Working memory and spatial judgments: Cognitive load increases the central tendency bias

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6 April 2015

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*We thank Roberto Barbera and Noha Emara for helpful comments. This project was supported by Rutgers University Research Council Grants (#202167, #202110) and NSF CAREER BCS 0954749.

ABSTRACT

Previous work demonstrates that memory for simple stimuli can be biased by information about the category of which the stimulus is a member. Specifically, stimuli with values greater than the category's average tend to be underestimated and stimuli with values less than the average are overestimated. This is referred to as the central tendency bias. This bias has been explained as an optimal use of both noisy sensory information and category information. In a largely separate literature, cognitive load experiments attempt to manipulate the available working memory of participants in order to observe its effect on choice or judgments. In three experiments, we demonstrate that participants under a high cognitive load exhibit a stronger central tendency bias than when under a low cognitive load. Although not anticipated at the outset, we also find that judgments exhibit an anchoring bias. (139 words)

Keywords: judgment, memory, anchoring, working memory, cognitive constraints, cognitive busyness

Memory is an essential function, yet a large body of research suggests that memory exhibits systematic biases. One well-known bias is central tendency, where individuals remember stimuli as being more typical of the category of which they are members (Goldstone, 1994). Once considered a perceptual or mnemonic distortion (e.g., Poulton, 1989) this bias has successfully been described as resulting from an adaptive, Bayesian process that combines inexact memories of individual stimuli with prior knowledge about the distribution of the category. Combining information in this manner improves the accuracy of judgments, even though it introduces some bias into individual estimates. Huttenlocher and colleagues (Crawford, Huttenlocher, & Engebretson 1999; Crawford, Huttenlocher, & Hedges, 2006; Duffy, Huttenlocher, & Crawford, 2007; Duffy, Huttenlocher, Hedges, & Crawford, 2008; Huttenlocher, Hedges, & Duncan, 1991; Huttenlocher, Hedges, & Vevea, 2001) propose the category adjustment model (CAM), where a category is summarized as a distribution of stimulus values along some dimension, such as size or shape, and a stimulus has a particular value along the relevant dimension. For most categories, the prototypical value is the average value of the category (Duffy & Crawford, 2008). A key prediction of the Bayesian approach is that when memory for a particular stimulus is more inexact, more weight should be given to the category during estimation, and thus estimates should be more strongly biased.

The CAM is similar to other Bayesian models that have been used to explain biases in memory for size estimation (Ashourian & Lowenstien, 2011), time perception (Jazayeri & Shadlen, 2010), and hue bias (Olkkonen & Allred, 2014; Olkkonen, McCarthy, & Allred, 2014). Research has found that these effects extend to judgments of realistic and familiar objects (Hemmer & Steyvers, 2009a, 2009b). Despite the success of CAM, there are mixed results regarding whether participants successfully execute the optimal Bayesian judgments by employing all available and relevant information (Sailor & Antoine, 2005; Xu & Griffiths, 2010).

In this paper, we study the central tendency bias through employing a cognitive load (CL) manipulation. Studies that employ CL manipulations often direct participants to engage in a memorization task in parallel to making a decision in another domain. The memorization task is designed to manipulate the available working memory of the participant. An extensive literature documents that cognitive resources are bounded, and that increasing CL can compromise judgments (Cornelissen, Dewitte, & Warlop, 2011; Hinson, Jameson, & Whitney, 2003; Swann, Hixon, Stein-Seroussi, & Gilbert, 1990; Van den Bos, Peters, Bobocel, & Ybema, 2006), limit the ability to process information (Gilbert, Pelham & Krull, 1988), decrease self-control (Mann & Ward, 2007; Shiv & Fedorikhin, 1999; Ward & Mann, 2000), affect strategic behavior (Allred, Duffy, & Smith, 2015; Duffy & Smith, 2014), increase the assimilation effect (Martin, Seta, & Crelia, 1990), affect duration judgments (Block Hancock, & Zakay, 2010), and prompt stereotyping (Wigboldus, Sherman, Franzese, & van Knippenberg, 2004).

We are not the first to examine the effect of CL on visual judgments. Allen, Baddeley, and Hitch (2006) find that increased CL, through requiring the memorization of numbers, reduces the accuracy of recall of colors and shapes. Morey and Cowan (2004) find a reduced performance on a visual memory task under a CL that required the memorization of 7 random digits. Morey and Bieler (2013) find that participants who are required to recall different tones have a reduced accuracy of recall of colors and shapes. Zokaei, Heider, and Husain (2014) find that CL affects performance in a variety of visual judgment tasks. Surprisingly, Cocchi et al. (2011) finds that participants are under a high visual memory CL exhibited better performance on a visual memory task than participants under a low visual working memory CL. However, to our knowledge, we are the first paper to examine the effect of CL on the central tendency bias.

In our three experiments we examine the effect of CL on the degree to which category information influences stimulus estimates. We use a sequential line estimation task in which people encode and reproduce lines that vary in length. Participants are shown a target line that disappears and reproduce its length from memory. This reproduction is accomplished by presenting a second adjustable line to the participants that has a randomly determined starting length. The participants increase or decrease the length of this adjustable line in order to attempt to match the target line length. We employ the CL manipulation by asking participants to remember a long string of numbers or letters (high load) or a short string of numbers or letters (low load). If decreasing the availability of cognitive resources decreases the exactness of memory for a particular stimulus, we predict that it will increase the weight given to categories during estimation, thus leading to more a more pronounced central tendency bias. Whereas we manipulate available cognitive resources via a CL, this is reminiscent of a study that measures working memory. Crawford, Landy, and Salthouse (2015) find that participants who had lower measures of spatial working memory capacity also tended to show stronger bias toward spatial category prototypes.

In addition to measuring the central tendency bias, this procedure also allows us to investigate potential anchoring effects. The literature finds that participants produce biased judgments in wide variety of settings, due to the influence of an uninformative anchor. See Furnham and Boo (2011) for a review of the anchoring literature. In Experiment 2c, Epley and Gilovich (2006) examine the effects of CL on anchoring in a numerical response setting. The authors find that participants under a high CL are more sensitive to the anchor than are participants under a low CL. LeBoeuf and Shafir (2006) examine whether anchoring effects can be found in the judgment of physical quantities. The authors find anchoring effects in judgments of length, weight, and loudness. Similarly, we explore anchoring effects in judgments of length, which to our knowledge, has not yet been studied together with the central tendency bias.

In our first experiment, the participants are placed either under a low CL or a high CL while estimating the length of lines of various lengths. The order of the load and line lengths was randomly determined.

Experiment 1: Randomly ordered CL with numbers

Participants:

Thirty-three people (20 females, 13 males) participated. No participants satisfied our exclusion criteria of correctly performing less than 50% of the high CL memorization tasks.

Design and Procedure:

Each trial began with participants viewing a 2-digit (low CL) or 6-digit (high CL) number that they were instructed to remember. Each of the 2 or 6 digits were randomly selected from the integers 0 to 9. The number was presented for 5 seconds. The participants then saw a line for 1.5 seconds. We refer to this line as the *target* line. Target lines ranged from 96 to 352 pixels at 9 unique stimulus sizes that varied in 32 pixel increments. After a 1.5 second delay, participants were shown a second, adjustable line. We refer to the initial length of the adjustable line as the *start* line. Unlike most previous studies, the length of the start line was randomly drawn from a uniform distribution ranging from the length of the shortest target line (96 pixels) to the longest target line (352 pixels). The participant's task was to increase or decrease the adjustable line, by pressing the mouse buttons. Once the participant was satisfied that the adjustable line matched the target line, the subject pressed Enter. We refer to this response of the participant as the *response line*. After participants provided their response line they were prompted to type in the 2 or 6 digit number.

There were a total of 90 trials, with 10 lines from each of the 9 possible stimulus values. Of the 10 trials at each stimulus value, 5 were conducted under high CL and 5 were conducted under low CL.

Results and discussion:

Participants in high CL trials are less accurate (79.19%) on the memorization task than in low CL trials (91.25%), $t(32) = 5.78$, $p < .001$. In order to examine overall accuracy, we calculate *absolute bias* as the absolute difference between the target and response length. Participants are less accurate under a high CL (*M*=29.76, *SD*=30.11) than under a low CL (*M*=25.18, *SD*=25.06), $t(2968)=-4.50$, $p<.001$. Despite this, participants do not adjust their responses, as measured by absolute difference between the start and the response, differently while under a high CL (*M*=92.91, *SD*= 68.57) than while under a low CL (*M*=93.95, *SD*=72.08), $t(2968)= 0.40$, $p=.69$.

We also calculate the *response bias* as the difference between the target and response line length. Figure 1 shows the response bias on the vertical axis and the stimulus size on the horizontal axis averaged across all nine stimulus values.

We analyze the central tendency effects, the anchoring effects, and the CL effects by performing a repeated measures regression with response bias as the dependent variable. We analyze these effects in the same specifications because it is not obvious that the anchoring effects are robust to the specifications that also account for the central tendency bias and the CL.

We include independent variables that characterize the CL associated with the observation, the target line length, and the length of the start line. In particular, we include a categorical variable, *High load*, which indicates whether the decision was taken under a high CL. We also include the *Centered target* variable, which is defined to be the length of the target line minus the mean of the lines. We also account for possible "bow effects" (Fitting, Wedell, & Allen, 2007; Fitting, Wedell, & Allen, 2008) by employing a method similar to that used by Haun, Allen, and Wedell (2005). Specifically, we include the variable *Centered target cubed*, which is the cube of the Centered target variable. In order to facilitate the nonlinear specification, we center these linear and cubic terms. Finally, in order to investigate possible "anchoring effects," we include the *Start* variable, which is the length of the start line.

We conduct a repeated measures analysis by estimating a compound symmetry covariance matrix clustered by participant. This implies that any two observations involving a participant are assumed to be correlated but any observations involving different participants are assumed to be independent. We report the unstandardized coefficient estimates and standard errors. Reporting the unstandardized coefficient estimates, rather than the standardized estimates, seem to be appropriate since the variables of interest - Centered target and Start - are both measured in pixels.

Finally, we report the results of F-tests that investigate whether there is an interaction between CL and the variables that measure the length of the target line. The reported F-test in the first specification tests whether the High load-Centered target interaction is different from zero. The reported F-test in the second specification tests whether both the High load-Centered target and the High load-Centered target cubed interactions are different from zero. A summary of this analysis can be found in Table 1.

The High load variable is not significantly different from zero, which suggests that CL does not lead to an overestimation or an underestimation of all lines. The negative coefficient estimates of the Centered target variable suggest that participants overestimated smaller lines and underestimated longer lines. In other words, this provides evidence of the central tendency bias. The negative coefficient estimate of the High load-Centered target interaction in the first regression suggests that the central tendency bias is stronger for participants under a high CL. In the second specification, we find that the cubic term and not the linear term, is significantly related to the CL. Based on the F-tests in both regressions, we find that the interaction between the CL and the target variables that were used in that specification are significantly different from 0. We therefore find evidence that the CL affects the extent of the central tendency bias, even while accounting for the bow effects. We also note that, although the Centered target cubed variable is significant, the second specification exhibits a larger AIC (Akaike, 1974) than the first, thereby suggesting that the second is a worse fit, relative to the number of variables included.

Across both specifications, the positive coefficient estimate of the Start variable suggests evidence of anchoring effects. Although we do not find evidence that these anchoring effects are affected by the CL. To address the statistically unlikely possibility that the observed effects result from a biased start length, we investigate the correlation between the target line length and the start line length. We do not find evidence that the start line length is correlated with the target line length, $r(2968)=-.0049$, $p=.79$. Therefore, a biased start line cannot explain the anchoring effects.

The results of Experiment 1 suggest that CL increases the central tendency bias. However, one concern is that the operationalization of the CL–memorization of numbers—has an idiocyncratic effect on length judgments. To test whether the effect of CL generalizes to other operational definitions, we conduct a second experiment in which CL was manipulated by requiring the memorization of strings of letters, rather than numbers.

Experiment 2: Randomly ordered CL with letters

Methodology

Participants:

Thirty-three people (22 females, 10 males) participated. We discarded 2 participants who did not correctly perform the memorization task in at least 50% of the high CL trials.

Design and Procedure:

The procedure is identical to Experiment 1, except that we required the memorization of a string of 2 or 6 letters. The 2 or 6 letters were drawn from the set BCFJKLPQSX. These letters were selected in order to prevent the participants from grouping letters into English words.

Results and discussion:

We analyze data as was performed in the analysis of Experiment 1. As expected, participants are less accurate on the memorization task in high CL trials (78.49%) than low CL trials (92.69%), $t(30) = 5.50$, $p < .001$. Responses under high CL are less accurate (M=28.85, SD=29.26) than under a low CL (M=25.06, SD= 25.46), $t(2788)$=-3.65, p<.001. Under a high CL, participants marginally adjust less (M=90.50, SD=69.48) than low CL (M=95.49, SD=70.77), $t(2788)$=1.88, p=.060.

Figure 2 illustrates the response bias given the CL and the stimulus size. We perform the analysis exactly as was done for Experiment 1. The summary of this analysis is found in Table 2.

Despite the different participants and different CL treatments, the results are qualitatively similar to that from Experiment 1. We do not find evidence of a relationship between high CL and response bias. We find evidence of the central tendency bias and that it is more pronounced under a high CL. Additionally, we find that the cubic term is significant, but that the second specification is associated with a worse fit, as seen by the larger AIC. Also, from the reported F-tests, we see that the interaction between the load and the target variables are significant in both specifications.

Finally, similar to Experiment 1, we find evidence of anchoring effects in both specifications. However, we do not find evidence that the start line is correlated with the target line ($r(2788) = .0024$, $p=.90$) and so a biased start line does not explain our anchoring effects.

In Experiments 1 and 2, the order of the CL was randomized. In other words, participants did not know before a given trial whether or not they would have a low or high load. It is possible that CL of both letters and numbers was unusually effective because the order of the load was randomized. Therefore, in Experiment 3 we investigated whether results would generalize to a design where participants knew in advance the load for that trial because CL alternated between high and low.

Experiment 3: Alternating CL with numbers

Methodology

Participants:

Forty people (25 females, 15 males) participated. No participants satisfied our exclusion criteria.

Design and Procedure:

The procedure is identical to Experiment 1, except that the load treatment alternated between the 2 and 6 digit numbers, with every participant first presented with a 2 digit number.

Results and discussion:

Data was analyzed as in Experiments 1 and 2. Under high CL, participants are less accurate in the memorization task (75.56%) than under low load (90.11%), $t(39) = 6.47$, $p < .001$. Under a high CL, responses are less accurate (M=32.70, SD=39.85) than under a low CL (M=28.06, SD=26.13), $t(3598)$=4.13, p=.001. Participants under a high CL adjusted less (M=91.90, SD=75.03) than participants under a low CL (M=96.81, SD=70.52), $t(3598)$=2.02, p=.04.

Figure 3 illustrates the response bias by CL and stimulus size. We perform a repeated measures analysis identical to that performed for Experiments 1 and 2. This analysis is summarized in Table 3.

Again, despite the different participants and different design, we observe many of the same results from Experiments 1 and 2. We do not find a relationship between the High load variable and Response bias. We find evidence of the central tendency bias and that it is more extreme under a high CL. Further, we find evidence that the interaction between CL and the target variables is significant in both specifications. This suggests that, even while accounting for the bow effects, we find evidence that CL affects the central tendency bias. Finally, we find evidence of anchoring effects but we do not find evidence that this is affected by the CL. To investigate the possibility that a biased start line lead to these anchoring effects, we examine the correlation between the target line and the start line. We do not find a significant correlation between the start line and the target line, $r(3598)$=-.03, p=.07.

General Discussion

Here we have demonstrated that judgments of length are affected by cognitive load (CL). In particular, we find that participants under high CL exhibit an increased central tendency bias. Although previous studies have found that CL affects visual judgments, to our knowledge, we are the first to demonstrate the effect of CL on the central tendency bias. We find that stimuli close to the category center are less affected by CL than stimuli far from the center. This finding is robust as it generalizes across three sets of participants, two operational definitions of CL, and two different condition orders. The increased central tendency bias under high cognitive load is consistent with the Bayesian approach described in the Category Adjustment Model.

We also find anchoring effects in the judgments of length. To our knowledge, we are the first to find anchoring effects in investigations of the central tendency bias. Prior studies used a constant starting length (Huttenlocher, et al. 2000; Crawford, Huttenlocher, & Engebretson, 2000) or a randomized starting length but did not analyze its effects (Duffy & Crawford, 2008). Here we find anchoring effects, in that estimates are biased toward the starting value of the adjustable response line. This anchoring effect does not seem to be consistent with the Category Adjustment Model.

However, unlike the central tendency bias, the anchoring effect was not affected by cognitive load. Since we did not design the study in order to examine anchoring effects, but rather we only noticed that the anchoring effects were present in the judgments, we hope that future studies employ an improved design: a random start length with a mean equal to the target length.

Consider a situation where the target line is slightly larger than the mean and the start line is greater than the target line. Also consider a target line that is slightly shorter than the mean and the start line is shorter than the target line. In these cases, the anchoring effects and the central tendency bias work in opposite directions. It is for this reason that we analyze the effects jointly in the same model and the fact that they can both be detected speaks to their robustness.

Note that, unlike Epley and Gilovich (2006), we do not find a relationship between CL and the anchoring effects in any of our three experiments. Despite this, our experiments exhibit a variety of relationships between CL and adjustment (the absolute difference between the start and response line). In Experiment 3, we find that participants under a high CL adjusted significantly less than under low CL. In Experiment 2, this relationship is only marginally significant, and we do not find such a relationship in Experiment 1. To the extent that a high CL can simulate the effect of having a lower cognitive ability, we look to the correlational literature. Bergman, Ellingsen, Johannesson, and Svensson (2010) find a relationship between a measure of cognitive ability and anchoring however Oechssler, Roider, and Schmitz (2009) do not find such a relationship. Perhaps a design better suited to studying anchoring effects would identify a relationship between anchoring and CL.

Finally, our design does not allow us to distinguish between the conjecture that CL affects either the encoding or the retrieval of the length of the target line. A design that could distinguish between these two conjectures would manipulate the time during which the participant was under a load: during encoding or retrieval. We hope that future work can address this issue.

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Table 1:

Dependent variable: Response bias (Experiment 1)

	(1)		(2)	
Variable	B	SE	B	SE
High load	-4.539	3.658	-4.632	3.651
Centered target	-0.0723***	0.011	-0.172***	0.0288
High load * Centered target	-0.117***	0.0156	-0.027	0.0406
Centered target cubed	-	-	0.00000829***	0.0000022
High load * Centered target cubed	-	-	-0.00000748*	0.00000311
Start	0.0573***	0.0104	0.0570***	0.0104
High load * Start	0.0201	0.0145	0.0205	0.0144
Intercept	-14.555***	3.261	-14.462***	3.257
F-test of load-target interactions	$F(1, 2932)=56.44$***		$F(2, 2930)=31.23$***	
AIC	29650.4		29684.5	

Notes: Repeated measures regressions that assume a compound symmetry covariance matrix. Specification (1) does not include the cubic terms and specification (2) includes the cubic terms. N=2970: 90 judgments from 33 participants. *** $p<.001$, ** $p<.01$, * $p<.05$

Table 2:

Dependent variable: Response bias (Experiment 2)

	(1)		(2)	
Variable	B	SE	B	SE
High load	2.763	3.710	2.506	3.708
Centered target	-0.0662***	0.0113	-0.124***	0.0295
High load * Centered target	-0.114***	0.0159	-0.100*	0.0417
Centered target cubed	-	-	0.00000479*	0.00000225
High load * Centered target cubed	-	-	-0.00000114	0.00000319
Start	0.0682***	0.0104	0.0675***	0.0104
High load * Start	-0.00089	0.0148	0.00021	0.0148
Intercept	-17.681***	3.234	-17.519***	3.233
F-test of load-target interactions	$F(1, 2754)=51.34$***		$F(2, 2752)=25.79$***	
AIC	27805.0		27846.2	

Notes: Repeated measures regressions that assume a compound symmetry covariance matrix. Specification (1) does not include the cubic terms and specification (2) includes the cubic terms. N= 2790: 90 judgments from 31 participants. *** p<.001, ** p<.01, * p<.05

Table 3:

Dependent variable: Response bias (Experiment 3)

	(1)		(2)	
Variable	B	SE	B	SE
High load	2.213	3.884	2.108	3.885
Centered target	-0.0933***	0.0116	-0.116***	0.0306
High load * Centered target	-0.102***	0.0166	-0.122**	0.0435
Centered target cubed	-	-	0.00000188	0.00000231
High load * Centered target cubed	-	-	0.00000176	0.00000334
Start	0.0693***	0.0109	0.0691***	0.0109
High load * Start	0.000656	0.0155	0.00148	0.0155
Intercept	-21.015***	3.487	-21.015***	3.486
F-test of load-target interactions	$F(1, 3555)=37.91$***		$F(2, 3553)=18.66$***	
AIC	37039.1		37084.2	

Notes: Repeated measures regressions that assume a compound symmetry covariance matrix. Specification (1) does not include the cubic terms and specification (2) includes the cubic terms. N= 3600: 90 judgments from 40 participants. *** p<.001, ** p<.01, * p<.05

Figure 1: Cognitive load affects the magnitude of the central tendency bias in the number task (Experiment 1). In this and the following figures, Response bias (target line length minus the response line length) is plotted as a function of the target line length under low cognitive load (open symbols) and under high cognitive load (solid symbols). Data points are averages across all trials for all observers. The solid (high load) and dashed (low load) lines are best fitting lines. Solid horizontal line represents a response bias of zero, or veridical memory.

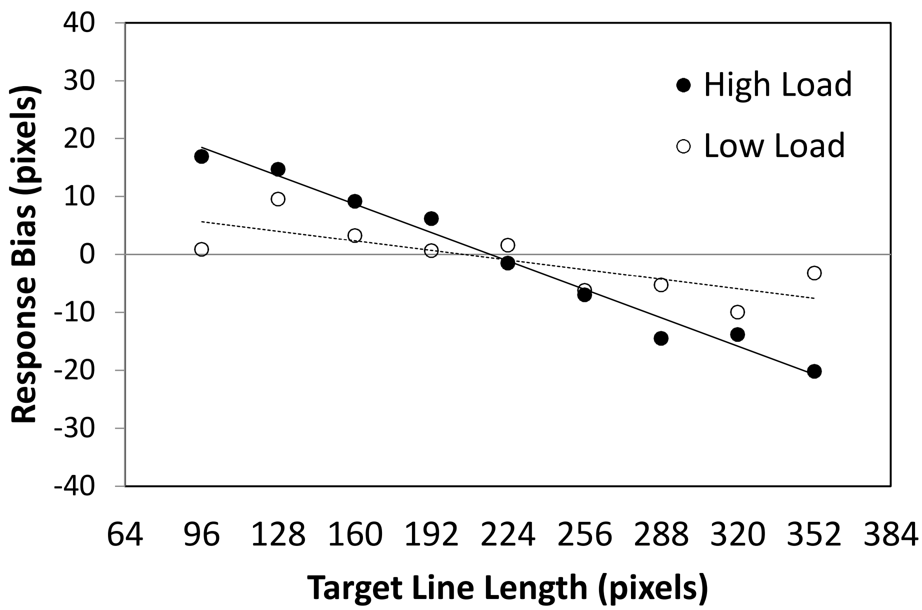

Figure 2: Cognitive load affects the magnitude of the central tendency bias in the letter task (Experiment 2).

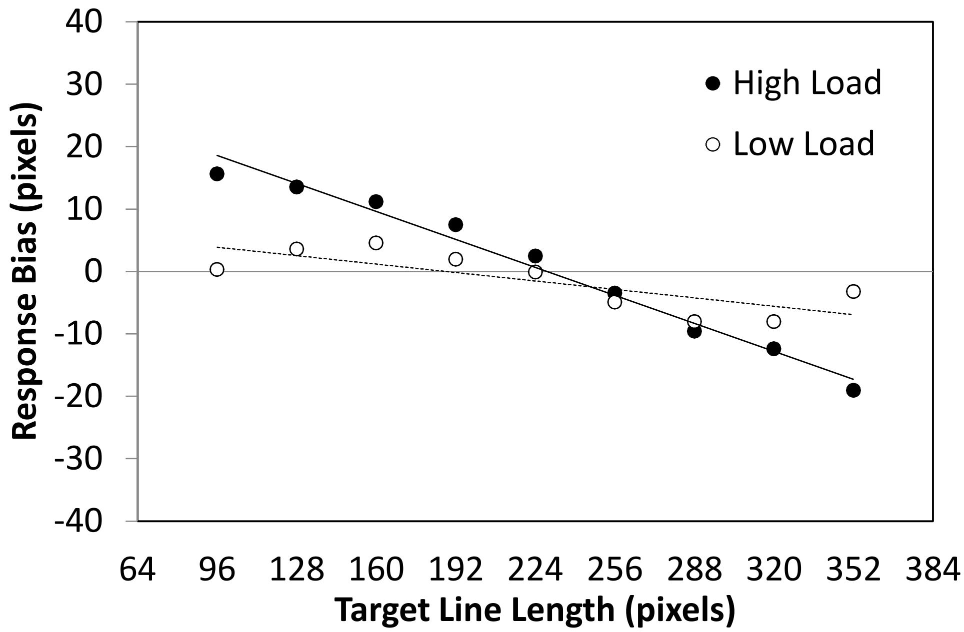

Figure 3: Cognitive load affects the magnitude of the central tendency bias in the alternating load task (Experiment 3).