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Awe and Accommodation: Do Feelings of Awe Support a Shift from Schema-Driven to Stimulus-Driven Processing?

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by

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ABSTRACT

Awe and Accommodation: Do Feelings of Awe Support a Shift from Schema-Driven to Stimulus-Driven Processing?

by

Elliott Daniel Ihm

Feelings of awe are associated with experiences that are meaningful and sometimes life-changing. Awe is elicited by complex, information-rich stimuli that may challenge one's understanding of the world, leading to a process of accommodation in which cognitive schemas are updated. However, it is unclear whether awe plays a causal role in accommodation, and by what mechanisms this may occur. These studies investigate whether awe leads to reduced reliance on existing cognitive structures (schemas) and increased exploration, in the context of attention, memory, and problem-solving tasks. It was hypothesized that awe will be associated with reduced schema-driven and increased stimulus-driven visual attention (Studies 1 and 2); reduced false memory for schema-consistent information and enhanced recognition of schema-inconsistent information in visual scenes (Study 2); and abandonment of a learned but inefficient problem-solving strategy (Study 3). Awe was shown to increase bottom-up (stimulus-driven) visual attention, although no reduction in schema-driven attention was found. Awe also led to reduced false recognition on a visual memory task, although this was not specific to schema-consistent items as predicted. Finally, feelings of awe predicted reduced persistence with an inefficient strategy on a problem-solving task. These results provide some support for the hypothesis that awe increases stimulus-driven attention. Although further research is needed to clarify the roles of schema-driven and stimulus-driven attentional processes in accommodation, these studies are consistent with a role for awe in accommodative processes of attention, memory, and problem-solving.

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Feelings of awe are associated with profound and meaningful experiences (Ihm et al., 2020; Rivera et al., 2018; Van Cappellen & Saroglou, 2012). Recent research suggests that past experiences of awe are often understood as the catalysts for major changes in identity and worldview (Ihm et al., in prep). Awe has been linked to *accommodation*, a process by which one's current understanding of the world is modified in order to account for a new experience (Piaget, 1952; Keltner & Haidt, 2003). However, the cognitive mechanisms by which awe may facilitate accommodation are not well understood. These studies examine the possibility that feelings of awe lead to changes in attention and memory that may support accommodation.

A. Schemas and Accommodation

Awe appears to be triggered by stimuli that cannot be assimilated to existing cognitive structures, or *schemas* (Keltner & Haidt, 2003; Shiota, et al., 2007). The term 'schema' has a history of varied usage in psychology, related to several theories of mental organization (Bartlett, 1932; Mandler, 1984; Ghosh & Gilboa, 2014). Schemas are typically defined as associative cognitive structures, representing spatial and conceptual relationships at multiple levels of scale and abstraction**.** Schematic knowledge is learned by abstracted across many different experiences, and it guides behavior and cognition according to the current context, mediated by regions of the medial prefrontal cortex (mPFC) that link multimodal contextual associations with emotional and behavioral responses (Alexander & Brown, 2011; Euston et al., 2012; Roy et al., 2012). The influence of previously learned schematic associations can be seen on tasks ranging from spatial navigation (Hirtle & Jonides, 1985; Marchette et al., 2017) to problem-solving and decision-making (Chen & Mo, 2004; Gick & Holyoak, 1983;

Kumaran et al., 2009; Rosseel & Anseel, 2001). The activation of learned associations influences behavior through a variety of cognitive processes, including visual attention (Awh et al., 2012; Eckstein et al., 2006; Kim & Anderson, 2018; MacLean & Giesbrecht, 2015; Wolfe & Horowitz, 2017) and the encoding, consolidation, and retrieval of memories (Smith & Graesser, 1981; Kroes & Fernandez, 2012; Santangelo et al., 2015; Tse et al., 2007; van Kesteren et al., 2010b; Webb & Dennis, 2020).

Schemas thus shape our interactions with the world, and they are adjusted over time by our experiences. Piaget (1952) described the development of knowledge and intelligence in terms of two schematic operations: *assimilating* the environment to one's schemas, and *accommodating* one's schemas to the environment. Assimilation occurs when a new situation can be incorporated into one's existing schemas, allowing it to be recognized and appropriate action to be taken. However, if a novel situation cannot be assimilated to one's existing schemas, the schemas must be accommodated to the situation. That is, they must be adjusted in order to account for the novel experience.

B. (Need for) Accommodation in Experiences of Awe

Keltner and Haidt (2003) reviewed theoretical approaches to awe across disciplines and argued that the violation of existing schemas produces a *need for accommodation*, or a motivation to revise the schemas that failed to assimilate the awe-eliciting stimulus. To examine the nature of awe-eliciting stimuli, Shiota and colleagues (2007) asked undergraduate students to describe a recent experience of either awe or happiness. They found that experiences of awe, unlike happiness, were often triggered by complex, information-rich stimuli, such as panoramic natural vistas or novel works of art, further suggesting an association between awe and the need for accommodation.

Subsequent studies have demonstrated that experiences of awe, both retrospectively reported and experimentally induced, are associated with subjective appraisals of a need for accommodation (e.g., “My view of the world was challenged”; Gordon et al., 2017; Ihm et al., 2020). Awe has also been shown to be frequently associated with major life events and turning points, including traditional cultural events (e.g., marriage, birth, graduation), singular events of societal importance (e.g., 9/11 attacks), as well as unique or idiosyncratic events with personal significance (e.g., discovering a personal interest; Ihm et al., in prep; Pearsall, 2007), including many events which are regarded by individuals as formative of their worldview and identity (Ihm et al., 2020). Some of these events, such as the 9/11 terrorist attacks, may require accommodation because they deviate from expectations.[1] Other events, such as giving birth or a child’s graduation, are predictable but may still require accommodation insofar as they indicate changes in how a person relates to the world or other people.[2] Still other events, such as sunsets, may be described as awe-inspiring or “awesome” for aesthetic or other reasons, without an obvious need for accommodation.

Although the association between awe-eliciting experiences and the revision of schemas is suggestive, little is known about the mechanisms by which feelings of awe may support

[1] Examples from descriptions of awe-eliciting experiences of the 9/11 terrorist attacks:

P1: “Everything changed in an instant about what the world was. I no longer felt as safe as I did just hours before.”

P2: “’It's not real,’ you're thinking. ‘This doesn't happen in the United States.... Acts of war haven't happened [sic] here since 1865. It says so right here in this textbook.’ Except it WAS an act of war and it was happening right in front of my face… unthinkable, incomprehensible. And when you are 14, you don't really know what to do with that realization” (Ihm, Baas, & Schooler, in prep)

[2] Examples from descriptions of pregnancy (P3, P4) and graduation (P5):

P3: “I felt complete and powerful as I looked at her and promised her that I would take care of her always.”

P4: “I could not believe that he belonged to me.”

P5: “My daughter's [high school] graduation… I knew she would now be on her known [sic], there'll be no morning alarms or running for the school bus…” (Ihm, Baas, & Schooler, in prep) processes of accommodation. Tooby & Cosmides (2005) argue that the function of emotions is to solve the problem of "mechanism coordination," or to deploy the relevant domain-specific cognitive modules to deal with the current situation. However, in the face of a situation that cannot be assimilated to existing schemas, the appropriate response may be one of recalibration (Griskevicius et al., 2010). Therefore, the function of states of awe may be to facilitate the adjustment of schemas through accommodation. The evidence reviewed below suggests that awe may support changes in attention, memory, and problem-solving that are consistent with this functional account of awe. Three studies then investigate whether the elicitation, or 'reactivation' (Niedenthal, 2007), of feelings of awe in the laboratory is associated with reduced schema-driven and increased stimulus-driven processing.

II. Visual Attention

Attention has a reciprocal relationship with schemas. The allocation of attention guides the formation of schemas (Mandler, 2004, 2008), and schematic knowledge in turn influences how attention is directed (Eckstein et al., 2006; Wolfe & Horowitz, 2017). One potential mechanism by which feelings of awe may facilitate accommodation is by supporting an exploratory mode of attention that relies less on expectations derived from existing schematic knowledge.

A. Schema-Driven vs. Stimulus-Driven Visual Attention

Attention is guided by a combination of factors. *Stimulus-driven* attention refers to attention guided by the physical salience low-level stimulus features. In the case of visual attention, this includes properties such as color and intensity (Itti & Koch, 1998; Harel et al., 2006). *Schema-driven attention* refers to attention guided by previously learned associations.

Schematic information may influence visual attention through explicit goals or task instructions (i.e., goal-driven attention; Corbetta & Shulman, 2002; Vossel et al., 2014). But schematic associations may also influence attention through a number of other pathways, including as the spatial organization of a scene (Eckstein et al., 2006), its semantic characteristics (Henderson et al., 2009; Henderson & Hayes, 2017, 2018), and previous experience with a scene or objects within it (Awh et al., 2012; Henderson, 2017; Kim & Anderson, 2018; MacLean & Giesbrecht, 2015; Wolfe & Horowitz, 2017).

The contributions of stimulus-driven and schema-driven attentional processes can be compared using eye-tracking during visual tasks such as memorization and free-viewing. Patterns of visual fixation on images tend to correspond well with physical salience maps, which are generated based on the visual features of an image and the extent to which they stand out relative to adjacent parts of the image (Itti & Koch, 1998; Harel et al., 2006). Physical salience maps model a stimulus-driven process of attention, guided by low-level visual characteristics. However, additional variance in eye gaze patterns can be accounted for by maps of semantic salience, which model a schema-driven process by which attention is guided toward stimuli whose relevance is determined by existing knowledge and the present context (Eckstein et al., 2006; Henderson et al., 2009). In a study by Henderson & Hayes (2017), human subjects generated semantic salience maps by rating a number of small, overlapping patches from scenes for their "meaningfulness," defined in terms of informativeness and recognizability. They found substantial overlap across physical (stimulus-driven) and semantic (schema-driven) salience maps, but semantic salience maps accounted for an additional 19% of the variance in observed gaze patterns beyond the variance shared by physical and semantic salience maps. Physical and semantic salience maps can be considered predictions of gaze distributions driven by stimulus-driven and schema-driven attentional processes, respectively, and thus they can be used to estimate the contributions of each to the allocation of visual attention (Henderson & Hayes, 2017, 2018).

B. Awe and Attention

Keltner & Haidt (2003) proposed that awe-eliciting stimuli may be too vast or complex to be assimilated to existing schemas, leading to a need for accommodation. As discussed above, these claims have received some empirical support (Shiota et al., 2007; Gordon et al., 2017; Ihm et al., 2020).

Earlier psychological treatments of awe describe a state of exploratory, stimulus-driven mode of attention that may facilitate accommodation. Nico Frijda (1986) described states of “wonder” or “amazement,” in contrast to the “surprise” response that humans share with many other animals. Drawing on the work of Darwin (1872) and Dumas (1933), Frijda describes the state of wonder/amazement as “a passive, receptive mode of attention,” with eyes wandering toward peripheral stimuli. These observations were echoed by a series of experiments by Shiota and colleagues (2003), demonstrating that awe was associated with widening of the eyes, dropping of the jaw, and leaning forward, as if trying to extract as much information as possible from the current situation.

Neuroimaging evidence is also consistent with a shift from schema-driven to stimulus-driven attentional strategies during states of awe. While absorbed in an awe-eliciting video, van Elk and colleagues (2019) showed reduced activation in areas associated with schema-driven processing, such as posterior cingulate cortex/precuneus and left mPFC (Davey et al., 2016; Euston et al., 2012; Roy et al., 2012; van Kesteren et al., 2010). While watching the same videos and performing a counting task, awe was associated with reduced activation in bilateral insula and supramarginal gyrus, which are involved in stimulus-driven processing (Downar et al., 2000; Corbetta & Shulman, 2002).

These observations, linking feelings of awe with a stimulus-driven state of attention, suggest a mechanism by which awe may facilitate accommodation. The mode of attention associated with awe may be characterized by reduced guidance by existing schemas, such that schemas can be revised through increased guidance by low-level stimulus features. Studies 1 and 2 will investigate whether awe is associated with a reduction in schema-driven visual attention (i.e., reduced correlation between semantic salience maps and eye gaze patterns) and an increase in stimulus-driven visual attention (i.e., increased correlation between physical salience maps and eye gaze patterns).

III. Memory

Like attention, memory is also sensitive to the activation of schematic associations (Bless et al., 1996; Smith & Graesser, 1981; Bower et al., 1979; Santangelo et al., 2015). The influence of schemas on memory may be mediated by attentional processes described above, but schematic knowledge can also influence memory encoding, consolidation, and retrieval processes (Kroes & Fernandez, 2012). Another potential mechanism by which awe may support accommodation is through reduced reliance on these schema-driven memory processes.

A. Schema-Driven Memory

Memory involves an interplay between stimulus-driven and schema-driven processes (Kroes & Fernandez, 2012; Santangelo et al., 2015). The encoding and consolidation of new memories is supported by the prior existence of relevant schematic associations, which depend on activity and connectivity in a mPFC-hippocampal network (Kroes & Fernandez, 2012; Tse et al., 2007, 2011; van Kesteren et al., 2010a; Zeithamova et al., 2012). Memory retrieval is also influenced by the activation of schemas, supporting both true and false recollection of schema-consistent information (Roediger & McDermott, 1995), as well as recollection that is inconsistent with schemas (Smith & Graesser, 1981). Schema-driven memory processes involve neural activity which overlaps to varying degrees with the mPFC-hippocampal network identified above, in both true and false recollection of schema-consistent stimuli (Guo & Yang, 2020; Liu et al., 2020; van Kesteren et al., 2010b, 2012; Webb et al., 2016).

One example of schematic memory processing involves the presentation of words from a common category (e.g., furniture) on a memory task. In the Deese-Roediger-McDermott paradigm, non-presented words in that same category (critical lures) are presented at retrieval, and they tend to be falsely recognized and recalled nearly as often as the presented words are correctly remembered (Deese, 1959; Roediger & McDermott, 1995). These findings are parsimoniously explained in part by schema-driven processing within an associative model of memory, in which the presented words activate schemas that are associated with the critical lures, leading to false recognition and recall of those items.

Schemas that contain knowledge of a generic event such as ‘eating at a restaurant’ is represented in an event schema known a *script* (Schank & Abelson, 1977). The ‘eating at a restaurant’ script is segmented into sub-events or ‘scenes’ (e.g., ordering), which include specific actions, roles, and objects (e.g., reading the menu, talking to a waiter). Memory for such events can be influenced by prior schematic associations, such that unstated but schema-consistent actions can be falsely remembered, and actions presented out of their usual order are often remembered in a more schema-consistent order (Bower et al., 1979).

Bless and colleagues (1996) proposed that positive moods would be associated with increased schema-driven processing, arguing that positive affect indicates a favorable situation in which one’s current understanding is serving them well. On the other hand, they argued that negative moods would be associated with increased stimulus-driven processing, in the service of exploration and problem-solving to address the unfavorable situation that is indicated by negative affect. Bless and colleagues (1996) tested this hypothesis by inducing either a happy, sad, or neutral mood before participants listened to a story describing a common situation (‘eating at a restaurant’). In support of the view that positive moods increase schema-driven processing, participants in more positive mood conditions were more likely to falsely recall details of the story that were consistent with the ‘eating at a restaurant’ script. This suggests a bias toward schema-driven memory processing during positive moods, consistent with other studies that show relationships between positive affect and outcomes associated with schema-driven processing, such as false memory (Storbeck & Clore, 2005), stereotypes (Bodenhausen, Kramer, & Susser, 1994; Huntsinger, Sinclair, & Clore, 2009), and reliance on heuristics (Ruder & Bless, 2003).

B. Awe and Schema Reliance in a Memory Task

In contrast to the typical association between positive mood inductions and increased schema-driven processing, the elicitation of awe may be associated with reduced schema-driven and increased script-driven processing (Danvers & Shiota, 2017). Danvers and Shiota (2017) elicited awe, or one of several control emotions, using either a video or a guided imagery procedure. Participants then listened to a story about going out to a restaurant, adapted from Bless et al. (1996). They found that participants in the awe condition were the least likely to report false recognition of script-typical details, for instance whether a waiter poured wine. Danvers and Shiota argue that this reduction in false recognition is the result of reduced reliance on schema-driven processing – specifically, reduced reliance on the ‘eating at a restaurant’ event script – at encoding. Additionally, Danvers and Shiota found that participants in the awe condition scored higher on true recognition of details that were not specified by event scripts, for instance whether the waiter was wearing glasses, however a significant effect was only shown in one of three studies. This finding is somewhat consistent with an increase in stimulus-driven processing. Overall, the evidence from the memory paradigm of Danvers & Shiota (2017) is largely consistent with the idea that awe facilitates accommodation through a shift from schema-driven to stimulus-driven processing. Study 2 will adapt this paradigm to the visual modality and examine its relationship to schema-driven and script-driven attentional processes.

IV. Problem-Solving

The effects of awe on attention and memory suggest a mechanism by which schemas may be discounted and revised. But more evidence from behavioral paradigms is needed to confirm that awe causes accommodative changes in schemas. The influence of schemas on problem-solving tasks provides an avenue for investigating the potential role of awe in accommodation.

A. Schematic Influences on Problem-Solving

Previously learned strategies and associations influence people's approach to decision-making and problem-solving tasks. A classic example can be seen in Luchins' (1942) water jar task, in which participants are first trained to use a relatively inefficient strategy. Then participants complete a critical set of problems, which can be completed either by the learned, indirect solution or a novel, more direct solution. Analogical application of problem-solving strategies can be seen in a variety of problem-solving tasks, and the strength of schematic influences on learning and transfer depends on the amount and variety of examples experienced during learning (Chen & Mo, 2004; Gick & Holyoak, 1983; Qiu et al., 2008). These effects of schemas on problem-solving also appear to be mediated by activity in the prefrontal and hippocampal network implicated above, and they may involve a combination of implicit and explicitly goal-driven processes (Euston et al., 2012; Hobeika et al., 2016; Kumaran et al., 2009; Reber et al., 2014; Roy et al., 2012).

Activation of schematic knowledge has been shown to hinder creative problem-solving. Rosseel & Anseel (2021) asked marketing students to generate creative solutions to product design problems. Some participants were instructed to reflect on the strategy they were currently using to solve the task. These participants generated significantly fewer unique ideas than participants who did not reflect on the task, as well as those who reflected on both their current strategy and another possible strategy. Overall, these studies suggest that the influence of schema-driven processing on behavior may be measurable in the context of problem-solving tasks.

B. Awe and Schema Reliance in a Memory Task

Behavioral research on awe has largely focused on prosociality (Piff et al., 2015; Prade & Saroglou, 2016; Rudd et al., 2012), and on cognitive effects that may influence interpersonal behavior (Perlin & Li, 2020; Shiota et al., 2007; van Cappellen & Saroglou, 2012), a handful of studies have linked awe to cognitive and behavioral aspects of problem-solving more generally.

Griskevicius et al. (2010) investigated the effect of awe on persuasion, arguing that the idea that the evolutionary function of awe may be supportive of systematic and accommodative processing. Participants recalled (Study 1) and imagined (Study 2) one of many emotion-eliciting events. Those in the awe condition were less likely than those in other positive emotion conditions or a neutral condition to be persuaded by a weak argument. Study 2 offered limited support for an accommodative mechanism, such that this effect was mediated by a tendency for those in the awe condition to express reduced certainty in the outcome of the situation they were evaluating (e.g., whether comprehensive exams should be given to seniors at the University of Virginia), although this effect was only marginally significant. This suggests that reduced confidence in existing knowledge may lead to cognitive changes in the interpretation and evaluation of stimuli and their contexts, which may support accommodation, although it requires further confirmation and extension to behavioral paradigms.

If awe leads to the discounting and revision of schemas, creative problem-solving is likely to improve as a result, insofar as it requires the production of novel solutions that deviate from standard schematic information. Indeed, when Chirico et al. (2018) showed participants awe-eliciting videos in virtual reality, they went on to score significantly higher on the Torrance Tests of Creative Thinking. Those who saw an awe-eliciting (vs. neutral) VR video scored higher on all four aspects (fluency, flexibility, originality, and elaboration) of both the unusual uses and product improvement subtests. Study 3 will extend these findings from creative problems to problems with a single, objective solution, to determine whether awe facilitates abandoning a learned problem-solving strategy and shifting to a more optimal one.

V. The Current Studies

A growing body of evidence links experiences of awe with the accommodative revision of schemas (Ihm et al., 2020; Chirico et al., 2018; Gordon et al., 2017; Keltner & Haidt, 2003). It is possible that encountering an awe-eliciting stimulus that cannot be readily assimilated may instigate a shift from schema-driven to stimulus-driven processes of attention (Frijda, 1986; Shiota et al., 2003) and memory (Danvers & Shiota, 2017), which in turn may facilitate the revision of schemas.

To investigate this possibility, we used a visualization exercise in which participants vividly recalled a past emotional experience (Griskevicius et al., 2010; Zeelenberg et al., 1998). The goal was to reinstantiate, as much as possible, the neurocognitive state that occurred during the original experience (Niedenthal, 2007), potentially reintroducing a state of reduced reliance on schemas and increased exploratory attention. To control for effects of valence, we compared past experiences of awe with past experiences of amusement.

Study 1 examined the effects of awe on schema-driven vs. stimulus-driven attention, and Study 2 investigated whether these attentional processes support memory processes that discount schema-relevant information in favor of information that falls outside the scope of existing schemas. Finally, Study 3 examined the impact of awe on learned problem-solving strategies. It was hypothesized that awe will be associated with (1) increased stimulus-driven and reduced schema-driven allocation of visual attention, (2) reduced false recognition of schema-consistent information and increased true recognition of schema-inconsistent information, and (3) reduced perseveration with a learned but inefficient problem-solving strategy.

VI. Study 1: Effects of Awe on Visual Attention

The evidence described above suggests that awe may facilitate accommodation through an exploratory mode of attention, involving reduced reliance on existing schemas and increased attention to peripheral stimuli (Frijda, 1986; Keltner & Haidt, 2003; Shiota, et al., 2003). Study 1 examines whether feelings of awe, elicited by the recollection and visualization of a past experience of awe, lead to reduced schema-driven attention and increased stimulus-driven visual attention. Eye gaze patterns of participants who have been induced to feel either awe or amusement will be compared with models of schema-driven and stimulus-driven visual attention. Semantic salience maps will be generated by a separate sample of participants rating the "meaningfulness" of small circular patches of the images (Henderson & Hayes, 2017), and physical salience maps will be generated in Matlab based on low-level visual features of the images (Harel et al., 2006). It is predicted that gaze patterns in the awe condition will be more similar to the semantic salience maps, and less similar to the physical salience maps, than those in the amusement condition.

A. Method: Salience Maps

1. Participants

Fifty-eight undergraduate students at UCSB were recruited to rate the scene patches that were used to construct the semantic salience maps. Eleven participants were excluded from analyses for failing compliance checks ("catch" trials described below). All participants provided informed consent and were compensated with course credit.

2. Materials

Image patches were created from 60 images of real-world scenes (Figure 1), 1024x1024 pixels each (taken from Koehler et al., 2014). Each image was decomposed into 64 overlapping circular patches with diameters of 280 pixels, for a total of 3,840 patches (Henderson & Hayes, 2017). Scene patches were given a meaning rating on a 6-point Likert (1: *Very Low*, 2: *Low*, 3*: Somewhat Low*, 4: *Somewhat High*, 5: *High*, 6: *Very High*).

Figure 1. Example scene images used in Study 1 (Koehler et al., 2014).

3. Procedure.

Participants were instructed to rate a series of scene patches based on how informative or recognizable they were, using example patches shown in Figure 2 (Henderson & Hayes, 2017). Each participant was shown 300 randomly selected scene patches and 20 “catch” patches with very low meaning, which served as compliance checks (Figure 3). Participants who rated the meaning of any catch patch as more than 2 (Low), or who rated more than two patches as more than 1 (Very Low), were excluded from analyses.

Figure 2. Image patches presented in the instructions of Studies 1 and 2 as examples of very low (2A) and very high (2B) semantic salience or “meaning” (Henderson & Hayes, 2017).

(2A) Very low meaning (2B) Very high meaning

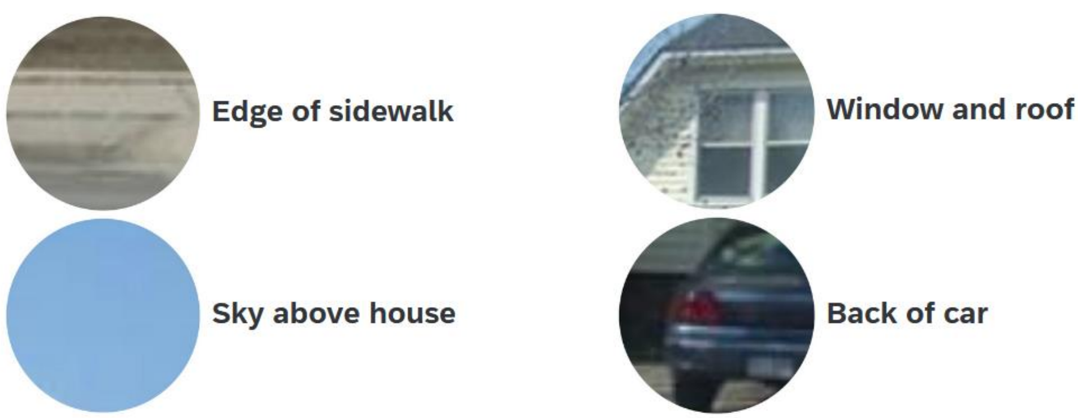
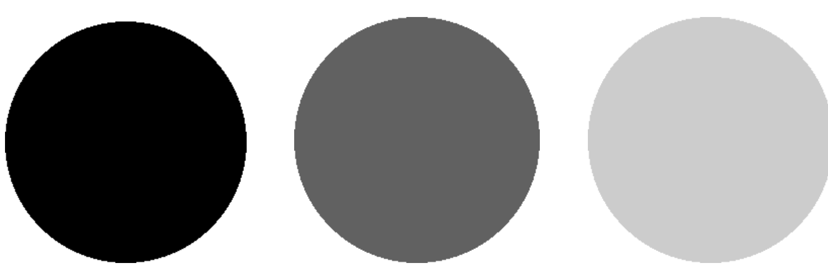


Figure 3. Catch trials with very low meaning. Participants who rated the meaning of any catch patch as more than 2 (Low), or who rated more than two patches as more than 1 (Very Low), were excluded from eye-tracking analyses in Studies 1 and 2.



A semantic salience map was constructed for each image by averaging and smoothing the ratings from its scene patches. Each pixel was first given a rating by averaging the ratings of all scene patches containing that pixel. These maps were then smoothed using a circular Gaussian low-pass filter with a -6dB cutoff, using code from the MIT Saliency Benchmark (https://github.com/cvzoya/saliency/blob/master/code_forMetrics/antonioGaussian.m).

A physical salience map was generated for each of the 60 scene images using the Graph-based Visual Saliency toolbox for Matlab (Harel et al., 2006). Each salience map was binned into a 64x64 matrix.

B. Method: Eye-Tracking

1. Participants

A power analysis conducted using G*Power software (Faul et al., 2007) indicated that 82 participants would be necessary to achieve 80% power to find a medium-sized effect using an independent samples *t*-test. Eighty-five undergraduate students at the University of California, Santa Barbara (UCSB) participated in the eye-tracking study. Six participants were excluded due to experimenter error or computer malfunction, and eight more participants were excluded because the eye tracker detected a signal less than 75% of the time on every trial. The remaining 71 participants had a mean age of 19.6 (SD = 1.4) and were 59% female (38 female, 26 male). All participants provided informed consent and were compensated with course credit.

2. Materials

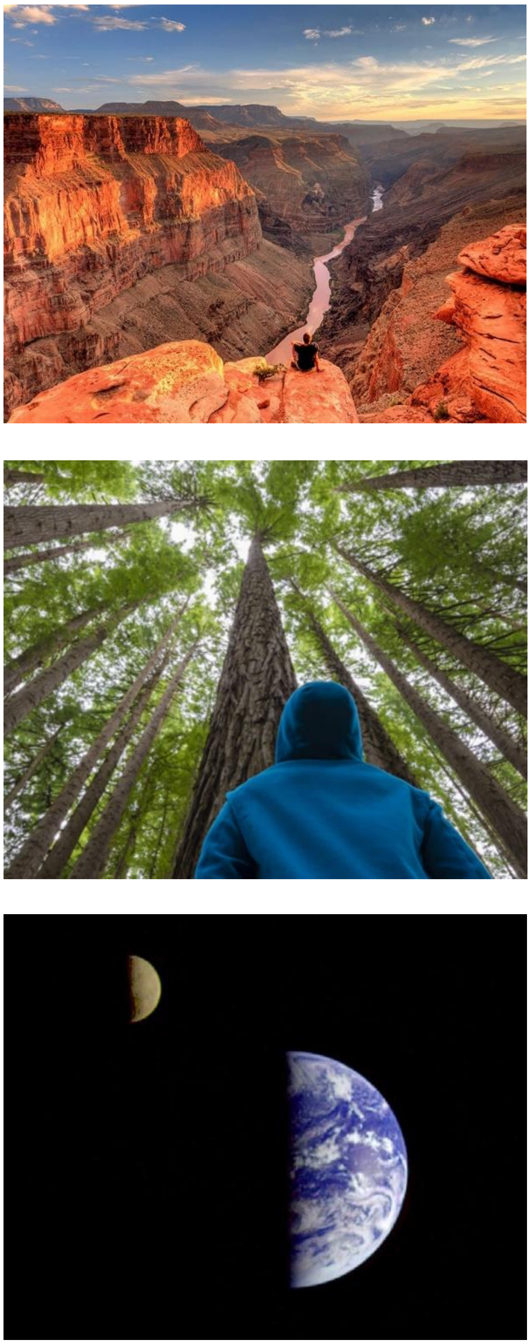
The emotion manipulation, in which participants vividly recall a past experience, was adapted from Griskevicius et al. (2010) and Zeelenberg et al. (1998). Participants were instructed to vividly recall and visualize a past experience of either “awe, wonder, or amazement” or “amusement”, and write a detailed description of a past experience in which they felt a strong sense of either awe or amusement, depending on their condition. This prompt included examples, such as “a natural scene like a view from a mountain” and “witnessing someone accomplish something great”, as well as a definition of either awe or amusement from Giskevicius et al. (2010), which emphasized the need for accommodation in the definition of awe (e.g., “Feeling amazed, as though your mind is stretching and your understanding of the world is expanding”; see Appendix for complete instructions).

The 60 scene images used to generate the meaning maps were used as the test images on which comparisons were performed. In addition to the test images, 14 ‘booster images’, seven to elicit awe and seven to elicit amusement, were included to reinforce the emotion manipulation (see Figure 4). Seven images of common awe-eliciting stimuli, such as natural landscapes, were taken from online search engines and databases, to be shown among the test images to participants in the awe condition (but not analyzed). Similarly, seven images that had been shown to produce high levels of arousal and positive valence, such as smiling children and a puppy in a teacup, were taken from the Open Affective Standardized Image Set (OASIS; Kurdi et al., 2017) to be shown in the amusement condition. Images were presented to participants using a Tobii XT300 Eye Tracker (Tobii Technology, Inc., 2014).

As a manipulation check, we asked participants to rate how much awe they felt while they were recalling their past experience, on a 7-point Likert scale from 1 (*Not at all)* to 7 (*Very much*), with a middle anchor of 4 (*Somewhat*). To determine whether the Awe and Amusement conditions varied in the amount of positive affect they produced, we asked participants how they felt while recalling their past experience, on a 7-point Likert scale form 1 (*Very positive*) to 7 (*Very negative*), with a middle anchor of 4 (*Neutral*).

Figure 4. Examples of booster images that were presented alongside test images to enhance the emotion manipulation in the Awe (4A) and Emotion (4B) conditions of Studies 1 and 2.

(4A) Awe booster images



(4B) Amusement booster images

3. Procedure

Participants were randomly divided into two conditions, Awe and Amusement. Each participant was asked to vividly recall and write a detailed description of a past experience in which they felt a strong sense of awe or amusement, depending on their condition (see Appendix for complete instructions). They were given as much time as they needed to complete the description. All participants took less than 20 minutes to complete the emotion manipulation.

Next, participants were guided through nine-point calibration of the eye tracker. They then completed a free-viewing task, in which they were instructed to look naturally at a series of images. The images were presented for three seconds each, but presentation of images was self-paced so participants could orient to a fixation cross in the center of the screen before seeing each image. After a practice round of six images, the experimenter left the room and each participant viewed a series of 60 test images, presented in ten blocks of six images, with one of seven booster images (awe or amusement) presented before each block in random order. Finally, participants completed the final set of manipulation check, imagination, and demographics questions.

C. Results

As described above, eight participants were removed because the eye tracker registered a signal less than 75% of the time for all scene images, leaving 71 participants total, 35 in the Awe condition and 36 in the Amusement condition. Remaining participants had an average of 36 trials with 75% signal or above. A two-tailed[3] independent samples *t*-test showed that participants in the Awe condition (*M* = 41, *SD* = 18) had more trials with 75%

[3] All subsequent *t*-tests were two-tailed.

signal or above than did those in the Amusement condition (*M* = 31, *SD* = 20; $t(69) = 2.08$, $p = .041$, $d = 0.50$). Procedures for dealing with differential dropout are described below.

1. Manipulation Checks

To assess the success of the awe manipulation, independent samples *t*-tests were used to compare the Awe and Amusement conditions on self-reported awe and affective valence (positive to negative). Due to missing data, two participants were excluded from these analyses. Participants in the Awe condition reported higher levels of awe (*M* = 5.7, *SD* = 1.1) than those in the Amusement condition (*M* = 3.4, *SD* = 1.9), $t(67) = 6.02$, $p < .001$, $d = 1.45$. Self-reports of affective valence during the manipulation did not significantly differ between the Awe (*M* = 1.5, *SD* = 0.76) and Amusement (*M* = 1.8, *SD* = 0.94) conditions, $t(67) = -1.54$, $p = 0.13$.

2. Salience Maps

Because differential dropout could artificially alter properties of gaze distributions (e.g., increasing dispersion), group differences in properties of the gaze distribution were analyzed by two complementary methods: (1) comparing images, by plotting the gaze distribution of all participants in a given condition, and (2) comparing participants, plotting each participant's gaze distribution separately. Gaze maps were created by binning all fixations for each image into a 64x64 probability distribution, both across each condition and individually, then smoothing using a Gaussian filter.

To determine the amount of variance in eye gaze patterns that was explained by semantic and physical salience maps in each condition, squared linear correlations were computed for each image's attention map and its corresponding semantic and physical salience maps. Semantic salience maps accounted for an average of 16.1% of variance per image in the Awe (*SD* = 0.09) condition and 15.5% of variance per image in the Amusement

(*SD* = 0.10) condition. A paired samples *t*-test showed no significant difference between conditions in the amount of variance explained by semantic salience maps, $t(69) = 1.16$, $p = 0.25$. At the individual level, semantic salience maps accounted for an average of 5.8% of variance in the Awe condition (*SD* = 0.013) and 6.4% of variance in the Amusement condition (*SD* = 0.025), and a paired samples *t*-test showed no significant difference, $t(69) = -1.25$, $p = 0.22$.

Physical salience maps accounted for an average of 28% of variance per image in the Awe condition (*SD* = 0.12) and 27% of variance per image in the Amusement condition (*SD* = 0.12). A paired samples t-test showed that this difference was not statistically significant, $t(69) = 0.82$, $p = 0.42$. At the individual level, physical salience maps accounted for an average of 10.3% of variance per participant in the Awe condition (*SD* = 0.024) and 9.6% of variance per participant in the Amusement condition (*SD* = 0.027). An independent samples t-test showed that this difference was not significant, $t(69) = 1.14$, $p = 0.26$.

D. Discussion

Although the awe manipulation was successful, hypotheses that awe would reduce schema-driven attention and increase stimulus-driven attention were not supported. Semantic and physical salience maps constitute predictions of the schema-driven and stimulus-driven patterns of visual attention, respectively. There were no differences between the Awe and Amusement conditions in the amount of variance in gaze patterns explained by semantic or physical salience maps, either at the level of images or participants.

One potential explanation for the lack of significant differences is the task-free nature of the free-viewing task. Any set-breaking effects of awe may have been minimal in the absence of task instructions requiring schema-driven attention, and the lack of a shared attentional set may add noise to the data. Study 2 addresses these concerns by replacing the free-viewing task with a memory task, which also allows the effects of awe on memory to be assessed.

VII. Study 2: Awe, Attention, and Memory

The effects of awe on attention may lead to downstream effects on memory encoding and recollection. Study 2 conceptually replicates Study 1 using a recognition memory task, giving participants a shared set of task demands. Additionally, Study 2 examines whether changes in the allocation of visual attention are associated with changes in recognition memory performance. Danvers & Shiota (2017) found that awe led to a reduction in false recognition of script-typical details of a story about a prototypical event. They also found an increase in true recognition of script-irrelevant details, but only in one out of three studies. These findings are consistent with a reduction in schema-driven processing and an increase in stimulus-driven processing, respectively. Study 2 extends this approach into the visual modality by presenting images of scenes, which contain objects that are either consistent or inconsistent with the overall context of the scene. It is predicted that participants in the awe condition will be less likely to falsely recognize schema-consistent objects that were not present in the image (i.e., critical lures), and more likely to correctly recognize schema-inconsistent objects that were present, similarly to the findings of by Danvers & Shiota (2017). It is also predicted that these effects will be mediated by the attentional changes predicted in Study 1, namely reduced correspondence of gaze patterns with semantic salience maps, and increased correspondence with physical salience maps, among participants in the awe condition.

A. Method: Salience Maps

1. Participants

Two hundred and one undergraduate students at UCSB were recruited to rate the scene patches that were used to construct the semantic salience maps. Nineteen participants were excluded from analyses for failing compliance checks. All participants provided informed consent and were compensated with course credit.

2. Materials

Image patches were created from 35 images of household scenes with multiple objects (Figure 5), 1080 x 712 pixels each (taken and resized from Santangelo et al., 2015). Images were divided into five schema-based groups of seven images each, based on the scene depicted in the image (Kitchen, Desk, Bathroom, Living Room, and Child's Room). Each image contained multiple schema-consistent objects (e.g., a stack of plates in a kitchen; Figure 5A). Twenty of the images also contained one schema-inconsistent object (e.g., a pepper grinder in a bathroom; Figure 5B). For true recognition trials, an object was extracted from 24 of the test images and placed on a grey background as stimuli for the recognition task. Twelve of the objects were schema-consistent, and twelve were schema-inconsistent. For false recognition trials, objects were similarly extracted from 24 more images taken from Santangelo et al. (2015). Twelve contained objects associated with the schemas that the test images were chosen to elicit (critical lures, e.g., a TV remote for the Living Room schema). Twelve more contained objects that were not generally included in any of the test image schemas (e.g., a watering can).

Each scene image was decomposed into 96 overlapping circular patches with diameters of 203 pixels, for a total of 3,360 coarse-scale patches, and separately into 291 patches with diameters of 86 pixels, for a total of 10,290 fine-scale patches (Henderson & Hayes, 2017). Scene patches were given a meaning rating as in Study 1.

Figure 5. Example scene images used in Study 2 (Santangelo et al., 2015). 5A: Images containing only schema-consistent objects. 5B: Images containing a schema-inconsistent object.

(5A) Study 2 images, schema-consistent objects only

(5B) Study 2 images with schema-inconsistent object

3. Procedure

The procedure for generating semantic and physical salience maps was identical to Study 1, with two exceptions. Images had a different resolution and were therefore binned into 80x53 rather than 64x64 matrices. To increase the granularity of predictions for stimulus-driven attention, we collected ratings for both coarse-grained and fine-grained patches of each image, which were combined to generate semantic salience maps (Henderson & Hayes, 2017).

B. Method: Eye-Tracking and Memory Test

1. Participants

Based on the same power analysis used in Study 1, Eighty-six undergraduate students at UCSB were recruited for the eye-tracking study. Three participants were excluded from analyses due to experimenter error or computer malfunction. The remaining 83 participants had a mean age of 18.7 (*SD* = 1.2) and were 70% female (58 female, 24 male, 1 agender). All participants provided informed consent and were compensated with course credit.

2. Materials

In addition to the 35 scene images used to generate the meaning maps, ten of the 'booster images' used in Study 1 were included, both to reinforce the emotion manipulation and to occupy participants' visual attention and working memory during the delay between the encoding and retrieval phases of the memory task. The eye tracker was the same as used in Study 1. Manipulation check items were the same as used in Study 1.

3. Procedure

The emotion manipulation was identical to Study 1. Participants were guided through nine-point calibration of the eye tracker. They then completed a five-round memory task, beginning with one additional practice round. In each round, they were shown a series of seven images for two seconds each. All images in a round were associated with the same scene schema (e.g., kitchen). As a filler task, participants were then shown a booster image for 8 seconds, designed to elicit either awe or amusement according to each participant's condition, and instructed that this image would not be tested. Each round ended with 9-10 recognition memory trials, in which participants were presented with an isolated object and used the keyboard to indicate whether it had been present in the test images. Trials were counterbalanced to include a roughly equal number of schema-consistent, schema-inconsistent, previously presented (old), and non-presented (new) objects. Finally, participants completed the final set of manipulation check, imagination, and demographics questions.

C. Results

1. Manipulation Checks

To determine the success of the awe manipulation, independent samples *t*-tests were used to compare the Awe and Amusement conditions on self-reported awe and affective valence (positive to negative). Participants in the Awe condition reported higher levels of awe (M = 5.5, SD = 1.2) than those in the Amusement condition (M = 4.2, SD = 1.9), $t(81)$ = 3.68, $p < .001$, d = 0.81. Self-reports of affective valence during the manipulation did not significantly differ between the Awe (M = 1.8, SD = 1.0) and Amusement (M = 1.8, SD = 1.0) conditions, $t(81)$ = -0.19, p = 0.85.

2. Memory Test

To determine whether there was an effect of emotion condition on false recognition of schema-consistent objects, an independent samples *t*-test was used to compare the number of critical lures (i.e., schema-consistent but non-presented items) that were falsely recognized (out of 12). Participants in the Awe condition (M = 4.6, SD = 2.7) falsely recognized significantly fewer of the critical lures than those in the Amusement condition (*M* = 5.8, *SD* = 2.69), *t*(81) = -2.09, *p* = 0.039, *d* = 0.46. To determine whether this reduced rate of false positives was restricted to schema-consistent objects as predicted, another *t*-test was used to compare the overall number of false positives (out of 24 possible). Participants in the Awe condition (*M* = 6.2, *SD* = 3.5) falsely recognized significantly fewer non-presented items than those in the Amusement condition (*M* = 8.5, *SD* = 4.4), *t*(81) = -2.61, *p* = 0.011, *d* = 0.57. There was one outlier in the overall number of false positives (>3 SDs above the mean). After removing him from the dataset, the difference between conditions in false positives remained significant, *t*(80) = -2.40, *p* = 0.019, *d* = 0.53, but the predicted difference in false recognition of critical lures was only marginally significant, *t*(80) = 1.90, *p* = 0.062[4], *d* = 0.42.

To determine whether there was an effect of emotion condition on true recognition (i.e., hit rate) of schema-inconsistent objects, an independent samples *t*-test was used to compare the number of hits on schema-inconsistent trials (out of 12). Participants in the Awe condition (*M* = 8.0, *SD* = 2.2) did not differ significantly from those in the Amusement condition (*M* = 8.1, *SD* = 2.1) in the number of schema-inconsistent hits, *t*(81) = -0.10, *p* = 0.919[5].

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[4] To further explore whether this difference in false recognition was a function of schema-consistency, a two-way repeated measures ANOVA was conducted, with stimulus type (schema-consistent vs. schema-inconsistent) as a within-subjects factor, emotion condition (Awe vs. Amusement) as a between-subjects factor, and false positives as the dependent variable. Although there were main effects of stimulus type, such that schema-inconsistent objects were falsely recognized less often than schema-consistent objects, [*F*(1,80) = -106.8, p < .001], and emotion condition, such that there were fewer false positives in the Awe condition [*F*(1,80) = -5.7, *p* = .019], there was no interaction between stimulus type and emotion on false recognition [*F*(1,80) = -0.50, *p* = .480].

[5] To further explore potential interactions between schema consistency type and emotion condition, a two-way repeated measures ANOVA was conducted, with stimulus type (schema-consistent vs. schema-inconsistent) as a within-subjects factor, emotion condition (Awe vs. Amusement) as a between-subjects factor, and hit rate as the dependent variable.

Independent samples t-tests were performed to determine whether the manipulation influenced overall discriminability and criterion (bias) in the memory task. Hit rates and false alarm rates were standardized among all participants except the outlier. Participants in the Awe condition had marginally higher discriminability (M = 0.22, SD = 1.1) than those in the Amusement condition (M = -0.21, SD = 1.2), $t(80) = 1.73$, $p = 0.088$, $d = 0.38$, indicating marginally better overall recognition memory performance. Participants in the Awe condition also had a marginally higher criterion (M = 0.15, SD = 0.82) than those in the Amusement condition (M = -0.15, SD = 0.80), $t(80) = 1.67$, $p = 0.099$, $d = 0.37$, indicating a greater bias toward rejecting stimuli (correctly or incorrectly)[6].

3. Eye-Tracking

Fourteen participants were removed because the eye tracker registered a signal less than 75% of the time for all scene images, leaving 69 participants total, 33 in the Awe condition and 36 in the Amusement condition. Remaining participants had an average of 21 trials with 75% signal or above. An independent samples t-test showed that there was no significant difference between Awe (M = 20.8, SD = 11.2) and Amusement (M = 21.9, SD = 10.6) conditions in the number of acceptable trials per participant, $t(67) = -0.42$, $p = 0.68$.

Gaze maps were created as in Study 1, except that images were binned into an 80x53 matrix. To determine the amount of variance in eye gaze patterns that was explained by

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Although there was a main effect of stimulus type, such that schema-inconsistent objects were correctly recognized more often than schema-consistent objects [$F(1,80) = 12.2$, p = 0.001], there was no main effect of emotion condition on hit rate, [$F(1,80) = 0.14$, $p = 0.71$], and there was no interaction between stimulus type and emotion on hit rate [$F(1,80) = -.01$, $p = 0.92$].

[6] Discriminability and bias were also computed separately for schema-consistent and schema-inconsistent objects. Participants in the Awe condition had marginally higher discriminability for schema-consistent objects than those in the Amusement condition, [$t(80) = 1.67$, $p = 0.098$], but there was no effect of condition on discriminability on schema-inconsistent objects ($p = 0.16$), or on criterion for schema-consistent ($p = 0.22$) or schema-inconsistent objects ($p = 0.14$).

semantic and physical salience maps in each condition, squared linear correlations were computed for each image's attention map and its corresponding semantic and physical salience maps.

Semantic salience maps accounted for an average of 18% of variance per image in both the Awe (M = 0.18, SD = 0.12) and Amusement (M = 0.18, SD = 0.13) conditions. A paired samples t-test showed no significant difference between conditions, $t(34) = -0.384$, $p = 0.70$. At the individual level, semantic salience maps accounted for an average of 10.3% of variance in the Awe condition (SD = 0.029) and 10.1% of variance in the Amusement condition (SD = 0.025), and a paired samples t-test showed no significant difference, $t(67) = 0.234$, $p = 0.82$.

Physical salience maps accounted for an average of 27% of variance per image in the Awe (SD = .14) condition and 24% of variance per image in the Amusement (SD = 0.15) condition. A paired samples t-test showed that this difference was statistically significant, $t(34) = 2.97$, $p = 0.005$[7], $d = 0.18$. To account for potential biases in image-level estimates due to missing data, the average variance explained by salience maps was computed for each participant, averaging across all images with 75% signal or above. Physical salience maps accounted for an average of 16% of variance per participant in the Awe condition (M = .16, SD = .03) and 13% in the Amusement condition (M = .13, SD = .04). A two-tailed independent samples t-test showed that this difference was significant, $t(67) = 3.47$, p = .001, $d = 0.84$. To ensure that this difference was not an artifact of differential dropout, given the relatively high variability across images in variance explained by salience maps,

[7] To examine whether differences in gaze maps across each condition may have been driven by differential dropout, gaze maps were recomputed for each image by resampling n-1 participants from each condition, where n is the number of participants in the condition with the fewest participants with acceptable signal quality (>75%). Resampling was performed five times and the t-test remained significant, with p-values ranging from .022 to .00078.

standardized estimates were obtained by creating z-scores for each participant on each image, and averaging these z-scores across all images with 75% signal or above. An independent samples *t*-test showed that the difference remained significant, $t(67) = 2.71$, $p = 0.009$, $d = 0.65$, such that salience maps explained significantly more variance for participants in the Awe condition ($M = 0.19$, $SD = 0.47$) compared to the Amusement condition ($M = -0.13$, $SD = 0.52$).

4. Memory and Attention

To determine whether group differences in memory performance were related to differences in visual attention, a mediated regression was performed using the PROCESS macro (Model 4; Hayes, 2018), with Condition as the IV, each participant's number of correct rejections as the DV, and variance explained by physical salience maps as the mediator. The indirect path from Condition to correct rejections was not significant[8] ($\beta = 0.15$, CI [-.06, .41]).

D. Discussion

The awe manipulation was successful, and hypotheses about the effects of awe on attention and memory were partially supported. Consistent with the findings of Danvers & Shiota (2017), participants in the Awe condition showed reduced false recognition (or increased correct rejection) of schema-consistent items compared to those in the Amusement condition, although this finding did not reach statistical significance after an outlier was removed. However, there was stronger evidence for a group difference in overall false recognition when both schema-consistent and schema-inconsistent items were included, such that those in the Awe condition had a lower overall rate of false alarms. This effect

[8] Results did not substantially change when excluding the outlier on correct rejections, $\beta = 0.07$, CI [-.14, .33].

may relate to awe-related changes in discriminability or bias, which were both marginally higher in the Awe condition. An increase in discriminability reflects an overall increase in the ability to discern presented from non-presented items, which would be consistent with increased stimulus-driven processing during encoding and reduced schema-driven processing during retrieval. An increase in criterion reflects a bias toward rejections (i.e., misses and correct rejections), which may reflect a reduction in confidence that would be consistent with reduced reliance on one's current knowledge during retrieval.

Physical salience maps predicted gaze patterns in the Awe condition significantly better than in the Amusement condition, both at the level of images and participants. This is consistent with an awe-related increase in bottom-up, stimulus-driven attention, in keeping with Frijda's (1986) hypothesis that awe is associated with an exploratory mode of attention. Although this effect was not observed in Study 1, it is possible that the shared set of task demands (not present in the free-viewing task used in Study 1) made it more likely that awe-related set-breaking effects would be observed. However, the observed increase in stimulus-driven patterns of visual attention were not related to differences in memory performance between conditions. Finally, semantic salience maps did not perform significantly better at predicting gaze patterns in either condition, providing no support for the prediction that awe would be associated with reduced schema-driven attention.

VIII. Study 3: Awe and Accommodative Problem-Solving

Study 3 examines a potential downstream behavioral consequence of awe-related shifts in attention and memory processes: deviation from a learned but inefficient problem-solving strategy. Previous research suggests that the cognitive effects of awe may influence decision-making and behavior (e.g., Griskevicius et al., 2010; Piff et al., 2015), including increased flexibility and originality on creative problem-solving tasks (Chirico et al., 2018).

Participants will learn a reliable but inefficient problem-solving strategy in Luchins' (1942) classic water jug task. It is predicted that participants in the awe condition will be more likely to discover a novel but more efficient problem-solving strategy after it becomes available.

A. Method

1. Participants

A power analysis conducted using G*Power software (Faul et al., 2007) indicated that 134 participants would be necessary to achieve 80% power to find a medium-sized effect using a nonparametric Mann-Whitney U Test. One hundred and sixty-four undergraduate students at UCSB participated in this study. Nine participants were excluded from analyses due to experimenter error or computer malfunction. The remaining 155 participants had a mean age of 19.5 (*SD* = 2.0) and were 57% female (88 female, 67 male). All participants provided informed consent and were compensated with course credit.

2. Materials

A computerized version of the Luchins water-jar task was set up using Inquisit (Millisecond Software, 2015; code adapted from https://www.millisecond.com/download/library/LuchinsWaterJugTask/). Stimuli consisted of nine algebra-based water-jar problems. Each problem involved filling a jar with a specific amount of water using multiples of three other jars. For example, "Given 3 containers of capacities 12, 40, and 5 gallons, how can exactly 18 gallons be measured out?". The task begins with a training (set-inducing) phase, consisting of six problems for which the simplest solution was relatively indirect, requiring adding the second jar, then subtracting the first jar and two of the second jar (i.e., B – A – 2C), as in the example above. Then there is a test phase, consisting of three critical problems (α = .76) on which either the convoluted solution or a more direct solution could be used (A – C). The number of critical problems solved using the indirect solution was used as a measure of perseveration on the original problem-solving strategy. Items assessing the success and vividness of the emotion manipulation were identical to those in Studies 1 and 2.

3. Procedure

Participants first completed the training phase of the water-jar task. Next, participants completed the same emotion manipulation used in Studies 1 and 2. Participants then completed the test phase of the water-jar task. Finally, participants answered questions about their feelings during the emotion manipulation.

B. Results

1. Manipulation Checks

To determine the success of the awe manipulation, independent samples *t*-tests were used to compare the Awe and Amusement conditions on self-reported awe and affective valence (positive to negative). Participants in the Awe condition reported higher levels of awe ($M = 5.5$, $SD = 1.3$) than those in the Amusement condition ($M = 3.9$, $SD = 2.0$), $t(152) = 6.16$, $p < 0.001$, $d = 0.99$. Self-reports of affective valence during the manipulation did not significantly differ between the Awe ($M = 2.1$, $SD = 1.2$) and Amusement ($M = 2.0$, $SD = 1.2$) conditions, $t(152) = 0.72$, $p = 0.47$.

2. Water-Jar Task

To determine whether the Awe and Amusement groups differed in perseveration on the indirect problem-solving strategy, a nonparametric independent samples Mann-Whitney U Test was used due to a strong positive skew in perseveration scores. Although participants in the Awe condition ($M = 0.44$, $SD = 0.91$) had numerically lower mean scores on perseveration than those in the Amusement condition ($M = 0.49$, $SD = 0.87$), there was no significant difference between the two conditions, $U = 2470$, $p = 0.42$[9]. However, nonparametric Spearman correlations showed a significant relationship between self-reported awe and perseveration across all participants ($\rho = -0.30$, $p < 0.001$), as well as within the Awe condition ($\rho = -0.35$, $p = 0.002$), and within the Amusement condition ($\rho = -0.26$, $p = 0.027$)[10], indicating that participants who reported higher levels of awe were less likely to maintain the learned but inefficient strategy on the water-jar task. In contrast, perseveration was not significantly correlated with self-reported amusement ($\rho = -0.13$, $p = 0.12$) or positive affect ($\rho = 0.13$, $p = 0.13$) during the emotion induction[11].

C. Discussion

Although the awe manipulation was successful, participants in the Awe condition were not significantly less likely to perseverate on the indirect problem-solving strategy, failing to support the central hypothesis relating awe to set-breaking. However, there was a significant correlation between awe and perseveration, such that participants across both conditions who reported feeling more awe were more likely to deviate from the inefficient problem-solving strategy that was established in during the training phase. No such association was found for amusement or general positive affect, suggesting that the association with perseveration was specific to feelings of awe rather than other dimensions of affect or task engagement. Thus, there was some support for the existence of an association between feelings of awe and set-breaking, a behavioral manifestation of the accommodative revision of schemas.

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[9] Results did not substantially differ when an independent samples *t*-test was used.

[10] Pearson correlation results were comparable across all participants ($r = -0.22$, $p = 0.009$) and in the Awe condition ($r = -0.27$, $p = 0.021$), however it was only marginally significant in the Amusement condition ($r = -0.22$, $p = 0.065$).

[11] Pearson correlation results were comparable for amusement ($r = -0.10$, $p = 0.21$), and positive affect ($r = -0.10$, $p = 0.24$).

IX. General Discussion

Psychological studies of awe increasingly point toward a role in accommodation: adjusting cognitive schemas in order to assimilate a novel, complex stimulus (Frijda, 1986; Gordon et al., 2017; Keltner & Haidt, 2003; Shiota et al., 2003, 2007). This may be accomplished in part by a shift from schema-driven to stimulus-driven attention and cognition (Chirico et al., 2018; Danvers & Shiota, 2017; Frijda et al., 1986). The current research aimed to clarify the relationship between awe and processes of visual attention, memory, and problem-solving that may support accommodation. Studies 1 and 2 examined whether awe is associated with reduced schema-driven and increased stimulus-driven visual attention.

Study 1 showed no effects of an awe manipulation on the correspondence between gaze patterns and predictions based on either semantic or physical salience in a free-viewing task. The lack of a significant finding may have been due in part to the relatively task-free nature of the free-viewing task, which may reduce signal and add noise compared to a task where participants share a goal set. Study 2 examined the same outcomes as Study 1 using images presented during a recognition memory task. Participants in the Awe condition showed a significantly greater correspondence of gaze patterns with predictions based on physical salience, determined by low-level visual features. This is consistent with an increase in stimulus-driven attention (Henderson & Hayes, 2017, 2018). This finding follows from Frijda's (1986) hypothesis that awe is associated with an exploratory mode of attention, and it adds to a growing body of research supporting Keltner & Haidt's (2003) argument that awe may facilitate accommodation (Gordon et al., 2017; Ihm et al., 2020; Shiota et al., 2007). Future research could apply neuroimaging to determine whether this effect is driven by activity in salience-related regions (Vossel et al., 2014) or by widespread changes in cortical excitability (Kosciessa et al., 2021), as well as to examine whether changes in stimulus-driven processing interact with higher-level schema-driven processes that integrate this low-level sensory information (Santangelo & Macaluso, 2013).

Study 2 showed no effect of awe on the ability of semantic salience maps to predict gaze patterns, failing to support a reduction in schema-driven processing associated with awe. Although semantic salience maps reflect more abstract, higher-order information than physical salience maps – i.e., they are based on judgments of conceptual meaning rather than low-level perceptual in information – it is possible that awe is associated with a more pronounced reduction in schema-driven processing at higher levels of schematic abstraction, such as overall scene context or explicit strategies and goals. Our finding that awe influenced stimulus-driven processing in a memory task, but not in a free-viewing task, also suggests that the effects of awe may vary depending on what high-level schemas or goals are operative in a given situation. Future research should consider a wide-range of schema-driven processes and task demands to clarify the mechanisms by which awe may discount existing knowledge and increase exploratory, stimulus-driven processing. For example, contextual salience maps could be generated by rating salience in reference to the overall context of a scene, rather than to isolated image patches (Henderson & Hayes, 2017), in the context of free-viewing or memory tasks. The schematic congruence of scenes could also be manipulated along spatial or semantic dimensions in the context of visual search, object recognition, or location judgment tasks following the elicitation of awe (Eckstein et al., 2006; Santangelo et al., 2015).

We did not find conclusive evidence that awe reduced false recognition of schema-consistent lures in Study 2's memory task. But there was a significant effect of the awe condition on overall false recognition (across both schema-consistent and schema-inconsistent items), and participants in the awe condition showed marginally higher discriminability and a marginal bias toward rejection of test items. Although this pattern of findings deviates somewhat from predictions, it could potentially be the result of a shift from schema-driven to stimulus-driven processes during encoding or retrieval. For example, an overall reduction in false recognition may be a result of reduced confidence in recognition judgments (Turner et al., 2011). This metacognitive difference could potentially stem either from reduced reliance on schematic structures at retrieval, or from increased reliance on a *distinctiveness heuristic* (Schacter et al., 1999), whereby participants depend on the detailed recollection of test stimuli in order to make positive recognition judgments, driven by increased stimulus-driven processing at either encoding or retrieval (Brainerd et al., 2019; Dodson & Schacter, 2002; McCabe & Smith, 2006). Additionally, the marginal difference in discriminability across conditions could be accounted for by increased stimulus-driven attention, which could enhance memory encoding more generally (Fine & Minnery, 2009; Ravizza & Hazeltine, 2013; Santangelo & Macaluso, 2013). However, no support was found for the prediction that awe enhances recognition memory for schema-inconsistent objects, and there was no evidence that increased schema-driven visual attention was responsible for the observed reduction in false recognition in the awe condition. It is therefore unclear from the present studies whether awe-related differences in false recognition are driven by encoding processes, retrieval processes, or a combination. Future research can address this, for example, by eliciting awe either during encoding or retrieval (or neither), as well as varying the length of the retention interval to determine whether the effects of awe influence memory consolidation. Longer retention intervals are also associated with increased schema-driven influences on memory, which may lead to more pronounced effects of awe on schema reliance (Smith & Graesser, 1981).

Overall, while findings relating awe to visual attention and memory were mixed, feelings of awe appeared to cause an increase in stimulus-driven visual attention during a memory task as well as a reduction in false recognition memory in Study 2.

Study 3 examined the relationship between awe and set-breaking, which can be considered an accommodative change in problem-solving strategy. Although there was no effect of the awe manipulation on perseveration with an inefficient problem-solving strategy, stronger feelings of awe were associated with reduced perseveration, both across all participants and within each condition. This finding echoes Chirico's (2018) finding that awe is associated with increased creative problem-solving, extending the behavioral evidence linking awe and accommodation to the domain of objective problem-solving. It also suggests that the changes in attention and memory observed in Study 2 may ultimately support accommodative changes in cognition and behavior. It is possible that the relationship between self-reported awe and perseveration could have been spurious, driven for example by positive affect or general success of the emotion induction. However, this would not necessarily explain the negative correlation between awe and perseveration in the Amusement condition. Additionally, given that perseveration was not correlated with amusement, or positive affect across conditions, it seems unlikely that the association between awe and perseveration was driven by overall levels of affect or arousal. Another potential confound is cognitive load, given the relative complexity of awe-eliciting stimuli (Shiota et al., 2007). Indeed, van Elk and colleagues (2019) showed that participants made more errors in a counting task following an awe-eliciting video, compared to a positive control condition. However, Griskevicius et al. (2010) showed cognitive benefits as a result of awe elicitation. Future studies should assess and control for the potential relationship between awe and cognitive load, which could potentially account for differences in schema reliance and task performance.

In Study 3, the emotion manipulation itself may have failed to yield a significant effect due to variability in the amount of awe evoked in both the Awe and Amusement conditions. Substantial variability across both conditions was revealed by the consistent positive correlations between awe and perseveration. Future studies should utilize more uniform methods of eliciting awe, such as virtual reality (Chirico, 2018; Gallagher et al., 2015) or psychedelic drugs (Hendricks, 2018), and recruit participants who may be more prone to feelings of awe and more susceptible to imagery-based emotion induction procedures, such as those high in absorption (Gallagher et al., 2014; van Elk et al., 2016).

While the findings of these studies need to be confirmed by further research, and the relationships between the different outcomes elucidated, they provide some support for associations between awe and attention, memory, and problem-solving. These associations are consistent with a role of awe in accommodation, which may depend on a shift from schema-driven to stimulus-driven processing.

A major shortcoming of the present research is that the most profound experiences of awe, with the most lasting consequences for schematic organization, are difficult to elicit in a laboratory setting. In the future, researchers should take advantage the growing possibilities to elicit more profound states of awe in participants, for instance through psychedelic drugs or immersive experiences such as virtual reality.

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Appendix:

Emotion manipulation instructions, adapted from Griskevicius et al. (2010) and Zeelenberg et al. (1998).

Instructions for the Awe condition:

Awe: Feeling amazed, as though your mind is stretching and your understanding of the world is expanding; the kind of feeling that freezes you in one spot and makes you want to memorize everything about your experience.

Please take a few minutes to think about a **specific** time when you felt a strong sense of **awe, wonder, or amazement**.

People describe many different kinds of awe experiences. It could be a natural scene like the view from a mountain or seeing a city skyline for the first time. It could be witnessing someone accomplish something great. It could be a unique life event that made you feel awe. The important thing is that you felt a strong sense of awe.

Instructions for the Amusement condition:

Amusement: Feeling playful, bubbly, and giggly, like you are having a lot of fun; makes you want to laugh and joke around.

Please take a few minutes to think about a **specific** time when you felt a strong sense of **amusement**.

People describe many different kinds of amusing experiences. It could be a funny conversation with friends, seeing someone do something outrageous, something you watched on TV, or anything else that made you feel amused. The important thing is that you felt a strong sense of amusement.

Instructions for both conditions:

Try to remember as vividly as you can what this situation was like: Think of what happened to make you feel **[awe/amusement]**, and what it felt like to feel awe in this particular situation. Immerse yourself as much as possible in the feelings you had at that moment. **Visualize** it by going through the event once more, step by step, thinking about the characteristics of the event, the thoughts you had, and the emotions that you felt.

When you have recalled such an event, please write about this event, and your feelings during the event, in as much detail as you can, using the front and back of this page. What you write will remain anonymous, and will not be linked to your name in any way.