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Awe arises in reaction to exceeded rather than disconfirmed expectancies

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Abstract

Awe is a fascinating emotion, associated with positive consequences such as greater prosociality, generosity and epistemic openness. Unfortunately, in spite of the weighty consequences of awe, the exact way in which it arises, and what it entails, is still a puzzle. Particularly puzzling is the question of whether awe is the result of expectancy violation. While awe is thought to arise in reaction to expectancy violating objects or events, classical expectancy violations (e.g., a red Queen of spades playing card) do *not* tend to cause awe. To shed light on this problem we distinguish two types of expectancy violations: those that *disconfirm* and those that *exceed* one's expectancies, and we investigate whether awe is more likely to arise in reaction to one vs. the other. We also look at what appraisals constitute and are most important to the awe experience and how they structurally interact. To do this, we utilize network analysis and map out the network structure of appraisals linked to awe and to expectancy violations. Across two experimental studies (N=823) we demonstrate that awe arises in reaction to exceeded (rather than disconfirmed) expectancies and that appraisals linked to exceeded expectancies (vastness and uniqueness) are central to awe, while appraisals linked to disconfirmed expectancies (uncertainty and inconsistency) are peripheral to the awe experience. Taken together, our investigation sheds new light on psychologists' understanding of expectancy violations and reveals when and how awe arises and what it entails.

Beauties of nature, great works of art, and intellectual epiphanies evoke an intense emotional response, best summarized as a sense of awe (Shiota et al., 2007). Awe is undoubtedly a fascinating and valuable phenomenon: feelings of awe have been associated with greater generosity (Piff et al., 2015), humility (Stellar et al., 2018) and creative thinking (Chirico et al., 2018). Awe, alongside surprise, interest and confusion, is an epistemic emotion (McPhetres, 2019; van Elk et al., 2019), and could potentially arise in reaction to complex expectancy violating situations, regulating people's behaviour toward seeking such situations (Vogl et al., 2019).

Epistemic emotions are responsible for people's willingness to explore and update existing information, and can affect a range of important societal outcomes, from education and scientific discovery (McPhetres, 2019) to processes of stereotyping and prejudice (Prati et al., 2015). For instance, feeling confused by an expectancy-violating poem might lead people to withdraw and become disinterested in its content (Silvia, 2010), while feeling interested (Fayn et al., 2019) in a counter-stereotypic person may lead people to approach that person in order to better understand their situation (Gocłowska et al., 2017). While confusion, surprise and interest are relatively well understood, how awe arises and what it entails is still a puzzle. Particularly puzzling is the question of whether awe arises as the result of expectancy violation. This question lies at the center of our investigation. Understanding how awe links to expectancy violation could help researchers predict and evoke awe, as well as distinguish it from other, related phenomena. Thus, gaining a better understanding of when and how awe arises and what it entails is fundamental for psychological science and a central question of our paper.

Awe and Expectancy Violations

According to a common definition, awe arises in reaction to scenes that are vast and that "overwhelm mental structures" (Keltner & Haidt, 2003). Thus, by definition, awe-

inducing scenes are thought of as expectancy violating. This is reflected in experimental work where movies used to elicit awe in the laboratory offer sweeping vistas from a bird's eye perspective, accelerated cloud movements or colorful droplets of water played in slow motion (Piff et al., 2015; Rudd et al., 2012). Such scenes, where real objects are presented in an unexpected way, have been shown to increase awe and to motivate a change and adjustment of existing beliefs, categories and schemas (the need for accommodation; Keltner & Haidt, 2003; Piff et al., 2015). However, while this research implies that awe is somehow linked to expectancy violations, the exact way in which this happens is not clear. For instance one study asked participants to recollect a scene that made them feel awe, and to describe what they felt when experiencing this emotion (Campos, Shiota, Keltner, Gonzaga, & Goetz, 2013). Open-ended responses indicated that when feeling awe participants' expectations were challenged (e.g., "seeing something not thought possible;" Campos et al., 2013), but the precise nature of this challenge (e.g., What class of expectancies are violated exactly?), and how it corresponds to what is known about forming and testing expectancies, is hard to establish based on this study.

Understanding awe and the best ways to evoke this emotion requires a better integration with research on the formation and violation of expectancies. Expectancy formation is a core psychological process: Our minds generate constant predictions (expectancies) about the world and attending to objects and situations that violate these predictions is a core function of the cognitive system (Clark, 2013). Expectancies are based on predictions derived from the cognitive schema, prototypes or exemplars stored in long-term memory (e.g., "cheese is salty"), and violations of such expectancies are of central interest in social psychology and in social cognition research (Abelson et al., 1968; Gawronski & Strack, 2012). Schema- and stereotype violations are typically operationalized as objects or targets that *disconfirm* expectancies: a woman who works as a car mechanic

(Hutter et al., 2009), a piece of cheese that tastes of marzipan, or a deck of cards with black hearts and red spades (Proulx & Major, 2013).

Contrary to what awe research seems to imply, these targets that disconfirm expectancies *do not* tend to evoke awe. In fact, understood solely as a disconfirmation of expectancies, expectancy violation is quite dissimilar from the experience of awe. One of the central assumptions of expectancy violation research is that *disconfirming* expectancy violations evoke an unpleasant sense of inconsistency, negative affect, uncertainty, and may, at least at first, lead to avoidance motivation (Noordewier & van Dijk, 2018; Proulx & Major, 2013). This research consistently demonstrates that people dislike and avoid inconsistencies and situations that disconfirm their expectations and are averse to having to change their mind or undergo "cognitive accommodation" (i.e., adjust their cognitive schemas in light of new information; Piaget, 1975). In contrast, typical awe experiences are thought to be pleasant[1] and to motivate the accommodation of new knowledge. Furthermore, awe experiences seem to be associated with a motivation to approach, or at least not to avoid the source of awe, as individuals typically report that they did not want the awe experience to stop (Campos et al., 2013).

Thus, upon closer inspection, the link between most awe experiences and expectancy violations (understood as disconfirmed expectancies) is not only unclear, but also unlikely. However, if awe does *not* arise in reaction to expectancy disconfirmation, why do participants experiencing awe report "seeing something not thought possible" (Campos et al., 2013)? We believe that this is the case because expectancies can be challenged in other ways too (not just via disconfirmation).

[1] A recent study demonstrated that ~80% of awe experiences are positive and ~20% of such experiences can be classified as threat-based, and associated with negative affect (Gordon et al., 2016).

An Overlooked Type of Expectancy Violation

We propose that awe arises in reaction to a type of expectancy violation that has hithero been overlooked by psychologists, and that is poorly understood. Namely, awe arises in reaction to *exceeded* (rather than disconfirmed) expectancies. In our view, awe inducing stimuli are characterized by extreme and unexpected *values* in terms of specific and highly appreciated *expected* properties. For instance a person gasping at the sight of a beautiful lake does not do so because the lake was unexpectedly yellow (therefore disconfirming expectancies), but because the lake was extremely blue – more blue than one might have ever imagined (therefore exceeding expectancies). In our view awe-inducing scenes are perceived as unexpected because they are positive outliers and because they extend (rather than disconfirm) what is already known. These types of scenes violate expectancies about the extent to which they should possess some central and mostly positive characteristic such as beauty, force, talent or courage.

In line with this hypothesis, natural scenes used in awe studies (e.g., BBC Planet Earth videos) tend to be extremely beautiful (e.g., sweeping vistas of mountains) or can be seen as extremely powerful (e.g., volcano eruptions and avalanches), while YouTube videos portraying “awesome daredevils” (e.g., skydivers, downhill bikers) represent people of exceptional courage and ability that “exceeds our wildest dreams”. Furthermore, a qualitative analysis by Bonner and Friedman (2011) revealed that awe-inducing scenes are characterized by an extreme vividness of color, sound and luminosity. This qualitative finding suggests that awe experiences emerge in reaction to scenes that are so intense that they are perceived as unique and out of this world. These descriptions of awe experiences suggest that, rather than violating schematic expectancies about the characteristics that they should possess, awe inducing scenes violate expectancies about *the intensity* or *extremity* of their core features. And more recently Taylor and Uchida (2019) demonstrated that while the experience of

horror was associated with a sense of mental overwhelm, experiences of awe were characterized by a greater sense of vastness. Thus, in line with those recent observations, we argue for the existence of two types of expectancy violations: those that *disconfirm* and those that *exceed* expectancies, and we hypothesise that feelings of awe should be mostly explained by the latter (but not the former) type of expectancy violation.

Mapping the Awe Experience

Like other epistemic emotions, awe is conceptualized as a complex interplay of appraisals (feelings and judgments) of the awe experience. Understanding which of these appraisals are key to the experience of awe could help better define awe and distinguish it from other, related emotions. While there is some indication as to what appraisals may consistute awe, how they structurally interact, and which of them are central to the construct of awe, remains unknown. In previous research awe experiences were associated with perceptions of vastness (Shiota et al., 2007; Stellar et al., 2018) and positive valence (in the case of 80% of awe experiences; Gordon et al., 2016). In addition, since awe-inducing scenes are thought to violate expectancies, there is also the distinct possibility that awe-inducing scenes are appraised as high in terms of collative properties such as surprise, uniqueness, or unusualness. Collative properties are highly arousing stimulus properties (Berlyne, 1970) and expectancy violating targets are often appraised in terms of these properties. For instance when persons, scenes, or objects are not the way people expected, they may be considered novel (Estes & Ward, 2002), complex (Berlyne, 1970), unusual (Rubin et al., 2011), inconsistent with expectations (Proulx & Major, 2013) or surprising (Noordewier & van Dijk, 2018). However, because our central hypothesis is that awe should be mostly linked to exceeded rather than disconfirmed expectancies, it may very well be that only some or even none of the above appraisals, that are already known to be linked to disconfirmed expectancies, will play a role in the experience of awe.

Whether certain appraisals are central or peripheral to a phenomenon can be established by employing network analysis. This new and increasingly popular statistical method could allow us to understand what appraisals constitute and are most central and essential to the awe experience and how they structurally interact (i.e., how they are grouped together). The results would allow us to better understand what awe entails and how it is different from other, related states. Furthermore, the analysis might help us tease apart whether appraisals linked to exceeded vs. disconfimed expectancy violations are important for the awe experience. In this way, network analysis should shed further light on the link between awe and expectancy violations.

Hypotheses and Goals

In the present paper we propose a disctinction between two types expectancy violations: those that *exceed* vs. those that *disconfirm* people's expectancies. Our first goal is to investigate whether awe is more likely to arise in reaction to the former rather than the latter type of expectancy violation. Secondly, using network analysis, we inquire about the content, structure and centrality of a range of emotion appraisals (e.g., vastness, uniqueness, inconsistency and uncertainty) linked to awe and to expectancy violations. We ask what appraisals, in general, are central to the experience of awe and whether appraisals linked to exceeded vs. disconfirmed expectancies play a different role in the awe experience.

Methodological Approach

Awe and Expectancy Violations. Our hypothesis, that awe arises in reaction to scenes that exceed (rather than disconfirm) expectancies, was tested in two experimental studies. In Study 1 we manipulated awe via a recall paradigm asking participants to think of a past nature scene (in general) vs. a past nature scene that made them feel awe and wonder. We then measured the extent to which the recalled scene disconfirmed or exceeded prior expectancies and the extent to which the scene was perceived as awe-inspiring. Within this

type of design, mediation analyses allowed us to test whether exceeding (vs. disconfirming) expectancies accounts for the arising feelings of awe. Because Study 1 relied on people's subjective construal of the awe experience, in Study 2 we decided to use a manipulation that did not explicitly mention the emotion label. Namely, we asked participants to view three videos that have been used in prior research either to evoke awe, to evoke amusement, or as a control condition. Next, we asked participants to rate these videos on a range of properties (similar to Study 1) and used mediation analysis to again test our hypothesis that the exceeding of expectations mediates the effects of our manipulation on feelings of awe.

Mapping the Awe Experience. To understand what appraisals consistute awe, how they structurally interact, and which of them are central to the construct of awe, we asked participants to rate the recalled experience (in Study 1) or viewed video (in Study 2) in terms of 41 adjectives. We then employed network analysis to estimate the relationships between the various appraisals and to learn which of those appraisals are central (vs. peripheral) to the experience of awe. Network analysis is particularly well suited for this purpose as it allows one to describe a large network of correlating data without making assumptions about an underlying latent factor structure and without making explicit predictions about the causal relations between individual variables (Epskamp et al., 2012). Importantly, network analysis goes beyond visually inspecting a table of correlations, and allows one to instead produce a range of centrality indices. These centrality indices capture the extent to which individual observed variables within the network are central or peripheral to the phenomenon in question. In other words, network analysis allows us to estimate what characteristics of awe-inducing scenery are considered central (vs. peripheral) to people's experience of awe.

Throughout the paper we focussed mainly on the experience of awe in nature, as this type of context has been well researched and is among those most commonly associated with awe (Gordon et al., 2016; Shiota et al., 2007). In all studies, all manipulations, data exclusions

and variables analyzed are reported and all data were collected prior to any analyses. Most analyses (unless otherwise stated) have been conducted using standard packages of IBM SPSS statistics v. 25.

Study 1

In Study 1 we used an emotion recall paradigm to better understand the characteristics of awe-inducing (vs. neutral) scenes.

Method

Participants

Two hundred and ninety-eight U.S. participants (M_{age}=48, SD_{age}=15, 80% females, 87% White) were recruited online via Research Match (https://www.researchmatch.org/). The study was approved by the Research Subjects Review Board at the University of Rochester (RSRB #00061388). Participation was voluntary and no remuneration or credit was offered to research participants. We aimed for an *a priori* sample size of at least 260 participants so that we could detect small to medium (d=.35) effects of the between-subject manipulation on the outcome variables (using a 2-tailed test with p=.05 and Power=.80).

Procedure and Manipulations

Study 1 employed a 2 condition between-subjects design. In the control condition (N=152) participants were asked to recall a nature scene, whereas in the experimental condition (N=146) they were asked to recall a nature scene that made them "feel awe and wonder". The manipulation was set up to allow participants to immerse themselves in the memory of the recalled scene as much as possible. In both conditions, using an open-ended response format, participants were asked to describe what they saw, when it happened, what they thought the scene was like, what emotions the scene evoked and the exact physical and visual properties of the scene (van Elk et al., 2015). To better understand participants' awe experiences we also asked "Was that particular day/moment the first time in your life that you

saw this particular scene?" using a yes/no response format. Following this awe-recall manipulation we asked participants to rate the extent to which various physical properties (e.g., light, sound, speed) of the scene violated (exceeded or disconfirmed) their expectancies. We also asked about participants' appraisals of the scene in terms of awe and various other properties (e.g., vastness, inconsistency). Upon completion of the procedure, participants answered demographic questions, were thanked and were given an opportunity to comment on the procedure and to contact experimenters with any questions.

Measures[2]

***Expectancy Violation*.** Participants were asked to indicate the extent to which the physical properties (such as "color", "vividness", "sound") of the recalled scene exceeded and disconfirmed their expectancies (e.g., "The color of the scene exceeded/disconfirmed my expectations" answered on a scale from 1= *was as expected* to 7=*exceeded/disconfirmed my expectations*). Both scales (exceeding and disconfirming expectancies; M_{Dis}=2.38, SD_{Dis}=1.58 and M_{Exc}=3.67, SD_{Exc}=1.76) were constructed using 13 nouns describing physical properties of the experience and both scales had good reliability (Cronbach's α_{Dis}=.96 and α_{Exc}=.94, respectively). At the beginning of the task participants were provided with definitions and examples of exceeding and disconfirming expectancies.

Awe. The experience of awe was measured using 14 items scored on a scale from 1=*not at all* to 7=*very much.* Seven adjectives (amazing, awe-inspiring, beautiful, moving, profound, gave me chills; see A1-A6 on Figure 4) were taken from the "profound experience" measure by Silvia, Nusbaum and Beaty (Silvia et al., 2015) with the remaining items (incredible, captivating, breathtaking, out of this world, unbelievable, overpowering, powerful and forceful; A7-A14) being generated based on a review of the literature and with the use of

[2] Study 1 additionally contained items for scale development measuring prototypicality and the need for accommodation.

a thesaurus. The resulting composite measure of awe (Cronbach's α=.92, *M*=4.93, *SD*=1.29) was used to test our key hypothesis.

Scene Appraisals. To uncover which appraisals are central to people's experience of awe we listed an additional 27 adjectives that could potentially be used to describe awe-inducing scenes or expectancy violating phenomena. This broad list was compiled following a review of the literature on awe and on expectancy violations and with the use of a thesaurus. To capture fine-grained differences between various appraisals we employed network analyses (Epskamp et al., 2012). Unlike traditional factor-analytic approaches, network analysis makes no assumptions about latent structures and is typically conducted on the level of observed variables (i.e., individual appraisal items). This was useful for our purpose because we wanted to observe which characteristics drawn from a broad (but not necessarily unitary) pool of features are most important to the experience of awe. To facilitate interpretation of the network structure we grouped the appraisal items in the thematic groups listed below and colour-coded them in respective network visualizations (see Figure 2); this grouping is intended as a visual aid and has no bearing on the statistical features of the network analysis.

The same respective appraisal items were used for analyses in Study 1 and Study 2. The various appraisal items measured were focused on perceptions of vastness (*vast, enormous, immense;* VS1-VS3), uniqueness (*unique, exceptional;* UQ1-UQ2), valence (*pleasant, positive, negative, unpleasant;* VL1-VL4), familiarity (*unfamiliar, novel, familiar;* F1-F3), clarity (*clear, harmonious,* CL1-CL2*),* complexity (*complicated, simple;* CM1-CM2), unusualness (*unusual, strange, typical;* US1-US3), surprise (*surprising, unanticipated, unforeseen, expected;* SR1-SR4), inconsistency (*inconsistent, clashing;* IN1-IN2) and uncertainty (*uncertain, ambiguous;* UC1-UC2).

Since network analysis relies on measured variables rather than summative scales or latent factors, the grouping of individual adjectives bears no consequences for the network analysis. However we did use summative scores of the above variables in order to compare and contrast the unique nomological networks of exceeded and disconfirmed expectancies, and the results of those analyses can be found in the methodological appendix (Supplementary Table 1). The picture that emerged was consistent with our proposition that the exceeding and disconfirmation of expectancies are, to an extent, qualitatively different from one another, with exceeded expectancies being perceived as more vast, unique, and positive and with disconfirmed expectancies being perceived as more inconsistent, uncertain, and negative. The commonalities of the two types of expectancy violations included a sense of unusualness, surprise, and unfamiliarity.

Results

Awe Experience

Participants were asked to recall one nature scene or one awe-inducing nature scene. To test whether instructions were followed correctly two authors coded described scenes from 10% of participants on the extent to which these scenes were awe-inducing (1="not at all" to 5="very much"). The coding was conducted in a separate excel spreadsheet that contained only the scene description and was blind to condition. Inter-rater reliability was good (*ICC*=.85) so the remaining scenes were coded by one rater only. A between-subjects ANOVA indicated that awe experiences were mentioned more often in the awe-inducing condition than in the neutral condition (see Table 1). We also looked at answers to the question whether the scene described was one that participants had seen for the first time in their life. Here, participants in the awe condition (vs. neutral condition) more often reported on a scene that they saw for the first time in their life (51% in the awe condition vs. 31% in the control condition; Chi-square=7.88, p=.019, φ = .03). Finally, one-way ANOVAs revealed

that the nature scene reported in the awe (vs. control) condition was seen as more awe-inspiring and had higher scores of both exceeding as well as disconfirming expectancies (for detailed statistical results see Table 1).

Expectancy Violations and Awe

Our main hypothesis was that awe should arise predominantly (or entirely) in reaction to scenes that exceed (rather than disconfirm) expectancies. Initial support for this was obtained in correlation analyses: the correlation of awe with exceeded expectancies was of high magnitude (r=.55, p < .001) while the correlation with disconfirmed expectancies was moderate (r=.29, p < .001). Furthermore these two correlation coefficients were significantly different from one another (Dunn & Clarks z=5.53, p<0.001) suggesting that awe is *more* linked to exceeded expectancies than it is linked to disconfirmed expectancies (Diedenhofen & Musch, 2015)[3].

Given the common variance of the two types of expectancy violation (r=.58, p < .001), entering these variables as *simultaneous* predictors of awe should allow us to draw more accurate conclusions about whether exceeded (but not disconfirmed) expectancies mediate the effect of the awe manipulation on awe appraisals. We did this by computing a simple mediation model (PROCESS macro for IBM Statistics; Model 4 with 10,000 bootstrap intervals) with the manipulation of awe entered as a predictor, the two types of expectancy violations entered as simultaneous mediators and awe appraisal entered as the dependent variable. Current reccomendations state that mediation models with multiple mediators should be evaluated based on bootstrap intervals (Hayes, 2013; Shrout & Bolger, 2002) and not based on the change in the regression paths, as the latter type of analysis may provide inaccurate results (MacKinnon et al., 2000). In line with those recommendations regression

[3] In both studies comparisons of correlation coefficients (same group, overlapping correlations, p < .05, CI = .95, Null value = 0, 2-tailed test) have been conducted online using the web-based COCOR package (http://comparingcorrelations.org). The package produces 10 test results for dependent groups overlapping correlations and all of those tests achieved significance.

coefficients were used to attain a better understanding of the relations between variables, while bootstrap intervals constituted a formal test of the mediation hypothesis.

The PROCESS macro estimated mediation effects based on 3 regression models (see Figure 2a). In Model 1 the first mediator (exceeding expectancies) was regressed on the manipulation and the second mediator (disconfirming expectancies) was regressed on the manipulation. The results of these analyses were identical to the analyses of variance (see Table 1): the manipulation had a significant influence on both the exceeding and the disconfirming of expectancies. In Model 2, appraised awe was regressed on the two mediators and the predictor: awe was significantly related to the manipulation (B=0.32, SE = .13, t(287)=2.50, p=.013, 95%CI[.07, .57]) and to the exceeding of expectancies (B=0.42, SE = .04 t(287)=9.40, p<.001, 95%CI[.33, .51]), but not to the disconfirmation of expectancies (B=-0.04, SE = .05 t(287)=-0.83, p=.405, 95%CI[-.14, .06]).

These results suggest that exceeding, but not disconfirming, expectancies may account for the effect of our manipulation on awe appraisals. To test this mediational pattern formally, we generated bootstrap confidence intervals (N_{boot}=10,000) in PROCESS (Model 4; Hayes, 2013). The analyses indicated that the indirect effect via exceeding expectancies was statistically significant at the .05 level: B_{boot}=0.27, SE_{boot}=0.09, 95%CI[.10, .46], but that the indirect effect via disconfirming expectancies was not: B_{boot}=-0.02, SE_{boot}=0.02, 95%CI[-.07, .01].

Mapping the Awe Experience

To uncover what appraisals are central (vs. peripheral) in people's experience of awe, we entered the 27 adjectives describing awe-inducing scenes and the 14 adjectives used to strictly measure awe appraisals as input for our correlation[4] network analysis. In this type of

[4] Because we focused on centrality, irrespective of whether it results from direct or of indirect relations, we analysed a correlation (vs. partial correlation) network. When the shared variance of an item with multiple other items is controlled for in a partial correlation network, this makes the items extremely hard to interpret (Lynam et al., 2006; Verschuere et al., 2018), and using a correlation network helped us avoid such problems.

analysis no assumptions are made about the relative (in)dependence or causal relations between the observed variables, or about the existence of latent factors underlying the observed variables. Instead, all observed variables are plotted as nodes and their associations as edges within a network. The strength of the associations and the position of the individual nodes provide information about the importance of each variable to the network. Important nodes are placed more centrally while strong relationships between nodes are indicated with a thicker edge weight. Beyond visual inspection of the network (Figure 2), the analysis provides centrality indices of respective nodes (Figure 3) and allows for a comparison of the differences in the magnitude of centrality (Figure 4). In our study we decided to rely on the index of strength, which reflects the overall connectivity of a node with other nodes by summing up the (absolute values of) weights of the node's associations with other nodes. The higher the strength index the greater the centrality (i.e., importance) of a node (i.e., observed variable) within the network.

Estimation Method. Correlation network analysis computes a network structure based on bivariate marginal correlations producing a saturated model with edges included in the model. This was computed on 15.03.2021 using the *cor* procedure in the *qgraph* package for R version 3.6.3. Graphical results of the stability and accuracy analysis (edge weight estimates and their confidence intervals; centrality stability) can be found in the supplemental materials (Figures 1 and 2 in the methodological appendix). These analyses should be routinely conducted as part of a network analysis, but are not central to the current paper .

Network Visualization. The awe experience network was computed using the qgraph package for R (Epskamp et al., 2012). In the visualization of our network (see Figure 2) nodes represent individual appraisals of the awe-inducing scene and the thickness and colour of their edges indicate strength and valence of their associations (green: positive associations, red: negative associations). More influential and strongly connected nodes are placed closer to one

another within the network. Fourteen awe-related adjectives and 27 adjectives measuring other features were entered into the network analysis. Furthermore, we chose to compute the network based on correlational data (pairwise comparisons) only from participants asked to recall the awe condition (N=146), as the experience described by those participants seems to be most suitable for our purpose (understanding which appraisals are central vs. peripheral *to the experience of awe*).

Figure 2 (left panel) represents the network structure of the features of the awe-inducing scene. The strength of relations between items can be inferred from the thickness of the edges and the distance between the individual nodes. Positive correlations are plotted in green while negative correlations are plotted in red. Edge thickness represents the magnitude of correlation. Very small correlation coefficients (r<.10) were not plotted, while large correlation coefficients (r>.50) have been emphasized by bolding the respective edges. For ease of interpretation, items of similar meaning have been plotted using the same colour, however this visual grouping has no bearing on the statistical analysis or its outcomes. Nodes related to awe (A1-A14) are at the very center of the network. Crucially to our main research question, nodes indicative of the expectancy exceeding features of vastness (VS1-VS3) and uniqueness (UQ1 & UQ2) also play a central role within the network, while nodes denoting the expectancy disconfirming appraisals of inconsistency (IN1 & IN2) and uncertainty (UC1 & UC2) are on the periphery of the network. Furthermore, two nodes relating to familiarity (F1 & F2), as well as all nodes denoting surprise (SR1-SR4), complexity (CM1 & CM2), clarity (CL1 & CL2), valence (VL1-VL4) and unusualness (US1-US3) are further away from the center of the network.

Centrality Index. We also produced an index of node strength (the overall connectivity of one node to all other nodes) which is helpful in interpreting the centrality (i.e., importance) of each node within the network. The higher the strength index of a node the

more central that node is within the network of variables. Additional analyses plotting centrality over increasingly smaller bootstrapped sub-samples indicated that the above order of the strength index is stable (see Supplemental Figure 2). This was further supported by a correlation stability coefficient that was well over the recommended value of .50 (CS-coefficient cor = .67), indicating we can confidently interpret differences in strength.

Figure 3 (left panel) depicts strength indices of the various awe appraisals in Study 1. All but one (A14="forceful") of the awe-related items have a positive strength score, and so do the nodes indicative of the expectancy exceeding features of vastness (VS1-VS3) and uniqueness (UQ1-UQ2). Nodes denoting the expectancy disconfirming appraisals of inconsistency (IN1 & IN2) and uncertainty (UC1 & UC2) have low strength scores and so have the nodes denoting clarity (CL1 & CL2), complexity (CM1 & CM2), surprise (SR1-SR4) and valence (VL1-VL4). Results for nodes related to familiarity (F1-F3) and unusualness (US1-US3) were mixed.

Centrality Differences. We also computed a bootstrapped centrality difference test using the *bootnet* package in R. This allowed us to test for significant differences in the magnitude of strength of individual nodes (parametric test, alpha=0.05, nBoot=10,000). Figure 4 (top panel) contains a grid representing all node strength comparisons with black squares reflecting significant strength differences. For 430 out of 820 possible comparisons there was a significant difference in node strength. Crucial to our main argument, the strength of all nodes indicating vastness (VS1-VS3) and uniqueness (UQ1-UQ2) was significantly different from the strength of nodes denoting the expectancy disconfirming appraisals of inconsistency (IN1 & IN2) and uncertainty (UC1 & UC2). In other words, this strength difference test shows that appraisals denoting the exceeding of expectancies are *significantly* more central to awe than appraisals denoting the disconfirmation of expectancies.

Study 2

Study 1 demonstrated that, in line with our predictions, the perception of exceeded (but not disconfirmed) expectancies mediated the effect of awe recall on awe appraisals. Furthermore, network analyses demonstrated that while the sense of vastness and uniqueness, characteristic of experiences that exceed expectancies, are central to the experience of awe, while appraisals that are typically associated with disconfirming expectancy violations - inconsistency and uncertainty - are peripheral to the experience of awe. Also, appraisals of valence as well as other appraisals associated with expectancy violations (e.g., complexity and surprise) have turned out to be peripheral in the awe experience. Taken together these results suggest that awe experiences are vast and unique and that they exceed expectancies, but that they are also quite different from traditionally understood (i.e., disconfirmed) instances of expectancy violations.

While supportive of our hypotheses, Study 1 was not without shortcomings. First, because we explicitly asked participants to recall a scene that made them feel "awe and wonder" it's not clear to what extent participants' responses reflected true feelings of awe rather than their construal of what awe should feel like, or what they thought should be said about awe in this study (i.e., demand characteristics). Secondly, because in Study 1 awe was compared to a nature condition where no emotion was specified, it's not clear to what extent the effects observed were specific to an awe experience rather than any type of positive emotion experience. Third, while the retrospective procedure asked participants to rate whether the scene that they had described was awe-inducing, it would also be good to see whether the results will replicate when participants are more directly asked about whether they feel awe following the manipulation. Finally, as network analysis is an exploratory technique, Study 2 would allow us to ascertain whether the obtained pattern of results holds with a new sample and a slightly different experimental procedure.

Study 2

Study 2 employed one of the most popular and most researched awe-induction manipulations -- a 5-minute long video from the TV show BBC Planet Earth, with the Icelandic band Sigur Ros playing in the background (Piff et al., 2015; Valdesolo & Graham, 2014). Using this video to manipulate awe would allow us to eliminate earlier concerns about how participants construe and react to the notion of awe (because words like "awe" or "wonder" would not be mentioned during the procedure, demand characteristics are less of an ussue in such a design). In addition, to address the potential concern that our results are specific to positive emotions in general, we compared the awe-inducing video not only to a neutral control condition (neutral video), but also to an amusing control condition (comedic animal videos from the series "Walk on the Wild Side"). These later videos presented scenes from nature videos in which animals appear to be having conversations dubbed with human voices. Finally, in Study 2 we asked participants, immediately after the video, whether they were feeling awe (along with other emotions) in that very moment; so rather than looking at whether the video was seen as awe-inducing, we asked participants about the extent to which they felt awe, and this constituted our main measure of awe for the mediation analysis. For the purpose of network analysis appraisals were measured in the same manner as in Study 1.

Method

Participants

For Study 2, U.S. participants (N=505, M_{age}=51, SD_{age}=16, 73% females, 87% White) completed the study via Research Match (https://www.researchmatch.org/). Our *a priori* target was to collect over 450 participants (d=.30 using a 2-tailed test with p=.05 and Power > .80). A larger sample size than Study 1 was needed because we introduced an additional condition and because we wanted to not only demonstrate a link between awe and the exceeding of expectancies, but also to *rule out* a link with the disconfirmation of

expectancies. Participation in the study was voluntary and no remuneration was offered to participants. Only fully completed questionnaires were analyzed. The study was approved by the Research Subjects Review Board at the University of Rochester (RSRB #00065107).

Procedure and Manipulations

Study 2 employed a 3 condition between-subjects design with a neutral (*N*=165), amusing (*N*=146) and awe inducing (*N*=194) video. Participants were randomly assigned to condition; however, due to a procedural error, slightly higher numbers of participants were collected in the awe condition.

To ensure an immersive experimental procedure (van Elk et al., 2015), we asked participants to view the video manipulation in full-screen mode and to use headphones plugged into the computer. Following the emotion induction manipulation we asked participants to rate their emotions as they felt them "right now". On the following page participants had to indicate to what extent various physical properties (e.g., light, sound, speed) of the scenes in the video violated (exceeded or disconfirmed) their prior expectancies, and they were asked to rate the scene in terms of various appraisals. Upon completion of the procedure participants answered demographic questions, were thanked and given the opportunity to comment on the procedure and to contact experimenters with any questions.

Measures[5]

Expectancy Violation was measured using the same format as in Study 1. Both exceeding expectancies (*M*=2.65, *SD*=1.59) and disconfirmation of expectancies (*M*=2.37, *SD*=1.49) had good reliability (Cronbach's α=.97 and α=.95, respectively).

Emotion Felt. To gauge the extent to which the video manipulation elicited various emotions we asked participants to indicate the emotions they felt "right now" (following Piff et al., 2015). Awe was measured using three items (awe, wonder, amazement; Cronbach's

[5] Study 2 also measured individual differences (need for closure, absorption and openness) and exploratory questions asking about connectedness with nature and participants' views on environmental concerns.

α=.90, *M*=3.85, *SD*=2.07) forming a scale of felt awe, and the remaining emotions (measured for control purposes) were measured using single items (happiness, amusement, surprise, anger, disgust, fear, and sadness) scored on a scale from 1=*not at all* to 7=*very much* (following Piff et al., 2015).

Scene Appraisals were measured using the same adjectives as in Study 1. The network analyses relied on observed variables (i.e., individual adjectives), however summative scores were produced to briefly compare the correlates of exceeded and disconfirmed expectancies. Consistent with Study 1, disconfirmed expectancies were linked to perceptions of inconsistency (with prior expectations) and uncertainty, and were negatively tinged, while events that exceed expectancies were linked to perceptions of vastness and uniqueness and were less negatively tinged (see Suplementary Table 1).

Results

Awe Experience

In Study 2 participants viewed an awe-inducing, amusing or neutral video. To evaluate the impact of the video, a General Linear Model (Table 2) compared the means of all of the emotions across the three conditions. Omnibus tests revealed a significant effect of the manipulation on all of the eight emotions measured. As indicated in Table 2, awe was highest in the awe-inducing condition (vs. the amusing condition and vs. the neutral condition) while amusement was highest in the amusing condition (vs. the awe and vs. the neutral condition), and both the awe condition and the amusement condition scored higher in happiness and in surprise, and lower in anger and disgust relative to the neutral control condition. Finally, fear and sadness were higher in the awe condition than in the amusement condition. There was also an effect on the exceeding but not disconfirming of expectancies, with exceeding expectancies significantly higher in the awe condition than in the neutral condition and when

compared to the amusing condition. As the omnibus test was not significant for the disconfirming of expectancies, we did not follow this up with simple comparisons.

Expectancy Violations and Awe

Again, our main hypothesis stated that awe should arise predominantly in reaction to scenes that exceed (rather than disconfirm) expectancies. As in Study 1, initial support was obtained in correlation analyses: the correlation of awe with exceeded expectancies was of high magnitude (r=.46, p < .001) while the correlation with disconfirmed expectancies was very small (r=.09, p=.06). These two correlation coefficients were significantly different from one another (Dunn & Clarks z=8.84, p<0.001), again suggesting that awe is *more* linked to exceeded expectancies than it is linked to disconfirmed expectancies (Diedenhofen & Musch, 2015). Furthermore, the analysis of variance demonstrated different levels of exceeding expectancies between the awe and the neutral condition (see Table 2).

Similar to Study 1, a mediation test using PROCESS entailed a model in which awe was regressed on the exceeding and disconfirming of expectancies (controlling for the effect of the manipulation), and the two types of expectancy violations were regressed on the manipulation. However, because the current study had three (rather than two) experimental conditions, the analysis needed to take into account both the difference between the awe and the amusement condition and the difference between the awe and the neutral condition. This was resolved by means of indicator coding (Hayes & Montoya, 2017; using the "Indicator" coding method in PROCESS) which led to the creation of two indicator-coded independent variables (also known as "relative indirect effects"): one comparing the awe and amusement conditions, and another comparing the awe and neutral conditions (see Figure 1b).

The PROCESS macro estimated mediation effects based on 3 regression models. In Model 1 the first mediator (exceeding expectancies) was regressed on each of the two indicator-coded variables (awe vs. amusement or awe vs. neutral) and the second mediator

(disconfirming expectancies) was also regressed on each of the two indicator-coded variables. The results for these models were in line with those obtained using ANOVA, showing that the awe manipulation significantly increased a sense of exceeded (but not disconfirmed) expectancies (see Table 2 and Figure 2). Furthermore, in Model 2 felt awe was regressed on the two mediators and the two indicator-coded variables. Here awe was significantly related to both indicator coded manipulation contrasts ($B_{awe.vs\ amusement}$=-2.44, SE = .16, t(4,483)=-15.46, p<0.001, 95%CI[-2.75, -2.13]; $B_{awe\ vs.\ neutral}$=-2.72, SE = .17, t(4,483)=-16.39, p<0.001, 95%CI[-3.05, -2.40]), as well as to exceeded expectancies (B=.37, SE = .05, t(4,483)=7.26, p<0.001, 95%CI[0.27, 0.47]), but not to disconfirmed expectancies (B=-0.01, SE = .05, t(4,483)=-0.13, p=.895, 95%CI[-0.11, 0.09]). This suggests that exceeding, but not disconfirming expectancies, accounts for the effect of our manipulation on felt awe.

To test this mediational pattern formally we generated bootstrap confidence intervals (N_{boot}=10,000) in PROCESS (Model 4; Hayes, 2013). This revealed an indirect effect via the exceeding of expectancies for both the awe vs. amusement contrast (B_{boot}=-0.15, SE_{boot}=0.07, 95%CI[-.30; -.02]) as well as the awe vs. neutral contrast (B_{boot}=-0.50, SE_{boot}=0.09, 95%CI[-.70; -.35]). For disconfirmed expectancies bootstrap intervals were not significant (B_{boot}=-0.003, SE_{boot}=0.02 95%CI[-.05; .04] and B_{boot}=-0.001, SE_{boot}=0.01 , 95%CI[-.03; .02] respectively). These results demonstrate that exceeding (but not disconfirming) expectancies mediate the effect of the manipulation on felt awe both when comparing the awe vs. the amusement condition and when comparing the awe vs. the neutral condition. The pattern of findings was additionally identical when appraised (rather than felt) awe was entered as a dependent variable.

Mapping the Awe Experience

Network analyses were conducted using the same appraisal items and following the same protocol as in Study 1. We chose to compute the network based only on data from

participants in the awe condition as the experience of these participants is most relevant for our purpose, and because that would make the results of Study 1 and Study 2 more comparable.

Network Visualization. Figure 2 (right panel) represents the correlational network structure of the features of the awe-inducing scene in Study 2. Nodes related to awe (A1-A14), as well as nodes indicating the expectancy exceeding features of vastness (VS1-VS3) and uniqueness (UQ1 and UQ2), play a central role within the network. However, nodes related to inconsistency (IN1 & IN2), uncertainty (UC1 & UC2), as well as to familiarity (F1-F3), surprise (SR1-SR3) and complexity (CM1 & CM2) play a peripheral role in the network.

Centrality Index. The order of the strength index was high stable for a wide range of increasingly smaller bootstrapped samples (Supplementary Figure 1) and this was further supported by a correlation stability coefficient that was well over the recommended value of .50 (CS-coefficient cor = .75), indicating that we can confidently interpret differences in strength.

Figure 3 (right panel) depicts strength indices of the various awe appraisals. All but three (A11="unbelievable", A12="overpowering" and A6="gave me chills") awe-related appraisals are strongly positioned in the network, and so are the three appraisals related to vastness (VS1-VS3) and two appraisals related to uniqueness (UQ1-UQ2). Notably, and in line with the results of Study 1, the items uniquely related to disconfirmed expectancies (IN1 & IN2; UC1 & UC2) had negative strength scores, indicating that they are not central to the experience of awe. A further examination of the results from both studies indicates that only items denoting awe, vastness and uniqueness are *consistently* central to the experience of awe across *both* studies.

Centrality Differences. The bootstrapped strength difference test (parametric, alpha=0.05, nBoot=10,000) revealed that this time on 513 out of 820 comparisons there was a

significant difference in terms of node strength (Figure 4, bottom panel). Smilar to Study 1, the strength of all nodes denoting the expectancy disconfirming properties of vastness (VS1-VS3) and uniqueness (UQ1-UQ2) was significantly different from the strength of nodes denoting the expectancy disconfirming appraisals of inconsistency (IN1 & IN2) and uncertainty (UC1 & UC2). In other words, also in Study 2 appraisals denoting the exceeding of expectancies were *significantly* more central to awe than appraisals denoting the disconfirmation of expectancies.

General Discussion

Awe is a fascinating and important emotion, often associated with intense spiritual and life changing experiences and positive consequences such as greater generosity and prosociality (Piff et al., 2015; Stellar et al., 2018). However, in spite of the weight of this emotion, the exact way in which awe arises, and what it entails, is still a puzzle. Understanding what kind of stimuli evokes awe is essential for predicting and evoking this emotion, and understanding what appraisals constitute awe can help define and distinguish awe from other, related emotions. To help better understand these issues we examined the relationship of awe and expectancy violations and mapped the network structure of a range of appraisals related to awe.

Awe and Expetancy Violations

To answer the question of *how awe arises* we looked at the link between awe and expectancy violations. At first glance the idea that awe is the result of expectancy violations (Keltner & Haidt, 2003) seems contrary to what is known about forming and testing expectancies. Namely, according to social psychology and social cognition research, expectancy violating situations tend to be unpleasant, linked to uncertainty and inconsistency, and characterized by a state of *disconfirmation* of what we have known or expected. Awe experiences, on the other hand, do not seem to *disconfirm* people's expectancies in any major

way, and seem to be experienced as valuable and (in 80% of cases) pleasurable (Gordon et al., 2016).

In response to this paradox, we drew a distinction between two types of expectancy violations: experiences that exceed versus those that disconfirm prior expectancies. In line with our observations and reading of the literature we argued that awe should arise in reaction to exceeded rather than disconfirmed expectancies. This is because while exceeded and disconfirmed expectancies share some commonalities (e.g., perceptions of surprise), they are also qualitatively different from one anther: while exceeded expectancies are linked to perceptions of positive valence, vastness and uniqueness, disconfirmed expectancies are linked to appraisals of negative valence, inconsistency and uncertainty (see Supplementary Table 1).

Our main hypothesis, that awe arises in reaction to exceeded (rather than disconfirmed) expectancies, was supported by mediation analyses. In these studies recalling a past experience of awe (Study 1), as well as watching an awe-inspiring video (Study 2), led to greater appraisals (Study 1 and 2) and feelings (Study 2) of awe, and this effect was mediated by a sense of exceeded (rather than disconfirmed) expectancies. Thus, by making a distinction between exceeded and disconfirmed expectancies, we demonstrated that awe arises in reaction to the former (rather than the latter) type.

Mapping the Awe Experience

To answer the question of *what awe entails* we investigated the centrality of a range of awe-related appraisals. Awe is a complex emotion associated with numerous and varied appraisals, and our goal was to better understand how those various appraisals structurally interact and which of them form the essential features of awe. Across two studies we found that appraisals related to exceeded expectations (vastness and uniqueness) are consistently central to the experience of awe. Beyond illustrating what appraisals are at the core of the awe

experience, the network analyses also illustrated what appraisal are peripheral to the awe experience. Zooming in on those appraisals is helpful because while some of them may be commonly associated with awe, they are not necessarily *defining* of this emotion. A good example of such an appraisal is valence. While in our own (and others') research awe was correlated with positive valence (medium to large size correlations), network analyses estimated that valence is a peripheral feature of the awe network. This, broadly speaking, is compatible with the finding that while most awe experiences are positive, a negative variant of awe exists and constitutes approximately 20% of awe experiences (Gordon et al., 2016). In other words, while awe experiences are often positive, valence is not a necessary feature of awe. In a similar vein, even though our studies have consistently shown a correlation of awe and clarity (medium to large effect sizes), clarity has also emerged as a peripheral feature of awe.

Implications to Emotions Research

The above findings have implications for research on awe and on other epistemic emotions. First and foremost, they offer a better understanding of the state of awe and how it arises. They help to disambiguate what it is about awe-inducing experiences that "challenges people's worldviews" and evokes a greater "need for accommodation" (a sense of exceeded expectations). Furthermore, our findings provide greater insight into the appraisal structure of awe and allow researchers to understand which features are most essential to the awe experience (vastness and uniqueness), and which of them are not central or defining of the experience of awe (e.g., valence, uncertainty, inconsistency). This should allow researchers to better understand when awe arises, and how it can be evoked experimentally. It may also aid practicioners, for instance teachers or educators, whose aim it is to captivate the audience in order to evoke awe and interest in an important topic (e.g., environmental science).

Going beyond these findings it is important to note that, while awe arises in reaction to exceeded expectancies and a sense of vastness and uniqueness, these stimuli features need not always result in feelings of awe. For instance, moral elevation is an emotion felt when witnessing another person perform a virtuous act (Algoe & Haidt, 2009). This state is very similar to awe in that the target person exceeds one's expectancies about a high moral standard. However, unlike awe, elevation is applied in a moral domain. Awe, on the other hand, may be more likely to arise in reaction to high levels of performance or in the context of aesthetic judgments (Shiota et al., 2007). Thus, whether exceeded expectancies, vastness and uniqueness are associated with awe could potentially depend on the context or domain in which expectancies are exceeded. Notably, context is not the only condition that will determine whether a sense of exceeded expectancies will lead to the rising of awe. Other factors, such as whether the exceeded dimension is highly valued, will likely act as moderators between exceeded expectancies and the rising of awe. Thus the question of *when* exceeded expectanicies are most likely to result in awe is a question for future research.

While the distinction between exceeded and disconfirmed expectancies disambiguates the experience of awe in nature, further studies are needed to better understand the role of expectancy violations in negative emotions from the awe-family, for instance the experience of horror (Taylor & Uchida, 2019) or the threat-based variant of awe (Gordon et al., 2016). Threatening natural events (e.g., hurricanes) may exceed one's expectations about the magnitude to which these events are powerful or destructive. Taylor and Uchida (2019) have argued that what differentiates horror from awe is a sense of severity, unusualness and overwhelm, and that an experience of horror entails the realization that vital resources, relationships or assumptions have become unviable or dangerous. From the perspective of our own findings, experiences leading to feelings of horror could exceed expectancies in a highly negative domain (e.g., exceeded expectancies about the extent of threat). Alternatively, or in

addition, such experiences could also disconfirm expectancies about some vital convinctions, for instance about the safety and security of the world around us (Taylor & Uchida, 2019). Finally, there is the distinct possibility that even negative and potentially threatening events posess extreme features that are worthy of appreciation. For instance, while hurricanes are potentially life threatening, they can also be appreciated for demonstrating extreme "forces of nature". Thus the notion of exceeded expectancies of a highly valued (but not necessarily safe or pleasant) property could explain the existence of the threat-based variant of awe. Further research, drawing a clearer distinction between the expectancy domain (e.g., morality, force, beauty, safety) and the *way* in which expectancies are violated (e.g., via the exceeding or disconfirming of expectancies) may succeed at illuminating these questions.

Finally, the distinction between different types of expectancies has the potential to not only elucidate the family of awe-related emotions (e.g., awe, elevation, adoration), but also various emotion states regarding the acquisition of knowledge ("epistemic emotions", e.g., interest, curiosity, surprise, confusion or boredom). For instance, in the present paper we were able to explain how awe is different from amusement. This was demonstrated in Study 2 where awe (but not amusement) was associated with the exceeding (but not disconfirming) of expectancies.

Implications to Expectancy Violations Research

Aside from informing work on epistemic emotions our findings also speak to expectancy violation research. While the bulk of expectancy research is focussed on the disconfirmation of expectancies, which tends to be associated with complex, inconsistent, uncertain and unusual phenomena, the present research suggests that expectancy violations that *exceed* expectancies may be appraised in different way – as vast and unique. The present research demonstrates that while both of these types of expectancy violations have some commonalities (e.g., both are associated with a sense of surprise and unfamiliarity), they are

also different. Namely, while disconfirmed expectancies are linked to negative affect, greater perceptions of complexity, unusualness, inconsistency and uncertainty, exceeded expectancies are linked to positive affect and greater perceptions of vastness, uniqueness and clarity (see Supplementary Table 1).

The notion of expectancy violations underlies a broad range of phenomena and thus connects a number of distinct fields: from emotions research, through dissonance-based theories, to the literature on stereotyping and prejudice, and applying the notion of exceeded expectancies could lead to new insights within these various fields. For instance, expectancy violations are vital for intergroup processes research, where counter-stereotypic acts and individuals (e.g., a Black President in the U.S.) are considered as an effective method of decreasing stereotyping and prejudice. While exposure to counter-stereotyopes can reduce prejudice (Prati et al., 2015), counter-stereotypic individuals themselves are often faced with negative, discriminatory reactions (e.g., Hunt et al., 2014), and recent evidence suggests that these outcomes differ depending on the way in which expectancies are violated. For example, foreign looking but native-accented job candidates tend to be highly evaluated if they are first seen (and therefore expected to speak with an accent) and later heard; however if the same job candidates are first heard and later seen (and therefore expected to be White), their evaluations tend to be much lower (Hansen et al., 2018). These findings parallel our own in suggesting that a better understanding of not just whether, but *how* (e.g., via exceeding vs. disconfirming expectancies; in a positive vs. negative way) expectancies are violated is key to a better understanding of their consequences across a wide range of domains.

Limitations

Finally, our research has some limitations. While the emotion recall manipulation in the first study was relatively clean and confound free, it may have imposed on participants an expectation of what awe should be like. Our second manipulation, on the other hand, was less

ecologically valid and, while widely used to elicit awe, was not free of confounding variables. For instance the BBC planet video had a song playing in the background, while the amusing videos contained animals that may have been seen as "cute" by participants. However, since results were consistent across both studies, these confounding influences were not critical.

Secondly, while demonstrating clear links between expectancy violations and awe, our study did not provide causal evidence that expectancy exceeding scenes cause awe. To demonstrate this, a study that directly manipulates exceeded and disconfirmed expectancies (for instance via recalling one type of experience) would be necessary. However since in both studies the awe condition was rated as higher in exceeded expectancies (relative to the remaining conditions) we can be confident that a causal relationship is extremely likely. Taking all this together, and given that our studies yielded clear, interpretable findings, we believe that that the effects presented in the current paper are likely quite robust.

Conclusion

In sum, we have argued for and demonstrated that the state of awe arises in reaction to exceeded rather than disconfirmed expectancies, and that appraisals of vastness and uniqueness, but not appraisals of inconsistency and uncertainty, are central to the awe experience. This finding, we hope, can help researchers better understand how awe arises and what it entails, and it can further enrich psychologist's understanding of epistemic emotions and their link to psychological expectancies.

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Table 1. Mean differences across the two experimental conditions (Study 1)

	Awe in nature		Nature				
	M	*SD*	*M*	*SD*	*F*	*p*	η^2
Mentions of awe	2.75	1.68	1.97	1.50	17.34	<.001	.06
Awe	5.23	1.12	4.64	1.39	15.80	<.001	.05
Exceeding	3.99	1.67	3.35	1.78	10.21	.002	.03
Disconfirming	2.59	1.67	2.19	1.49	4.49	.035	.02

Note: Test results are based on a General Linear Model with listwise deletion. N_{awe}=141, $N_{neutral}$=147; *df*(1,286).

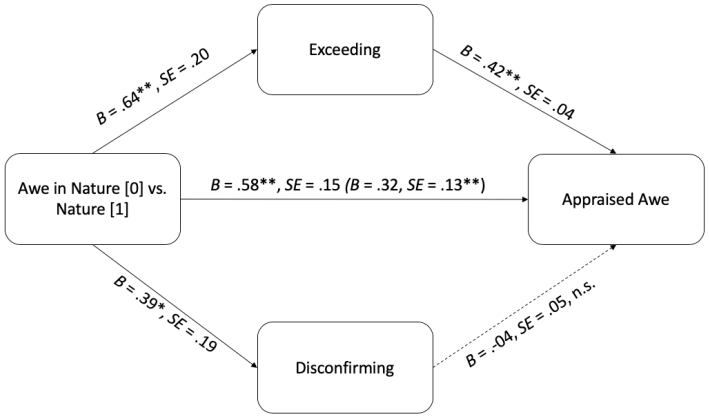
Table 2. Mean differences across the three experimental conditions (Study 2)

	Awe		Amusement		Neutral				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F*	*p*	η^2
Awe	5.67_a	1.48	3.08_b	1.66	2.45_c	1.27	232.53	<.001	0.49
Happiness	5.03_a	1.62	4.98_a	1.89	2.10_b	1.43	164.40	<.001	0.41
Amusement	3.33_a	1.83	5.77_b	1.69	2.54_c	1.67	135.82	<.001	0.36
Surprise	2.95_a	1.89	3.45_b	1.94	2.50_a	1.64	9.94	<.001	0.04
Anger	1.32_a	1.00	1.27_a	0.88	1.94_b	1.45	17.02	<.001	0.07
Disgust	1.24_a	0.86	1.34_a	1.05	2.24_b	1.75	30.23	<.001	0.11
Fear	1.35_a	0.82	1.04_b	0.36	1.62_c	1.24	14.94	<.001	0.06
Saddness	2.02_a	1.56	1.16_b	0.62	2.22_a	1.72	22.78	<.001	0.09
Exceeding	3.20_a	1.69	2.78_b	1.57	1.84_c	1.07	37.05	<.001	0.13
Disconfirming	2.18	1.55	2.59	1.42	2.34	1.43	2.98	.052	0.01

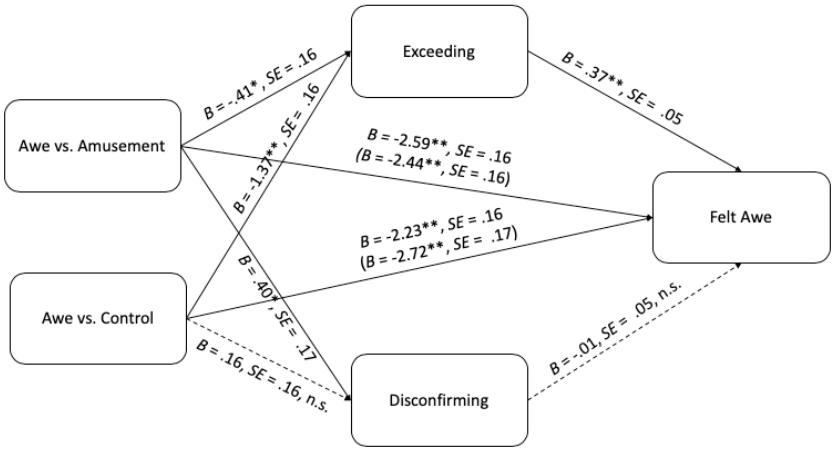
Note: Omnibus test results are based on a General Linear Model with listwise deletion. N_{awe}=188, $N_{amusement}$=137 and $N_{neutral}$=156; *df*(2,478). Mean Values in the same row and not sharing the same subscript are significantly different at $p < .05$, two-tailed test, Bonferroni correction.

Figure 1. Mediation analyses indicated that the exceeding (but not disconfirming) of expectancies was the key expectancy violation associated with awe appraisals.

Study 1

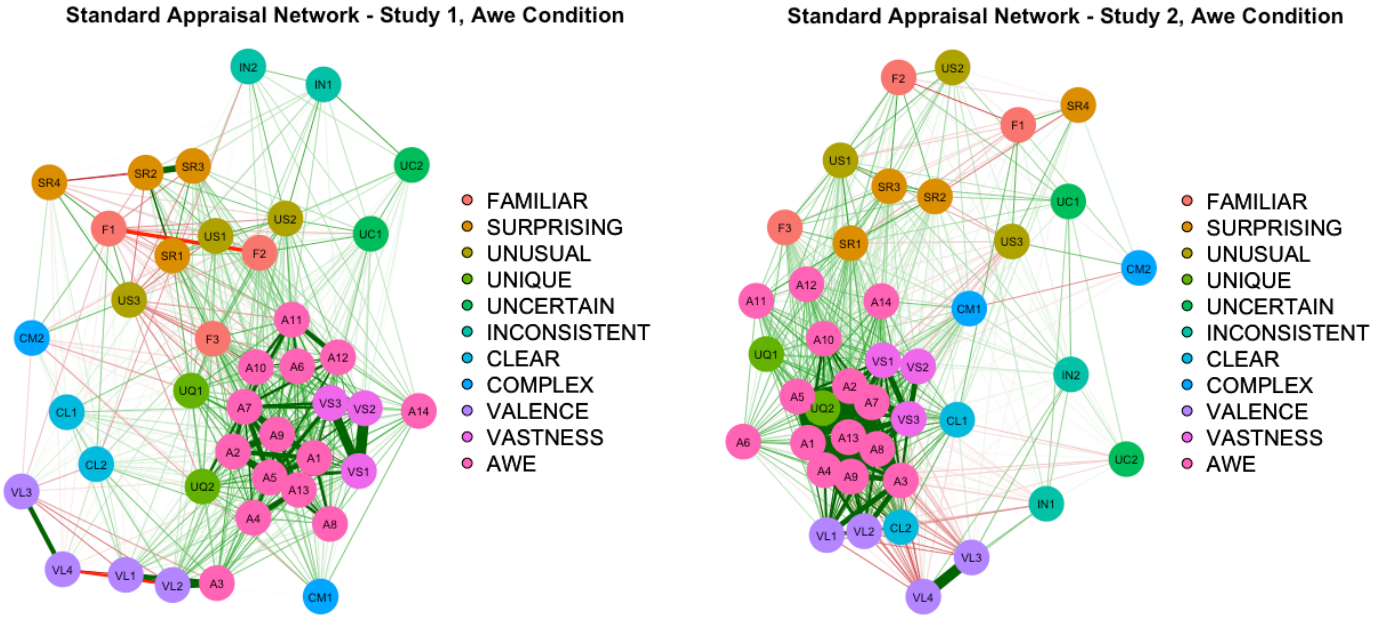


Study 2



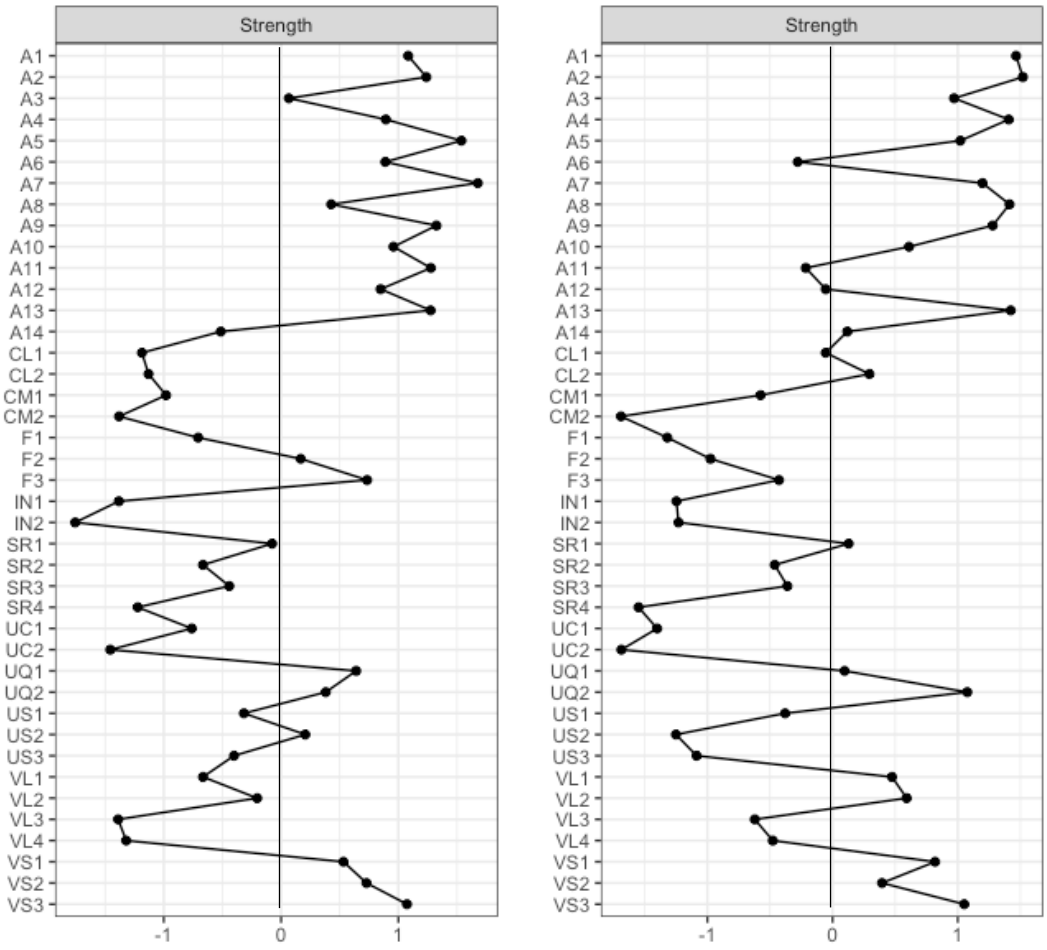
Note: *p<.05, **p<.01; In Study 1 the nature condition was coded as "0" and the awe in nature condition was coded as "1"; In Study 2 the independent variable was coded as awe=1, amusement=2, neutral=3. Coefficients represent unstandardized *B*-coefficients. Numbers in parentheses are path coefficients after controlling for the mediator.

Figure 2. Visualization of the networks of awe-related appraisals depicts data from the awe condition in Study 1 (left panel) and Study 2 (right panel). Across both studies, adjectives indicating awe, vastness, and uniqueness emerged as the most central features of the awe experience, while adjectives indicating inconsistency and uncertainty were not central to the awe experience.



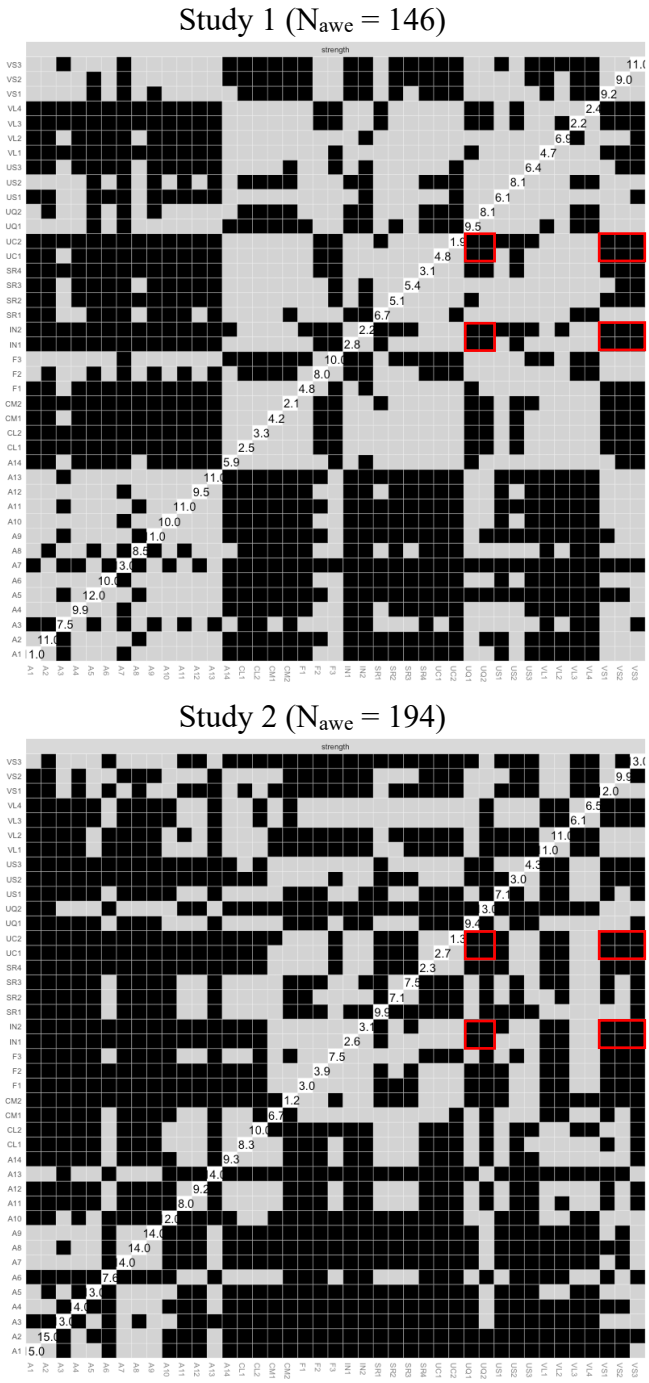
Note: Network of the awe experience based on pairwise correlation coefficients between individual appraisals in the awe induction condition (N_{Study1}=146, N_{Study2}=194). Positive correlations are plotted in green, negative correlations are plotted in red. Edge thickness represents magnitude of correlation. Extremely small correlation coefficients (r<.1) have been omitted while large correlation coefficients (r>.5) have been emphasized in bold. To ease interpretation, adjectives are colour coded according to thematic relatedness. A1=amazing, A2=awe-inspiring, A3=beautiful, A4=moving, A5=profound, A6=gave me chills, A7=incredible, A8=captivating, A9=breathtaking, A10=out of this world, A11=unbelievable, A12=overpowering, A13=powerful and A14=forceful; VS1=vast, VS2=enormous, VS3=immense; UQ1= unique, UQ2=exceptional; VL1=pleasant, VL2=positive, VL3=negative, VL4=unpleasant; F1= familiar, F2=unfamiliar, F3=novel, CL1=clear, CL2=harmonious, CM1=complicated, CM2=simple, US1=unusual, US2=strange, US3=typical, SR1=surprising, SR2=unanticipated, SR3=unforeseen, SR4=expected, IN1=inconsistent, IN2=clashing, UC1=uncertain, UC2=ambiguous.

Figure 3. Visualization of the network of awe-related appraisals in Study 1 (left panel) and Study 2 (right panel). Across both studies, most adjectives indicating awe (A), all adjectives indicating vastness (VS), and all adjectives indicating uniqueness (UQ) emerged as central to the awe experience. Across both studies, all adjectives indicating inconsistency (IN), as well as most adjectives indicating surprise (SR), complexity (CM) and unusualness (US), emerged as low in centrality.



Note: Centrality index of the individual appraisals in the awe induction condition. A1=amazing, A2=awe-inspiring, A3=beautiful, A4=moving, A5=profound, A6=gave me chills, A7=incredible, A8=captivating, A9=breathtaking, A10=out of this world, A11=unbelievable, A12=overpowering, A13=powerful and A14=forceful; CL1=clear, CL2=harmonious; CM1=complicated, CM2=simple; F1= familiar, F2=unfamiliar, F3=novel; IN1=inconsistent, IN2=clashing; SR1=surprising, SR2=unanticipated, SR3=unforeseen, SR4=expected; UC1=uncertain, UC2=ambiguous; UQ1= unique, UQ2=exceptional; US1=unusual, US2=strange, US3=typical; VL1=pleasant, VL2=positive, VL3=negative, VL4=unpleasant; VS1=vast, VS2=enormous, VS3=immense

Figure 4. Strength bootstrapped difference test in Study 1 (top panel) and Study 2 (top panel).



Note: Black squares indicate significant differences in strength (<.05). Out of 820 possible strength comparisons 430 were significant is Study 1 and 513 were significant in Study 2. Strength difference tests for items indicative of exceeded vs. disconfirmed expectancies are indicated with a white frame. A1=amazing, A2=awe-inspiring, A3=beautiful, A4=moving, A5=profound, A6=gave me chills, A7=incredible, A8=captivating, A9=breathtaking, A10=out of this world, A11=unbelievable, A12=overpowering, A13=powerful and A14=forceful; CL1=clear, CL2=harmonious; CM1=complicated, CM2=simple; F1= familiar, F2=unfamiliar, F3=novel; IN1=inconsistent, IN2=clashing; SR1=surprising, SR2=unanticipated, SR3=unforeseen, SR4=expected; UC1=uncertain, UC2=ambiguous; UQ1= unique, UQ2=exceptional; US1=unusual, US2=strange, US3=typical; VL1=pleasant, VL2=positive, VL3=negative, VL4=unpleasant; VS1=vast, VS2=enormous, VS3=immense.

Running head: AWE AND EXPECTANCY VIOLATION

Supplementary Materials for the article

"Awe arises in reaction to exceeded rather than disconfirmed expectancies"

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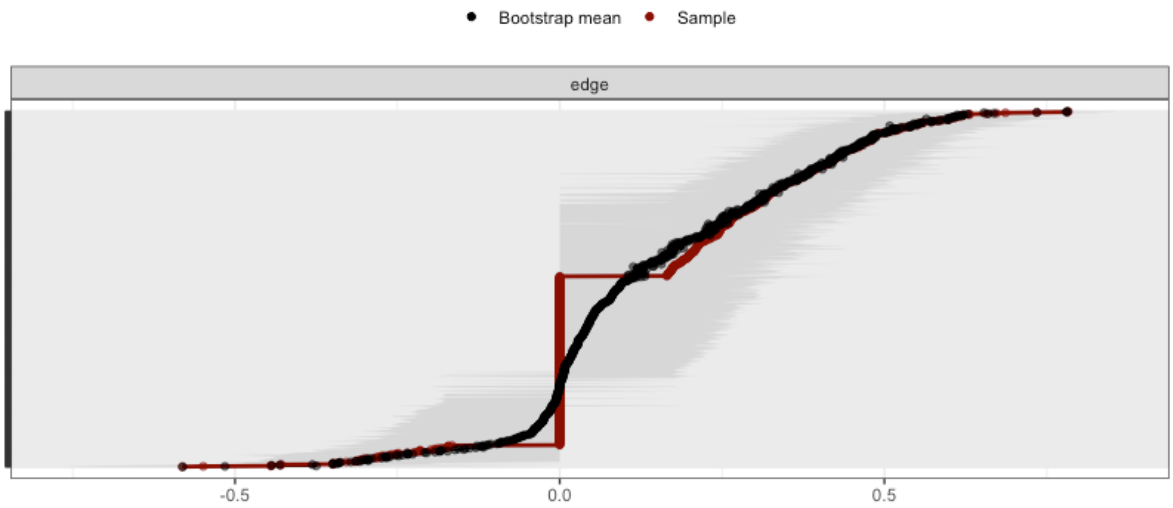
Supplementary Table 1. Exceeded expectancies were positively linked to vastness, uniqueness, valence, and clarity, while disconfirmed expectancies were negatively linked to positively linked to inconsistency and uncertainty and negatively linked to valence. Both exceeded and disconfirmed expectancies were consistently associated with decreased familiarity and increased unusualness and surprise. Due to low alpha reliabilities, results for familiarity and unusualness should be interpreted with caution.

		Study 1 (N = 298)				Study 2 (N = 505)				Summary
Outcome	Predictor	Beta	t	p	$\mathbf{R^2}$	Beta	t	p	R^2	S1/S2
VS1-3(Vastness)	EXC	**.48**	**7.32**	**.00**	**.19**	**.53**	**11.47**	**.00**	.21	+/+
	DIS	-.09	-1.41	.16		-.24	-5.24	.00		Ø/-
UQ1-2 (Uniqueness)	EXC	**.51**	**7.90**	**.00**	**.23**	**.53**	**11.66**	**.00**	.24	+/+
	DIS	-.05	-0.72	.47		-.11	-2.32	.02		Ø/ -
VL1-4 (Valence)	EXC	**.18**	**2.45**	**.02**	**.03**	**.44**	**9.17**	**.00**	.15	+/+
	DIS	**-.18**	**-2.56**	**.01**		**-.21**	**-4.30**	**.00**		-/-
F1-3 (Familiarity)	EXC	**-.22**	**-3.27**	**.00**	**.16**	**-.12**	**-2.25**	**.03**	.05	-/-
	DIS	**-.23**	**-3.50**	**.00**		**-.14**	**-2.78**	**.01**		-/-
CL1-2 (Clarity)	EXC	**.20**	**2.81**	**.01**	**.03**	**.47**	**9.89**	**.00**	.17	+/+
	DIS	-.11	-1.56	.12		-.27	-5.74	.00		Ø/-
CM1-2 (Complexity)	EXC	.02	0.23	.82	**.06**	**.17**	**3.21**	**.00**	.03	Ø/ +
	DIS	**.24**	**3.45**	**.00**		.04	0.67	.50		+/ Ø
US1-3 (Unusualness)	EXC	**.17**	**2.52**	**.01**	**.14**	**.11**	**2.08**	**.04**	.07	+/+
	DIS	**.25**	**3.71**	**.00**		**.20**	**3.97**	**.00**		+/+
SR1-3 (Surprise)	EXC	**.24**	**3.69**	**.00**	**.22**	**.27**	**5.64**	**.00**	.18	+/+
	DIS	**.29**	**4.53**	**.00**		**.22**	**4.59**	**.00**		+/+
IN1-2 (Inconsistency)	EXC	.03	0.37	.72	**.05**	-.05	-0.92	.36	.02	Ø/ Ø
	DIS	**.20**	**2.78**	**.01**		**.15**	**2.88**	**.00**		+/+
UC1-2 (Uncertainty)	EXC	.07	0.99	.32	**.08**	-.08	-1.55	.12	.03	Ø/ Ø
	DIS	**.23**	**3.32**	**.00**		**.19**	**3.75**	**.00**		+/+

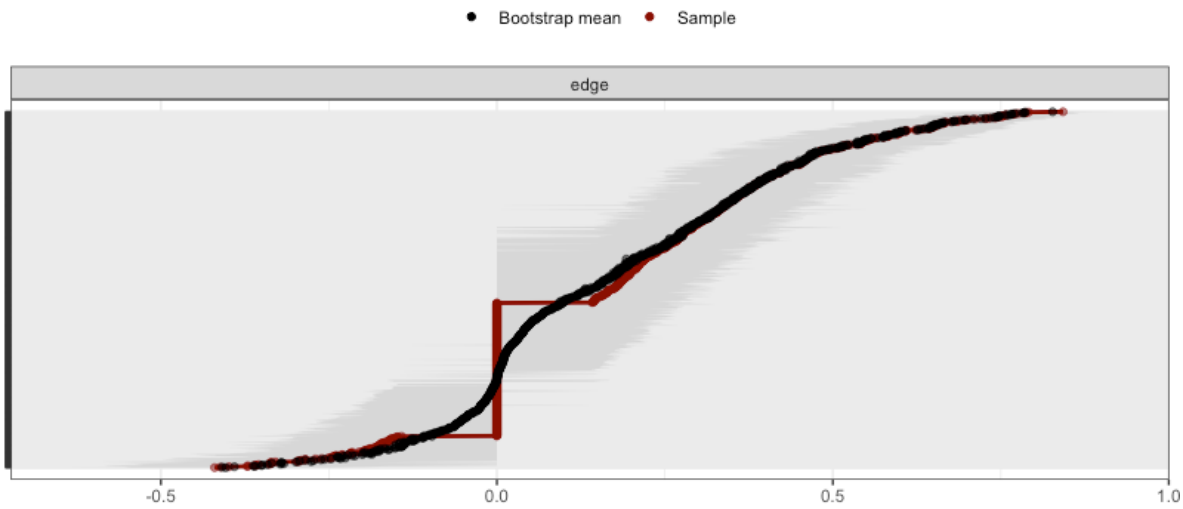
Note: Average appraisals were computed for variable groupings where the observed variables formed a reliable scale or where 2 variables were at least moderately correlated. VS1-3 denotes the mean score of *vast, enormous,* and *immense* (S1/S2 Cronbach's α = .90/.94); UQ1-2 denotes the mean score of *unique* and *exceptional* (S1/S2 r = .50/.55); VL1-4 denotes the mean score of *pleasant, positive, negative* (reverse scored) and *unpleasant* (reverse scored; S1/S2 Cronbach's α = .86/.86); F1-3 denotes the mean score of *familiar, unfamiliar* (reverse scored) and *novel* (reverse scored; S1/S2 Cronbach's α = .75/.48); CL1-2 denotes mean score of *clear* & *harmonious* (S1/S2 r = .41/.52); SR1-3 denotes mean score of *surprising, unanticipated, unforeseen* and *expected* (reverse scored; S1/S2 Cronbach's α = .81/.72); IN1-2 denotes mean score of *inconsistent* and *clashing* (S1/S2 r = .37/.36) and UC1-2 denotes mean score of *uncertain* and *ambiguous* (S1/S2 r = .30/.45). Each scene appraisal was simultaneously regressed on the 2 types of expectancy violation. In the most right hand side column "Ø"denotes a non-significant relationship; "+" denotes a significant positive relationship while "-" denotes a significant negative significant relationship. Grey cells highlight results that were consistent across both studies.

Supplementary Figure 1. Accuracy of edge-weights for the estimated network model. In general, edge weights in Study 1 and Study 2 exhibited rather large confidence intervals, indicating that the *order* of edges should be interpreted with caution.

Study 1

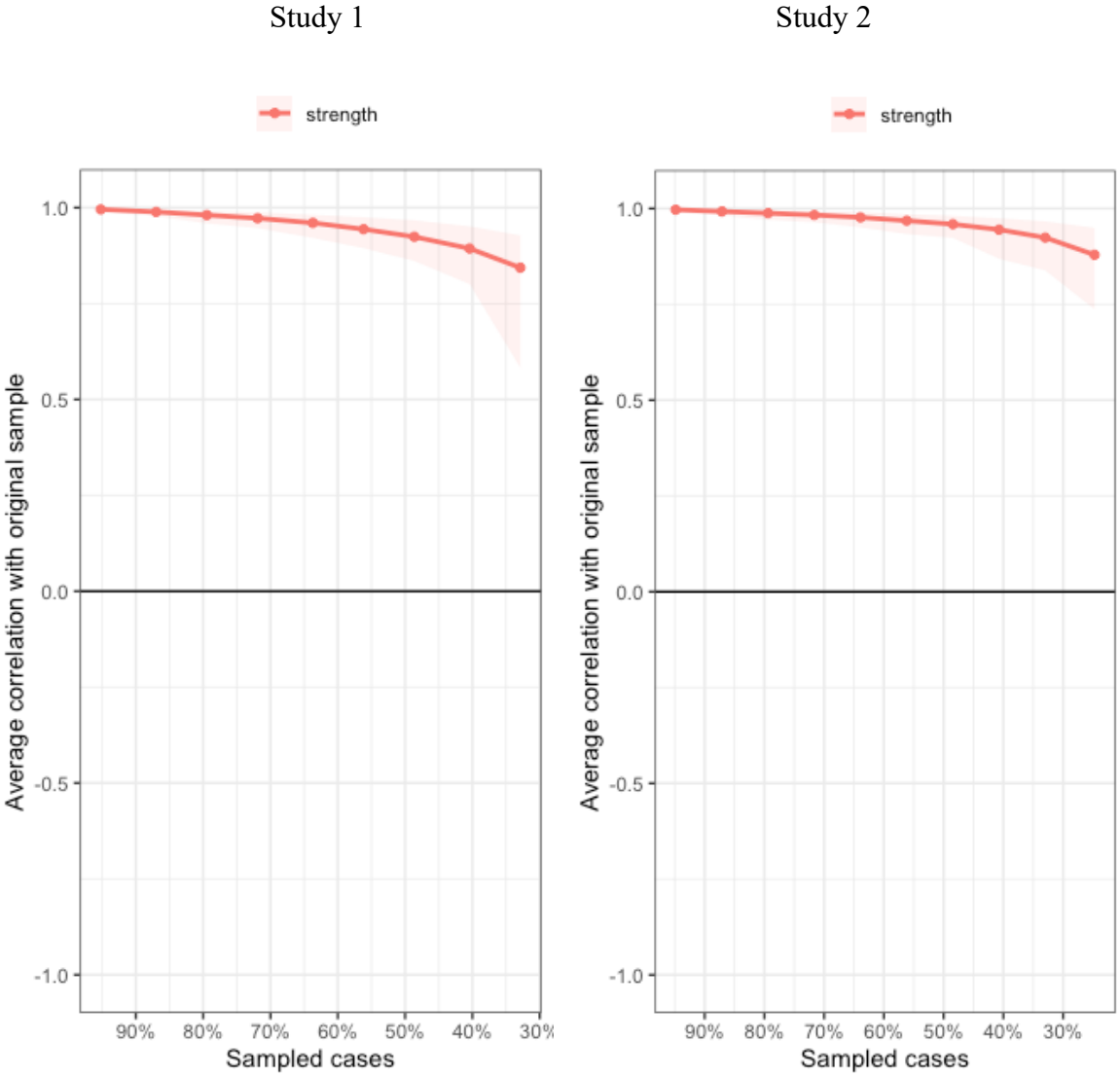


Study 2



Note: Accuracy of edge-weights for the estimated network model was estimated by drawing bootstrapped *CI*s using a parametric resampling bootstrap method. Wide bootstrapped *CI*s indicate whether the *strength* of an edge can be interpreted with confidence, but the static cannot be used to judge whether an edge is different from zero or whether it is positive or negative . The horizontal area within the plot represents the 95% quantile range of the parameter values across 1000 bootstraps. The red dots indicate the sample values, while the black dots indicate the bootstrap mean values.

Supplementary Figure 2. Stability of differences in centrality strength in Study 1 and in Study 2. The plot demonstrates high stability for a wide range of increasingly smaller bootstrapped samples, suggesting that we can confidently interpret differences in strength of the individual items.



Note: To assess the stability of our centrality (strength) indices we we conducted the routine implemented in the *bootnet* package using parametric bootstrapping based on 10,000 bootstrap samples .