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

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# Introduction

A certain amount of cognitive resources are required for 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 and regulation (Deveney & Pizzagalli, 2008; Ward & Mann, 2000). As such, when cognitive resources are limited (i.e., cognitive depletion), there may be a greater difficulty in effortful self-regulation of cognitive and affective processes (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 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 impact of social (CITE) and emotional functioning (CITE). For example, in emotionally demanding occupations (e.g., healthcare positions), cognitive resource limitations are associated with job performance (Ihle, Borella, Rahnfeld, Müller, Enge, Hacker, Wegge, Oris, & Kliegel, 2015; Motowidlo, Packard, & Manning, 1986) and job-related stress that reduces executive functioning (Privitera, Rosenstein, Plessow, & LoCastro, 2014; Starcke, Wiesen, Trotzke, & Brand, 2016).

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. Additionally, cognitive load has been linked to changes in emotional responses (Blair et al., 2007; Van Dillen, Heslenfeld, & Koole, 2009). Higher loads during a working memory task (Van Dillen et al., 2009) and increased cognitive demands (Blair et al., 2007) reduce subjective emotional experience, as well as brain responses to emotion (i.e., amygdala and inferior frontal gyrus activation). Further, behavioral performance of a cognitively demanding task (i.e., Stroop task) suffers during trials with emotional distractors (Blair et al., 2007). Other work has demonstrated the negative effects of cognitive load on affective bias in older adults, showing that cognitively demanding tasks (e.g., distraction during memory encoding) reduces age-related positivity bias (Mather & Knight, 2005; Knight et al., 2007). Together, these effects suggest an overlap between cognitive demands and emotional processes, with high cognitive demands interfering with typical emotion processing.

Additionally, cognitive load characteristics (e.g., whether the load has emotional properties) can differentially recruit cognitive resources (Egner, Etkin, Gale, & Hirsch, 2008; Neta & Whalen, 2011). In other words, the emotional properties of a task or the stimuli (e.g., gender judgments vs. expression judgments of happy and fear faces in a Stroop task) can affect the brain regions recruited during a task, highlighting the dissociable neural processing of emotional and non-emotional information under the similar task goals (Egner, Etkin, Gale, & Hirsch, 2008). Other work has shown that the amygdala is recruited when participants are asked to remember the emotional expression of a face, rather than the identity (Neta & Whalen, 2011). Behavioral evidence also suggests a dissociation in the processing of emotional and non-emotional stimuli, as stimuli with emotional properties more readily recruit attentional resources than their neutral counterparts (e.g., emotional images are more easily detected than neutral images as the second target in attentional blink paradigms; Keil, Ihssen, & Heim, 2006). The divergence in neural resources for processing emotional and non-emotional cognitive loads suggests a boundary or division between emotional and non-emotional cognitive resources. As such, it follows that there may be domain-specificity in the allocation of cognitive resources to deal with loads, such that emotional loads will recruit the same resources needed for other regulatory affective processing.

In fact, cognitive loads with emotional properties (i.e., emotional loads) do impact concurrent affective processing more strongly than non-emotional loads. Behavioral evidence has shown that performing a working memory task in which participants needed to maintain representations of the emotion a face expressed, rather than its identity, worsened performance on a concept-property verification task requiring participants to make judgments that were either emotional or sensory in nature (e.g., lemon-yellow, couple-happy; Vermeulen, Niedenthal, Pleyers, Bayot, & Corneille, 2014). One model for understanding the mechanism through which emotional loads may interfere with concurrent affective processing more so than non-emotional loads is the dual competition framework, which suggests that emotional properties result in greater recruitment of cognitive and neural resources at the perceptual and executive levels than neutral stimuli (Pessoa, 2009). Indeed, others have also suggested that emotional loads recruit additional inputs from emotion and arousal related brain regions (Grimm, Weigand, Kazzer, Jacobs, & Bajbouj, 2012). As such, these resources are no longer available for regulating other affective goals and performance on these will suffer.

**Valence bias and initial negativity**

Humans readily make judgments about others based on facial expressions, including judgments about personality traits (e.g., trustworthiness; Bar, Neta, & Linz, 2006; Said & Todorov, 2011; Todorov, Baron, & Oosterhof, 2008), aesthetics (e.g., attractiveness; Cloutier, Heatherton, Whalen, & Kelley, 2008), and emotion (Brooks, Chikazoe, Sadato, & Freeman, 2019; Carroll & Russell, 1996). One primary decision we make when processing facial expressions is related to valence (i.e., the inherent positive or negative emotional value of a stimulus), which 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). Interestingly, although some facial expressions are easily categorized as positive (approach a happy face) or negative (avoid an angry face), 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). Indeed, surprised expressions can predict both positive (e.g., winning the lottery) and negative (e.g., a car accident) outcomes. This tendency to interpret surprised faces as having a more positive or negative meaning is known as one’s *valence bias* (Neta, Kelley, & Whalen, 2013; Neta et al., 2009; Neta & Whalen, 2010), and likely leads to different downstream social behaviors (e.g., Krieglmeyer et al., 2010). For instance, individuals that interpret ambiguous 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).

Despite individual differences in valence bias, there is generally an initial response to ambiguity that appears to be negative across people (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 (see Neta et al., 2009; Neta & Whalen, 2010; Neta et al., 2011). To describe a few examples, reaction times are longer on trials where surprised faces are rated as positive versus negative (Neta et al., 2009). And, when instructed to take longer to deliberate, there was a shift towards 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, was associated with more negative ratings, and the ventromedial prefrontal cortex (vmPFC), a putative top-down regulatory region, was associated with more positive ratings (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 taxes the resources used for emotion regulation (i.e., emotional load), should result in a more negative valence bias. In other words, interpretations of emotionally ambiguous cues should be shifted toward negativity, as a result of a decrease in regulation ability due to the demands of a concurrent cognitive load. However, 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 ofa purely cognitive load remembering a on One potential explanation for this null finding is the domain-specificity of the cognitive load. In other words, it could be that an emotional load will engage a process similar to that of the valence bias task (i.e., attending to and assessing emotional images), and in turn be more likely to interfere with the resources used for valence interpretations than a purely cognitive load without emotional properties.

Interestingly, while the previous work did not show an effect on subjective interpretations of surprised expressions, high cognitive load did alter the response process in other ways. Notably, cognitive load interfered with the response trajectories (quantified using mousetracker; Freeman & Ambady, 2010), such that high cognitive load mitigated the tendency for response competition to be lowest for response trajectories in line with one’s bias (Mattek et al., 2016). Indeed, mouse trajectories 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). In the context of ambiguity (surprised faces), mouse trajectories reveal an initial attraction toward the negative response on trials in which participants rated surprised faces as positive, supporting the initial negativity hypothesis (Brown, Raio, & Neta, 2017). Taken together, we predict that domain-general cognitive load (load that is irrespective of cognitive or emotional domain) will likely be associated with intereference in the response trajectories, such that the typically observed pattern (i.e., positive ratings will be characterized by an initial attraction toward the negative response option; Brown et al., 2017) are mitigated.

## 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 content (cognitive or emotional). To do this, we manipulated the emotional properties of images as well as the amount of material that participants needed to maintain in working memory while concurrently making valence judgments of facial expressions. First, we predict that there will be no effect of ~~cognitive~~ load on ratings of surprised faces, replicating Mattek and colleagues (2016). However, we do expect to find an effect of load for loads with emotional properties, such that high emotional load will result in more negative interpetations than low emotional working memory load. We also predict 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 cognitive load (Mattek et al., 2016), but that this effect will not be impacted by the load domain.

# 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.

## Stimuli and procedure

After arriving at the lab, participants provided informed consent prior to completing the task. Participants then completed the task using MouseTracker software (Freeman & Ambady, 2010), which included 144[[1]](#footnote-1) trials in which an image matrix, face, and single image memory probe were presented. The experimenter guided participants through a practice face rating and memory probe trial. Participants responded with the mouse to indicate their response for both the face ratings and the memory probe, and their mouse movements were recorded throughout. 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 which the participants were instructed to remember for the duration of the trial (i.e., until the memory probe portion of the trial). The task 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), followed by a valence judgment of a face and then a single digit probe which participants indicated as either present or absent from the previous numeric sequence. Here, we presented 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). 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). These images are widely used and previous studies have used IAPS images for assessing the effects of emotional compared to non-emotional stimuli (Blair et al., 2007; Ciesielski, Armstrong, Zald, & Olatunji, 2010). For the matrices with emotional properties, there were an equal number of positive and negative images within a matrix. Disambiguating the effects of positive and negative valence loads would prove difficult as these valence effects could result in priming effects (e.g., Flexas, Rosselló, Christensen, Nada, La Rosa, & Munar, 2013), and previous work has shown that participants’ valence bias shifts towards the valence of more frequently occurring stimuli when surprised expressions are consistently preceded and followed by either angry or happy faces, (Neta et al., 2011).

After the image matrix, either 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. face selections fromAfter the face rating, a single image probe appeared (5000 ms), and participants indicated whether the image probe was present in the previous image matrix by clicking either yes (i.e., the image was present) or no (i.e., the image was not present).

A screenshot of a cell phone

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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 indicating manipulation failure over alternative explanations for the incorrect response. Next, each participants’ 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. For the main test of our hypothesis, we tested for differences in valence bias (i.e., percent negative rating of surprised faces) among the different working memory load conditions. Additionally, we assessed mouse trajectories (i.e., maximum deviations) among these same conditions, while also testing for differences as a function of subjective rating (i.e., positive or 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 with interpretations of surprise as a factor (i.e., some participants were missing values if they never interpreted surprise as positive [negative]). Mixed effects approaches are an extension of ordinary least squares (OLS) regressions, but which include both fixed and random effects. The interpretations of fixed effects follow the conventions of OLS regression (i.e., 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). The intraclass correlation was .75 for subjective interpretations of ambiguity and .17 for maximum deviations, meaning that there was statistical dependency among the measurements for any given subject for both dependent variables. This provided additional justification for the decision to use mixed effects modeling.

Prior to completing the analyses, all rating and mouse data were assessed for normality using Shapiro-Wilks tests. The results of all four tests were highly significant (*p*’s < .001) for the rating data, as ratings of ambiguity are typically negatively skewed. As such, we assessed alternative distributions for use in a generalized linear mixed model; however, the model fit of the traditional linear mixed model with a Gaussian error distribution fit better than alternative model options (i.e., gamma distribution). Notably, other work has shown that linear mixed models are robust to violations of normality (Knief & Forstmeier, 2018). 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 images 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 cognitive loads) that is best modeled as a separate intercept for each subject, as expected with an individual difference measure with repeated measurements.After, a fixed component for the effect of content type (i.e., non-emotional vs. non-emotional), load (i.e., low vs. high), and their interaction were added to the model uncentered at level one. The effect of content type significantly contributed to the model (ß10 = 8.06, S.E. = 2.47, *t*(147) = 3.26, *p* = .001), such that the interpretations of surprise 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 content type (emotional versus neutral) did.

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

**![A screenshot of a social media post

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**Figure 2: Percent negative ratings across the working memory load 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 cognitive load. Error bars represent the standard error of the mean.**

**Memory probe accuracy**

We next assessed accuracy on the memory probe to assess differences in task difficulty. While accuracy on the probes was high overall (i.e., 94.41%), there were differences across the different loads and content types. Table 1 shows average percent correct responses per condition. A mixed effects model was not used to assess the effects of load and content type on accuracy due to a ICC of 0, the random intercept model had singular fit, and likelihood ratio tests did not suggest any benefit to modeling the intercept randomly (*p* > .999). This is likely due to a large proportion of the data having the same value (i.e., 100% correct) as a result of the high performance across participants in the task, particularly in the low load conditions. As such, we instead assessed differences in memory probe accuracy using a repeated measures ANOVA, 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).

The results showed significant effects of load (*F*(1, 49) = 50.28, *p* < .001) andcontent type (*F*(1, 49) = 10.49, *p* = .002), as well as an interaction of the two factors (*F*(1, 49) = 11.06, *p* = .002). Post-hoc comparisons showed that there was no significant difference between memory accuracy for emotional compared to non-emotional working memory loads at low load (*t*(96) = .44, *p* = .661; Bonferoni corrected significance *p* < .013). Additionally, performance on the memory probe was worse for emotional working memory loads than neutral during high load trials (*t*(96) = -4.63, *p* < .001; Bonferoni corrected significance *p* < .013). While there was an effect of load for accuracy on trials with emotional working memory loads (*t*(95) = -7.10, *p* < .001; Bonferoni corrected significance *p* < .013), such that performance was worse on high load trials, there was no effect of load for accuracy on trials with neutral working memory loads (*t*(95) = -1.99, *p* = .05; Bonferoni corrected significance *p* < .013). Descriptive statistics are available in Table 1.

**Table 1**

|  |  |  |
| --- | --- | --- |
| **Condition** | **Mean** | **Standard Deviation** |
| **Low emotional loads** | **98.83%** | **.04%** |
| **Low neutral loads** | **98.18%** | **.05%** |
| **High emotional loads** | **88.33%** | **.11%** |
| **High neutral loads** | **95.23%** | **.07%** |

**Descriptive statistics for memory probe accuracy across all working memory conditions.**

**Maximum deviation**

Next, we tested for differences in maximum deviation (a measure of response competition in mouse trajectory) across the working memory conditions, as well as by subjective rating (i.e., positive and negative ratings of surprised faces) in order to assess for mitigation of typical mouse response trajectories during the interpretations of surprised expressions. Specifically, we expected to find that high cognitive load mitigates the tendency for a greater draw towards the competing response when surprise is interpreted 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 cognitive loads), and that the best fitting model includes an intercept for each subject individually.After, fixed parameters for the effect of content type (i.e., non-emotional vs. emotional), load (i.e., low vs. high), rating (i.e., positive or negative), and their interactions were added to the model. There was a significant Rating × Load interaction (β = .32, *t*(314) = 3.55, S.E. = .09, *p* < .001; Figure 3), showed that positive ratings had larger maximum deviations than negative ratings (*t*(325) = 4.39, S.E. = .05, *p* < .001; Bonferroni corrected significance *p* < .013) during low load trials. However, this difference was not present during the high load conditions (*t*(327) = -.31, S.E. = .05, *p* = .758; Bonferroni corrected significance *p* < .013), a pattern which provides support for our hypothesis that typical trajectories would be altered under high load. Additionally, there were larger maximum deviations for negative ratings following a high load compared to low load image matrix (*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 cognitive load on cognitive-motor dynamics for surprised expressions interpreted as negative. These results are averaged across the content type factor. Error bars represent the standard error of the mean.**

**Mixed Model:** Maximum Deviationti = (β00 + r0i) + β10\*(Domainti) + β20\*(Loadti) + β30\*(Ratingti) + β40\*(Loadti)\*(Domainti) + β50\*(Loadti)\*(Ratingti) + β60\*(Ratingti)\*(Domainti) + β70\*(Loadti)\*(Domainti)\*(Ratingti) + eti

**Discussion**

Here we tested the effects of 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 extends previous work testing the effects of cognitive load on valence bias (Mattek et al., 2016), and aligns with literature demonstrating that the emotional properties of cognitively demanding tasks affect both task performance and the neural systems engaged during tasks (Egner et al., 2008). We also found evidence that maximum deviations varied across the working memory conditions and subjective ratings. Previous work has shown that negative interpretations of ambiguous facial expressions are more direct than positive interpretations (Brown et al., 2017), and here we demonstrate that this difference is mitigated under high cognitive load. This parallels other work showing that high cognitive load increases distractor processing (Lavie & De Fockert, 2005) and that increased cognitive control demands (i.e., incongruent trials within a Stroop task) increase 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 cognitive loads with emotional properties, suggesting that these loads specifically taxed the resources required for positive interpretations of ambiguity. In other words, working memory loads with emotional properties interfered with subjective interpretations of emotional ambiguity, most likely due reliance on a similar domain-specific process (i.e., assessing emotional images). These results show that domain-specificity of emotional content matters for altering subjective interpretations of ambiguity, and provides further evidence that load demands themselves do not (Mattek et al., 2016).

Previous work supports the idea that emotional properties of tasks or stimuli recruit neural processes associated with emotion processes (Etkin et al., 2006; Neta et al., 2011). For instance, Neta and Whalen (2011) found that performing an emotional expression-based n-back task recruited greater amygdala activation when compared to an identity-based task. Given the initial negativity hypothesis’ prediction that positivity relies on regulation, it may be that working memory loads with emotional properties interfered with regions known to regulate amygdala activity. One such region, the anterior cingulate cortex, is known to correlate positively with amygdala during emotional face processing (i.e., increases in anterior cingulate and amygdala activity occur together) in youth and young adults with higher levels of anxiety (Kujawa, Wu, Klumpp, Pine, Swain, Fitzgerald, Monk, & Phan, 2017). Indeed, the emotional Stroop task differentially activates anterior cingulate cortex when compared to a non-emotional Stroop task (i.e., gender judgment; Etkin et al., 2006), suggesting that the working memory loads with emotional properties may have done so as well. Taken together, we interpret this effect of content type on interpretations of ambiguity as evidence that regulatory resources needed for positive interpretations of ambiguity are susceptible to domain-specific cognitive 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 content type of cognitive loads, the underlying cognitive-motor dynamics (i.e., maximum deviations) of these decisions were instead susceptible to differences in domain-general cognitive load demands. That is, maximum deviations varied as a function of low compared to high cognitive load. Specifically, there was evidence that high cognitive loads of any type mitigate the more direct trajectories characteristic of negative interpretations of emotional ambiguity (Brown et al., 2017). In other words, while positive judgments typically result in trajectories showing greater response competition, there was no difference between the maximum deviations of positive and negative judgments when individuals maintain more demanding working memory loads. This replicates previous work showing that the cognitive-motor dynamics underlying the valence bias task are susceptible to increases in cognitive demands generally, but that final interpretations are not (Mattek et al., 2016). One interpretation of these differences in maximum deviations 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). At the least, high cognitive load appears to interfere with typical mouse-based response trajectories during resolution of emotional ambiguity.

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 conclusions**

However, the present study is subject to limitations. Notably, performance in the working memory task most likely relies on visual working memory, rather than other subsystems like verbal working memory (Baddeley, 1998). This is a potentially important difference between the demands of our task and that of previous work (Mattek et al., 2016), as the numerical sequences used in that work may have been rehearsed using verbal working memory instead. Additionally, the cognitive demands in the present study did not tax cognitive resources extensively. For instance, despite the effect of content type on subjective interpretations 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). This suggests that the high cognitive load may not have taxed resources to the fullest extent possible, perhaps weakening some effects. Indeed, 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). Future work could address this by increasing the demands of the task, either through larger sets of image matrices (e.g., eight, ten, or more), increasing the number of trials so that participants view the same images across several matrices, or relying on a different stimulus type altogether (e.g., emotional or non-emotional words). In the present study, each image appeared within only one image matrix and each matrix was only presented once, perhaps facilitating participants’ ability to recognize the image during the memory probe. As another future direction, eye tracking could be used to assess which images participants attend 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 used to predict interpretations of surprised expressions.

Here we have provided both a conceptual replication and a novel extension of previous work which tested the effects of high cognitive load on subjective interpretations of ambiguity (Mattek et al., 2016). Notably, the previous work did not include working memory demands intended to recruit neural resources related to the processing of emotional stimuli, and as such did not show an effect on interpretations of ambiguity. In other words, only cognitive loads which tax emotion-related processing will lead to more negative interpretations of ambiguity, highlighting the importance of domain-specificity in cognitive demands. We posit that this effect relies on taxing neural resources related to ambiguity resolution and results in an increase in negativity as a result of a mitigated ability to employ regulatory processing, which is in line with our initial negativity hypothesis. We also demonstrated a domain-general effect of cognitive load on mouse trajectories, which could be further understood in future studies, but is likely related to the domain-general demands of high cognitive load within the cingulo-opercular network. Future work should explore these effects to verify the neural processes underlying these behavioral phenomena. Improving the field’s understanding of 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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1. Nineteen participants only completed 142 trials and fifteen completed 146 trials due to a programming error. [↑](#footnote-ref-1)