Domain-specific working memory loads selectively increase negative interpertations of surprised facial expressions

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# Introduction

## Facial expressions and individual differences

Facial expressions are important social signals; they communicate emotion between individuals and even spark emotional responses in others (Frith, 2009). Indeed, humans readily make judgments about personality traits (e.g., trustworthiness), aesthetics (e.g., attractiveness), and emotions from faces (Carroll & Russell, 1996; Said & Todorov, 2011; Todorov, Baron, & Oosterhof, 2008). Interpretations of valence (i.e., the inherent positive or negative emotional value of a stimulus) are one instance of judgments of facial expressions guiding potential social (i.e., approach-avoidance) behavior (Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010).

While most people can accurately differentiate the emotional valence of facial expressions, such as consistently interpreting angry faces as negative and happy faces as positive, there are individual differences in valence judgments of emotionally ambiguous facial expressions, like a surprised face (Neta et al., 2009; Petro, Tong, Henley, & Neta, 2018 ). This difference in valence interpretations of surprised expressions is attributable to this expression’s predictive value for both positive and negative outcomes in an individual’s previous experience. For instance, a surprised expression could signal positive (e.g., winning the lottery) or negative (e.g., a car accident) events. These differences in valence interpretations represent an important individual difference, as the same stimulus can result in two equally valid but alternative interpretations between individuals–likely leading to different downstream behaviors (e.g., Krieglmeyer et al., 2010). For instance, individuals that interpret ambiguous expressions negatively may avoid the expresser, and vice-a-versa, given the relevance of emotional valence in approach-avoidance bevahiors (Bradley, 2009; Frijda, 1986; Lang, 1985). This individual difference in interpretations of emotionally ambiguous stimuli is known as one’s *valence bias*, and a growing body of work has used both facial expressions and emotional scenes to better understand this bias (Neta, Kelley, & Whalen, 2013; Neta et al., 2009; Neta & Whalen, 2010).

Despite one’s valence bias, the initial response to ambiguity appears to be negativity (Neta, Davis, & Whalen, 2011; Neta et al., 2009; Neta & Whalen, 2010; Petro et al., 2018). Under this framework, which is known as the *initial negativity* hypothesis, positive interpretations rely on the implementation of some emotion regulation strategy in order to override the initial negativity. Several studies provide evidence to suggest that initial interpretations are negative. For instance, containing aretheir counterparts Additionally.

Conversely, other research supports the notion that positive interpretations rely on regulatory processes. A recent study manipulated reaction times and demonstrated that instructions to delay reaction times result in a shift towards positivity for those with a negative baseline bias (Neta & Tong, 2016). Neuroimaging work has shown that vthat valence found Taken together, initial responses to ambiguity appear to be negative, and positive interpretations rely on regulatory processes, perhaps through an emotion regulation mechanism like cognitive reappraisal.

Cognitive reappraisal is a form of emotion regulation in which one reinterprets or reappraises the intial perceptions of an emotional experience to have an alternative meaning (Lazarus & Alfert, 1964; Gross, 2003). Similarly, the initial negativity hypothesis posits that individuals’ initial perception of surprised expressions is negative, and that those arriving at a positive interpretation must implement a regulatory mechanism to alter their interpretation.Recent work suggests that cognitive reappraisal is effortful, in that cognitive costs (i.e., reaction time) increase as intensity increases for negative emotional stimuli (Ortner, Marie, & Corno, 2016), just as positive interpretations of ambiguity are associated with increased reaction times (Neta et al., 2009). Given the cognitive cost of regulatory strategies, concurrent cognitive demands will likely interfere with individuals’ ability to effectively implement regulatory strategies in the face of ambiguity.

## Cognitive loads and task interference

In daily life, cognitive resources are limited, which can lead to difficulty in effortful self-regulation of cognitive and affective processes (Baumeister & Heatherton, 1996; Kahneman, 1973; Storbeck, 2012; Scalf, Torralbo, Tapia, & Beck, 2013). For example, imagine a student attending a lecture. If the student is frequently distracted by notifications and directing cognitive resources towards a text message conversation, then the student’s ability to understand and remember the lecture material will likely suffer. Directing cognitive resources between different tasks in this manner taxes an already limited pool of cognitive resources (Baumeister & Heatherton, 1996; Kahneman, 1973). Indeed, cognitive resource competition leads to a phenomenon known as cognitive load, which negatively impacts executive processes (Lavie, Hirst, Fockert, & Viding, 2004; Murphy, Groeger, & Greene, 2016). High levels of cognitive load alter performance on cognitively demanding tasks, including those in both cognitive and emotional domains (Jiaping et al., 2017; Kron, Schul, Cohen, & Hassin, 2010; Nagamatsu et al., 2011; Pontari & Schlenker, 2000; Thomas, Donohue-Porter, & Stein Fishbein, 2017; Mather & Knight, 2005; Knight et al., 2007). For instance, individuals show larger neural responses to others’ pain under high cognitive load (Jiaping et al., 2017), perhaps a sign of emotion dysregulation. Other work demonstrated the negative effects of cognitive load on affective bias in older adults, showing that cognitively demanding tasks (e.g., distraction during memory encoding) reduce age-related positivity bias (Mather & Knight, 2005; Knight et al., 2007).

~~One typical method for assessing the impact of cognitive load is through manipulation of working memory demands. These tasks, which require participants to maintain some stimulus representation in working memory, are often used for testing cognitive load effects (e.g., Burnham, 2010; Lavie & De Fockert, 2005; or see Murphy et al., 2016 for a review). Notably, working memory capacity is a strong predictor of multitasking performance (Konig, Buhner, & Murling, 2005), and task-switching performance is associated with working memory costs (Liefooghe, Barrouillet, Vandierendonck, & Camos, 2008). Other work has linked larger working memory capacity with enhanced emotion regulation ability (Schmeichel, 20XX). Taken together, these results suggest that working memory may be one of the underlying resources necessary successful achievement of goal-relevant behavior under cognitive load.~~

Indeed, cognitively demanding tasks often interact with concurrent affective processes (e.g., face categorization, subjective emotional experience), perhaps as a result of a shared resource pool for these processes (Ahmed, 2018, Blair et al., 2007; Muraven, Tice, & Baumeister, 1998; Mather & Knight, 2005; Knight et al., 2007). For instance, Ahmed (2018) showed that performance on a facial expression categorization task suffers when participants are under high cognitive load. Other work has linked cognitive load to changes in emotional responses (Blair et al., 2007; Van Dillen, Heslenfeld, & Koole, 2009). For example, higher loads during a working memory task reduce subjective emotional experience, as well as amygdala activity (Van Dillen et al., 2009). Other neuroimaging work has shown that emotional responses in the brain (i.e., amygdala and inferior frontal gyrus activation) were lower during trials with cognitive demands compared to trials with no concurrent task demands (Blair et al., 2007). This study also showed evidence that behavioral performance of a cognitively demanding task (i.e., Stroop task) suffers during trials with emotional, rather than neutral, distractors. Other work highlights the importance of cognitive load task characteristics on a logical reasoning task, in which participants assessed the logic of a conclusion given some provided premises. The authors demonstrated that participants perform worse on tasks with emotional, rather than neutral, content when under high cognitive load (Trémolière, Gagnon, & Blanchette, 2016). Together, these effects suggest an overlap between cognitive demands and emotional processes, with high cognitive demands interfering with typical emotion processing.

Previous work has tested the effects of cognitive load on valence bias to assess both subjective ratings of surprise and the underlying cognitive-motor dynamics of the ratings via mousetracking. While there was no effect of load on subjective interpretations of surprised expressions, participants did show altered response (computer mouse) trajectories, such that mouse movements were less drawn towards their modal response option (i.e., positive or negative) in line with one’s bias (Mattek, Whalen, Berkowitz, & Freeman, 2016). That is, the cognitive load did not interfere with the tendency to interpret surprised expressions as positive or negative, but instead interfered with the cognitive-motor dynamics of *how* one arrived at a response. However, given the initial negativity hypothesis, one might have predicted that a cognitive load, specifically one which taxes the same resources used for emotion regulation, would lead to more negative interpretations of surprise. One potential explanation for the null effect of load on ratings is the domain-specificity of the cognitive load. In other words, some research has shown that one task (i.e., Stroop task) can recruit different brain regions depending upon the emotional properties of the task stimuli, highlighting the dissociable processing of emotional and non-emotional stimuli within similar tasks (Egner, Etkin, Gale, & Hirsch, 2008). Critically, Mattek and colleagues (2016) used non-emotional stimuli (i.e., number sequence) in their manipulation of cognitive load during interpretations of surprised facial expressions. The cognitive demand required for maintaining emotional (but perhaps not non-emotional) information in working memory may be necessary for taxing resources used for emotion regulation.

## The present study

In the present study we tested the effect of high cognitive load on valence bias, and directly compare the effects of load that carries emotional versus non-emotional properties. First, we predict a null main effect of load on valence bias (i.e., ratings of surprised faces will not differ under low versus high load), replicating Mattek et al (2016). Notably, we expect to find a main effect of load type (emotional versus non-emotional) on interpretations of surprise, such that interpretations made under emotional load are more negative than those made under non-emotional working memory loads. Further, we predict an interaction effect, such that high emotional working memory load will result in more negative interpetations than low emotional working memory load.

# Methods

## Participants

Fifty-eight participants (*M*age = XX years, SD = XX years, XX female) were recruited from the undergraduate research pool at the University of Nebraska-Lincoln. The data from eight participants were excluded due to technical difficulties that prevented data from being saved (?). The final sample included the remaining 50 participants (*M*age = 18.82 years, SD = 1.19 years, XX female), and all identified as White/Caucasian without Hispanic/Latinx ethnicity). All subjects provided written informed consent in accordance with the Declaration of Helsinki and all procedures were approved by the University of Nebraska-Lincoln Institutional Review Board (Approval #20141014670EP). Each participant received course credit for completing the study.

## Material

### Stimuli

The stimuli included faces from the NimStim (Tottenham et al., 2009) and Karolinska Directed Emotional Faces (Lundqvist, Flykt, & Öhman, 1998) stimuli sets, as in previous work (Brown et al., 2017; Neta & Whalen, 2010). The faces consisted of 34 unique identities including 11 angry, 12 happy, and 24 surprised expressions organized pseudorandomly. The scene stimuli were selected from the International Affective Picture System (Lang, Bradley, & Cuthbert, 2008). A total of 288 scenes (72 positive, 72 negative, and 144 neutral) were selected for the image matrices. The positive and negative images did not differ in arousal (Z = -0.23, p = 0.82). The scenes were organized into low (two images) and high (six images) cognitive load of either neutral or emotional (equal number of positive and negative) images (Figure 1).

## Procedure

After arriving at the lab, participants provided informed consent prior to completing the task. Participants were randomly assigned to complete one of the task versions, which included 144[[1]](#footnote-1) trials split between working memory probe and face rating trials. The task was completed using MouseTracker software (Freeman & Ambady, 2010) and participants responded with a mouse to indicate the appropriate response for the face ratings (i.e., “POSITIVE” or “NEGATIVE”) and the memory probe (i.e., “YES” or “NO”). The trials were self-initiated; that is, the participant clicked a “start” button at the bottom of the screen at the beginning of each trial at their own pace. After initiating the trial, a fixation cross appeared (1000 ms), then participants viewed an image matrix, which the participants were instructed to remember for the duration of the trial. The image matrix was presented for 4000 ms and the image was either a low or high load matrix consisting of either emotional (equal positive and negative) or neutral images. After the image matrix a happy, angry, or surprised face appeared for 1000 ms and the participants rated the face by clicking on either the positive or negative response option. After the face rating, a single image probe appeared (5000 ms), and participants indicated whether or not the image probe was present in the previous image matrix.

## Data analysis

We used R (Version 3.6.0; **???**) and the R-packages \* }dplyr\* [@ }R-dplyr], *BayesFactor* (Version 0.9.12.4.2; **???**), *broom* (Version 0.5.2; **???**), *circlize* (Version 0.4.6; **???**), *coda* (Version 0.19.2; **???**), *cstab* (Version 0.2.2; **???**), *diptest* (Version 0.75.7; **???**), *dotCall64* (Version 1.0.0; **???**; **???**), *fastcluster* (Version 1.1.25; **???**), *fields* (Version 9.8.3; **???**), *forcats* (Version 0.4.0; **???**), *foreach* (Version 1.4.7; **???**), *ggplot2* (Version 3.1.1; **???**), *jpeg* (Version 0.1.8; **???**), *lattice* (Version 0.20.38; **???**), *magrittr* (Version 1.5; **???**), *maps* (Version 3.3.0; **???**), *Matrix* (Version 1.2.17; **???**), *mousetrap* (Version 3.1.2; **???**), *openxlsx* (Version 4.1.0; **???**), *papaja* (Version 0.1.0.9842; **???**), *plyr* (Version 1.8.4; @ }R-dplyr; **???**), *pracma* (Version 2.2.5; **???**), *processx* (Version 3.3.1; **???**), *psych* (Version 1.8.12; **???**), *purrr* (Version 0.3.2; **???**), *RColorBrewer* (Version 1.1.2; **???**), *Rcpp* (Version 1.0.1; **???**; **???**), *readbulk* (Version 1.1.2; **???**), *readr* (Version 1.3.1; **???**), *readxl* (Version 1.3.1; **???**), *Rmisc* (Version 1.5; **???**), *scales* (Version 1.0.0; **???**), *spam* (Version 2.2.2; **???**; **???**; **???**), *stringr* (Version 1.4.0; **???**), *tibble* (Version 2.1.3; **???**), *tidyr* (Version 0.8.3.9000; **???**), *tidyverse* (Version 1.2.1; **???**), and *yarrr* (Version 0.1.5; **???**) for all our analyses. Data preprocessing was completed in R using the mousetrap package (**???**). First, percent negative ratings were calculated for happy, angry, and surprised faces across all trial types, as well as a percent correct score for the memory probe trials. After, trials were screened for RT outliers. Any trials that were greater than three standard deviations from the mean were removed from the analyses. Additionally, we removed the preceding face rating trial for any incorrect memory probe trials, as these trials can be considered a manipulation failure.

For the main test of our hypothesis, wPrior to completing the analyses, all data were assessed for normality using Shapiro-Wilks tests. Friedman’s test was used to assess overall differences and pairwise comparisons were completed using Wilcoxon signed rank tests using Bonferroni correction. Next, given a normal distribution, we tested for differences among maximum deviations in each working memory load condition using a Load (low, high) X Domain (emotional, neutral) repeated-measures ANOVA.

# Results

## Subjective ratings

Friedman’s test results showed significantly different rank-order distributions across the conditions (3.00) = 27.79, p < .001. Follow up Wilcoxon signed rank tests revealed that surprise is rated as more negative when holding emotional content in working memory compared to neutral content, and this was true for both low and high loads. Low emotional load ratings were significantly more negative than low neutral, Z = 3.27, p = .001, and high neutral loads, Z = 3.67, p < .001. Similarly, high emotional load ratings were also significantly more negative than low neutral, Z = 4.55, p < .001, and high neutral loads, Z = 3.81, p < .001. However, there was no significant difference between low emotional and high emotional load (Z = -1.35, p = .176) or between low neutral and high neutral load (Z = -0.06, p = .954). 

Next, we assessed differences in absolute maximum deviation (MD) across the working memory trial conditions. There was a significant effect of Load, F(1.00,196.00) = 5.51, p = .020, such that MD was larger on trials with a high load compared to those with a low load. There was no significant effect of Domain (emotional versus neutral load) on MDs, F(1.00 196.00) = 0.01, p = .912, nor a significant Load x Domain interaction, F(1.00 196.00) = 0.00, p = .960. 

# Discussion

Here we tested the effects of high cognitive loads with either emotional or non-emotional properties on valence bias. As predicted, interpretations of surprise were more negative under cognitive loads with emotional properties than loads with non-emotional properties. This result deviates from previous work testing the effects of cognitive load on valence bias (Mattek et al., 2016), but aligns with other literature demonstrating that the emotional properties of the task affect task performance (Egner et al., 2008). We also found evidence that MADs were larger during high cognitive load, suggesting that response competition increased with the cognitive demands of the task. This effect of increased response competition parallels other work suggesting that high cognitive load increases distractor processing (Lavie, 2005).. We discuss these results in the context of the initial negativity hypothesis below.

The intial negativity hypothesis posits that positive interpretations of ambiguous stimuli require regulatory resources (Neta et al., 2009; Petro et al., 2018…). We used a working memory paradigm, commonly used in the cognitive load literature (Ahmed, 2018; Burnham, 2010; Lavie & De Fockert, 2005), to induce high cognitive load with either emotional or non-emotional properties while participants made valence judgments of surprised facial expressions. Participants interpreted surprise as more negative only during high cognitive loads with emotional properties, suggesting that these loads specifically taxed the resources required for positive interpretations of ambiguity. There was no effect of high cognitive load with non-emotional properties, providing a conceptual replication of previous work (Mattek et al., 2016). We interpret these results as evidence that domain-specific regulatory resources are used for regulating responses to emotional ambiguity, rather than domain-general cognitive resources.

In other words, the *type* of resources available determine the propensity for individuals to regulate responses to ambiguous emotional cues. Previous work has shown that ambiguity resolution relies on the cingular-opercular network (Neta et al., 2013); though speculative, our cognitive load manipulation may have taxed these resources specifically due to the dual valence of the emotional load. Future work should manipulate positive and negative loads independently, but it will be difficult to tease priming effects out of this design… Previous work has shown both domain-general and domain-specific effects in the resolution of emotionally ambiguous faces and scenes ().

Indeed, this may account for some of the ego depletion literature which suggests that cognitive load reduces emotional impact and depletion leads to larger emotional responses…

**Summary of the results**

* **Cognitive loads w/ emotional properties shift bias towards negativity**
* **High cognitive load (across emo and non-emo domains) result in larger MDs (i.e., greater response competition)**

**The rating results support the initial negativity hypothesis:**

* **Cognitive load interferes with resources for regulation**
* **Domain-specificity**

**MD effects suggest a successful cognitive load manipulation (cognitive load theory)**

* **This means that DESPITE the good WM task performance, the load manipulation (low vs. high) probably worked… as it’s at least seen on these MD data.**

**Limitation and future work**

* Working memory performance near ceiling
* Positive and negative loads not manipulated independently

**Wrap up: Our work extends previous work testing the effects of high cognitive load on subjective interpretations on ambiguity, highlighting the importance of domain-specific cognitive loads. In other words, only cognitive loads which tax the resources used for interpreting ambiguity as positive will alter interpretations.**

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1. Some versions of the task only included 142 trials due to a programming error. [↑](#footnote-ref-1)