Emotional working memory loads selectively increase negativity bias

|  |
| --- |
| Nicholas R. Harp1 & Maital Neta1 |
| 1 University of Nebraska-Lincoln |
|  |

# Author note

Correspondence concerning this article should be addressed to Nicholas R. Harp. E-mail: [nharp@huskers.unl.edu](mailto:nharp@huskers.unl.edu)

**Abstract**

Cognitive resources are needed for successful executive functioning; when resources for a particular task are limited due to cognitive load, task performance is impaired. In the face of emotional ambiguity (i.e., stimuli that do not convey a clear positive or negative meaning, such as a surprised facial expression), our decisions to approach or avoid rely heavily on domain-specific emotion resources. Specificially, previous work has shown that the default response to surprised faces is negative, and that positive categorizations are thought to require top-down regulatory resources. Here, we employed a 2x2 design to investigate the effects of load (low versus high) and domain (non-emotional vs. emotional) on evaluations of emotional ambiguity (i.e., positive or negative categorizations). As predicted, a mixed effects model revealed domain-specific effects, such that categorizations of surprise were more negative for emotional (*p* < .001) loads. Consistent with prior work, low load (regardless of domain; i.e., domain-general) was associated with greater attraction towards the competing – negative – response during positive categorizations, showing that positive categorizations are characterized by an initial negativity, but this effect was diminished under high load. These results suggest emotional load depletes the regulatory resources necessary for positive categorizations of emotional ambiguity, but that greater domain-general load impacts the ~~response competition~~ process underlying the subjective categorizations.

Keywords: [up to 5 words / phrases]

Emotional working memory loads selectively increase negativity bias

The availability of cognitive resources is necessary for employing adaptive processes in everyday life, including strategies for attentional deployment (Franconeri, Alvarez, & Cavanagh, 2013), decision-making (Deck & Jahedi, 2015; Whitney, Rinehart, & Hinson, 2008), cognitive control (Deveney & Pizzagalli, 2008), and emotion regulation (Johns, Inzlicht, & Schmader, 2008; Richards & Gross, 2002). Engagement in a task that taps a cognitive resource (i.e., a cognitive load) often results in a state of depletion, which leads to impaired performance on concomitant or subsequent tasks that rely on those depleted resources (Richeson & Trawalter, 2005; Baumeister & Heatherton, 1996; Franconeri, Alvarez, & Cavanagh, 2013; Kahneman, 1973; Storbeck, 2012). For example, imagine a student attending a lecture while also text messaging a friend. As the student considers their text message—directing cognitive resources (attention) towards the conversation and away from the lecture—the student’s ability to attend to and remember the lecture material suffers. Directing cognitive resources between different tasks in this manner taxes the already limited pool of resources (Baumeister & Heatherton, 1996; Kahneman, 1973). On a larger scale, this cognitive depletion can have widespread societal implications, such as 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 can have adverse downstream effects on executive functioning (Privitera, Rosenstein, Plessow, & LoCastro, 2014; Starcke, Wiesen, Trotzke, & Brand, 2016).

Although cognitive load interferes with a broad range of control (e.g., attention; Lavie, Hirst, de Fockert, & Viding, 2004) and regulatory processes (Ward & Mann, 2000), the domain of the load can modulate its effects on other processes. In other words, when cognitive load does not deplete the specific resources needed for a concurrent or subsequent task, performance on the latter task may be unaffected. These domain-specific divisions of cognitive resources have been well-studied at the level of loads on verbal and visuospatial processes (Brooks, 1967; Logie, 1995), and there is accumulating evidence for domain-specific divisions of load effects depending on the load’s emotional properties. For instance, when asked to remember the emotional expression of a face, participants were less accurate on a subsequent task that required pairing emotional concepts (e.g., couple-happy) compared to pairing perceptual properties (e.g., lemon-yellow; Vermeulen, Niedenthal, Pleyers, Bayot, & Corneille, 2014). Neuroimaging and lesion studies suggest a mechanism for these findings, as resolving conflicting emotional cues (i.e., a happy face with an incongruent label, such as “fear”; Egner, Etkin, Gale, & Hirsch. 2008; Maier & di Pellegrino, 2012) or inhibiting responses to task-irrelevant emotional information (i.e., emotional expressions during an identity-based n-back task; Neta & Whalen, 2011) reliably elicit activity in rostral anterior cingulate cortex. This region is critical for exercising cognitive control in tasks with emotional content (Bush et al., 1998; Whalen et al., 1998), and is located more ventrally in prefrontal cortex than other regions implicated in domain-general cognitive load (e.g., dorsolateral prefrontal cortex; Neta & Whalen, 2011). In other words, when resources are engaged with an emotional load—regardless of the emotional content’s task-relevancy—those resources are no longer available to regulate other emotional processes. In turn, regulatory performance on these tasks will likely be impaired, meaning that the effect of load on a concurrent or subsequent task can illuminate the underlying resources engaged during that task. This insight is particularly useful for tasks which rely on cognitive resources (e.g., using theory of mind to interpret the behavior of others; Lin, Keysar, & Epley, 2010).

**Resources used for categorizing emotional ambiguity**

Humans readily make judgments about others based on limited information (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). For example, we instinctively sort information, including facial expressions, into valence categories which are crucial for guiding social behavior (e.g., approach-avoidance; Krieglmeyer, Deutsch, De Houwer, & De Raedt, 2010; and group membership or affiliation; Taskhay & Rule, 2015; Taskhay & Rule, 2018). Although some facial expressions are easily categorized as positive (happy) or negative (angry), others (surprise) 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, and without contextual information to disambiguate these expressions, there are individual differences in the tendency to categorize surprised faces as having a more positive or negative meaning (i.e., valence bias; Neta, Kelley, & Whalen, 2013; Neta et al., 2009; Neta & Whalen, 2010).

Despite this variability in valence bias, there appears to be an initial negativity in categorizations of surprise 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 categorizations rely on emotion regulation resources that help to override the initial negativity. Support for this model comes from studies using MouseTracker (Freeman & Ambady, 2010), which offers a rich insight into the process ~~rather than the products~~ of the decision-making and quantifies response competition through the measurement of deviations from straight-line trajectories towards the ultimately selected response (Calcagni, Lombardi, & Sulpizio, 2017; Freeman, Dale, & Farmer, 2011; Hehman, Stolier, & Freeman, 2015). Specifically, response trajectories to the negative response option are more direct, whereas positive categorizations were characterized by greater attraction to the unselected (negative) response (Brown et al., 2017; Mattek et al., 2016). Neuroimaging work has also supported this initial negativity hypothesis, demonstrating that the amygdala—associated with bottom-up signals of emotion (Aggleton and Saunders, 2000; Adolphs, 1994; LeDoux, 2000)—and the ventromedial prefrontal cortex (vmPFC)—a putative top-down regulatory region (Motzkin, Philippi, Wolf, Baskaya, & Koenigs, 2015)—show inverse activity that is predictive of subjective categorizations of surprised expressions (Kim et al., 2003). Specifically, more frequent negative categorizations are associated with more amgydala and less vmPFC activity (Kim et al., 2003; Neta & Whalen, 2010), but the reverse was shown for positive categorizations (Kim, Somerville, Johnstone, Alexander, & Whalen, 2003). These findings support the notion that positive categorizations rely more heavily on regulatory resources than do negative categorizations.

Given this reliance on regulatory resources, we would predict that a cognitive load that depletes emotion-related regulatory resources would interfere with the likelihood of seeing ambiguity in a positive light. Although judgments of emotional expressions are vulnerable to resource depletion (e.g., load decreases accuracy of emotional expression categorization; Ahmed, 2018), other work found no effect of load on valence categorizations of surprised faces (Mattek et al., 2016). An important caveat is that this study used only non-emotional load (i.e., remembering a number sequence), which may not have depleted emotion-related regulatory resources. Thus, we predict that a domain-specific (emotional) load will more effectively deplete the resources putatively required for a positive bias, resulting in more negative categorizations.

## The present study

In the present study we tested the effect of cognitive load on responses to emotional ambiguity as a function of load (low versus high) and domain (non-emotional versus emotional). To do this, we manipulated both the amount and the domain of material that participants needed to remember while they categorized the valence of facial expressions. This allowed us to examine two distinct components of responses to ambiguity: the product of the responses (proportion of positive versus negative categorizations of surprised faces) and the process (response trajectories). Regarding the product of responses to ambiguity, we expect to replicate previous work showing no effect of domain-general load on categorizations (Mattek et al., 2016). However, we do expect a domain-specific effect, such that emotional load will result in more negative categorizations than non-emotional load, suggesting that emotional load depletes the resources that are useful for seeing ambiguity in a positive light. Further, we predict domain-general load effects on the response process, such that there will be greater response competition for positive than negative categorizations under low load, consistent with previous work (Brown et al., 2017; Mattek et al., 2016), and that this effect will be mitigated under high load (Mattek et al., 2016).

# 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 to control for potential effects of cross-racial judgments. 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

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. An additional set of 63 IAPS images were used during memory probes, but never appeared in the image matrices – only 36 of these 63 images were randomly selected for each participant, and this subset varied across participants. The positive and negative images used in the matrices did not differ in arousal after testing with a Wilcoxon signed-rank test (*Z* = -0.23, *p* = 0.82). For the matrices with emotional images, there were an equal number of positive and negative images within a matrix in order to avoid priming effects on the subsequent face ratings (e.g., Flexas, Rosselló, Christensen, Nada, La Rosa, & Munar, 2013), as previous work has shown categorizations 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 – some showing all three expressions and others showing only a subset of the expressions – for a total of 12 angry, 12 happy, and 24 surprised expressions presented pseudorandomly.

## 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) memory load followed by a one digit memory probe. Participants 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) with either emotional or non-emotional properties (equal number of trials) for 4000 ms (Figure 1). Participants were instructed to remember these images for the duration of the trial (i.e., until the memory probe at the end of the trial). After the image matrix, a happy, angry, or surprised face appeared for 1000 ms, and the participants categorized the face as positive or negative using the computer mouse. Finally, participants initiated the memory probe trial by clicking the “start” button and a single image probe appeared (5000 ms). Participants used the computer mouse to indicate 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). The experimenter guided participants through a practice face rating and memory probe trial, after which they completed a total of 72 trials while theirmouse movements were recorded. Notably, in two-choice designs, maximum deviations are often conceptualized as a measure of response competition, and can quantify the extent to which trial-wise ratings are characterized by an attraction to the competing (unchosen) response (Calcagni, Lombardi, & Sulpizio, 2017; Freeman, Dale, & Farmer, 2011; Hehman, Stolier, & Freeman, 2015).

A screenshot of a cell phone

Description automatically generated

## Figure 1: Example of a single trial. At the start of each participant-initiated trial, a fixation cross appeared (1000 ms), followed by an image matrix consisting of 2 (low load) or 6 (high load) images with either non-emotional or emotional properties. Participants were instructed to remember these images for the duration of the trial. Then, a happy, angry, or surprised face appeared for 1000 ms, which the participants were instructed to categorize as positive or negative using the computer mouse. Finally, participants initiated the probe portion of the trial by pressing the start button again which presented another 1000 ms fixation followed by a single image probe appeared (5000 ms). Then participants used the computer mouse to indicate whether the image probe was present (yes) or not (no) in the previous image matrix.

## Data analysis

We used R (Version 3.6.0; R Core Team, 2019) for all our analyses. Data preprocessing, analysis, and plotting were completed in R using the mousetrap (Kieslich, Henninger, Wulff, Haslbeck, Schulte-Mecklenbeck, 2019), lme4 (Bates, Maechler, Bolker, & Walker, 2015), TOSTER (Lakens, 2017), diptest (Maechler, 2016), and ggplot2 (Wickham, 2016) 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 if participants were attempting to remember the images in the matrix. Our primary dependent measures were valence bias, calculated as percent negative ratings for surprised faces across all trials, and maximum deviation, or the extent to which a response trajectory deviated or was attracted to the competing – unselected – response option. For the main test of our hypotheses, we examined effects of load (low, high) and domain (non-emotional, emotional) in a 2x2 design, and explored the effects of these four conditions and trialwise categorizations (positive and negative) on maximum deviation.

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 either negative or positive on all trials (there were missing values for the analysis of surprise using trial-by-trial rating as a factor). 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 average effect for each one unit increase in the predictor, while random effects allow the model to fit effects which vary randomly across the nested structure of the data. In other words, random effects allow the partitioning of variance to either lower or higher level units of analysis. In this analysis, the lower level units are the repeated measurements and the higher level units are the participants. Allowing the intercept to vary randomly as a function of the higher level units accounts for individual differences in bias or other measures, thus allowing better estimation of the working memory condition effects at the lower level of analysis: the repeated measurements. Additional justification for the mixed effects modeling approach comes from tests of 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: non-emotional versus 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 in our data 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 or negative).

# Results

## Subjective categorizations of ambiguity (products of the response)

First, a random intercept-only model was tested and likelihood ratio test results supported the decision to model the intercept randomly across individuals (*p* < .001). This indicates individual variance in valence bias at baseline (i.e., even under low, non-emotional loads) that is best modeled as a separate intercept for each subject.Next, fixed effects for Load (low versus high), Domain (non-emotional versus emotional), and their interaction were added to the model. There was a significant effect of Domain, such that categorizations of surprised faces following an emotional load (M = 74.0, S.E. = 3.49) were more negative than those following non-emotional loads (M = 65.0, S.E. = 3.49; ß = 9.03, *t*(153) = 5.17, *p* < .001). There was no significant effect of Load (low load: M = 68.9, S.E. = 3.49; high load: M = 70.2, S.E. = 3.49; ß= 1.34; *t*(153) = .77, *p* = .45), nor was there a significant Domain × Load interaction (ß30 = 1.93, , S.E. = 3.46, *t*(150) = .56, *p* = .58).

Given the non-significant effect of Load in the model, we next completed equivalence testing (Lakens, Scheel, & Isager, 2018) for the low and high load conditions to assess whether there was evidence to support an effect size statistically equivalent to zero. The smallest effect size of interest (see Lakens et al., 2018) for the present study was determined to be d = .22 or a raw score difference of 5.9% negativity between the conditions, which a post-hoc power analysis suggests the current study was powered at 33% to detect. The result of the equivalence test (*t*(197.69) = 1.22, *p* = 0.112) was non-significant, and thus does not support the claim that the effect of Load is equivalent to zero.

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

![A screenshot of a cell phone

Description automatically generated]()

**Figure 2: Percent negative ratings across conditions.** Ratings during emotional loads were more negative than ratings during non-emotional loads (*t*(153) = 5.17, *p* < .001), but there was no effect of load on ratings (*t*(153) = .77, *p* = .45). Error bars represent the standard error of the mean. \*\*p ≤ .001.

**Maximum deviation (process underlying the response)**

Next, we examined the effect of our experimental manipulation and trial-wise surprise categorizations (positive versus negative trials) on maximum deviation. First, a random intercept-only model was tested for maximum deviation, 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., under low, non-emotional loads), and that the best fitting model includes an intercept for each subject individually.Next, fixed effects of Load (low versus high), Domain (non-emotional versus emotional), Rating (positive versus negative categorizations of surprise), and their interactions were added to the model. A significant Load × Rating interaction (β50 = .32, *t*(314) = 3.55, S.E. = .09, *p* < .001; Figure 3) revealed that, as expected, positive categorizations (M = .50, S.E. = .04) had larger maximum deviations than negative (M = .30, S.E. = .04; *t*(325) = 4.39, S.E. = .05, *p* < .001; Bonferroni corrected significance for these analyses *p* < .013) on low load trials. However, this difference was not present on high load trials (positive: M = .41, S. E. = .04; negative: M = .42, S. E. = .04; *t*(327) = -.31, S.E. = .05, *p* = .76), supporting our hypothesis that high load would diminish the attraction towards the ‘negative’ response. Specifically, maximum deviations for negative trials were larger on high than low load trials (*t*(320) = -2.81, S.E. = .05, *p* = .005), and there was a trend for smaller maximum deviations for positive trials on high than low load trials (*t*(324) = 1.93, *p* = .055).

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



**Figure 3: Response competition as a function of load and categorization.** There was greater response competition, operationalized as maximum deviation, for positive than negative categorization, but only under low load (*t*(325) = 4.39, S.E. = .05, *p* < .001). Response competition under high load increased for negative categorizations (*t*(320) = -2.81, S.E. = .05, *p* = .005) and tended to decrease for positive categorizations (*t*(324) = 1.93, *p* = .055). Error bars represent the standard error of the mean. +*p* < .06, \**p* < .05, \*\**p* ≤ .001.

The changes in maximum deviation under high load could result from either a change in response competition (e.g., for negative trials, an increased attraction towards the competing – positive – response option that weighs in across the decision-making process) or a qualitative change in the trajectories (e.g., erratic “flip-flopping” trajectories). To adjudicate between these alternatives, we examined the modality of the response trajectories (Freeman & Dale, 2013), where evidence for multimodality would suggest the latter (i.e., multiple subpopulations of trajectory patterns or flip-flopping at play). Hartigan’s dip statistic (HDS; Hartigan & Hartigan, 1985) was calculated for each trial condition, and revealed no evidence of multimodality for the ‘positive’ and ‘negative’ categorizations in both the low (positive: HDS = .03, *p* = .98; negative: HDS = .02, *p* = .99) and high load conditions (positive: HDS = .04, *p* = .68; negative: HDS = .03, *p* = .80).

**Memory probe accuracy**

To determine if memory probe accuracy – one potential indicator of successfully maintaining the working memory load – is driving the more frequent negative categorizations of surprise under emotional load, we compared performance (accurate vs. inaccurate) and frequency of categorizations (positive vs. negative) on emotional load trials. If accurately responding to the memory probe is critical to the emotional load depletion effect, memory probe accuracy should be related to the proportion of surprise faces categorized as negative. Specifically, the proportion of negative categorizations under emotional load for accurate trials should be greater than that of inaccurate trials. McNemar’s test of the contingency table was significant (*X2*(1) = 767.12, *p* < .001), suggesting that the proportion of surprised faces categorized as negative differed when comparing accurate to innacurate memory trials. Comparing the proportion of positive and negative categorizations for accurate and inaccurate trials provides evidence against the notion that accuracy is driving the increased negativity under emotional load, as there was a greater proportion of negative categorizations (71.43%) preceding innacurate memory probe responses than accurate responses (52.34%).

~~We examined accuracy on the memory probe to determine if differences in task difficulty might be driving the reported effects. Although accuracy on the probes was high across all trials (94.41%), there were differences as a function of Load and Domain (Table 1). Given that assumptions for mixed models were not met (e.g., large proportions of the data had the same value of 100% correct), we used a repeated measures ANOVA to examine differences in memory probe accuracy as a function of the experimental conditions. If memory probe accuracy were driving the effects of interest, we would expect to see more accurate performance on emotional trials (which result in more negative categorizations) or on high load trials (which modulate response trajectories). There was a significant effect of Load (~~*~~F~~*~~(1, 49) = 50.28,~~ *~~p~~* ~~< .001) and~~~~Domain (~~*~~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; Bonferroni corrected significance for these analyses p < .013), but under high load, accuracy was higher for non-emotional than emotional load (~~*~~t~~*~~(96) = -4.63,~~ *~~p~~* ~~< .001). Further, the effect of Load did not survive Bonferroni correction on non-emotional trials (~~*~~t~~*~~(95) = -1.99,~~ *~~p~~* ~~= .05), but on emotional trials, accuracy was higher on low load than high load trials (~~*~~t~~*~~(95) = -7.10,~~ *~~p~~* ~~< .001).~~

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

|  |  |  |
| --- | --- | --- |
| **~~Domain~~** | **~~Load~~** | **~~Mean (SD)~~** |
| **~~Non-emotional load~~** | **~~Low load~~** | **~~98.18% (.05)~~** |
| **~~High load~~** | **~~95.23% (.07)~~** |
| **~~Emotional load~~** | **~~Low load~~** | **~~98.83% (.04)~~** |
| **~~High load~~** | **~~88.33% (.11)~~** |

**Discussion**

Here we tested the effects of cognitive load with either non-emotional or emotional properties on responses to emotional ambiguity. We explored effects on the products of these categorizations and found, as predicted, that categorizations of surprise were more negative under emotional than non-emotional load. This result extends previous work showing that higher non-emotional load did not affect categorizations (Mattek et al., 2016) by demonstrating that it is likely something about the emotional properties of the load per se that impact categorizations. Further, this result 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 explored the effects on the process of categorization and found evidence that response trajectories were modulated by domain-general cognitive load (i.e., across both domains) as a function of trial-by-trial categorizations. Specifically, previous work has shown that positive categorizations of surprised faces are associated with greater response competition (i.e., more attraction to the competing – negative – response) than negative categorizations (Brown et al., 2017), and here we demonstrate that this difference is mitigated under higher domain-general load. Specifically, negative categorizations were associated with increased response competition under high load compared to low load, whereas positive categorizations showed a trend towards decreased competition under high load. This parallels other work showing that high 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 categorizations of ambiguous stimuli rely on regulatory resources that override an initial negativity (Neta et al., 2009; Petro et al., 2018). Here, we used a standard working memory paradigm (Ahmed, 2018; Burnham, 2010; Lavie & De Fockert, 2005) to induce high cognitive load with either non-emotional or emotional properties while participants made valence judgments of surprised facial expressions. As expected, participants categorized surprise as more negative under emotional loads, suggesting that the emotional resources required for a positive interpretation were depleted by the emotional load. Indeed, increased cognitive load that has an emotional component has been associated with increased activity in the vmPFC and decreased activity in the amygdala (Kompus et al., 2009), a pattern of activity that has also been linked to emotion regulation (Ochsner et al., 2002; Jackson et al., 2003; Urry et al., van Reekum et al., 2007) and to a more positive valence bias (Kim et al., 2003).

These results also corroborate evidence that resource depletion is associated with a greater reliance on bottom-up emotional responses and weaker top-down responses. For example, some work has shown negative images recruited greater amygdala (bottom-up) and less prefrontal (top-down) activity under depletion (Wagner & Heatherton, 2013). In the context of surprised faces, this pattern of activity is linked with more negative categorizations (Kim et al., 2003; Neta & Whalen, 2010; Petro et al., 2018). Taken together, these findings, in association with previous work using emotional load and resource depletion, lend support for the initial negativity hypothesis.

**Domain-general effects**

While subjective categorizations of ambiguity were susceptible only to domain-specific load, response competition during ambiguity resolution was instead vulnerable to domain-general load demands. Previous work has shown that this valence bias task recruits a set of regions in the cingulate and anterior insular that are central to a domain-general task control network called the cingulo-opercular network (Neta et al., 2013). Indeed, these regions are 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). Though speculative, it could be that the domain-general cognitive loads in the present study taxed these domain-general cingulo-opercular resources. Indeed, some work has demonstrated that cognitive loads preoccupy resources in the cingulo-opercular network (e.g., dorsal anterior cingulate cortex; Etkin et al., 2008), and that these central regions in the cingulate and anterior insula show reliable activitation 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 load, regardless of the domain, likely increased demands in these regions.

Alternatively, these domain-general load effects may be the result of the load interfering with cognitive resources needed for motor processing. Working memory loads reliably interfere with the planning and successful execution of motor movements (e.g., temporal control of discrete movements; Maes, Wanderley, & Palmer, 2015; anti-saccades; Mitchell, Macrae, & Gilchrist, 2002), which may account for the increased (decreased) response competition for negative (positive) categorizations of surprise in the present study. In other words, the initial negativity typically seen under low (or no) load appears to be mitigated by the increased cognitive demands of the working memory task, resulting in a sort of averaging out of the trajectories under high load.

**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 not depleted heavily. Relatedly, participants may have been able to rely on recognition (rather than active working memory maintenance) for the memory probes, which renders the task easier (Shepard, 1967). 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. Future work could address these limitations by increasing the task difficulty, 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., identifying the location of the image in the previous matrix rather than just a present/not judgment).

Here, we attempted to use a similar working memory task that could directly compare loads with non-emotional versus emotional properties. 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). One interesting avenue for future work with visual working memory 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.

Finally, the effects of high load on response trajectories are different from those of stress. Indeed, a stress induction has been shown to result in more direct response trajectories for negative categorizations of surprise compared to baseline (Brown et al., 2017). In contrast, we report here that cognitive load resulted in greater response competition (i.e. less direct trajectories) for these negative categorizations. These differing effects may be the result of the load interfering with cognitive resources needed for motor processing. Working memory loads reliably interfere with the planning and successful execution of motor movements (e.g., temporal control of discrete movements; Maes, Wanderley, & Palmer, 2015; anti-saccades; Mitchell, Macrae, & Gilchrist, 2002), but acute stressors may actually enhance attention and motor control when the stress is considered a challenge (Vine, Freeman, Moore, Chandra-Ramanan, & Wilson, 2013). In other words, the more direct (efficient) trajectories towards negativity under stress may reflect enhanced attention towards the negative response option, whereas the mitigated trajectories under cognitive load would reflect motor interference. Future work will be needed to further disentangle these effects.

**Conclusions**

Here we have provided both a conceptual replication and a novel extension of previous work which tested the effects of cognitive load on categorizations of ambiguity (Mattek et al., 2016). Notably, these findings illuminate the processes putatively underlying positive categorizations by demonstrating that, under emotional load, these positive categorizations were less frequent. As such, these findings lend further support for the initial negativity hypothesis by suggesting that positivity (more so than negativity) relies on additional emotion-specific resources. We also demonstrated a domain-general effect of load on response competition, 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. 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). Further, this work 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.

**Acknowlegements:** This work was supported by the National Institutes of Health (NIMH111640; PI: Neta), and by Nebraska Tobacco Settlement Biomedical Research Enhancement Funds.We thank Hannah E. Raila for early discussions about the hypotheses and approach, Michael D. Dodd, Jeffrey R. Stevens, Catherine C. Brown, Nathan M. Petro, Joshua E. Zosky, and Kayla Clark for suggestions and comments on an earlier version of the manuscript, and Rebecca L. Brock for statistical consultation.

# References

Ahmed, L. (2018). Knowing how you are feeling depends on what’s on my mind: Cognitive load and expression categorization. *Emotion*, *18*(2), 190–201. doi:[10.1037/emo0000312](https://doi.org/10.1037/emo0000312)

Baddeley, A. D. (1986). Working memory. *Philosophical Transactions of the Royal Society of London*, *302*(110), 311–324.

Barrett, L. F., Adolphs, R., Marsella, S., Martinez, A. M., & Pollak, S. D. (2019). Emotional expressions reconsidered: Challenges to inferring emotion from human facial movements. *Psychological Science in the Public Interest: A Journal of the American Psychological Society*, *20*(1), 1–68. doi:[10.1177/1529100619832930](https://doi.org/10.1177/1529100619832930)

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software*, *67*(1), 1-48. doi:10.18637/jss.v067.i01.

Baumeister, R. F., & Heatherton, T. F. (1996). Self-regulation failure: An overview. *Psychological Inquiry*, *7*(1), 1–15. doi:[10.1207/s15327965pli0701\_1](https://doi.org/10.1207/s15327965pli0701_1)

Blair, K. S., Smith, B. W., Mitchell, D. G. V., Morton, J., Vythilingam, M., Pessoa, L., … Blair, R. J. R. (2007). Modulation of emotion by cognition and cognition by emotion. *NeuroImage*, *35*(1), 430–440. doi:[10.1016/j.neuroimage.2006.11.048](https://doi.org/10.1016/j.neuroimage.2006.11.048)

Brown, C. C., Raio, C. M., & Neta, M. (2017). Cortisol responses enhance negative valence perception for ambiguous facial expressions. *Scientific Reports*, *7*(1), 15107. doi:[10.1038/s41598-017-14846-3](https://doi.org/10.1038/s41598-017-14846-3)

Bundt, C., Ruitenberg, M. F. L., Abrahamse, E. L., & Notebaert, W. (2018). Early and late indications of item-specific control in a stroop mouse tracking study. *PLOS ONE*, *13*(5), e0197278. doi:[10.1371/journal.pone.0197278](https://doi.org/10.1371/journal.pone.0197278)

Burnham, B. R. (2010). Cognitive load modulates attentional capture by color singletons during effortful visual search. *Acta Psychologica*, *135*(1), 50–58. doi:[10.1016/j.actpsy.2010.05.003](https://doi.org/10.1016/j.actpsy.2010.05.003)

Calcagnì, A., Lombardi, L., & Sulpizio, S. (2017). Analyzing spatial data from mouse tracker methodology: An entropic approach. *Behavior Research Methods*, *49*(6), 2012–2030. doi:[10.3758/s13428-016-0839-5](https://doi.org/10.3758/s13428-016-0839-5)

Carroll, J. M., & Russell, J. A. (1996). Do facial expressions signal specific emotions? Judging emotion from the face in context. *Journal of Personality and Social Psychology*, *70*(2), 205–218. doi:[10.1037//0022-3514.70.2.205](https://doi.org/10.1037//0022-3514.70.2.205)

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293–332. doi:[10.1207/s1532690xci0804\_2](https://doi.org/10.1207/s1532690xci0804_2)

Darwin, C. (1872). *The expression of the emotions in man and animals*. John Murray.

Duncan, J., & Owen, A. M. (2000). Common regions of the human frontal lobe recruited by diverse cognitive demands. *Trends in Neurosciences*, *23*(10), 475–483. doi:[10.1016/s0166-2236(00)01633-7](https://doi.org/10.1016/s0166-2236(00)01633-7)

Egner, T., Etkin, A., Gale, S., & Hirsch, J. (2008). Dissociable neural systems resolve conflict from emotional versus nonemotional distracters. *Cerebral Cortex (New York, N.Y.: 1991)*, *18*(6), 1475–1484. doi:[10.1093/cercor/bhm179](https://doi.org/10.1093/cercor/bhm179)

Ekman, P., & Friesen, W. V. (1971). Constants across cultures in the face and emotion. *Journal of Personality and Social Psychology*, *17*(2), 124–129. doi:[10.1037/h0030377](https://doi.org/10.1037/h0030377)

Etkin, A., Egner, T., Peraza, D. M., Kandel, E. R., & Hirsch, J. (2006). Resolving emotional conflict: A role for the rostral anterior cingulate cortex in modulating activity in the amygdala. *Neuron*, *51*(6), 871–882. doi:[10.1016/j.neuron.2006.07.029](https://doi.org/10.1016/j.neuron.2006.07.029)

Flexas, A., Rosselló, J., Christensen, J. F., Nadal, M., Rosa, A. O. L., & Munar, E. (2013). Affective priming using facial expressions modulates liking for abstract art. *PLOS ONE*, *8*(11), e80154. doi:[10.1371/journal.pone.0080154](https://doi.org/10.1371/journal.pone.0080154)

Freeman, J. B., & Ambady, N. (2010). MouseTracker: Software for studying real-time mental processing using a computer mouse-tracking method. *Behavior Research Methods*, *42*(1), 226–241. doi:[10.3758/BRM.42.1.226](https://doi.org/10.3758/BRM.42.1.226)

Freeman, J., Dale, R., & Farmer, T. (2011). Hand in motion reveals mind in motion. *Frontiers in Psychology*, *2*. doi:[10.3389/fpsyg.2011.00059](https://doi.org/10.3389/fpsyg.2011.00059)

Frijda, N. H. (1986). *The emotions*. Paris, France: Editions de la Maison des Sciences de l’Homme.

Frith, C. (2009). Role of facial expressions in social interactions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1535), 3453–3458. doi:[10.1098/rstb.2009.0142](https://doi.org/10.1098/rstb.2009.0142)

Green, C., & Guo, K. (2018). Factors contributing to individual differences in facial expression categorisation. *Cognition & Emotion*, *32*(1), 37–48. doi:[10.1080/02699931.2016.1273200](https://doi.org/10.1080/02699931.2016.1273200)

Hehman, E., Stolier, R. M., & Freeman, J. B. (2015). Advanced mouse-tracking analytic techniques for enhancing psychological science. *Group Processes & Intergroup Relations*, *18*(3), 384–401. doi:[10.1177/1368430214538325](https://doi.org/10.1177/1368430214538325)

Izard, C. E. (1994). Innate and universal facial expressions: Evidence from developmental and cross-cultural research. *Psychological Bulletin*, *115*(2), 288–299. doi:[10.1037/0033-2909.115.2.288](https://doi.org/10.1037/0033-2909.115.2.288)

Jiaping, C., Yuejia, L. U. O., Fang, C. U. I., Jiaping, C., Yuejia, L. U. O., & Fang, C. U. I. (2017). Empathy for pain influenced by cognitive load: Evidence from an ERP study. *Acta Psychologica Sinica*, *49*(5), 622–630. doi:[10.3724/SP.J.1041.2017.00622](https://doi.org/10.3724/SP.J.1041.2017.00622)

Kieslich, P.J. , Henninger, F., Wulff, D. U., Haslbeck, J. M., Schulte-Mecklenbeck, M. (2019). Mouse-tracking: A practical guide to implementation and analysis. In Schulte-Mecklenbeck M, Kühberger A, Johnson JG (eds.), *A Handbook of Process Tracing Methods*, 111-130. Routledge, New York, NY.

Kim, H., Somerville, L. H., Johnstone, T., Alexander, A. L., & Whalen, P. J. (2003). Inverse amygdala and medial prefrontal cortex responses to surprised faces. *Neuroreport*, *14*(18), 2317–2322. doi:[10.1097/00001756-200312190-00006](https://doi.org/10.1097/00001756-200312190-00006)

Kim, H., Somerville, L. H., Johnstone, T., Polis, S., Alexander, A. L., Shin, L. M., & Whalen, P. J. (2004). Contextual modulation of amygdala responsivity to surprised faces. *Journal of Cognitive Neuroscience*, *16*(10), 1730–1745. doi:[10.1162/0898929042947865](https://doi.org/10.1162/0898929042947865)

Knight, M., Seymour, T. L., Gaunt, J. T., Baker, C., Nesmith, K., & Mather, M. (2007). Aging and goal-directed emotional attention: Distraction reverses emotional biases. *Emotion*, *7*(4), 705–714. doi:[10.1037/1528-3542.7.4.705](https://doi.org/10.1037/1528-3542.7.4.705)

Krieglmeyer, R., Deutsch, R., De Houwer, J., & De Raedt, R. (2010). Being moved: Valence activates approach-avoidance behavior independently of evaluation and approach-avoidance intentions. *Psychological Science*, *21*(4), 607–613. doi:[10.1177/0956797610365131](https://doi.org/10.1177/0956797610365131)

Kron, A., Schul, Y., Cohen, A., & Hassin, R. R. (2010). Feelings don’t come easy: Studies on the effortful nature of feelings. *Journal of Experimental Psychology: General*, *139*(3), 520–534. doi:[10.1037/a0020008](https://doi.org/10.1037/a0020008)

Kujawa, A., Wu, M., Klumpp, H., Pine, D. S., Swain, J. E., Fitzgerald, K. D., … Phan, K. L. (2016). Altered development of amygdala-anterior cingulate cortex connectivity in anxious youth and young adults. *Biological Psychiatry : Cognitive Neuroscience and Neuroimaging*, *1*(4), 345–352. doi:[10.1016/j.bpsc.2016.01.006](https://doi.org/10.1016/j.bpsc.2016.01.006)

Lang, P., Bradley, M. M., & Cuthbert, B. N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual., Technical Report A–8. University of Florida, Gainesville, FL.

Lavie, N., & De Fockert, J. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin & Review*, *12*(4), 669–674. doi:[10.3758/BF03196756](https://doi.org/10.3758/BF03196756)

Lavie, N., Hirst, A., Fockert, J. W. de, & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology. General*, *133*(3), 339–354. doi:[10.1037/0096-3445.133.3.339](https://doi.org/10.1037/0096-3445.133.3.339)

Lazarus, R. S., & Alfert, E. (1964). Short-circuiting of threat by experimentally altering cognitive appraisal. *The Journal of Abnormal and Social Psychology*, *69*(2), 195–205. doi:[10.1037/h0044635](https://doi.org/10.1037/h0044635)

Lundqvist, D., Flykt, A., & Öhman, A. (1998). The karolinska directed emotional faces—KDEF (CD ROM)., Stockholm: Karolinska Institute, Departmentof Clinical Neuroscience, PsychologySection.

Mather, M., & Carstensen, L. L. (2005). Aging and motivated cognition: The positivity effect in attention and memory. *Trends in Cognitive Sciences*, *9*(10), 496–502. doi:[10.1016/j.tics.2005.08.005](https://doi.org/10.1016/j.tics.2005.08.005)

Mattek, A. M., Whalen, P. J., Berkowitz, J. L., & Freeman, J. B. (2016). Differential effects of cognitive load on subjective versus motor responses to ambiguously valenced facial expressions. *Emotion*, *16*(6), 929–936. doi:[10.1037/emo0000148](https://doi.org/10.1037/emo0000148)

Muraven, M., Tice, D. M., & Baumeister, R. F. (1998). Self-control as a limited resource: Regulatory depletion patterns. *Journal of Personality and Social Psychology*, *74*(3), 774–789. doi:[10.1037/0022-3514.74.3.774](https://doi.org/10.1037/0022-3514.74.3.774)

Murphy, G., Groeger, J. A., & Greene, C. M. (2016). Twenty years of load theory—where are we now, and where should we go next? *Psychonomic Bulletin & Review*, *23*(5), 1316–1340. doi:[10.3758/s13423-015-0982-5](https://doi.org/10.3758/s13423-015-0982-5)

Nagamatsu, L. S., Voss, M., Neider, M. B., Gaspar, J. G., Handy, T. C., Kramer, A. F., & Liu-Ambrose, T. Y. L. (2011). Increased cognitive load leads to impaired mobility decisions in seniors at risk for falls. *Psychology and Aging*, *26*(2), 253–259. doi:[10.1037/a0022929](https://doi.org/10.1037/a0022929)

Nee, D. E., Wager, T. D., & Jonides, J. (2007). Interference resolution: Insights from a meta-analysis of neuroimaging tasks. *Cognitive, Affective, & Behavioral Neuroscience*, *7*(1), 1–17. doi:[10.3758/CABN.7.1.1](https://doi.org/10.3758/CABN.7.1.1)

Neta, M., Davis, F. C., & Whalen, P. J. (2011). Valence resolution of ambiguous facial expressions using an emotional oddball task. *Emotion*, *11*(6), 1425–1433. doi:[10.1037/a0022993](https://doi.org/10.1037/a0022993)

Neta, M., Kelley, W. M., & Whalen, P. J. (2013). Neural responses to ambiguity involve domain-general and domain-specific emotion processing systems. *Journal of Cognitive Neuroscience*, *25*(4), 547–557. doi:[10.1162/jocn\_a\_00363](https://doi.org/10.1162/jocn_a_00363)

Neta, M., Norris, C. J., & Whalen, P. J. (2009). Corrugator muscle responses are associated with individual differences in positivity-negativity bias. *Emotion (Washington, D.C.)*, *9*(5), 640–648. doi:[10.1037/a0016819](https://doi.org/10.1037/a0016819)

Neta, M., Schlaggar, B. L., & Petersen, S. E. (2014). Separable responses to error, ambiguity, and reaction time in cingulo-opercular task control regions. *NeuroImage*, *99*, 59–68. doi:[10.1016/j.neuroimage.2014.05.053](https://doi.org/10.1016/j.neuroimage.2014.05.053)

Neta, M., & Tong, T. T. (2016). Don’t like what you see? Give it time: Longer reaction times associated with increased positive affect. *Emotion*, *16*(5), 730–739. doi:[10.1037/emo0000181](https://doi.org/10.1037/emo0000181)

Neta, M., & Whalen, P. J. (2010). The primacy of negative interpretations when resolving the valence of ambiguous facial expressions. *Psychological Science*, *21*(7), 901–907. doi:[10.1177/0956797610373934](https://doi.org/10.1177/0956797610373934)

Petro, N. M., Tong, T. T., Henley, D. J., & Neta, M. (2018). Individual differences in valence bias: fMRI evidence of the initial negativity hypothesis. *Social Cognitive and Affective Neuroscience*, *13*(7), 687–698. doi:[10.1093/scan/nsy049](https://doi.org/10.1093/scan/nsy049)

Pontari, B. A., & Schlenker, B. R. (2000). The influence of cognitive load on self-presentation: Can cognitive busyness help as well as harm social performance? *Journal of Personality and Social Psychology*, *78*(6), 1092–1108. doi:[10.1037/0022-3514.78.6.1092](https://doi.org/10.1037/0022-3514.78.6.1092)

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Said, C. P., & Todorov, A. (2011). A statistical model of facial attractiveness. *Psychological Science*, *22*(9), 1183–1190. doi:[10.1177/0956797611419169](https://doi.org/10.1177/0956797611419169)

Scalf, P. E., Torralbo, A., Tapia, E., & Beck, D. M. (2013). Competition explains limited attention and perceptual resources: Implications for perceptual load and dilution theories. *Frontiers in Psychology*, *4*. doi:[10.3389/fpsyg.2013.00243](https://doi.org/10.3389/fpsyg.2013.00243)

Sheppes, G., & Meiran, N. (2008). Divergent cognitive costs for online forms of reappraisal and distraction. *Emotion*, *8*(6), 870–874. doi:[10.1037/a0013711](https://doi.org/10.1037/a0013711)

Sterzer, P., Russ, M. O., Preibisch, C., & Kleinschmidt, A. (2002). Neural correlates of spontaneous direction reversals in ambiguous apparent visual motion. *NeuroImage*, *15*(4), 908–916. doi:[10.1006/nimg.2001.1030](https://doi.org/10.1006/nimg.2001.1030)

Storbeck, J. (2012). Performance costs when emotion tunes inappropriate cognitive abilities: Implications for mental resources and behavior. *Journal of Experimental Psychology: General*, *141*(3), 411–416. doi:[10.1037/a0026322](https://doi.org/10.1037/a0026322)

Thomas, L., Donohue-Porter, P., & Stein Fishbein, J. (2017). Impact of interruptions, distractions, and cognitive load on procedure failures and medication administration errors: *Journal of Nursing Care Quality*, *32*(4), 309–317. doi:[10.1097/NCQ.0000000000000256](https://doi.org/10.1097/NCQ.0000000000000256)

Thompson-Schill, S. L., D’Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A reevaluation. *Proceedings of the National Academy of Sciences of the United States of America*, *94*(26), 14792–14797. doi:[10.1073/pnas.94.26.14792](https://doi.org/10.1073/pnas.94.26.14792)

Todorov, A., Baron, S. G., & Oosterhof, N. N. (2008). Evaluating face trustworthiness: A model based approach. *Social Cognitive and Affective Neuroscience*, *3*(2), 119–127. doi:[10.1093/scan/nsn009](https://doi.org/10.1093/scan/nsn009)

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., … Nelson, C. (2009a). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. doi:[10.1016/j.psychres.2008.05.006](https://doi.org/10.1016/j.psychres.2008.05.006)

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., … Nelson, C. (2009b). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*(3), 242–249. doi:[10.1016/j.psychres.2008.05.006](https://doi.org/10.1016/j.psychres.2008.05.006)

Trémolière, B., Gagnon, M.-È., & Blanchette, I. (2016). Cognitive load mediates the effect of emotion on analytical thinking. *Experimental Psychology*, *63*(6), 343–350. doi:[10.1027/1618-3169/a000333](https://doi.org/10.1027/1618-3169/a000333)

Van Dillen, L. F., Heslenfeld, D. J., & Koole, S. L. (2009). Tuning down the emotional brain: An fMRI study of the effects of cognitive load on the processing of affective images. *NeuroImage*, *45*(4), 1212–1219. doi:[10.1016/j.neuroimage.2009.01.016](https://doi.org/10.1016/j.neuroimage.2009.01.016)

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag: New York.