory recognition were investigated with the use of linear mixed-effects models using the *lmer* and *glmer* functions within the *lme4* package (Bates et al., 2018).

We conducted parallel analyses for these outcomes, with negative affect modeled as a continuous measure using linear regression, and recognition memory (subsequent hit/miss[1]) modeled as a categorical measure using logistic regression. For each of these outcomes, we conducted two sets of analyses: (1) For all emotion regulation task trials, testing for fixed effects of Motivation-Condition (baseline, incentive), Trial-Type (Look-Neutral, Look-Negative, Regulate-Negative) and their interaction; (2) In Regulate-Negative trials only, testing for fixed effects of Motivation-Condition (baseline, incentive), Regulation Strategy (Reappraisal, Distract, Other, None), and their interaction. Reported negative affect on Day 1 (during the regulation task) and on Day 2 (at re-exposure) were examined in separate models. All models also included subject and stimulus image as random intercepts. Trial number was also added as a covariate to all models to help address time-on-task and order effects, given that the Baseline block always preceded the Incentive block. Maximum likelihood estimation was employed.

Mixed-effects models, also known as multi-level models, offer several advantages over traditional linear models (such as repeated-measures ANOVA). This modeling approach allows researchers to test for conditions of interest on a

[1] We collapsed across high- and low-confidence responses in our main memory analyses reported below, but include analyses examining recognition memory separated by high- and low-confidence in our Supplement in Section S8.

trial-by-trial basis, while accounting for variability within and across participants and stimulus items simultaneously (Brown, 2021). Furthermore, mixed-effects models are relatively robust to heterogeneity of variance owing to unequal samples, which can result from missing data and unbalanced designs (Singer & Willet, 2003). In the mixed-effects modeling framework, conditions with a smaller number of cases have weaker influences on parameter estimates and extreme values are "shrunk" towards the mean (Snijders & Bosker, 2011). This statistical approach thus offered important advantages given our present design; we were interested in both participants' choices of regulation strategy under baseline and incentive contexts, as well as the consequences of those strategy choices for affective and memory outcomes in Regulate-Negative trials. Given free choice of regulation strategy on Regulate-Negative trials, the numbers of trials associated with each strategy condition thus varied across task blocks and participants. The mixed-effects modeling approach accounts for this variability during statistical analysis.

To identify the most parsimonious model for each analysis, a series of model comparisons were conducted following current best practices guidelines for mixed-effects models (Meteyard & Davies, 2020). Simple models were iteratively compared to more complex models using the ANOVA function (R stats library; provided likelihood ratio test statistics and related *p* value). If a more complex model was a statistically better fit for the outcome variable, the predictors in the more complex model were included in the final model. Models were conducted and compared as follows: (1) a null model, containing subject and image as random intercepts and trial number as a covariate, but no other fixed effects; (2) more complex models examining the fixed main effects of Motivation-Condition and Trial-Type (or Regulation Strategy); and (3) a more complex model, including the two-way interaction term as well as the two fixed main effects, which was compared against the model with the two fixed main effects alone. If the two-way interaction term was significant, it was retained in the final model, along with both fixed main effects; if the interaction was not significant, it was removed, as were any insignificant fixed main effects. After this model-building and comparison procedure, the statistical significance of the fixed effects included in the final model was assessed as detailed below. Output for the final models is available in the Supplement (S3).

We also examined whether choice of regulation strategy on Regulate-Negative trials differed with Motivation-Condition using a multinomial mixed-effects model implemented in the *mlogit* package in R (Croissant, 2012). Motivation-Condition was examined as a fixed effect in predicting Regulation Strategy choice (Reappraisal, Distraction, Other, or None coded as categorical outcomes) on each trial. Subject and stimulus image were again treated as random intercepts within the model and trial number was included as a covariate. This approach accounts for the nonindependence of strategy outcomes from each other while avoiding data aggregation. We computed six contrasts between the four strategy outcome categories: Reappraisal vs. Distraction, Reappraisal vs. Other, Reappraisal vs. None, Distraction vs. Other, Distraction vs. None, Other vs. None.

In addition to these primary analyses, we conducted exploratory tests examining whether individual differences in habitual cognitive reappraisal (measured using the ERQ-Reappraisal subscale) significantly interacted with regulation strategy and motivation context to predict subsequent memory and negative affect. None of these analyses indicated a significant role for ERQ-Reappraisal. The full details and results of these analyses are reported in the Supplement (S5).

Results

Negative affect – effects of trial type and motivation-condition on all trials at regulation (Day 1)

Results are visualized in Fig. 2A, and final model output is in the supplement (Table S3.1). With reported negative affect on Day 1 as an outcome, adding fixed effects of both Trial-Type and Motivation-Condition significantly improved the model fit over baseline (Trial-Type: $\chi^2 = 229.05$, $p < 0.001$; Motivation-Condition: $\chi^2 = 14.388$, $p < 0.001$). Further, adding a Trial-Type × Motivation-Condition interaction term significantly improved model fit over the model with fixed main effects ($\chi^2 = 20.538$, $p < 0.001$). Final model structure, using R notation, was as follows: *Day 1 Negative Affect ~ Trial-Type + Motivation-Condition + Trial-Type:Motivation-Condition + Trial Number + (1|Subject) + (1|Picture).*

The model indicated that negative affect differed by Trial-Type. As expected, lower negative affect was reported in Look-Neutral trials compared with both Look-Negative ($\beta = 1.768$, 95% confidence interval [CI] = [1.557, 1.979], $p < 0.001$) and Regulate-Negative trials ($\beta = 1.570$, 95% CI = [1.360, 1.782], $p < 0.001$). Negative affect was also lower in Regulate-Negative trials compared to Look-Negative Trials ($\beta = 0.198$, 95% CI = [0.150, 0.246], $p < 0.001$), suggesting successful down-regulation of negative affect on Regulate trials. Negative affect also significantly differed by Motivation-Condition, with lower levels reported in the Incentive versus Baseline block ($\beta = -0.881$, 95% CI = [−1.134, −0.629], $p < 0.001$). The Trial-Type × Motivation-Condition interaction was driven by smaller Trial-Type differences in negative affect in the Incentive block for Look-Neutral vs. Look-Negative trials ($\beta = -0.698$, 95% CI = [−0.995, −0.400], $p < 0.001$) and for

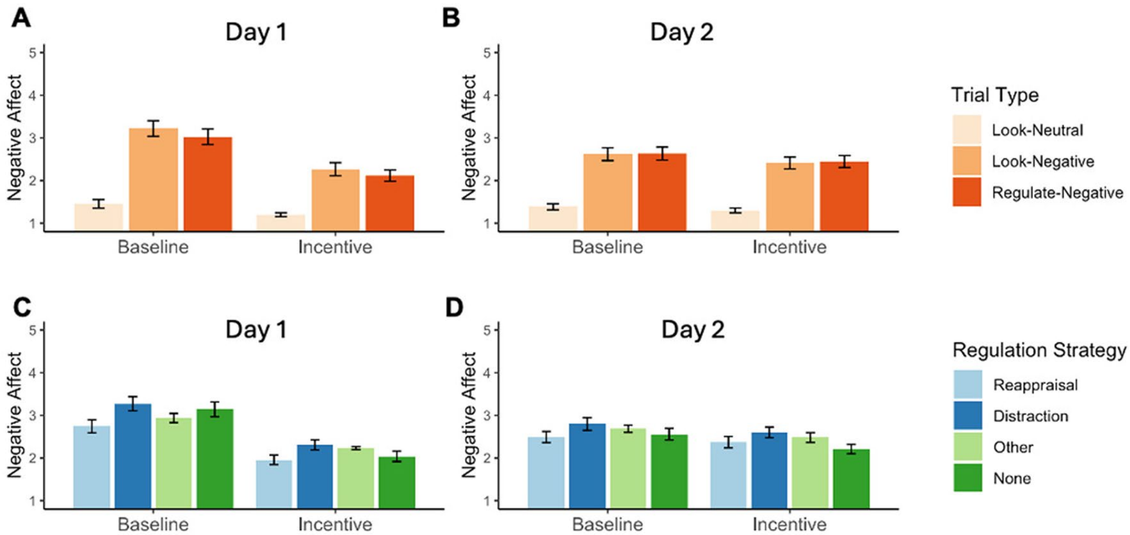

Fig. 2 Negative affect, as reported on 5-point Likert scales (1 = lowest, 5 = highest), divided by Motivation-Condition. A) On Day 1, on all trials; **B**) On Day 1, on Regulate-Negative trials; **C**) On Day 2, for stimuli on all trials; **D**) On Day 2, for stimuli on Regulate-Negative trials

Look-Neutral vs. Regulate-Negative trials (β = − 0.652, 95% CI = [− 0.949, − 0.354], $p < 0.001$). Motivation-Condition did not modulate differences in negative affect between Look-Negative and Regulate-Negative Trials (β = − 0.046, 95% CI = [− 0.114, 0.022], $p = 0.182$).

Negative affect – effects of regulation strategy and motivation-condition on Regulate-Negative trials at regulation (Day 1)

Results are visualized in Fig. 2B, and final model output is in the supplement (Table S3.2). With reported negative affect on Day 1 as an outcome, adding fixed effects of both Regulation-Strategy and Motivation-Condition significantly improved the model fit over baseline (Regulation-Strategy: $\chi^2 = 124.000$, $p < 0.001$; Motivation-Condition: $\chi^2 = 24.273$, $p < 0.001$). Adding a Regulation-Strategy × Motivation-Condition interaction term did not significantly improve model fit further, so it was omitted from the final model ($\chi^2 = 1.874$, $p = 0.599$). Final model structure was as follows: *Day 1 Affect ~ Regulation-Strategy + Motivation-Condition + Trial Number + (1|Subject) + (1|Picture).*

The significant effect of Regulation Strategy was driven by lower negative affect on trials when Reappraisal was reported versus Distraction or None (Reappraisal vs. Distraction: β = 0.327, 95% CI = [0.270, 0.385], $p < 0.001$; Reappraisal vs None: β = 0.123, 95% CI = [0.030, 0.217], $p = 0.010$). Negative affect did not significantly differ in Reappraisal versus Other trials (β = 0.127, 95% CI = [− 0.075, 0.327], $p = 0.219$). Interestingly, negative affect was higher with use of Distraction versus Other and None strategies—a pattern that was significant for Distraction versus None (β = − 0.204, 95% CI = [− 0.297, − 0.111], $p < 0.001$) and trending for Distraction versus Other (β = − 0.201, 95% CI = [− 0.402, − 0.000], $p = 0.050$). Other vs. None trials did not significantly differ in negative affect (β = 0.001, 95% CI = [− 0.004, 0.006], $p = 0.826$). The main effect of Motivation-Condition was also significant in the final model, indicating that lower negative affect was reported in the Incentive versus Baseline block (β = − 0.930, 95% CI = [− 1.284, − 0.576], $p < 0.001$).

Negative affect – effects of trial type and motivation-condition on all trials at re-exposure (Day 2)

Results are visualized in Fig. 2C, and final model output is in the supplement (Table S3.3). With reported negative affect upon re-exposure on Day 2 as an outcome, the addition of Trial-Type, but not Motivation-Condition, as fixed effects significantly improved the model over baseline (Trial-Type: $\chi^2 = 161.280$, $p < 0.001$; Block: $\chi^2 = 1.519$, $p = 0.218$). A model with a Trial-Type × Motivation-Condition interaction term, as well as both Trial-Type and Motivation-Condition main effects, was compared against a model with fixed main effects only. The addition of the Trial-Type × Motivation-Condition interaction term did not significantly improve model fit ($\chi^2 = 1.240$, $p = 0.538$). Thus, final model structure was as follows: *Day 2 Negative Affect ~ Trial-Type + Trial Number + (1|Subject) + (1|Picture).*

We again observed a basic valence effect, whereby participants reported lower negative affect for images previously presented in Look-Neutral trials compared to both Look-Negative and Regulate-Negative trials (Look-Neutral vs. Look-Negative: $\beta = 1.181$, 95% CI = [1.051, 1.310], $p < 0.001$; Look-Neutral vs Regulate-Negative: $\beta = 1.203$, 95% CI = [1.071, 1.332], $p < 0.001$). However, we did not observe a significant difference in negative affect between images previously presented on Look-Negative versus Regulate-Negative trials ($\beta = -0.022$, 95% CI = [−0.052, 0.009], $p = 0.157$), suggesting that effects of previous regulation did not carry over. Thus, only a basic valence effect (distinguishing neutral from negative images) was observed on Day 2 negative affect ratings when examined across all trials, with no significant differences as a function of prior Motivation-Condition or Look vs. Regulate manipulations.

Negative affect – effects of regulation strategy and motivation-condition on Regulate-Negative trials at re-exposure (Day 2)

Results are visualized in Fig. 2D, and final model output is in the supplement (Table S3.4). With reported negative affect upon re-exposure on Day 2 as an outcome, adding Regulation-Strategy, but not Motivation-Condition, as a fixed effect significantly improved the model over baseline (Regulation-Strategy: $\chi^2 = 35.386$, $p < 0.001$; Motivation-Condition: $\chi^2 = 1.578$, $p = 0.209$). Additionally, the addition of a Regulation-Strategy × Motivation-Condition interaction term did not significantly improve model fit over a model with both fixed main effects ($\chi^2 = 1.874$, $p = 0.599$). Final model structure was as follows: *Day 2 Affect ~ Regulation-Strategy + Trial Number + (1|Subject) + (1|Picture).*

The significant effect of Regulation Strategy was driven by lower negative affect reported for previously Reappraised vs. Distracted images ($\beta = 0.124$, 95% CI = [0.074, 0.174], $p < 0.001$). No significant differences in negative affect were observed for images on previously Reappraised versus Other or None trials (Reappraisal vs. Other: $\beta = -0.067$, 95% CI = [−0.243, 0.109], $p = 0.453$; Reappraisal vs. None: $\beta = -0.067$, 95% CI = [−0.149, 0.015], $p = 0.107$). Previously Distracted images were associated with significantly higher negative affect than on images where Other or None were previously reported (Distraction vs. Other: $\beta = -0.191$, 95% CI = [−0.367, −0.016], $p = 0.033$; Distraction vs. None: $\beta = -0.191$, 95% CI = [−0.272, −0.110], $p < 0.001$). Finally, images on previously reported Other versus None trials did not significantly differ in reported negative affect ($\beta = 0.000$, 95% CI = [−0.182, 0.182], $p = 0.881$). Together, these results are consistent with prior work in showing that emotion regulation strategy can have prolonged effects on affect, with lasting benefits of reappraisal but not distraction in downregulating negative affect over time. In contrast, the motivation manipulation (Baseline vs. Incentive block) was not associated with differences in negative affect at re-exposure.

Recognition memory (Hit vs. Miss) – effects of trial type and motivation-condition on all trials

Results are visualized in Fig. 3A, and final model output is in the supplement (Table S3.5). With 24-h recognition memory (hit vs. miss) as a categorical outcome, adding both Trial-Type and Motivation-Condition as fixed effects significantly improved the model fit over baseline (Trial-Type: $\chi^2 = 33.534$, $p < 0.001$; Motivation-Condition: $\chi^2 = 9.156$, $p = 0.003$). The addition of a Trial-Type × Motivation-Condition interaction term did not further improve model fit ($\chi^2 = 1.2874$, $p = 0.525$) and was removed from the final model. The final model structure was as follows: *Recognition Memory ~ Trial-Type + Motivation-Condition + Trial Number + (1|Subject) + (1|Picture).*

The significant effect of Trial-Type on recognition memory was driven by significantly lower recognition of images in Look-Neutral trials than in Look-Negative trials (odds ratio [OR] = 1.68, 95% CI = [1.29, 2.18], $p < 0.001$) or Regulate-Negative trials (OR = 0.47, 95% CI = [0.36, 0.62], $p = 0.001$); these contrasts indicate that, consistent with extensive prior evidence, recognition memory was higher for negatively versus neutrally valenced images. Additionally, we observed higher recognition memory for images in Regulate-Negative versus Look-Negative trials (OR = 0.80,

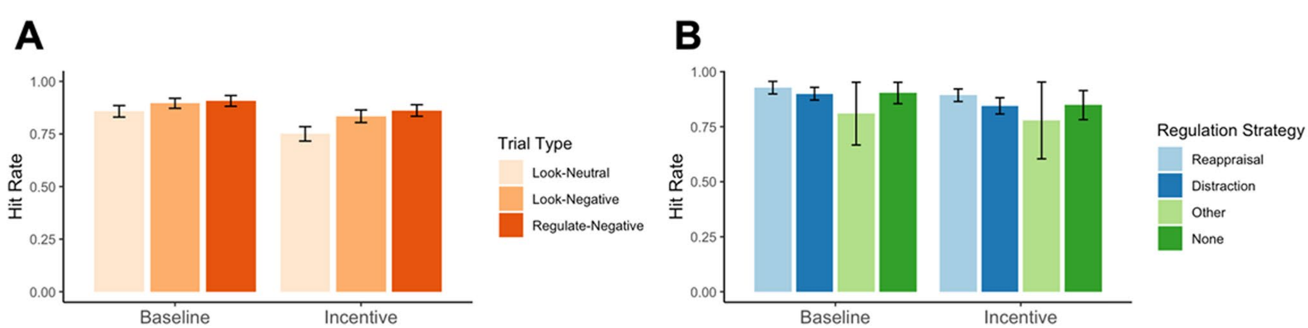

Fig. 3 **A**) Recognition memory uncorrected hit rates as a function of Trial Type and Block. **B**) Recognition memory uncorrected hit rates, as a function of Regulation Strategy and Motivation-Condition

95% CI = [0.70, 0.91], $p < 0.001$), suggesting that actively regulating emotions elicited by negative images was associated with memory benefit. The significant effect of Motivation-Condition was driven by higher recognition memory for images presented in the Baseline versus Incentive block (OR = 0.49, 95% CI = [0.30, 0.78], $p = 0.002$), tentatively suggesting that incentive did not automatically enhance memory and may have, by decreasing negative affect, been associated with reduced memory for target stimuli instead.

Recognition memory (Hit vs. Miss) – effects of regulation strategy and motivation-condition on Regulate-Negative trials

Results are visualized in Fig. 3B, and final model output is in the supplement (Table S3.6). With 24-h recognition memory (hit vs. miss) as a categorical outcome, adding Regulation-Strategy as a fixed effect significantly improved model fit over baseline ($\chi^2 = 17.942$, $p < 0.001$), while adding Motivation-Condition as a fixed effect resulted in a trend-level improvement ($\chi^2 = 3.602$, $p = 0.058$). Following our analysis plan, we then compared a model with a Regulation-Strategy × Motivation-Condition interaction term, Regulation-Strategy, and Motivation-Condition fixed effects to a simpler model with Regulation-Strategy and Motivation-Condition fixed main effects, but observed that the interaction term did not significantly improve model fit over fixed main effects alone ($\chi^2 = 2.603$, $p = 0.457$). Notably, we observed that when entered together with Regulation-Strategy as a predictor, the fixed effect of Motivation-Condition reached significance. Given this observation and its strong theoretical importance, we elected to retain this predictor in the model. Thus, final model structure, using R notation, was as follows: *Recognition Memory ~ Regulation Strategy + Motivation-Condition + Trial Number + (1|Subject) + (1|Picture).*

Consistent with prior evidence suggesting that reappraisal can improve memory (Dillon et al., 2007; Yeh et al., 2020), use of Reappraisal was associated with higher memory recognition than any other reported strategy (Reappraisal vs. Distraction: OR = 0.62, 95% CI = [0.50, 0.78], $p < 0.001$; Reappraisal vs. Other: OR = 0.48, 95% CI = [0.25, 0.90], $p = 0.023$; Reappraisal vs. None OR = 0.67, 95% CI = [0.46, 0.96], $p = 0.031$). Memory recognition did not significantly differ for images presented on Distraction versus Other trials (OR = 0.77, 95% CI = [0.41,1.44], $p = 0.410$), Distraction versus None trials (OR = 1.07, 95% CI = [0.75, 1.53], $p = 0.694$), or Other versus None trials (OR = 1.40, 95% CI = [0.71, 2.73], $p = 0.328$). As in the all-trials analysis outlined above, the significant effect of Motivation-Condition was driven by lower recognition memory for stimuli presented in the Incentive versus Baseline block (OR = 0.51, 95% CI = [0.27, 0.95], $p = 0.034$).

Regulation strategy – effects of motivation-condition

To examine the effects of Motivation-Condition on Regulation Strategy choice, we ran the following model: *Regulation Strategy ~ Motivation-Condition + Trial Number + (1|Subject) + (1|Picture).* We found that Motivation-Condition was associated with significant differences in strategy outcomes for the following contrasts: Reappraisal vs. Distraction (OR = 0.69, 95% CI = [0.55, 0.87], $p = 0.002$), Reappraisal vs. Other (OR = 0.36, 95% CI = [0.15, 0.83], $p = 0.017$), and Reappraisal vs. None (OR = 0.54, 95% CI = [0.38, 0.77], $p = 0.001$). These results indicated increased use of Reappraisal, relative to all other strategy outcomes, in the Incentive block compared to the Baseline block. In contrast, Motivation-Condition was not associated with significant differences in the use of Distraction vs. Other (OR = 0.51, 95% CI = [0.22, 1.20], $p = 0.122$), Distraction vs. None (OR = 0.78, 95% CI = [0.55, 1.11], $p = 0.173$), or Other vs. None (OR = 1.52, 95% CI = [0.63, 3.69], $p = 0.350$) strategies. Results are visualized in Fig. 4. Final model output is also reported in the supplement (Table S6.1) along with a

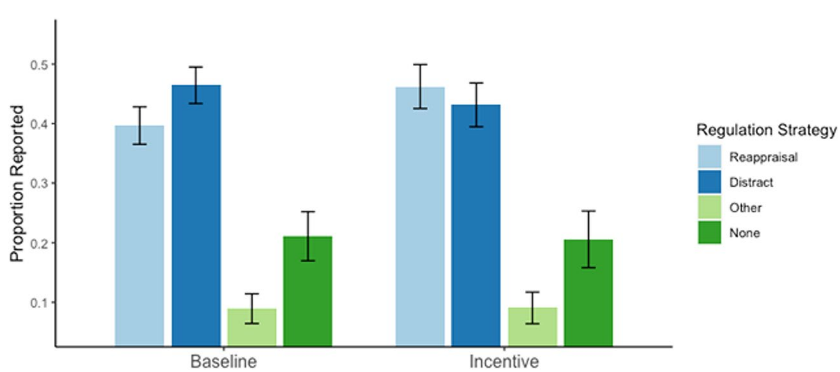

Fig. 4 Proportion of Regulate-Negative trials associated with each reported Regulation Strategy (Reappraisal, Distraction, Other, or None) in each Motivation-Condition (Baseline, Incentive)

table reporting mean numbers of strategies used within the Baseline and Incentive blocks (Table S7.1).

Correlation between motivation-related changes in day 1 negative affect and recognition memory

Given that we observed motivation-related decreases in negative affect on Day 1 and in recognition memory, we investigated post-hoc whether these changes were correlated. Mean rates of negative affect on Day 1 and mean hit rates for recognition memory were calculated by Motivation-Condition (Baseline, Incentive) for each participant. To determine motivation-related changes in negative affect, the mean rate of negative affect in the Baseline block was subtracted from the mean rate of negative affect in the Incentive block for each participant, resulting in a difference score. Similarly, motivation-related changes in recognition memory were determined by subtracting the mean hit rate scores in the Baseline block from the scores in the Incentive block, again resulting in a difference score. Potential association between these difference scores was subsequently examined using a Pearson correlation. We did not observe evidence that motivation-related changes in negative affect on Day 1 correlated with motivation-related changes in recognition memory ($r(124) = 0.076$, $p = 0.40$).

These same analyses were run on a subset of the data that only included Regulate-Negative trials to determine whether the relationship between motivation-related changes in negative affect and recognition memory might be specific to trials where individuals were regulating. Again, we did not observe a significant correlation between motivation-related differences in negative affect and recognition memory on Regulate-Negative trials ($r(124) = -0.008$, $p = 0.93$).

Discussion

Emotion regulation has long been recognized as important to mental health and well-being. In recent years, it also has been increasingly appreciated as a key element of adaptive behavior. As such, research demonstrates that emotion regulation relies on cognitive control, is shaped by motivational influences, and is associated with consequences for downstream memory and affect. The present study used an experimental emotion regulation paradigm where participants were instructed to react naturally or regulate emotional responses to stimuli, using their choice of regulation strategy on each Regulate-Negative trial. We manipulated motivation to regulate emotion with monetary incentives (following extensive work in the motivated cognition literature; Braver et al., 2014) and examined effects on subsequent memory for and affective responses to previously viewed target stimuli. This work extends on our previously reported findings from this dataset that monetary incentives were associated with increased use of reappraisal and reduced negative affect (Herrera, Ferron, Asmar, & Chiew, 2024). We interpreted these changes in regulation strategy use as consistent with evidence that motivation can increase willingness to expend cognitive effort during goal pursuit. Given findings that incentives for task performance can change attention allocation to and downstream memory for task stimuli (Poh et al., 2019), we wanted to examine whether motivating emotion regulation would likewise predict momentary affective changes as well as downstream consequences for later affect and memory.

We observed expected differences in affective responses to negative versus neutral stimuli, as well as lower negative affect in Regulate- versus Look-Negative trials. These observations suggested that our experimental stimuli were having their intended emotional effect and that participants could successfully downregulate emotion when instructed. When the effect of incentive was examined across all trials in the emotion regulation task (Day 1), we observed reduced negative affect in both Look-Negative and Regulate-Negative trials. Surprisingly, when examining the effect of incentive block on Day 2 recognition memory for target stimuli, we observed lower recognition memory for stimuli presented in the Incentive versus Baseline block. No accompanying changes in Day 2 affect were observed for stimuli as a function of Day 1 Motivation-Condition. When our analysis was restricted to Regulate-Negative trials only, we observed differences in affect with chosen Regulation Strategy, both immediately with implementation on Day 1 as well as on Day 2 re-encounter. We also observed differences in recognition memory as a function of Regulation Strategy. Effects of Motivation-Condition and Regulation Strategy did not significantly interact to predict either memory or affective outcomes. We discuss these results and their implications more fully below.

We first consider effects of our motivation manipulation on momentary (Day 1) affect. As previously reported in Herrera et al. (2024), monetary incentives for successful emotion regulation were associated with increased use of reappraisal as well as decreased negative affect relative to baseline. Given that reappraisal has been suggested as a highly effortful regulation strategy (Sheppes et al., 2009), this pattern might suggest that motivational incentives can increase cognitive effort and enhance regulation performance. However, while participants were instructed that incentives were linked only to responses on Regulate-Negative trials, we observed reduced negative affect across *both* Regulate-Negative and Look-Negative trials in the Incentive versus Baseline block. This suggests that incentive-related decreases in negative affect were not limited to Regulate-Negative trials but also may have occurred in Look-Negative trials. We suggest two potential mechanisms by which incentive could have led to this effect. First, it is possible that reduced negative affect in Look-Negative trials, along with Regulate-Negative trials, could reflect increased spontaneous emotion regulation. Past evidence indicates that people may spontaneously regulate even when instructed to respond naturally instead (Suri et al., 2015), and it is possible that rates of spontaneous regulation may have increased under Incentive relative to Baseline. Second, the prospect of reward incentives in the Incentive block may have directly increased positive affect, independent of their effects on controlled regulation. Reward incentives for cognitive performance have been shown to increase incidental positive affect (Forbes et al., 2009; Gable & Dreisbach, 2021) but have not been studied in the context of emotion regulation. More detailed querying about spontaneous regulation on Look-Negative trials could help distinguish between these possibilities in future studies. Such measures could help clarify the extent to which motivational incentives might change emotion through controlled regulation versus through global, potentially automatic, influences on affect.

Along with incentive-related changes in momentary affect, we observed changes in recognition memory for target stimuli. Contrary to our predictions, recognition memory was lower with stimuli encountered in the Incentive versus Baseline block. Notably, this pattern is contrary to much prior evidence that rewards enhance memory, both when they are contingent on as well as incidental to memory performance (reviewed in Chiew & Bowen, 2022). One critical difference between the present study and past studies that have reported reward-enhanced memory is the fact that incentives in this study were linked to down-regulation of affect. Given that arousal is recognized as a key mechanism by which memory for emotional information is enhanced, often through amygdala-hippocampus interactions (Cahill & McGaugh, 1998; Mather, Clewett, Sakaki, & Harley, 2016), incentive-induced reduction of negative emotion and associated arousal may have contributed to reduced memory recognition. This interpretation remains tentative, given the lack of direct measures of arousal in the present study, as well as a null correlation between incentive-related decreases in negative affect and recognition memory. However, we used a single self-report measure for negative affect, as opposed to separate report measures for valence and arousal. More nuanced affective measures such as these may have been better positioned to capture a relationship between incentive-related decreases in experienced arousal and subsequent memory. A second possibility that could have accounted for reduced memory under incentive is the fact that participants were required to monitor and report their affective response on each trial. Specifically, participants may have increased their monitoring of affective responses in the Incentive block, given their relevance to reward payout. This may in turn have reduced attention to and memory encoding of the target stimuli, as has been observed in dual-task paradigms (Logie et al., 2007). This attention competition may have reduced engagement with target stimuli and interfered with the earliest stages of memory consolidation, when the memory trace is most vulnerable to interference (Dewar et al., 2007).

A third factor that could account for reduced memory under incentive is the possibility that the incentive manipulation was treated as *sustained* over the task block, as opposed to a *transient,* trial-by-trial basis. While participants were instructed that incentives would be awarded on the basis of successful performance on Regulate-Negative trials in the Motivation block, we presented dollar cues as a reminder of the motivation manipulation on all trials. We also observed affective changes on Look-Negative trials as well as Regulate-Negative trials, suggesting that reward prospect was associated with a sustained effect instead of being limited to Regulate-Negative trials. On the basis of neural evidence that sustained and transient reward effects may reflect dissociable aspects of dopaminergic activity, we recently demonstrated that *transient*, trial-level reward was more reliably linked to memory benefit than *sustained,* block-level reward (Gholston et al., 2023). It is possible that our motivation manipulation operated on a sustained timescale rather than a transient one and that could help account for the lack of memory benefit observed. Given that the present study only included behavioral measures, we are limited in our ability to attribute incentive-related decreases in memory to these or other causes. Follow-up research incorporating physiological measures (i.e., eye gaze to index attention, pupillometry or skin conductance to index arousal), as well as more nuanced measures of self-report during emotion regulation may be informative in addressing these surprising findings further.

When focusing specifically on Regulate-Negative trials, we observed differences in both momentary (Day 1) and delayed (Day 2) affect as well as in recognition memory as a function of selected Regulation Strategy. When examining Day 1 performance, we were somewhat surprised to observe that distraction was associated with higher negative affect than reappraisal, given that both strategies have been identified as effective at momentarily reducing negative emotion (McRae et al., 2010; Strauss et al., 2016). Our task design differed from many previous emotion regulation studies by allowing participants to select their preferred strategy, instead of being assigned an instructed strategy for each trial. Prior work investigating emotion regulation choice suggests that people are more likely to use reappraisal for low-intensity stimuli and distraction for high-intensity stimuli (Shafir et al., 2016; Sheppes et al., 2014). If distracted stimuli tended to be higher in emotional intensity, this could have contributed to higher negative affect levels even under regulation. To check this, we reran our analyses of Day 1 negative affect with

IAPS arousal norms for each stimulus added as a predictor. Consistent with Sheppes, our participants tended to use reappraisal more with lower-arousal stimuli and distraction more with higher-arousal stimuli, but we continued to observe a significant effect of Regulation Strategy even when controlling for arousal (see S4 in Supplement). This suggests that differences in Day 1 affect between reappraisal and distraction cannot fully be accounted for by variations in stimulus intensity. A second possibility, given our free-choice design, is that participants may have deliberated over what strategy to use. Distraction is typically characterized as an early disengagement strategy whereby attention is directed away from the stimulus before emotion unfolds (Gross, 2002); if participants deliberated over strategy use before implementing distraction, this could have reduced its effectiveness. A third possibility, particularly with high-arousal stimuli, is that participants may have initially attempted to reappraise but switched to distraction. Prior evidence suggests that unsuccessful reappraisal attempts are associated with elevated negative affect compared to both successful reappraisal and unregulated response (Yeh et al., 2020). In considering these potential mechanisms, it is unclear whether individuals perceive regulation strategies in terms of differing relative desirability (i.e., considering reappraisal "better" to use than distraction) and whether such perception changes emotion regulation choice. Future work could incorporate additional measures—e.g., using mouse-tracking to capture choice deliberation (Stillman et al., 2018), self-reports of regulation attempts versus successes (Yeh et al., 2020), or post-task assessments of the relative desirability of different strategies—to address these possibilities further.

Along with effects on Day 1 affect, differences in regulation strategy were also associated with subsequent differences in memory as well as affective response on Day 2 re-encounter. We observed enhanced memory for Reappraised stimuli, versus stimuli associated with all other regulation strategies (Distraction, Other, and None). This pattern is consistent with much prior evidence that has suggested a memory benefit to reappraisal, typically interpreted as reflecting increased attention to and semantic elaboration of target stimuli (Dillon et al., 2007; Wang et al., 2017; Yeh et al., 2020). We also observed differences in Day 2 affect for re-encountered stimuli as a function of regulation strategy used. Specifically, we found higher negative affect for previously Distracted stimuli than for stimuli previously associated with Reappraisal, Other, or None responses. Reductions in negative affect to previously reappraised, but not previously distracted, stimuli have been characterized in the research literature (Denny et al., 2015; Hermann et al., 2017). Such reappraisal benefits have been argued to reflect adaptive re-access and use of appraisals from memory (Denny et al., 2015).

Taken together, these reported differences in memory and Day 2 affect are largely consistent with prior literature. However, somewhat surprisingly, recognition memory did not significantly differ for stimuli associated with Distraction versus Other/None strategies, and Day 2 affective benefits did not differ between stimuli associated with Reappraisal and Other/None strategies as well. As with observed strategy differences on Day 1 momentary affect, it is possible that these unexpected patterns may have emerged with our free-choice design. Our self-report design also provides limited information regarding "Other" and "None" responses. For example, it is unclear what "Other" strategies were used, and whether "None" responses reflect unsuccessful regulation or a failure to attempt regulation at all. Given recent work suggesting that regulation strategy selection versus implementation have separable consequences for emotion regulation (Vlasenko et al., 2023), follow-up studies may reveal additional insights about regulation strategy use and its consequences for memory and affect.

It is notable that motivational incentive was associated with increased reappraisal *and* reduced memory relative to baseline, given prior research suggesting that reappraisal is typically associated with enhanced memory (Knight & Ponzio, 2013); a relationship borne out in our data as well. With incentive, we noted a seemingly paradoxical pattern of memory outcomes; reappraisal use increased, but memory decreased in the Incentive versus Baseline block, even though memory was enhanced for reappraised stimuli. This pattern may be the product of observed reductions in recognition memory for stimuli in the Incentive block across all trial types, including both Look-Neutral and Look-Negative trials as well as Regulate-Negative trials. Even though the proportion of Regulate-Negative trials where participants reported reappraising was larger in the Incentive versus the Baseline block, this increase and related memory benefit may have been overwhelmed by incentive-related reductions in memory across all trial types. As detailed above, reduced negative affect was observed across both Look- and Regulate-Negative trials in the Incentive block, suggesting that incentive-related effects occurred in a global and automatic fashion, as opposed to having a specific effect on control processes in Regulate-Negative trials. It is possible that related decreases in emotional arousal, as well as increases in dual-tasking given our incentive structure, could have led to global reductions in memory for Incentive block stimuli as a result. We suggest that more detailed self-report measures during emotion regulation performance, as well as biological measures of affective response, may be important in disentangling these influences further.

Further supporting the idea of incentive as a global effect, we did not observe a significant Motivation-Condition × Regulation Strategy interaction on any memory or affective outcomes, although main effects of both emerged in our analyses. This suggests that motivation- and strategy-related influences on memory and affect may have been independent—a surprising finding, given that use of reappraisal as a strategy increased in the Incentive versus Baseline block. This presents an interesting possibility: that incentive may have been associated with *selection* of a more effortful regulation strategy, but not necessarily with increased effort *implementation* in the strategy itself. To our knowledge, the distinction between choosing between options differing in cognitive effort, and the extent to which effort is implemented once an option is chosen, is relatively uncharacterized in the motivated cognition literature. In the emotion regulation literature, reappraisal strategy selection versus implementation have been recognized as separable stages (Waugh et al., 2022), but these stages have yet to be studied in terms of other regulation strategies and contextual influences. A clearer distinction between strategy selection and implementation, as well as their respective modulation by motivation, might be important to consider as theoretical frameworks of motivated cognition are expanded to more complex behaviors.

While incentives were associated with robust decreases in negative affect during the Day 1 emotion regulation task, we did not observe differences in Day 2 affective responses as a function of Motivation-Condition. This null effect suggests that the benefits of extrinsic incentives can be limited and short-lived, an observation that has been explored in the behavioral economics literature (Bonner & Sprinkle, 2002; Gneezy et al., 2011). Additionally, given that the benefits of emotion regulation to sustained affect have been posited to be memory related (Moyal, Cohen, Henik, & Anholt, 2015) and lower memory was observed for incentive-related stimuli overall, it seems unlikely that our motivation manipulation promoted memory-based, long-lasting benefits to affect in the present paradigm. This could illustrate a potential limitation of monetary incentives in terms of promoting adaptive memory and behavior in more complex contexts and over longer-term timescales.

Despite their potential limitations, monetary incentives have been commonly used in the motivated cognition literature to parametrically manipulate motivation and examine associated changes in cognitive performance (Bijleveld & Aarts, 2014). In comparison, the use of monetary incentives as a motivator is relatively rare in the emotion regulation literature (although see Sheppes et al., 2014, Study 1). Much past research examining the role of motivation in emotion regulation has instead distinguished between different types of motives (i.e., between *hedonic* motives, whereby the goal of regulation might be the inherent change in emotion itself; and *instrumental* motives, whereby emotion change might serve a secondary purpose; Tamir, 2016) and how emotion regulation motives might differ with development and context (Kaspi et al., 2024; López-Pérez, Gummerum, Jiménez, & Tamir, 2023). Additionally, past work has distinguished between emotion regulation *goals* and *means* (Tamir et al., 2019). Tamir et al. (2019) demonstrated that activating an emotion regulation goal might be sufficient for promoting regulatory success, even in the absence of instructing specific means or strategies. While our paradigm allowed participants to choose freely between regulation strategies (i.e., arguably, did not specify regulation *means*), it is unclear whether goal activation (instructing participants to down-regulate negative affect) in the absence of direct incentives would have had a similar effect. Given extensive use of monetary incentives to motivate cognitive performance (Botvinick & Braver, 2015), along with robust evidence that emotion regulation depends on cognitive control (Ochsner et al., 2012), we believe that the present work examining effects of monetary incentives on emotion regulation and related outcomes is an important step in integrating across these literatures. However, it will be important to examine the effects of more complex motivators, as well as probing the distinction between regulatory goals and means. This work has the potential to help advance research on both emotion regulation as well as motivated cognition, ultimately integrating both as aspects of adaptive human behavior.

The present research study has important limitations and considerations for future research. First, this study was conducted online, limiting the ability to verify participants' understanding of the task during training and assess whether the motivation manipulation was convincing. Comprehension checks and post-task reports were utilized, but future work using this paradigm could be conducted in-person to better address this issue. Conducting the study in-person would also allow for tighter experimental control of potential interruptions during task performance. Given that our study relied on behavioral and self-report outcomes, acquisition of biological measures during task performance would be beneficial in characterizing the mechanisms underlying our observed effects. For example, skin conductance or pupillometry to index emotional arousal (Cacioppo et al., 2007) and eye-tracking to characterize deployment of attention during emotion regulation (Bardeen & Daniel, 2017) would be important potential measures to consider in future work.

It is also possible that order and demand effects could have contributed to our observed effects. The two task blocks were conducted in a static order, with the Baseline block always preceding the Incentive block. While this was done to minimize the impact of the incentive manipulation on baseline task performance, it is possible that performance in the Incentive block could have been subject to greater fatigue and/or practice effects as a result (Ackerman et al., 2010). All of our analyses controlled trial order across the two task blocks to help address this concern, but follow-up work could employ counterbalanced or between-subjects designs. In addition to order effects, demand effects could have been an influence on reported task performance, particularly in the Incentive block where participants were instructed to down-regulate and report their negative affect. While this is possible, aspects of our design and data suggest against this possibility. First, participants were trained and instructed to use both reappraisal and distraction strategies without being told that one strategy was more desirable than the other. Given this, we suggest that observed incentive-related increases in reappraisal use likely do not reflect demand effects. Second, affect and strategy reports on each Regulate-Negative trial were solicited in a counterbalanced order to encourage deliberate responding and make it more difficult to provide demand-based ratings. Third, participants' post-task reports did not reveal skepticism regarding the motivation manipulation or evidence of demand effects. These considerations do not eliminate the possibility of demand effects in the data, but suggest that they may not fully account for our results. Follow-up studies, particularly in-person, could employ more extensive pre-task training and post-task reports to help minimize demand effect concerns.

As a final consideration, giving participants the option of freely choosing a regulation strategy on each Regulate-Negative trial may have introduced complexity and limitations to the present study. While providing participants with the option of freely choosing a regulation strategy arguably improves ecological validity and more closely reflects real-world emotion regulation, this aspect of our experimental design also means that emotional stimuli were not fully controlled across strategy conditions and uneven numbers of task trials were associated with each regulation strategy. Prior work suggests that stimulus intensity can be associated with regulation strategy selection in free-choice paradigms (Sheppes et al., 2014); the combination of stimulus intensity and regulation strategy selection, along with motivational context, may have impacted affective and memory outcomes. To initially address this issue, we re-ran our analyses with IAPS norms for each image stimulus used as a covariate (see Supplement S4). None of our fixed effects changed in significance, suggesting that even when employing a free-choice approach, our findings should not be considered the product of stimulus-level variation. Additionally, while the mixed-effects modeling approach is robust to uneven data per condition (Brown, 2021), the variation in trial numbers across our regulation strategy conditions may have presented a concern for statistical power. Future work could employ more sophisticated analytical approaches such as decision tree modeling (Song & Ying, 2015), which explicitly models decisions and outcomes as separable stages, with outcome predictions taking into account the preceding decision. Such an approach could more closely reflect the psychological process of choosing a regulation strategy, with downstream consequences for affect and memory outcomes. A final limitation of the free-choice design is the fact that it may have allowed more complex patterns of regulation response (i.e., deliberating, attempting one strategy and switching when unsuccessful) that were not fully captured in our self-report measures. Soliciting more detailed reports from participants during emotion regulation may be helpful in capturing these nuances. While these aspects of the free-choice design do present limitations for the present work, this paradigm also presents important new possibilities for studying emotion regulation and its consequences in a more naturalistic fashion.

Taken together, the present study findings suggest that motivational incentives presented in the context of an emotion regulation task might influence both memory and affective outcomes. In general, incentives were associated with decreased momentary negative affect and reduced subsequent memory, but were not associated with affective changes upon re-encounter 24 hours later. Additionally, incentive effects on memory and immediate affect were independent of effects of regulation strategy, suggesting that incentive may have had a relatively global and automatic influence, rather than modulating cognitive control processes specifically. The extent to which these surprising findings might be the product of our free-choice, emotion regulation task design is currently an open question. Given the possibility that reward incentive may have directly decreased negative affect and arousal to influence memory outcomes, follow-up studies should investigate the boundary conditions of this effect. For example, future work could examine whether punishments lead to similar effects to those observed with rewards (Yee et al., 2022) and whether incentives have similar effects when participants are required to upregulate versus downregulate affect (Gyurak et al., 2012). Follow-up work could use biological measures and more nuanced self-report metrics to better characterize the mechanistic changes that may be occurring in motivated emotion regulation. Such work will be important in unraveling the multiple potential pathways by which motivation, cognitive control, and affective experience might influence the consequences of emotion regulation. Ultimately, such efforts may be important in integrating the emotion regulation and motivated cognition research literatures to inform a more comprehensive account of mental health and adaptive behavior.

Supplementary information The online version contains supplementary material available at https://doi.org/10.3758/s13415-024-01248-y.

Acknowledgements The authors thank Lyneé Herrera for assistance conceptualizing and developing the study.

Authors' contributions K.S.C. acquired funding for the project. A.J.A. and K.S.C. designed the study. A.J.A. collected the data and conducted data analysis. A.J.A. and K.S.C. wrote and edited the manuscript.

Funding This project was funded by the University of Denver.

Data availability Data, analysis code, and materials from the study will be made available upon publication on Open Science Framework (OSF).

Declarations

Ethics approval/Consent to participate/Consent to publish This study protocol was approved by the University of Denver Institutional Research Board (Protocol 1501215). The procedures used in this study adhere to the tenets of the Declaration of Helsinki. All participants provided written informed consent prior to participation and consented to the publication of de-identified data resulting from the study.

Open practices statement Data and materials for the experiments reported here will be made available at https://osf.io/k5vf6/ upon publication. The study was not preregistered.

Employment A.J.A. is a graduate student at the University of Denver and K.S.C. is an Associate Professor at the University of Denver.

Conflicts of interest A.J.A. and K.S.C. claim that there is no conflict of interest in this project and that they have no relevant financial or non-financial interests to disclose.

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