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Effects of cognitive load and type of object on the visual looming bias

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Abstract
According to the behavioral urgency hypothesis, organisms have evolved various mechanisms that facilitate their survival by focusing attention and resources on approaching danger. One example of such mechanisms is the looming bias—the tendency for an individual to judge an approaching object's distance as being closer or time-to-collision as being sooner than receding or stationary objects. To date, most research on the looming bias has explored the ways in which human factors and object characteristics influence the strength and direction of the bias. The current study expanded on this field of research in two novels ways by exploring (a) whether cognitive vulnerabilities may influence the strength of the looming bias in the visual domain, and (b) whether the combination of human factors (i.e., cognitive load) and object characteristics (i.e., object threat) interact to create an additive effect on looming bias strength. Findings appear to only partially support the hypotheses that cognitive vulnerabilities can influence looming bias strength in the visual domain, and that factors related to both the individual and the looming object may interact to create a stronger looming bias. These findings help to highlight possible evolutionary advantages of the looming bias and its presence across modalities, as well as add some strength to the claims that the margin of safety theory can be generalized to include psychological factors.

Keywords Looming bias · Visual perception · Cognitive load · Threat

According to the behavioral urgency hypothesis (Franconeri & Simons, 2003; Rossini, 2014), humans have innate mechanisms that have evolved to increase survivability by drawing attention to changes in one's environment (Abrams & Christ, 2006; Cacioppo & Fredberg, 2012) and to stimuli that could be dangerous or threatening (Franconeri & Simons, 2003). One such mechanism is the tendency to evaluate an approaching object's distance from the evaluator as being closer, or its time-to-collision (TTC) as being shorter, than what it actually is. This perceptual tendency to underestimate the time of arrival or distance of an object from the individual is often referred to as the *looming bias* (Neuhoff, 2018; Parker & Alais, 2007; Vagnoni et al., 2017). By perceiving an object as being closer or as arriving faster than it actually is, individuals may react sooner and have more time than expected to prepare for the approaching object. The additional time to prepare is likely to increase their chances of survival (Neuhoff et al., 2009; Seifritz et al., 2002; von Mühlenen & Lleras, 2007). The looming bias appears to be a fairly robust phenomena associated with the perception of moving objects, as it has been observed across the life span for humans (Freiberg et al., 2001) and been observed in nonhuman primates (e.g., Ghazanfar, Neuhoff, & Logothetis, 2002).

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Factors moderating the looming bias

Because the looming bias is important for one's survival, a main goal of research on the looming bias is identifying the factors that might increase or decrease the intensity or strength of the bias. Understanding what may influence the strength of the looming bias can provide important information about the relevant processes associated with perception in situations where there is a risk to one's safety and a need for behavioral action. Thus, studying the looming bias has implications for understanding the ways in which humans discriminate and judge relevant stimuli in the environment and provides researchers with an opportunity to study possible evolutionary processes related to perception (Barkow, Cosmides, & Tooby, 1995).

Research on the looming bias often requires participants to make distance or TTC judgements using auditory or visual information, such as an individual pressing a button when they believe an object will hit them, estimating the distance of an object from them, or reporting whether they could touch an object based on the perceived distance (e.g., Neuhoff, 2018; Vagnoni et al., 2017). In the auditory domain, this might involve listening to a sound that changes in amplitude to simulate an object coming closer (i.e., amplitude increasing) or getting farther away (i.e., amplitude decreasing). In the visual domain, approaching objects might be simulated by showing a picture or other visual stimuli growing in size to simulate the object coming closer (or shrinking in size to simulate the object moving away). Response time or judgements of the distance or impact of the potential object are then examined in association with certain factors or compared between groups. In an attempt to identify possible factors affecting human perception to oncoming objects, the field has examined two main categories of factors: object-related characteristics (e.g., images that may be perceived as threatening) and human factors (e.g., personality traits and physical fitness).

Object characteristics When it comes to object-related characteristics associated with the looming bias, one of the most widely studied characteristics is how threatening the object is. Multiple studies have demonstrated that threatening objects tend to illicit a stronger looming bias. For example, Vagnoni et al. (2015) examined participants' reactions to both threatening (snakes and spiders) and nonthreatening (rabbits and butterflies) visual objects in a visual looming bias task. They found that participants perceived threatening objects as approaching quicker than the nonthreating visual objects (see also Vagnoni et al., 2012). Similar findings were also reported by Brendel et al. (2012), who found that threatening images, such as humans and animals attacking, as well as threatening faces, were judged as being closer than neutral pictures or faces in a visual looming task. This can also occur in the auditory domain, where sounds may be judged as being closer if an individual perceives the sound as threatening or if an individual is induced with fear prior to judging the distance of a sound (Kolarik, Moore, Zahorik, Cirstea, & Pardhan, 2016). Overall, there is ample evidence suggesting that threatening objects elicit a stronger visual and auditory looming bias.

Human factors Most of the research on individual differences has focused on the margin-of-safety theory, which posits that the more "vulnerable" an individual is the greater margin of safety they need to prepare for a threat. A bigger margin, in turn, is associated with a greater looming bias (Neuhoff et al., 2012). For example, a study conducted by Neuhoff et al. (2012) examined the impact of physical fitness on the strength of the looming bias when individuals were asked to judge the perceived position of looming sounds. Results showed that stronger participants (as measured by a dynamometer) perceived looming sounds with a smaller margin of safety, compared with weaker participants (Neuhoff et al., 2012). Thus, suggesting that those individuals who may not have been as strong or as capable of managing a possible threat perceived the looming object as being closer than it is to give them more time to respond. Similarly, research on sex differences in the looming bias has shown that females exhibit a larger auditory looming bias than males, which Neuhoff et al. (2009) suggested may be due to males tending to be physically stronger than females.

Research on psychological vulnerabilities is partially consistent with the research on physical vulnerabilities. For example, Riskind et al. (2014) examined how symptomatology level correlated with intensity of the looming bias in the auditory domain. They found a positive association between anxiety symptoms and the strength of the looming bias, such that higher level of anxiety symptoms was associated with a larger auditory looming bias, or a higher likelihood to perceive an approaching object as being closer than it really is when judging the distance of a moving sound. In another study on the auditory looming bias and psychological vulnerability, McGuire et al. (2016) examined psychological vulnerability using cognitive load. In this study, individuals were asked to judge a sound approaching (i.e., sound increasing in volume) them while having to memorize either (a) a seven-digit number (i.e., high cognitive load) or (b) a two-digit number (i.e., low cognitive load). In support of the margin of safety theory, McGuire and colleagues found that individuals under a higher cognitive load induced by the number memorization task (i.e., less cognitive capacity to process environmental stimuli) exhibited a larger auditory looming bias.

These studies on individual differences provide convergent evidence to support a positive correlation between some physiological and psychological vulnerability and the looming bias. It is important to note, however, that Riskind et al. (2014) found that people with more depressive symptoms showed a decrease of the looming bias. This may have been associated with lower energy levels and decreased vigilance or arousal among depressed individuals (Kertzman et al., 2010), which could have influenced the perception of the looming object. These findings suggest that while there is substantial evidence to support the margin of safety theory, there is a need to further investigate the association between psychological weakness or vulnerability and the looming bias.

One question necessitating further research is whether findings, such as those from the McGuire et al. (2016) and Riskind et al. (2014), might apply to both the auditory and visual modality, as most research on psychological vulnerabilities has been conducted in the auditory domain. Despite similarities between visual and auditory information processing (Abrams & Christ, 2006; Cappe et al., 2009), there are several differences between the two modalities that may dictate whether a looming bias will be observed or not. For example, individuals are thought to be more accurate in determining the distance of visually approaching objects than auditory ones in part because of attentional resource availability and utilization (DeLucia et al., 2016; Neuhoff, 2018). This may result in a smaller looming bias or more accurate distance judgement because there is a greater availability of cognitive resources allocated to processing approaching visual objects. However, visual processing may also require more conscious attentional resources to help an individual attune to and sustain attention to moving objects and complex motion, as compared with auditory processing (e.g., Lewis et al., 2000; Neuhoff, 2018). Thus, this may suggest that when the looming bias does occur in the visual modality, a psychological vulnerability like a cognitive load may have a stronger influence on perception and the looming bias. As with the auditory looming bias, which is thought to be an unconscious automatic process but was influenced by cognitive load in the McGuire et al. (2016) study, one might predict that a less automated looming bias in the visual domain may be even more influenced by cognitive load.

Another area of research on the looming bias largely unexplored is the interaction between object characteristics and human factors. When testing which factors might influence the intensity of the looming bias, researchers have tended to examine either object factors (e.g., visual or auditory, threatening or nonthreatening), or human factors (e.g., physical or psychological vulnerability) separately. This applies to looming bias studies in both the auditory and visual domains. For example, McGuire et al. (2016) did not control or examine how factors associated with the auditory looming object (e.g., threat) may have impacted the strength of the looming bias. It is unclear whether factors associated with the object and the individual may cancel each other out or alternately have an additive or multiplicative influence that intensifies the looming bias.

Current study

The current study had two primary goals. Given the differences between the processing of auditory and visual objects, it is unclear whether certain factors that influence the perception of auditory looming stimuli will also influence the perception of visually looming objects. In particular, this study sought to further examine whether the findings of McGuire et al. (2016), regarding the increase in the looming effect under cognitive load obtained with auditory looming stimuli, will generalize to visual looming objects. In light of the dearth of research on interactions among object characteristics and human factors, another goal of the current study was to examine the interaction of threat (i.e., object characteristic) and psychological vulnerability (i.e., human factor). It was hypothesized that (1) participants under a high cognitive load, as compared with a low cognitive load, would have a stronger looming bias (i.e., quicker response times) when judging the time of impact for approaching visual stimuli, and (2) the looming bias would be stronger (i.e., quicker response times) when participants are responding to threatening images (spiders and snakes), as compared with nonthreatening images (rabbits and butterflies). In turn, (3) the largest looming bias would be observed in situations where individuals are responding under a high cognitive load and are presented with threatening images, as compared with low cognitive load and nonthreatening image conditions.

Method

Participants

Ninety-one undergraduate students at a large Midwestern university (62% identified as female; M_{age} = 19.01, SD = 1.38) participated in the current study for course credit. The study sample was primarily White or non-Hispanic (52%), followed by students identifying as multicultural (20%), and either Asian, Black, or Native American (all 9%). No participants reported problems with their hearing or vision, and participants with glasses were permitted to wear their glasses during testing. Participants were told they were taking part in a memory task while also having to perform computer and speech tasks. Participants were not informed about the real purpose of the study until the debriefing section of the study. Nine participants were excluded for not following study directions (e.g., not pressing the computer keys when directed, not finishing the visual looming task), making the final sample size 82.

Stimulus and apparatus

For the visual looming task, 160 images were included, which consisted of 40 real-life images taken from the internet of two nonthreatening objects (butterflies and rabbits) and 40 real-life images of two threatening objects (snakes and spiders). Each image was cropped so that the animal or bug encapsulated the full image and any background in the image was modified to match the background used in the program. The background of the image was a solid light-gray color, similar to the image structure used by Vagnoni et al. (2012). All editing was completed using Adobe Photoshop CS5 (Adobe Systems, San Jose, CA).

Measures

Fear To measure the potential fear induced by the objects used in the current study, participants were asked to rate how afraid they were of the four image types (butterfly, rabbit, snake, and spider) on a Likert scale from 1 (*not afraid*) to 5 (*very afraid*).

The highest rated mean fear was for spiders (M = 3.66, SD = 1.32), followed by snakes (M = 3.18, SD = 1.54), butterflies (M = 1.24, SD = .66), and rabbits (M = 1.07, SD = .36).

Demographics Participants self-reported information about gender, age, and ethnicity.

Design and procedure

After consenting, participants were randomly assigned into either a high cognitive load or low cognitive load condition. To manipulate cognitive load, participants were asked to complete a number memorization task presented on a sheet of paper placed in front of the participant on a desk. Participants were given 20 seconds to memorize either a two-digit number (low cognitive load, n = 40), or a seven-digit number (high cognitive load, n = 42), and were told they would need to recall the number at the end of the visual looming task.

Immediately after the cognitive load task, participants began the visual looming task. The visual looming task was based on the Vagnoni et al. (2012) study on fear and visual looming objects. A custom Java script was used for the task. Participants sat in front of a computer monitor (18.6 in × 9 in × 15.3 in display; vertical refresh rate = 75 Hz; horizontal refresh rate = 83 kHz), with their heads on a head mount that was stationed 40 cm away from the monitor. Participants were instructed to press a key on the computer keyboard when they believed the image was going to make contact with them. Specifically, participants were told to "*pretend like the object is coming at you and you need to hit the space bar when you think the object will hit you*." Participants were also specifically instructed with how to respond when the image disappeared on the screen by being told: "*Even if the object disappears, you still need to pretend that the object is continuing to approach you and hit the space bar when you believe it will hit you.*"

A trial in the program began by displaying an image in the first frame at one of two sizes, which represented two different starting distances. Images would start at a 400 × 400 pixel size (i.e., "far" starting distance), or a 500 × 500 pixel size (i.e., "close" starting distance). An equal number of pictures for each type of stimulus was presented during the session at each size or starting distance (e.g., 20 spider images starting at the 400 × 400 pixel size, and 20 spider images starting at the 500 × 500 pixel size). For each image trial, the image would appear and then increase in size by 500 pixels per second for 1 second before disappearing on the screen. The image would disappear before the increase in size if the participant pressed the indicated key first before the first second on-screen. If the participant did not press the indicated key, the next trial would automatically begin after 5 seconds. The time in between each trial would vary randomly between 300 milliseconds (ms) and 800 ms. The program would measure participant's response time (RT) between the start of the image and when they pressed the key. There was a total of 160 trials per testing session, and each trial displayed a different picture at random.

After the visual looming task, participants were asked to write down on a piece of paper the number they were asked to memorize, followed then by completion of the study's battery of online questionnaires. Finally, participants were debriefed and informed about the true purpose of the project. On average, participants took approximately 20 minutes to complete the study.

Results

Response time (RT) in milliseconds (ms) was used as the dependent variable in data analysis. Each participant received eight mean RT scores, one for each type of image (rabbit, butterfly, snake, and spider) at both far (pixel start size 400 × 400) and close (pixel start size 500 × 500) start distances: Rabbit close RT, Rabbit far RT, Butterfly close RT, Butterfly far RT, Snake close RT, Snake far RT, Spider close RT, and Spider far RT. RTs greater than 4,000 ms (0.29% of total responses) were excluded because this would represent situations where participants waited too long to respond potentially because they were not paying attention. RTs less than 400 ms (0.26% of total responses) were also excluded from data analysis because participants may have responded prematurely immediately after the image appeared on the screen. This time was selected because previous research on initial image recognition for image types similar to those used in the current study suggests that most participants are able to accurately first identify an image using a behavioral response (i.e., pressing a key) at times greater than 400 ms (e.g., Coelho et al., 2019; Kolassa et al., 2005; Soares, Lindström, Esteves, & Öhman, 2014). Quicker RTs indicate that the participant perceived the object as being closer than it actually was, and hence would make contact with them in a shorter amount of time.

The mean RTs and effect sizes for measuring differences between the response times (RTs) under each condition are presented in Table 1. First, to examine overall differences in RTs based on the different factors examined the current study (i.e., starting distance, image type, and cognitive load), t tests were performed using mean RTs. In examining overall RTs of starting distance using paired-sample t tests, there was an overall significant difference in mean RT (M_{diff}) between the far and close starting distances RTs, M_{diff} = 76.56, SE = 9.77, $t(82)$ = 7.84 $p < .01$, suggesting that as expected participants tended to respond to the close starting distance images quicker than the far starting distance images. Moreover, there were several overall RT differences in image type overall, regardless of load condition and starting sizes (all ts > 3.47, ps < .05): butterfly RT higher than snake RT (M_{diff} = 93.18, SE = 18.23),

Table 1 Mean response times by image starting size and condition

Picture type	High load	Low load	Cohen's *d* [95% CI]
Far starting size			
Butterfly	1,408.02 (74.97)	1,586.88 (111.13)	−.29 [−.75, .14]
Rabbit	1,411.70 (79.85)	1,532.03 (105.27)	−.20 [−.63, .23]
Snake	1,334.87 (74.92)	1,474.19 (104.75)	−.24 [−.67, .19]
Spider	1,371.49 (75.79)	1,523.31 (99.28)	−.26 [−.70, .17]
Close Starting Size			
Picture type	High load	Low load	Cohen's *d* [95% CI]
Butterfly	1,346.58 (75.22)	1,507.25 (106.62)	−.27 [−.70, .16]
Rabbit	1,319.43 (76.26)	1,469.23 (112.20)	−.24 [−.67, .19]
Snake	1,211.28 (71.93)	1,420.07 (106.19)	−.35 [−.79, .08]
Spider	1,279.08 (70.79)	1,410.90 (102.83)	−.23 [−.66, .20]

Means and standard errors for each image type are provided. High load = high cognitive load condition; Low load = low cognitive load condition. Far starting size = mages presented at the 400 × 400 pixel starting size. Close starting size = images presented at the 500 × 500 pixel starting size. CI = confidence interval.

butterfly RT higher than spider RT (M_{diff} = 65.02, *SE* = 17.08), and rabbit RT higher than snake RT (M_{diff} = 69.20, *SE* = 19.95). When examining RT differences between the high cognitive and low cognitive load condition using independent-sample *t* tests, there was no significant differences for any image type between the high and low cognitive load conditions (all *t*s < 1.60; all effect sizes 95% confidence intervals crossed zero; Cohen, 1992). However, trends were observed in the hypothesized direction for each image type, such that participants in the high cognitive load condition responded slightly quicker to each image type, as compared with participants in the low cognitive load condition responding to the same image type.

As a part of a follow-up analysis, the associations between RTs and fear ratings were examined for each image and fear rating type. The correlations between the RTs and fear ratings for each image type are provided in Table 2. Not surprisingly, there was a strong, positive correlation between the RTs for each image type at each starting distance. In examining the correlations between the fear ratings and RTs, only the fear rating for the spider was associated with both RTs for the close starting size ($r = -.22$) and far starting size ($r = -.22$) spider images, such that higher fear for spiders was associated with quicker RTs. Fear was also associated with the close starting size snake image ($r = -.23$). There was a small, positive correlation between the snake and spider fear ratings and the butterfly fear ratings ($r = .21$ for butterfly-snake; $r = .24$ for butterfly-spider), suggesting that those with higher fear ratings for spiders and snakes also reported higher fear ratings for butterflies. Lastly, there was a strong, positive correlation between fear of snakes and fear of spiders ($r = .54$), indicating that those who reported a high fear of spiders also tended to report a high fear of snakes.

Repeated-measures analysis of covariance (ANCOVA) was used to compare mean RTs within condition across start sizes using a 4 (image: rabbit, butterfly, snake, and spider) × 2 (start size: close [400 × 400 pixel], far [500 × 500 pixel]) × 2 (condition: high cognitive load, low cognitive load) design. In the model, self-rated fear of each stimulus image type (butterfly, rabbit, snake, and spider) was included as a covariate. The ANCOVA revealed only a two-way interaction of Image Type × Condition, $F(3, 74) = 2.89$, $p = .04$, $\eta_p^2 = .67$. No other main effects or interactions were significant. To probe the two-way interaction of Image Type × Condition in the repeated-measures ANCOVA, post hoc least-square differences adjusted pairwise comparisons were calculated between the high and low cognitive load conditions for each image. This involved testing whether the mean difference in RT between the high and low load conditions were significant for each image type. Additionally, the two-way interaction was examined by comparing the RTs for each image under both the high and low cognitive load conditions.

The pairwise comparisons in the ANCOVA examining the differences between image RTs for each condition revealed several significant differences (i.e., mean RT between the image types $p < .05$). The mean RTs for each image (across both starting distances) under each condition are presented in Fig. 1. For RTs in the low cognitive load condition, participants tended to respond significantly slower to the butterfly image as compared with all other image types. For the RTs in the high cognitive load condition, participants tended to respond significantly faster to the snake image, as compared with all other image types. When examining the RTs by starting distance for each image type and condition, the pairwise comparison from the ANCOVA revealed no significant difference between the high and low cognitive load response times for each of the four image types across both the close and far starting points (all *p*s > .16).

Discussion

To date, research on the looming bias—the tendency to judge the distance or time of arrival of an approaching object as being closer than in actuality—has focused on the factors that influence human perception under these circumstances. In particular, researchers have sought to determine the ways in which characteristics of the individual perceiving the object and characteristics of the approaching object itself, influence the strength and direction of this perceptual phenomenon. Research on individual factors has mostly examined the vulnerabilities people may have that increase the looming bias strength, potentially as a way to increase a margin of safety (e.g., physical strength; Neuhoff et al., 2012). Conversely, research on object factors as it relates to the looming bias has been mainly done on the threatening quality

Table 2 Correlations between mean response times and mean fear ratings

Variables	1	2	3	4	5	6	7	8	9	10	11
1. RT Butterfly 400											
2. RT Rabbit 400	.97*										
3. RT Snake 400	.95*	.94*									
4. RT Spider 400	.95*	.94*	.96*								
5. RT Butterfly 500	.96*	.98*	.96*	.95*							
6. RT Rabbit 500	.96*	.97*	.95*	.93*	.96*						
7. RT Snake 500	.92*	.91*	.96*	.93*	.92*	.94*					
8. RT Spider 500	.95*	.94*	.97*	.97*	.95*	.94*	.95*				
9. Butterfly Fear Rating	.11	.10	.09	.07	.08	.09	.11	.08			
10. Rabbit Fear Rating	−.02	−.09	−.07	−.05	−.09	−.08	−.08	−.05	.12		
11. Snake Fear Rating	−.08	−.07	−.13	−.11	−.07	−.08	−.16	−.12	.21*	.19	
12. Spider Fear Rating	−.14	−.14	−.19	−.22*	−.14	−.16	−.23*	−.22*	.24*	.08	.54*

*$p < .05$. RT = Response time. 400 = 400 × 400 pixel starting size (far starting distance); 500 = 500 × 500 pixel starting size (close starting distance).

of the object. The current study tested how previously established human and object factors (i.e., mental strength and threat) influence the looming bias both independently and together in the visual modality.

Participants in the current study tended to demonstrate an overall looming bias, given that the average response time (RT) across all image types and starting distances was well below 2,000 ms. Although there is not a clear time-to-collision (TTC) or contact time since images disappeared on-screen and there was variance in the potential contact time given differences in perceived image content size (e.g., size of an average spider vs. size of a rabbit), this time was well below the time it would have taken for the images to fill up the computer screen had the images not disappeared on the screen while appearing to continue toward the participant (approximately 4,000 ms). However, the findings of the current study did not fully support the study's hypotheses as it relates to the influence of cognitive load on the looming bias. If the effect of cognitive load on the visual looming bias does exist, the results of the current study suggest it is small. Overall, participants tended to respond slightly faster to images under a high cognitive load compared with a low cognitive load, and this was the case across all image types and starting distances. However, differences in RTs across the cognitive load conditions were not significantly different. The trends observed in the current study are only partially in line with the findings of

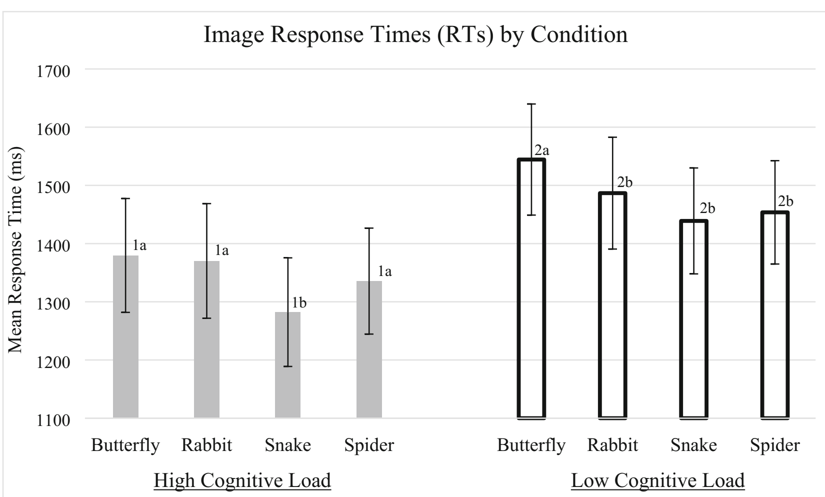

Fig. 1 Image response times by cognitive load condition. Image response times (RTs) include RTs from both the 400 × 400 pixel and 500 × 500 pixel starting distances. Ms = milliseconds; 1 = comparisons among the high cognitive load conditions; 2 = comparisons among the low cognitive load conditions. Error bars represent response time standard errors. Differences in letters after each number represent a significant difference in RTs for the two images (at $p < .05$ level). For example, in the high cognitive load condition, the RT for the snake image was significantly lower compared with the RTs for the butterfly, rabbit, and spider images

McGuire et al. (2016), who reported that individuals under a high cognitive load (i.e., cognitive or psychological vulnerability) exhibited a larger looming bias to auditory looming sounds, as compared with individuals under low cognitive load.

There were two competing hypotheses that could be made on the looming bias in the visual domain and the effects of cognitive load on it. On the one hand, individuals could be more accurate when determining the distance of approaching visual objects as compared with auditory ones because there is more attentional or cognitive resources to draw from (DeLucia et al., 2016; Lewis et al., 2000; Neuhoff, 2018). If this hypothesis was correct, then the looming bias in the visual domain should not have been influenced at all, or would only be minimally influenced, by a cognitive load. On the other hand, visual processing may require more conscious attention in order to properly attend to moving objects. If this hypothesis was correct, there should have been a notable differences in RTs between the load conditions as the cognitive load results in a stronger looming bias because individuals perceiving the approaching object would have less attentional resources to use. The findings from the current study are more in line with the former hypothesis, as small and nonsignificant trends in RTs were found between the conditions, such that there appears to only have been a small addition of bias or inaccurate perception with the addition of a high cognitive load or psychological vulnerability in the visual domain. These findings appear similar to those of DeLucia et al. (2016) and Neuhoff (2018), who both showed that individuals were able to determine the distance of visually approaching objects with more accuracy than auditory ones. In the current study, additional evidence for this theory may have also been observed given the overall lack of significant differences in RTs between each of the image types when comparing RTs across the low and high cognitive load conditions.

Moreover, results from the current study may suggest that visual processing is efficient, such that when individuals need to manage an additional cognitive task and have fewer available cognitive resources to draw from, they can still focus on approaching objects and accurately process perceived distance associated with the object. This may be associated with a natural preference toward visual, rather than auditory information, in processing environment stimuli. Thus, any available attentional resources may be automatically allocated to the information that is most helpful, which tends to be visual processing information. Support for this idea comes from DeLucia et al. (2016), who found that when participants judged approaching objects using auditory, visual, and auditory-visual cues, there appeared to be no added benefit for TTC judgements when having both auditory and visual information simultaneously. Moreover, the authors found that visual information was given more attention in judging approaching objects, as compared with auditory information.

An important distinction between the current study and many other studies on the looming bias is the presentation of stimuli. In most existing studies, researchers tend to combine auditory and visual looming stimuli when examining the visual looming bias in particular, such that there might be a tone or sound accompanying the visual looming stimulus (e.g., Cappe et al., 2009). In the current study, the looming bias in the visual domain was tested without accompanying auditory stimuli. The use of this approach helped to isolate the potential influence of a cognitive load on visually looming stimuli specifically, as opposed to it being unclear whether a cognitive load was influencing auditory stimuli, visual stimuli, or both. This is especially important to consider given the previous findings from McGuire et al. (2016) that cognitive load may influence the looming bias in the auditory domain. Moreover, the use of both auditory and visual looming stimuli simultaneously may have required more attentional resources, making it more challenging to determine whether it was the cognitive load or the need to focus on two stimuli that created a stronger looming bias. It may have been the case that having two sources of stimuli, combined with a cognitive load, would have created a larger looming bias because of a greater lack of cognitive resources, thus making the individual "more vulnerable." However, in following with the findings from DeLucia et al. (2016), it could also be the case the individuals would show a preference for the visual stimuli, thus there would be relatively small differences in perception with a cognitive load. Future studies should examine this possibility by further examining looming auditory and visual stimuli separately and together. This may provide a more accurate indication of potential differences in response behaviors when considering how attentional or cognitive resources influence looming bias strength.

In addition to examining the looming bias when participants might experience a psychological vulnerability, another goal of the current project was to examine the potential influence of combining multiple factors that may increase the strength of the looming bias. Previous research on the looming bias tends to examine individual and object characteristics separately; thus, it is largely not understood how factors associated with both the individual and the object interact to affect the looming bias (e.g., do they have an accumulative effect), or whether these factors will interact at all. The results of the current study partially support the idea that individual and object factors can interact to create an additive effect on the looming bias. This was demonstrated in part by the RT differences in some of the image types between the two load conditions. In the low cognitive load condition, participants responded to the butterfly image markedly slower than any other image type, and in the high load condition, participants responded to the snake image faster than all other images. However, the other observed differences between image types in each condition were small and nonsignificant. These findings only partially support the additive effect hypothesis. To achieve full support, it should have been observed that in both conditions, participants responded to the spider and snake images significantly faster than both the butterfly and rabbit images, and that RTs for all image types were significantly different from each other across the low cognitive load and high cognitive load conditions.

There are a few possible explanations for why the two factors in this situation appear to have created a small additive effect and the current study's patterns in RTs were observed, as opposed to a cancellation effect. One is that perceived threat from certain objects, such as spiders and snakes, are evolutionary in nature and hence override any other factors that may influence perception (Öhman & Mineka, 2003), especially in situations where these types of objects are looming. There is evidence to suggest that these types of threatening objects receive preferred processing when encountered in the environment (e.g., Masataka et al., 2018). As a result, attentional resources may be naturally directed to the processing of these types of objects, which may make the processing slightly more susceptible to the influence of cognitive load because there is a greater cognitive resource pool being used in the processing of these types of images. There is also evidence suggesting that snakes are perceived by humans as greater threats than spiders (LoBue & Rakison, 2013), which may in part explain why the snake images had faster RTs as compared with all other images in the high load condition, but the spider images did not and that these findings were not observed in the low cognitive load condition.

Another possible explanation associated with the combination of both a high cognitive load and threatening image is that this increased arousal, which may have created an additional affective component in the processing of the object. For example, there is some research suggesting that individuals under a higher cognitive load may experience more arousal (e.g., Jackson et al., 2014). There is also research indicating that an individual's emotions may influence looming bias strength (Gagnon et al., 2013; Riskind et al., 2014). This includes emotions that have been shown to influence arousal levels. For example, anxiety and fear have been shown to be associated with an increase in arousal, whereas depressive symptoms (as compared with anxiety) have been shown to be associated with lower arousal (e.g., Goddard et al., 2010; Kertzman et al., 2010). In the current study, it may have been the case that participants experienced greater anxiety and arousal as a result of exposure to the threatening objects and being under a cognitive load. Some additional support for this idea comes from the follow-up analysis examining the correlations between reported fear levels and RTs. For example, for the spider fear ratings, there was a significant small correlation between the fear ratings and the spider RTs, suggesting that greater fear of spiders was associated with shorter RTs (i.e., perceiving the object as being closer). However, this pattern (i.e., fear ratings for the image being associated with that image's RT) was only observed for spiders, and not for any of the other images. If these were to be robust findings, it would be expected that this same pattern would be observed with the snake's image fear rating and RTs, as well as possibly for the nonthreatening images. Furthermore, even for spiders, only one association between fear and RTs was significant at the 500 × 500 pixel starting distance. Overall, it is difficult to determine the potential role of arousal since arousal levels were not examined in the current study. Future research is needed to determine the exact role of arousal in the visual looming bias, as well as how various individual factors, such as worry and fear, may interact to influence arousal and the looming bias strength.

The results of the current study should be interpreted in light of its limitation. There was a lack of control stimuli or condition for which to examine more global differences in visual perception that may be influenced by cognitive load or visual stimuli. While nonthreatening images could be considered a control condition for threatening images, another control could have been neutral objects, such as a simple shape, as used in other visual looming studies (e.g., circle; Cappe et al., 2009). This could have helped ensure that the effect was not due to the images being arousing (creating positive or negative affect), or being complex (i.e., an animal is more complex than a shape; Rolls, 1991; Ullman, Vidal-Naquet, & Sali, 2002). A second limitation was the lack of a validated measure assessing the fear for each of the four different types of visual stimuli evoked, as a single question on fear for these types of images was used. There are some specific fear or phobia measures for spiders (e.g., Fear of Spiders Questionnaire; Szymanski & O'Donohue, 1995), but there are not well-validated measures for all the image types. The use of a multidimensional tool for measuring fear or a more specific tool of phobia to the image types may be useful in future research for determining the exact nature of how fear or threat may influence the looming bias. This might also include examining fear to specific types of objects, as well as more general fears and arousal. For example, this could involve using a measure of a more general fear of bugs (i.e., entemophobia; Lockwood, 2013) or general perception of threat, given the observed correlations in fear ratings between the bug images (spider, butterfly) and fear ratings among the threatening objects (spider, snake) in the current study.

Despite this limitation, the current study adds to the understanding of the looming bias, in addition to contributing information on human perception more generally, by examining the effects of a human factor (load) and object characteristic (threat), as well as their interaction, on this bias. The findings provide some support for both the margin-of-safety theory and the behavioral urgency hypothesis, such that individuals who are not as capable of handling an approaching threat (i.e., having a greater higher cognitive load), or are under a high cognitive load, may tend to perceive objects as being closer than they actually are. This provides these individuals with more time to respond in case of threat or danger (Neuhoff et al., 2012). Finally, the current study's findings also show that researchers studying the looming bias should take into account both object and individual factors, as these appear to interact during the processing of visual, approaching stimuli.

Author note None of the data or stimuli material of the study are available online; however, we will gladly provide them if requested. The experiment was not preregistered.

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