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

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# Introduction

The availability of cognitive resources is necessary for successfully navigating our daily lives, including for adaptive processes in attention deployment (Franconeri, Alvarez, & Cavanagh, 2013), planning (Hayes-Roth & Hayes-Roth, 1979; Kliegel, Martin, McDaniel, & Phillips, 2007), decision-making (Deck & Jahedi, 2015; Whitney, Rinehart, & Hinson, 2008), inhibition (Ward & Mann, 2000) and cognitive control (Deveney & Pizzagalli, 2008). Thus, engagement in one task that taps a cognitive resource (i.e., cognitive load) impairs performance on a concomitant or subsequent task tapping the same resource (Richeson & Trewalter, 2005; Baumeister & Heatherton, 1996; Franconeri, Alvarez, & Cavanagh, 2013; Kahneman, 1973; Storbeck, 2012; Scalf, Torralbo, Tapia, & Beck, 2013). For example, imagine a student attending a lecture while also text messaging a friend. As the student considers how to respond in their next message and directs cognitive resources (attention) towards the conversation and away from the lecture, the student’s ability to understand and remember the lecture material will suffer. Directing cognitive resources between different tasks in this manner taxes an already limited pool of cognitive resources (Baumeister & Heatherton, 1996; Kahneman, 1973). And on a larger scale, the accumulation of cognitive depletion can have widespread societal implications (e.g., burnout and absenteeism; Diestel & Schmidt, 2011). For instance, in emotionally demanding occupations (e.g., healthcare positions), cognitive depletion is associated with worse job performance (Ihle, Borella, Rahnfeld, Müller, Enge, Hacker, Wegge, Oris, & Kliegel, 2015; Motowidlo, Packard, & Manning, 1986) and increased job-related stress that has adverse downstream effects on executive functioning (Privitera, Rosenstein, Plessow, & LoCastro, 2014; Starcke, Wiesen, Trotzke, & Brand, 2016).

Furthermore, many emotional processes are affected by cognitive depletion, perhaps as a result of a shared resource pool for the concurrent emotional and cognitive demands (Ahmed, 2018, Blair et al., 2007; Muraven, Tice, & Baumeister, 1998; Mather & Knight, 2005; Knight et al., 2007). For example, several studies have used a distracting task to ’occupy’ PFC resources related to cognitive control and thereby limit attention to emotional stimuli, usually pain (Ochsner & Gross, 2005). Also, Ahmed (2018) showed that participants are less accurate at categorizing emotional facial expressions when under high cognitive load. Other work has demonstrated the deleterious effects of cognitive load on emotional bias in older adults, demonstrating that cognitively demanding tasks (i.e., distraction during memory encoding) reduced the age-related positivity bias (Mather & Knight, 2005; Knight et al., 2007). Neuroimaging work has shown that emotion regulation regions of the brain are recruited a() (Blair et al., 2007). These findings suggest that, in order to preserve cognitive resources required for task performancean emotion regulation mechanism may be employed to eIn other words, there appears to be a clear overlap between the resources used to handle cognitive demands and those involved in the maintenance of emotional processes, such that cognitive demands deplete resources which might otherwise be dedicated to the maintenance of emotional processing.

Notably, the domain of the resource depletion matters; that is, if the resources required for a particular task are not depleted, then task performance may be unaffected by the load. In other words, if it were the case that cognitive resources were not required to complete a task (e.g., emotional categorization?), then cognitive depletion may have no behavioral consequences on one’s task performance. For instance, when asked to maintain representations of the emotion a face expressed, rather than its identity, participants were less accurate on subsequent judgments of emotional than perceptual pairs of a concept-property verification task (e.g., lemon-yellow, couple-happy; Vermeulen, Niedenthal, Pleyers, Bayot, & Corneille, 2014). Neuroimaging research has supported these findings by suggesting separable effects of load as a function of the (cognitive versus emotional) domain. For instance, changing the nature of cognitively demanding tasks to include an emotional component (e.g., remembering an emotional expression instead of an identity; judging the congruency of a face and label for emotional expressions instead of sex), even when stimuli themselves remain consistent, results in the recruitment of dissociable neural resources (Egner, Etkin, Gale, & Hirsch, 2008; Neta & Whalen, 2011). Indeed, emotional loads are receive priority processing at the perceptual and executive levels (Pessoa, 2009) and are thus highly competitive for cognitive resources. As such, when these resources are engaged with an emotional load, the resources are no longer available for regulating other emotional processes and performance on these will likely be affected. In other words, emotional loads are likely to impact concurrent emotional processing more strongly than comparable cognitive (i.e., non-emotional) loads.

**Resources required for resolving emotional ambiguity**

Humans readily make judgments about others with only limited information and resources (e.g., judging trustworthiness, attractiveness, and emotion; Bar, Neta, & Linz, 2006; Said & Todorov, 2011; Todorov, Baron, & Oosterhof, 2008; Cloutier, Heatherton, Whalen, & Kelley, 2008; Brooks, Chikazoe, Sadato, & Freeman, 2019; Carroll & Russell, 1996). Notably, assessing valence is a primary decision we make when processing facial expressions, as it is a crucial component that guides social behavior (e.g., approach-avoidance; Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010; and group membership or affiliation; Taskhay & Rule, 2015; Tskhay & Rule, 2018). For instance, individuals that interpret facial expressions negatively may avoid the expresser, and vice versa, given the relevance of emotional valence in approach-avoidance behaviors (Bradley, 2009; Frijda, 1986; Lang, 1985). However, there are some situations where more resources are required for these interpersonal judgments. For example, while some facial expressions are easily categorized as positive (happy) or negative (angry), others (surprise) appear to require more resources due to the nature of their valence ambiguity (Neta et al., 2009; Neta & Tong, 2016; Petro, Tong, Henley, & Neta, 2018). Indeed, surprised expressions can predict both positive (e.g., winning the lottery) and negative (e.g., a car accident) outcomes. Thus, there are individual differences in the tendency to interpret surprised faces as having a more positive or negative meaning, which is known as one’s *valence bias* (Neta, Kelley, & Whalen, 2013; Neta et al., 2009; Neta & Whalen, 2010).

Despite the individual differences in valence bias, some work has provided evidence for an initial negativity across people (i.e., *initial negativity hypothesis*; Neta, Davis, & Whalen, 2011; Neta et al., 2009; Neta & Whalen, 2010; Petro et al., 2018). Under this framework, positive interpretations rely on the implementation of some emotion regulation strategy in order to override the initial negativity. To describe a few examples, mouse trajectories (quantified using mousetracker; Freeman & Ambady, 2010) offer a rich insight into the process underlying decision-making (Freeman, Dale, & Farmer, 2011) and associated response competition (Calcagni, Lombardi, & Sulpizio, 2017; Freeman, Dale, & Farmer, 2011; Hehman, Stolier, & Freeman, 2015). Previous work demonstrated a more direct trajectory to the negative response option, but on trials that are rated as positive, there is greater response competition characterized by an attraction toward the competing (negative) response (Brown et al., 2017). And, when instructed to take longer to deliberate, participants show a shift toward more positive ratings of surprised faces (Neta & Tong, 2016). Neuroimaging work has shown that the amygdala, which responds to more bottom-up signals of emotion (CITE), shows greater activity associated with more negative interpretations (Kim et al., 2003; Neta & Whalen, 2010), and the ventromedial prefrontal cortex (vmPFC), a putative top-down regulatory region, was associated with more positive interpretations (Kim, Somerville, Johnstone, Alexander, & Whalen, 2003). More recently, Petro, Tong, Henley, & Neta (2018) found that participants with a more positive valence bias showed greater activity for surprised faces in brain regions recruited during an explicit emotion regulation (cognitive reappraisal) task. 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. However, given the cognitive cost of regulatory strategies (Richards & Gross, 2000; Sheppes & Meiran, 2008), concurrent cognitive demands will likely interfere with individuals’ ability to effectively implement regulatory strategies in the face of ambiguity.

Building on these findings, we would predict that increasing cognitive load, specifically one which depletes the resources used for emotion regulation (i.e., emotional load), should result in a more negative valence bias. In other words, the increased load will result in a decrease in regulation ability, which will produce more negative (default) interpretations of emotionally ambiguous cues. Notably, previous work has revealed that cognitive load does not impact subjective ratings of surprised expressions (Mattek et al., 2016). However, this study examined the effect of a non-emotional load (i.e., remembering a number sequence) on interpretations of surprised facial expressions. One potential explanation for the null effect on valence ratings of surprise is the domain-specificity of the cognitive load. In other words, it could be that an emotional load (i.e., attending to and assessing emotional images) will engage a process similar to that required for a positive valence bias, and in turn be more likely to interfere with the resources used for valence interpretations than a non-emotional load.

Interestingly, while the previous work did not show an effect on subjective interpretations of surprised expressions, the non-emotional load did alter the response trajectories. Specifically, high non-emotional load resulted in faster response trajections, suggesting decreased response competition (Mattek et al., 2016). Taken together, we predict that domain-general cognitive load (i.e., load that is irrespective of cognitive or emotional domain) will likely be associated with faster response trajectories, particularly diminishing the response competition evident on positive trials.

## The present study

In the present study we tested the effect of cognitive load on valence bias, as a function of the load (low or high) and domain (non-emotional or emotional). To do this, we manipulated the the amount of material that participants needed to maintain in working memory and the domain of that material while concurrently making valence judgments of facial expressions. First, we predict that there will be no effect of load on ratings of surprised faces, replicating Mattek and colleagues (2016). However, we do expect to find an effect of domain on ratings, such that an emotional load will result in more negative ratings than a neutral load, suggesting that emotional load requires the same resources as those when resolving the ambiguity in surprised faces emotional ambiguity. Consistent with previous work, we predict that response competition (i.e., attraction toward the competing – unselected – response) will be mitigated under high load (Mattek et al., 2016), but that this effect will not be impacted by the domain of the load.

# Methods

## Participants

Fifty-nine participants (*M*age = 19.03 years, SD = 1.70 years, 49 female) were recruited from the undergraduate research pool at the University of Nebraska-Lincoln. The data from nine 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, 41 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.

## Procedure

The task was conducted using MouseTracker software (Freeman & Ambady, 2010) and was structured to closely resemble the cognitive load task used by Mattek, Whalen, Berkowitz, and Freeman (2016), which used a single digit (low load) or seven digit sequence (high load). The trials were self-initiated; that is, the participant initiated each trial at their own pace by clicking the “start” button at the bottom of the screen. After initiating the trial, a fixation cross appeared (1000 ms), then participants viewed an image matrix consisting of 2 or 6 images (low or high load, respectively), which the participants were instructed to remember for the duration of the trial (i.e., until the memory probe portion of the trial). The image matrices which were designed to induce either low (two images) or high (six images) cognitive load with either non-emotional or emotional properties (Figure 1). After the image matrix, either a happy, angry, or surprised face appeared for 1000 ms, and the participants rated the face by using the computer mouse to click on either the positive or negative response option. again used the computer mouse to , after which they completed a total of 144 trials, Notably, in two-choice designs, maximum deviations are often conceptualized as a measure of response competition for ultimately unchosen responses or the degree of uncertainty during the response process (Calcagni, Lombardi, & Sulpizio, 2017; Freeman, Dale, & Farmer, 2011; Hehman, Stolier, & Freeman, 2015).

## Stimuli

A total of 288 scenes (72 positive, 72 negative, and 144 neutral) were selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008) for use in the matrices, and the positive and negative images did not differ in arousal after testing with a Wilcoxon signed-rank test (*Z* = -0.23, *p* = 0.82). For the matrices with emotional properties, there were an equal number of positive and negative images within a matrix. We used a combination of positive and negative images for this condition in order to avoid priming effects on the subsequent face ratings (e.g., Flexas, Rosselló, Christensen, Nada, La Rosa, & Munar, 2013), particularly given that previous work has shown that ratings of surprised faces are sensitive to valence priming (Neta et al., 2011).

The face stimuli included images 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.

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## Figure 1: Instructions for the working memory and valence bias task and sample images.

## Data analysis

We used R (Version 3.6.0; **???**) for all our analyses. Data preprocessing, analysis, and plotting were completed in R using the mousetrap (**???**), lme4 (???), and ggplot2 (???) packages. While it is possible that trials in which participants responded incorrectly to the memory probe indicated a manipulation failure (i.e., the participant was not maintaining the images in memory), we included all trials regardless of accuracy due to the lack of an objective method for determining whether or not the participants were attempting to remember the images in the matrix. Our primary dependent measures were accuracy (percent correct) for the memory probe trials and valence bias, which is calculated as percent negative ratings for surprised faces across all trials. For the main test of our hypothesis, we compared the valence bias for the different working memory load conditions (high and low load, emotional and non-emotional load). Additionally, we calculated maximum deviation, or the extent to which a response trajectory deviated or was attracted to the competing – unseleced – response option, for each condition. Finally, we explored the effects on maximum deviation and load conditions as a function of the trial-by-trial rating (i.e., comparing trials in which surprise was rated as a positive versus negative).

In order to account for the interdependence among measurements due to the repeated measures design, we used a mixed effects modeling approach. Unlike the repeated measures ANOVA, mixed effects models can account for missing data in repeated measures designs, which was a concern in our analyses given that some participants rated surprise as negative on all trials (i.e., missing values for the condition of surprise rated as positive). Mixed effects approaches are an extension of ordinary least squares (OLS) regressions that also include both fixed and random effects. The interpretations of fixed effects follow the conventions of OLS regression, where the slope describes the effect on average across participants for each one unit increase in the predictor), while random effects (i.e., slopes and/or intercepts) allow the model to fit effects which are not averaged across the entirety of the sample (i.e., individual differences across participants here). Additional justification for the mixed effects modeling approach comes from the statistical dependency among the measures for any given subject, which was revealed through an intraclass correlation (ICC) of .75 for ratings of surprised faces and .17 for maximum deviations.

To test the effects of experimental conditions (load: high versus low, and domain: emotional versus non-emotional) on ratings and maximum deviations, we used a linear mixed model with a Gaussian error distribution. This approach demonstrated better model fit than alternative options (i.e., gamma distribution), and is robust to violations of normality (Knief & Forstmeier, 2018) evidenced by Shapiro-Wilks tests (*p*’s < .001). All model building was completed using full information maximum likelihood estimation to account for any missing data (e.g., if a participant did not rate any surprised faces as positive).

# Results

## Subjective ratings of ambiguity

First, a random intercept-only model was tested and the likelihood ratio test results supported the decision to model the intercept randomly across individuals (*p* < .001). This suggests there was individual variance in percent negative ratings at baseline (i.e., low, non-emotional loads) that is best modeled as a separate intercept for each subject, as expected with an individual difference measure with repeated measurements.Next, a fixed component for the effect of Load (low versus high), Domain (emotional versus non-emotional), and their interaction were added to the model uncentered at level one. The effect of Domain significantly contributed to the model (ß10 = 8.06, S.E. = 2.47, *t*(147) = 3.26, *p* = .001), such that ratings of surprised faces following an emotional load were more negative than those following non-emotional loads. The effect of Load did not significantly contribute to the model (ß20 = .37, *t*(147) = .15, S.E. = 2.47, *p* = .881), nor did the Domain × Load interaction (ß30 = 1.94,*t*(147) = .55, S.E. = 3.50, *p* = .581). Together, these results suggest that load did not significantly affect ratings, but that domain did.

**Mixed Model:** Percent Negative Ratingsti = (β00 + r0i) + β10\*(Domainti) + β20\*(Loadti) β30\*(Domainti \* Loadti) + eti

**![A screenshot of a social media post

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**Figure 2: Percent negative ratings across conditions. Ratings during emotional loads were more negative than ratings during non-emotional loads, but there was no difference between ratings under low or high loads. Error bars represent the standard error of the mean.**

**Maximum deviation**

Next, we examined the effect of our experimental manipulation and of surprise ratings (positive versus negative trials) on maximum deviation, a measure of response competition in mouse trajectory. We predicted that high load would diminish response competition, as evidenced by more direct response trajectories (i.e., lower maximum deviation), particularly on trials that are characterized by greater competition (i.e., trials where surprised faces are rated as positive). First, a random intercept-only model was tested for absolute maximum deviation of mouse trajectories, and a likelihood ratio test supported this decision to model the intercept randomly (*p* < .001). This means that individuals differed in their average maximum deviations at baseline (i.e., low, non-emotional loads), and that the best fitting model includes an intercept for each subject individually.Next, fixed parameters for the effect of Load (low versus high), Domain (emotional versus non-emotional), Rating (positive versus negative ratings of surprise), and their interactions were added to the model. A significant Rating × Load interaction (β = .32, *t*(314) = 3.55, S.E. = .09, *p* < .001; Figure 3) revealed that, as expected, positive ratings had larger maximum deviations than negative ratings (*t*(325) = 4.39, S.E. = .05, *p* < .001; Bonferroni corrected significance *p* < .013) on low load trials. However, this difference was not present on high load trials (*t*(327) = -.31, S.E. = .05, *p* = .758; Bonferroni corrected significance *p* < .013), supporting our hypothesis that high load would impact response trajectories. Specifically, the effect of high load was that maximum deviations for negative ratings were larger on high load compared to low load trials (*t*(320) = -2.81, S.E. = .05, *p* = .005; Bonferroni corrected significance *p* < .013).

![A screenshot of a video game

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**Figure 3: The interaction of Rating** × **Load for maximum deviations shows the influence of high load (both emotional and non-emotional) on response trajectories for surprised faces that are rated as negative. Error bars represent the standard error of the mean.**

**Memory probe accuracy**

We examined accuracy on the memory probe to assess differences in task difficulty. While accuracy on the probes was high across all trials (94.41%), there were differences as a function of Load and Domain. Table 1 shows average accuracy by condition. Given that the ICC was 0, the random intercept model had singular fit, and likelihood ratio tests did not suggest any benefit to modeling the intercept randomly (*p* > .999, which is likely due to a large proportion of the data having the same value of 100% correct), a mixed effects model was not used to examine the effects on on accuracy. As such, we used a repeated measures ANOVA to examine differences in memory probe accuracy as a function of the experimental conditions, but note that caution is warranted in interpretations of the model given the undesirable structure of the data (i.e., lack of variability, strong non-normality).

There was a significant effect of Load (*F*(1, 49) = 50.28, *p* < .001) andDomain (*F*(1, 49) = 10.49, *p* = .002), such that accuracy was higher for low than high load, and for non-emotional than emotional load. Further, there was a significant Load × Domain interaction (*F*(1, 49) = 11.06, *p* = .002), such that Domain had no significant effect in low load conditions (*t*(96) = .44, *p* = .661), but under high load, accuracy was higher for non-emotional than emotional load (*t*(96) = -4.63, *p* < .001). Further, Load had no significant effect on emotional trials (*t*(95) = -1.99, *p* = .05; Bonferoni corrected significance *p* < .013), but on non-emotional trials, accuracy was higher on low load than high load trials (*t*(95) = -7.10, *p* < .001; Bonferoni corrected significance *p* < .013). Descriptive statistics are available in Table 1.

**Table 1: Descriptive statistics for memory probe accuracy across all conditions.**

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| --- | --- | --- |
|  | **Condition** | **Mean (SD)** |
| **Emotional load** | **Low load** | **98.83% (.04)** |
| **High load** | **88.33% (.11)** |
| **Neutral load** | **Low load** | **98.18% (.05)** |
| **High load** | **95.23% (.07)** |

**Discussion**

Here we tested the effects of cognitive load with either emotional or non-emotional properties on valence bias. As predicted, ratings of surprise were more negative under emotional load, but non-emotional load. This result extends previous work showing that a cognitive (numeric) load did not affect valence bias (Mattek et al., 2016), and aligns with literature demonstrating that the emotional properties of cognitively demanding tasks impact both behavioral and neural responses during those tasks (Egner et al., 2008). We also found evidence that response trajectories were modulated by cognitive load also as a function of the trial-by-trial ratings. Specifically, previous work has shown that positive ratings of surprised faces are associated with greater response competition (i.e., less direct trajectories) than negative ratings (Brown et al., 2017), and here we demonstrate that this difference is mitigated under high cognitive load. In other words, negative ratings were associated with increased response competition under high load compared to low load, resulting in similar competition for positive and negative trials under high load. This parallels other work showing that high cognitive load increases distractor processing (Lavie & De Fockert, 2005) and response competition measured with mouse-based response trajectories (Bundt, Ruitenberg, Abrahamse, & Notebaert, 2018). We discuss these results in the context of the initial negativity hypothesis below.

**Domain-specific effects**

The initial negativity hypothesis posits that positive interpretations of ambiguous stimuli rely on regulatory resources (Neta et al., 2009; Petro et al., 2018). We used a standard working memory paradigm (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. As expected, participants interpreted surprise as more negative during emotional loads (i.e., when the emotional resources likely required for a positive interpretation are being taxed). In other words, working memory loads with emotional properties interfered with subjective interpretations of emotional ambiguity, most likely due to a reliance on overlapping domain-specific resources. These findings provides further insight into previous findings that demonstrated that cognitive (numeric) load does not appear to affect ratings of surprised faces (Mattek et al., 2016).

These findings are also consistent with previous work showing that emotional properties of a cognitively demanding task that deplete resources required for concurrent emotion processes (Etkin et al., 2006; Neta et al., 2011). For instance, performing an emotional expression-based n-back task recruited greater amygdala activation when compared to an identity-based task (Neta & Whalen, 2011). Given the initial negativity hypothesis’ prediction that positivity relies on regulation, it may be that emotional loads interfered with regions that are functionally connected with the amygdala and are important for emotion regulation. One such region, the ventromedial prefrontal cortex (vmPFC) shows anatomical, functional, and structural connectivity with the amygdala, as demonstrated through human and non-human animal studies (Amaral et al., 1992; Milad & Quirk, 2002; Johansen-Berg et al., 2008; Kim & Whalen, 2009; Amaral, 1992; Ghashghaei et al., 2007). Functionally, a regulatory role for the mPFC as it relates to the amygdala has since been established. For example, the vmPFC shows increased activity for positive interpretations of surprised faces that accompanies a decrease in amygdala activity (Kim et al., 2003), and increased vmPFC is associated with decreased amygdala activity when subjects are asked to suppress their reaction to emotional pictures (Ochsner et al., 2002; Jackson et al., 2003; Urry et al., xxxx; van Reekum et al., 2007). With specific relevance to the present line of work, there is greater activity in the vmPFC? for the emotional compared to non-emotional Stroop task (Etkin et al., 2006). Taken together, we interpret this effect of domain on interpretations of ambiguity as evidence that regulatory resources needed for positive interpretations are susceptible to domain-specific load demands, and that domain-general (cognitive) resources are less critical for regulating subjective interpretations of emotional ambiguity.

**Domain-general effects**

While subjective interpretations of ambiguity were susceptible to the load domain, the underlying cognitive-motor dynamics (i.e., response trajectories) of these decisions were instead vulnerable to domain-general cognitive demands. That is, maximum deviations varied as a function of low compared to high load, regardless of the load domain. Specifically, under a low load, positive ratings typically are associated with greater response competition than negative ratings, but this effects was no longer present under high load. Further, this effect was driven by an *increase* in response competition for negative trials under high load. This replicates previous work showing that the cognitive-motor dynamics underlying the valence bias task are susceptible to increases in cognitive demands generally (Mattek et al., 2016). One interpretation of these findings is that the tendency for individuals to be drawn towards an unselected response may reflect a type of distraction effect (Spivey, Grosjean, & Knoblich, 2005). This mirrors effects seen in the cognitive load literature, where high cognitive loads lead to deficits in the ability to filter out task-irrelevant information (Lavie, Hirst, de Fockert, & Vidling, 2004).

I think this is a good place to talk about why Catie found lower MD for negative in response to stress but you find higher MD for negative for high load. Add a paragraph talking about how load and stress might be different.

Previous work has shown that emotional ambiguity resolution relies on a domain-general task control network called the cingulo-opercular network (Neta et al., 2013); though speculative, the cognitive loads may have taxed these resources, as this network is recruited in response to many types of ambiguity (Neta et al., 2013; Neta et al., 2014; Sterzer, Russ, Preibisch, & Kleinschmidt, 2002; Thompson-Schill, D’Esposito, Aguirre, & Farah, 1997). Other neuroimaging work supports the notion that cognitive loads would preoccupy resources in the cingulo-opercular network; for instance, regions in the network (i.e., anterior cingulate cortex and anterior insula) regularly show activity increases during cognitively demanding tasks, such as those requiring increased attention and control (Duncan & Owen, 2000; Nee, Wager, & Jonides, 2007). As such, the demands induced during high cognitive load, regardless of the emotional properties of the load, likely increased demands in this network. Ultimately, this increase in demands for this domain-general network are one explanation for the observed increase in response competition (i.e., maximum deviations) during high cognitive loads.

**Limitations and future directions**

There are a few limitations to the present study. First, acuracy on the memory probe task, even under high load, was high, suggesting that the cognitive resources were likely not very taxed. For instance, despite the effect of domain on ratings of ambiguity and the effect of high load on response trajectories, working memory performance was near ceiling across all conditions (i.e., approximately 90% correct). Relatedly, participants may have been able to rely on recognition, rather than active working memory maintenance, for the memory probes, as humans are readily able to identify previously seen images after exposure to a large amount of material (i.e., 600 images) at high accuracy (Shepard, 1967). Also, iFuture work could address this by increasing the demands of the task, either by using more than six images in the high load matrix, re-using some images across trials making it more difficult to remember in the image probe was presented on that specific trial, or making the probe task more difficult (e.g., testing the location of the image in the previous matrix rather than just a present/not judgment).

Further, we attempted to use a similar working memory task that could directly compare emotional versus non-emotional properaties. Thus, unlike previous work that used numerical sequences that could be rehearsed using verbal working memory, our task likely relies more on visual working memory (Baddeley, 1998). In the context of visual working memory, perhaps one interesting avenue for future work is to incorporate eye tracking to explore which images participants attended to the most within a matrix, offering insight into which images may be most likely to be held in working memory. In turn, this would allow testing on a trial-by-trial basis, such that attention towards either positive or negative emotional images could be quantified and explored in the context of subsequent ratings of surprised expressions.

**Conclusions**

Here we have provided both a conceptual replication and a novel extension of previous work which tested the effects of cognitive load on ratings of ambiguity (Mattek et al., 2016). Notably, the previous work did not examine working memory demands intended to tax resources related to the emotion processing that might specifically be important for valence bias (Kim et al., 2003; Petro et al., 2018), and as such did not show an effect on ratings of ambiguity. These findings highlight the importance of domain-specificity in cognitive demands. Further, they lend support for the initial negativity hypothesis by suggesting that a positive valence bias relies on emotional regulatory resources. We also demonstrated a domain-general effect of load on response trajectories, which is likely related to the domain-general demands of high load within the cingulo-opercular network. Future work should explore the underlying neural mechanisms of these processes to further disentangle these domain-related effects. Notably, elucidating the neural mechanisms through which individuals become more negative would offer insight into a range of clinical disorders characterized by negativity bias (e.g., anxiety, depression) and may even shed light on mechanisms through which those in cognitively and emotionally demanding positions (e.g., healthcare workers) experience negativity related to workplace burnout.

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