To Fear or Fly to the Unknown: Tolerance for Ambiguity and Big Five Personality
Traits¹

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Abstract

The present study investigated whether ambiguity tolerance relates to personality traits that are theoretically grounded in fear (neuroticism) or attraction (openness to experience; extraversion) for the unknown. Our hypotheses were supported for self-report measures (and openness to experience predicted ambiguity tolerance controlling for intelligence), but behavioral choice measures of ambiguity tolerance demonstrated poor reliability and were unrelated to self-reported ambiguity tolerance and basic personality traits. An exploratory network analysis revealed that ambiguity tolerance was more strongly related to the intellectual curiosity (vs. aesthetic appreciation) facet of openness to experience, and the assertiveness (vs. energy or sociability) facet of extraversion. Our findings reinforce the fragmented literature in this area, and support predictions derived from psychological entropy theories of personality.

Keywords: Openness to experience, extraversion, neuroticism, ambiguity, uncertainty, entropy, Ellsberg paradigm

Ambiguity is a ubiquitous part of life. A researcher may spend her career searching for the cure for a rare disease, without knowing if the search will be in vain. A tourist may stare at an abstract painting on a gallery wall, uncertain if the vague shape is a bicycle or a product of his own imagination. A smile could indicate enjoyment or derision of your attempt at a joke.

The tendency to view ambiguous and uncertain situations as appealing versus threatening is known as *ambiguity tolerance* (Frenkel-Brunswik, 1949; Budner, 1962) or *uncertainty intolerance* (Freeston, Rhéaume, Letarte, Dugas, & Ladouceur, 1994). People who are more tolerant of ambiguity report being happier (Bardi, Guerra, Sharadeh, & Ramdeny, 2009), more motivated to learn (Tapanes, Smith, & White, 2009), more self-efficacious (Wolfradt, Oubaid, Straube, Bischoffm, & Mischo, 1999), and more likely to engage in cross-cultural experiences (Caligiuri & Tarique, 2012). Conversely, people who are less tolerant of ambiguity and uncertainty tend to be more worried (Burh & Dugas, 2006; Dugas, Gosselin, & Ladoucer, 2001), anxious and depressed (Bardi et al., 2009; Carleton et al., 2012), obsessive-compulsive (Tolin, Abramowitz, Brigidi, & Foa, 2003), and show greater stress-related physiological responses (Greco & Roger, 2001).

Despite extensive research linking ambiguity tolerance to such diverse outcomes, there has been far less research assessing where ambiguity tolerance is located within dominant models of the structure of personality traits such as the Big Five (John, Naumann, & Soto, 2008). Similarly, within the mainstream personality literature, ambiguity tolerance is a construct that is discussed surprisingly little. Perhaps owing to the lack of cross-talk between personality and ambiguity tolerance literatures, an interesting correspondence between mechanistic theories of personality and concepts of ambiguity has been overlooked. Specifically, *psychological entropy*

theories of personality propose that some domains of the Big Five are partially underpinned by individual differences in responses to the unknown (Hirsh, Mar, & Peterson, 2012; DeYoung, 2013). Whereas *openness to experience* and *extraversion* have been attributed to individual differences in one's motivational drive to explore the unknown (DeYoung, 2013), *neuroticism* and its narrower sub-trait of *anxiety* have been attributed to individual differences in aversive responses to the unknown (Hirsch et al., 2012). As unknown situations are inherently ambiguous, it is possible to test the initial stages of psychological entropy theories by measuring the relation between ambiguity tolerance and the basic domains of personality. In the current study, we first expand the theoretical justification for this argument, and subsequently consolidate the sparse existing literature by conducting a pre-registered investigation of whether ambiguity tolerance relates robustly to openness to experience, extraversion, and neuroticism.

1.2 Personality and Psychological Entropy

At the heart of the theories by Hirsh and colleagues (2012) and DeYoung (2013) is the concept of entropy. Entropy is a measure of uncertainty and disorder within a system (Wiener, 1961), and has been used to describe the behavior of complex systems throughout diverse fields such as information theory, thermodynamics, and cybernetics. Mathematically, outcomes that are certain have an entropy of zero, and more probable outcomes will have lower entropy than less probable outcomes (Weaver, 1964; Shannon, 1948). For example, the entropy of a two-headed coin will be zero, as the outcome will always be heads². And as the outcome of flipping a coin (a one-in-two chance) is more predictable than that of

² For sticklers considering the event of a coin balancing on its edge, please indulge in imagining the entropy of a two-headed coin to be slightly higher than zero.

rolling a six-sided die (a one-in-six chance), the former has a lower entropy than the latter.

Extending this concept to preferences as well as events, Hirsh and colleagues define *psychological entropy* as the number of possible options available to an individual—either for their perception of the world, or for their behavior. When there are multiple potential interpretations or actions, and it is unclear which interpretation or action is best, psychological entropy will be high. Conversely, when there is a single clear path forward, or multiple paths but a clear choice, psychological entropy will be low. Consider the example of deciding whether to attend a party or stay at home. Psychological entropy will be higher when there are two parties to choose from, and higher still with three parties, so long as no alternative is clearly more appealing than the other.

The Cambridge online dictionary defines ambiguity as “the fact of something having more than one possible meaning and therefore possibly causing confusion”. This description converges with Hirsh and colleagues’ (2012) definition of psychological entropy given above. It is difficult to imagine a situation where psychological entropy would increase without also increasing ambiguity; and likewise, for psychological entropy to decrease without there being a corresponding decrease in ambiguity. In the example of considering parties to attend, all other things being equal, the option of two parties is a more ambiguous a single party. Thus, in the current paper, psychological entropy and ambiguity will be treated as highly overlapping and, for the contexts discussed herein, equivalent.

Hirsh et al. (2012) contended that (1) increases in psychological entropy will lead to increased distress and anxiety, and thus (2) individuals desire to reduce their experience of entropy to a manageable level. However, given that individual

differences in one's tolerance for ambiguity have been extensively documented in survey research (Budner, 1962; McLain, 2009), responses to increases in entropy might not uniformly involve stress and anxiety. This is central to DeYoung's (2013) argument that entropy (and thus, we argue, ambiguity) can be simultaneously aversive and enticing: although it can signal a potential threat, it can also signal a potential reward. DeYoung (2013) contended that the rewarding nature of psychological entropy would be most relevant for the personality traits extraversion (i.e., the tendency to engage with the social and material world with energy, enthusiasm, and assertiveness; Wilt & Revelle, 2017) and openness to experience (i.e., the tendency to experience and appreciate depth, originality, and complexity in one's mental and experienced life; McCrae & Costa, 1997). Specifically, extraverts would be motivated by the potential for rewards in the unknown (Depue & Colins, 1999), whereas those higher in openness to experience would be motivated by the potential to gain future information from the unknown. DeYoung (2013) also argued that the shared motivation to explore the uncertain nature of the environment—to "increase the experience of uncertainty to an interesting level" (p. 8)—partially explained the shared variance between extraversion and openness to experience, which together form the higher-order meta-trait *plasticity*. As explorers must place themselves in a state of temporary ambiguity in order to gain their rewards—whether they be social, financial, informational, or purely aesthetic—this theory predicts that openness to experience and extraversion are related to higher ambiguity tolerance. In contrast, neuroticism—which describes the tendency to experience negative states such as anxiety, depression, and volatility—would be expected to relate to stronger aversive responses to ambiguity, as these individuals would be more likely to perceive threats in the unknown. Thus, the theory also predicts that neuroticism would be related to

greater *intolerance* of ambiguity. If there is sufficient evidence linking ambiguity tolerance to these traits in the expected direction, then this is consistent with DeYoung's (2013) hypothesis that extraversion and openness to experience share variance due to a tendency to explore of the unknown; and is also consistent with the view that neuroticism is grounded in aversive responses to uncertainty (Hirsh et al., 2012; DeYoung, 2013; 2014).

1.3 Empirical Links Between Ambiguity Tolerance and Big 5 Personality Traits

To our knowledge, no existing paper has focused solely on assessing how openness to experience, extraversion, and/or neuroticism relate to one's attitude toward ambiguity. However, there have been several studies where these relations were reported tangentially to the central research question. For example, Caligiuri and Tarique (2012) investigated predictors of leadership effectiveness, measuring personality traits and ambiguity tolerance as part of their test battery. They found that openness to experience and extraversion correlated positively with ambiguity tolerance (r s for both = .24) but did not observe a significant correlation between neuroticism and ambiguity tolerance.

Given the shared variance between extraversion and openness to experience, it is possible that extraversion would only predict ambiguity tolerance via its relation to openness to experience. However, Caligiuri and Tarique (2012) found that extraversion was a significant predictor of ambiguity tolerance after accounting for openness to experience. This would be promising for entropy theories of personality, but the study is limited by employing an early 4-item measure of ambiguity tolerance with poor internal consistency, making it possible that this incremental prediction (and the pattern of correlations) would not replicate.

In a more recent study, Lauriola and colleagues (2016) conducted a principal components analysis of seven ambiguity tolerance measures and assessed how each component correlated with a range of variables, including personality traits. They found that extraversion and openness to experience were weakly negatively related to distress or discomfort for ambiguous situations ($r = -.22$ and $r = -.16$, respectively), more strongly and positively related to need for complexity and novelty ($r = .20$ and $r = .35$, respectively), but only openness to experience was significantly (weakly) related to the third component, moral absolutism and rigid thinking ($r = -.12$). Conversely, neuroticism was only significantly related to the first component, discomfort for ambiguity ($r = .29$).

These two studies are the only ones we have found measuring ambiguity tolerance and extraversion or neuroticism, but neuroticism has demonstrated strong correlations ($r \sim .50$) with *uncertainty intolerance* (de Bruin, Rassin, & Muris, 2007; Greco and Roger, 2001; Berenbaum, Bredemeier, & Thompson, 2008; McEvoy & Mahoney, 2012). Uncertainty intolerance and ambiguity tolerance are sometimes conceptualized as separate constructs. However, measures of uncertainty intolerance and ambiguity tolerance demonstrate close empirical and conceptual overlap, as evidenced by the very high correlations between measures when they are included in the same study (e.g., Lauriola et al., 2016).³ Thus, the present study treats ambiguity tolerance and uncertainty intolerance as interchangeable constructs. Nevertheless, as the example items above demonstrate, the items included in intolerance of uncertainty

³ One apparent distinction is that uncertainty intolerance includes a future-orientation absent in ambiguity tolerance (Furnham & Marks, 2013). However, this is not consistent across items in uncertainty intolerance scales. For example, the uncertainty intolerance scale used for the present study (Carleton, Norton, & Asmundson, 2007) includes several items related to inhibitory anxiety in which no future orientation is specified, such as *when it's time to act, uncertainty paralyzes me*. Indeed, there is a very similar item employed in a common measure of ambiguity tolerance, *I find it hard to make a choice when the outcome is uncertain* (McLain, 2009).

scales tend to be more negatively valenced, and to employ more strongly emotional language. Thus, it is possible that the high association between neuroticism and uncertainty intolerance is driven by the negative item content, rather than to uncertainty or ambiguity per se. This would lead neuroticism to be a better predictor of uncertainty intolerance than ambiguity tolerance, even if uncertainty intolerance and ambiguity tolerance are conceptually measuring the same construct. This may provide an explanation for the non-significant relationship observed by Caligiuri and Tarique (2012), and the smaller effect sizes documented by Lauriola et al. (2016). The current study aims to assess the relative association between neuroticism and measures of ambiguity tolerance and uncertainty intolerance, and to assess whether neuroticism is a better predictor of uncertainty intolerance than openness to experience.

For openness to experience, one additional high-powered study measured how openness to experience and ambiguity tolerance related to wellbeing in the context of academic life transitions (Bardi et al., 2009), finding the correlation between openness and ambiguity tolerance to be stronger for first year university students ($r = .42$) than for final year students ($r = .25$). Though we have found no further studies that directly test these relations, some researchers have found associations between ambiguity tolerance and measures conceptually related to openness to experience. For example, Wolfradt et al. (1999) found that interpersonal ambiguity tolerance was associated with a drive to learn things and understand the world. Rajagopal and Hamouz (2009) observed that ambiguity tolerance correlated positively with openness to try food from many cultures and styles. Also of relevance is a study by Swami, Stieger, Pietchnig, and Voracek (2010), who found that ambiguity tolerance correlated positively with appreciation of surrealist art and films (which open people tend to be

more interested in). Finally, openness to experience was also related to the tendency to experience mixed (i.e., more ambiguous) emotions (Barford & Smillie, 2016), and to provide mixed appraisals of art (Barford, Fayn, Silvia, & Smillie, 2018).

Importantly, openness to experience correlates with intelligence at $r \sim .30$ (DeYoung et al., 2014). It is plausible that any observed relation between openness to experience and ambiguity tolerance could be driven primarily by intelligence. For instance, more intelligent individuals may think more comprehensively about their choices when options are ambiguous, and thus be less affected by any aversive properties in ambiguity. To our knowledge, no prior study has tested whether openness to experience relates to ambiguity tolerance after controlling for g . We evaluate this in the current study.

1.4 Measuring Tolerance for Ambiguity Via Self-report and Behavior

Until recently, most measures of ambiguity tolerance had lower than acceptable psychometric properties (Furnham & Marks, 2013): for example, internal consistency for the most well-cited ambiguity tolerance scale was $\alpha = .49$ (Budner, 1962). Two recent scales of ambiguity tolerance have been developed with much improved psychometric properties: the Multiple Stimulus Types Ambiguity Tolerance Scale-II (MSTAT; McLain, 2009) and the Tolerance for Ambiguity measure (TfA; Herman, Stevens, Bird, Mendenhall, & Oddou, 2010). Each of these have reported internal consistencies of $\alpha > .70$. The MSTAT (version I) was included in Lauriola et al. (2016) and most items loaded heavily on the need for complexity/novelty component. Meanwhile, items comprising the TfA appear on face value to tap more diverse sub-domains of ambiguity tolerance. Indeed, Herman et al. (2010) found evidence of four dimensions: valuing diverse others, change versus stability, challenging perspectives, and unfamiliarity versus novelty. In the current study, we will use both the MSTAT

and TfA along with a measure of uncertainty intolerance (Carleton et al., 2007), thereby aiming to provide comprehensive coverage of this construct.

In parallel to the research on ambiguity tolerance as measured by self-report, *behavioral* measures of ambiguity tolerance have a long history of use in economics and decision theory (Ellsberg, 1961). In these fields, ambiguity tolerance is assessed using the *Ellsberg paradigm* as the preference for an ambiguous versus unambiguous gamble (for reviews, see Camerer & Weber, 1992; and Trautmann & Kuilen, 2015). For example, a participant may be given a choice between two equally risky gambles: a 50/50 chance of winning \$1, or an entirely unknown chance of winning \$1. Both options are equivalent in terms of their subjective expected utility, and should be equally valued for that reason (Camerer & Weber, 1992). The options are also equivalent in terms of risk, and thus participants' choices should not be influenced by risk aversion (which has well-documented links to neuroticism; Nicholson, Soane, Fenton-O'Creevy, & Willman, 2005; Soane & Chmiel, 2005). Critically, however, the latter option (unknown chance of winning) is the more ambiguous of the two, suggesting that a preference against this option is indicative of intolerance of ambiguity.

In previous studies using such choice gambles, participants tend to be ambiguity averse (with the exact percentage varying by amount of reward or degree of ambiguity), but there is a substantial minority who choose more ambiguous options (Trautmann & Kuilen, 2015). To our knowledge, no study has yet assessed how Big Five personality traits may relate to behavioral responses to ambiguity as measured by the Ellsberg paradigm. Thus, in the current study, we employ five variations of this paradigm to assess whether openness to experience, extraversion, and neuroticism predict behavioral ambiguity tolerance.

1.5 Exploring Facets of Personality and Ambiguity Tolerance

Each of the Big Five factors is composed of lower-order facets, providing a less parsimonious but more complete depiction of personality structure. For instance, the Big Five Inventory-2 (BFI-2; Soto & John, 2017) divides openness to experience into the three facets *intellectual curiosity*, *aesthetic sensitivity*, and *creative imagination*. Studies have demonstrated value in assessing differential relations between personality trait facets and variables such as wellbeing (Sun, Kaufman, & Smillie, 2018), creative achievement in the arts versus sciences (Kaufman et al., 2016), and prosociality (Zhao, Ferguson, & Smillie, 2016). Evidence suggests that ambiguity tolerance can also be subsumed by more fine-grained factors (Lauriola et al., 2016). As summarized in Section 1.3, these factors appear to be differentially related to personality traits. In the current study, we aim to explore empirically derived sub-dimensions of our three ambiguity/uncertainty tolerance measures, and subsequently assess whether these differentially relate to facets of openness to experience, extraversion, and neuroticism. In so doing, we can (a) observe whether sub-components derived by Lauriola et al. (2016) are represented in our data, and whether they map onto personality traits in a similar fashion, and (b) explore new patterns of associations that may not yet have been discovered, from which future researchers may wish to conduct confirmatory investigations.

For this task, we employ a network model (Cramer, 2012; Costantini et al., 2015). A network model represents variables of interest as *nodes*, and correlations between variables as *edges*. It is possible to construct a network in which edges are computed between two nodes, controlling for all other nodes in the network. This comprises a network of partial correlations, where only the unique variance between variables is represented. This thus provides all the advantages of a traditional partial

correlation analysis, but includes important checks on inferring signal from noise, such as the creation of sparse network structures via regularization, and estimation of bootstrapped confidence intervals around edge weights (Epskamp, Borsboom, & Fried, 2018). An additional benefit is easy interpretability: networks are able to condense a substantial amount of information into an intuitive visualization, allowing patterns of associations to be grasped efficiently.

1.6 The Present Study

To sum up, there is suggestive evidence that openness to experience, extraversion, and neuroticism may relate to ambiguity tolerance, in line with theoretical perspectives on psychological entropy offered by Hirsh et al. (2012) and DeYoung (2013). The aim of the present study is to strengthen this fledging literature through a comprehensive evaluation of these associations, across both self-reported and behavioral measures of ambiguity tolerance. In additional exploratory analyses, we assess the partial correlation network of key variables with a network analysis, aiming to further clarify how sub-components of ambiguity tolerance are related to facets of Big Five personality traits.

For self-report measures, we hypothesize that openness to experience, extraversion, and plasticity will relate positively to ambiguity tolerance, and will relate negatively to intolerance to uncertainty. We also expect that openness to experience will predict ambiguity tolerance even controlling for intelligence.

We hypothesize that the opposite pattern will appear for neuroticism: specifically, that neuroticism will negatively relate to ambiguity tolerance, and positively relate to intolerance of uncertainty. We also expect that neuroticism will be a better predictor of ambiguity tolerance when it is measured as uncertainty

intolerance rather than openness to experience⁴. Finally, we explore whether extraversion continues to predict ambiguity tolerance controlling for openness to experience.

For behavioral measures, we hypothesize that openness to experience, extraversion, and plasticity will predict preference for an ambiguous (versus unambiguous) gamble; that the relation between openness to experience and choosing an ambiguous gamble will hold even when controlling for intelligence; and that neuroticism will predict choosing an unambiguous (versus ambiguous) gamble.

This study was preregistered, and all materials, data, and analysis code for this study are freely available on the Open Science Framework (OSF; <https://osf.io/4mruh/>)

2. Method

2.1 Participants

Participants were United States residents who were recruited from Amazon Mechanical Turk in June of 2018. Our target sample was 300 individuals. In total, 327 participants began the study. After removing 19 participants who completed less than 90% of the survey (our pre-registered exclusion criteria)⁵, the final sample was $N = 308$ ($M_{\text{age}} = 36.23$, $SD_{\text{age}} = 10.82$, 38% female). This provides $> 90\%$ power to detect a correlation of $r = .20$, the approximate average effect size observed in personality psychology (Gignac & Szodorai, 2016). Ethical approval for the study was obtained from the Melbourne School of Psychology Human Ethics Advisory Group (ID. 1851766.2).

⁴ This prediction can be found in the “Analysis plan” section of the preregistration, rather than the hypotheses section.

⁵ One additional participant completed more than 90% of the survey, but did not complete the study to obtain an identifying code that was necessary to obtain payment, and additionally failed both attention checks and a comprehension check. Their data was not included in the study.

2.2 Materials and Procedure

Participants completed a battery of questionnaires and behavioral tasks (full survey questions available on the OSF) and were informed that they would be reimbursed \$2.00 USD for their time, with an additional \$0.50 USD conditional upon correctly completing attention checks. In addition, participants were told that they had the chance to win an additional \$0.50 USD in the behavioral tasks. To maintain fairness among participants, all participants received this second bonus money after study completion. All scales included in the survey are described below. All used a 5-point scale from *Strongly Disagree* to *Strongly Agree*.

2.2.1 Big Five personality traits. The five major domains of personality (extraversion, neuroticism, conscientiousness, agreeableness, and openness to experience) were measured with the BFI-2 (Soto & John, 2017). Each domain is assessed using 12 items (e.g., *Is outgoing, sociable*), and can be divided into three facet scales, measuring narrower conceptualizations of the trait (e.g., extraversion divides into Energy Levels, Sociability, and Assertiveness). For an additional measure of openness to experience, we administered Openness/Intellect from the Big Five Aspect Scales (BFAS; DeYoung, Quilty, & Peterson, 2007), a 20-item measure of openness to experience which can be divided into two narrower aspect scales, Openness (appreciation of sensorial and perceptual complexity) and Intellect (appreciation of intellectual complexity).

2.2.2 Self-reported ambiguity/uncertainty tolerance. As mentioned earlier, the two scales of ambiguity tolerance used were the TfA (Herman et al., 2010), and the MSTAT (McLain, 2009). Of the many measures available, these appeared the most valid and reliable. Items also appeared relatively different from each other on face value (e.g., *I don't tolerate ambiguous situations well* from the MSTAT; *I would*

like to live in a foreign country for a while from the TfA), allowing for an exploratory investigation of the construct space for these measures. In addition, participants completed the Intolerance of Uncertainty Scale-12 (Carleton et al., 2007), a 12-item measure with evidence of high internal consistency and evidence of convergent validity, discriminant validity and clinical validity.

2.2.3 Behavioral ambiguity tolerance. We used five variants of the Ellsberg paradigm (Ellsberg, 1961; described in Camerer & Weber, 1992). In this paradigm, participants are required to choose between two gambles. Both gambles are equally risky, but one is more ambiguous than the other. The five tasks are described below. To increase participant engagement, we altered the traditional task design from one in which participants were told they were choosing balls from urns, to a design in which participants were informed they were explorers moving through various rooms in a cave, with an aim to collect treasure (the equivalent of balls) from chests (the equivalent of urns) guarded by a trickster ghost. The online documentation contains the full script shown to participants.

The five variants were as follows. First, in the *two-color problem*, participants choose between a 50/50 probability of winning *or* a completely unknown probability of winning. Next, two versions of the *three-color problem* were presented. In the first, participants choose between a 3/9 chance of winning, or an unknown/9 chance of winning. In the second, participants choose between an unknown/9 chance at winning versus a 6/9 chance of winning. Finally, participants completed two versions of the *two-color problem with second-order probability*. Second-order probabilities refer to gambles where the participants are made aware of how ambiguous an option may be (Camerer & Weber, 1992). In the first of these tasks, participants choose between a 50/50 probability of winning, or a chance that is somewhere between 40/100 and

60/100. In the second of these tasks, participants have the same 50/50 chance for the first option, but the ambiguity of the second option was increased to a chance of winning that is anywhere between 20/100 and 80/100.

2.2.4 Intelligence. To assess whether any relation between openness to experience and ambiguity tolerance might be driven primarily by intelligence, we employed the publicly available International Cognitive Ability Resource (Condon & Revelle, 2014). This 16-item measure is an open-access intelligence test that has strong psychometric properties, including excellent internal consistency, and compelling evidence of construct validity, convergent validity, and discriminant validity.

2.3 Attention and Comprehension Checks

Participants were asked to complete a simple comprehension check following the behavioral ambiguity task (in which they were asked the number of gems possible to be drawn from a treasure chest in the final behavioral task), and two attention checks threaded into the survey questions (“Respond ‘strongly agree’” and “Respond ‘strongly disagree’”). Of the 308 participants whose data we included in the study, 14 failed the comprehension check, and following our pre-registered plan, their data was excluded from computations involving behavioral ambiguity tolerance. Seventeen participants failed the first attention check, and 15 failed the second attention check. Of these, seven participants failed both attention checks. As results based on self-report measures did not substantially change when we removed these participants, we followed our pre-registered plan to retain this data in order to maximize statistical power.

2.4 Data Analysis

2.4.1 Indices. When we had multiple measures of the same construct, we computed a single factor using exploratory factor analysis. This was performed to avoid duplicating analyses for both scales, and to increase measurement precision (as assuming that the two scales are valid and reliable, a general factor combining these measures will be superior to one scale alone). Specifically, we employed ordinary least squares with a direct oblimin rotation, and saved factor scores with the correlation-preserving (“ten Berge”) method (ten Berge, Krijnen, Wansbeek, & Shapiro, 1999). This procedure was applied to (1) our two measures of openness to experience (BFAS and BFI-2), (2) our two measures of ambiguity tolerance (TfA and MSTAT), and (3) the meta-trait plasticity (BFI-2 Open Mindedness and Extraversion). These saved scores were used in the inferential analyses described below, except when specified. Finally, we also planned to use this approach with the five variants of the Ellsberg paradigm to create an overall measure of behavioral ambiguity tolerance, conditional on acceptable reliability amongst responses to these items (omega greater than .60). However, as reliabilities did not meet this threshold in our sample, we analyzed behavioral results separately (see Section 3.3.2).

2.4.2 Exploratory Network Analysis. Prior to commencing the network analysis, it was necessary to assess the dimensionality of our measures of ambiguity tolerance. The supplementary information (Section S3) contains full methodological details of this analysis. In brief, we used exploratory graph analysis (Golino & Epskamp, 2017), an alternative to exploratory factor analysis developed from the network approach. This method has previously been used to assess the dimensionality of personality measures (Christensen, Cotter, & Silvia, 2018; Christensen, Gross, Golino, Silvia, & Kwapil, 2018) and simulation studies indicate it can successfully retrieve the correct number of dimensions in a dataset (Golino & Epskamp, 2017).

Exploratory Graph Analysis is comparable to common methods of deriving the correct number of factors (e.g., parallel analysis), and can perform better than traditional methods when factors are highly correlated (Golino & Epskamp, 2017).

Subsequent to dimension reduction, we conducted the network analysis following the guidelines of Epskamp, Borsboom, and Fried (2018). Edge weights (i.e., partial correlations) were estimated with a Gaussian graphic model including LASSO regularization to create a sparse network structure. Regularization reduces false positives relative to partial correlations, such that a measured edge can be more confidently inferred to represent a true structural relation between two variables (Costantini et al., 2015; though note that a lack of edge may simply mean that the statistical power is not sufficiently high to detect an edge). To estimate the accuracy of edge weights, we used a nonparametric bootstrap with 1,000 samples to construct 95% bootstrapped confidence intervals (CIs) around edge weights.

Network analyses often include additional tests from graph theory, such as measures of centrality (Fried & Cramer, 2017). However, as our main interest in the network analysis was viewing the partial correlation matrix rather than assessing which nodes were the most central in the network, we have not assessed these elements.

2.4.3 Packages. All analyses were deployed using *R* (version 3.5.0; R Core Team, 2018), and making use of the following packages: *bootnet* (Epskamp et al., 2018), *EGA* (Golino, 2018), *lavaan* (Rosseel, 2012), *lm.beta* (Behrendt, 2014), *lsr* (Navarro, 2015), *psych* (Revelle, 2018), *qgraph* (Epskamp, Cramer, Waldorp, Schmittmann, & Borsboom, 2012), *tidyverse* (Wickham, 2017), and *TOSTER* (Lakens, 2017).

3. Results

3.1 Descriptive Statistics

Table 1 displays means, standard deviations, skew, kurtosis, and internal consistency values (omega hierarchical, omega total, and Cronbach's alpha) for all measured variables. All variables were normally distributed with minimal skew or kurtosis. Internal consistency was acceptable for most variables, with the notable exception of our behavioral measure of ambiguity tolerance ($\alpha = .39$, $\omega_h = .19$, $\omega_t = .47$). This falls short of the acceptable lower bound of reliability (.60) that we specified in our preregistration.

Table 1.

Descriptive Statistics and Internal Consistency Measures for All Variables

Variable	Mean	SD	Skew	Kurtosis	<u>Internal Consistency</u>		
					Omega H	Omega T	Alpha
Behavioral AT	0.39	0.26	0.29	-0.72	.19	.47	.39
Ambiguity TfA	3.07	0.59	0.03	0.28	.40	.83	.76
Ambiguity MSTAT	3.13	0.80	0.06	-0.25	.73	.93	.91
Uncertainty Intolerance	3.06	0.83	-0.09	-0.49	.72	.92	.90
Intelligence	7.56	3.83	0.34	-0.77	.61	.84	.82
Extraversion	2.99	0.81	-0.11	-0.59	.62	.91	.88
Negative Emotionality	2.59	0.92	0.33	-0.51	.78	.94	.93
Conscientiousness	3.70	0.76	-0.35	-0.45	.76	.93	.91
Agreeableness	3.66	0.71	-0.36	-0.13	.64	.91	.88
BFI-2 Open Mindedness	3.78	0.78	-0.35	-0.44	.68	.93	.90
BFAS Openness/Intellect	3.75	0.65	-0.06	-0.68	.53	.93	.90

Note: SD = standard deviation, Omega H = Omega Hierarchical, Omega T = Omega Total, Behavioral AT = Behavioral Ambiguity Tolerance, TfA = Tolerance for Ambiguity Scale, MSTAT = Multiple Stimulus Types Ambiguity Tolerance Scale-II, Uncertainty Intolerance = The Short Form Intolerance of Uncertainty Scale. BFAS Openness/Intellect drawn from the Big Five Aspects Scale (DeYoung et al., 2007), with the remaining personality trait measures drawn from the Big Five Inventory-II (Soto & John, 2017). Behavioral AT is coded as 0 = Ambiguity avoidant, 1 = Ambiguity tolerant.

Table 2.

Zero-Order Correlations Between Study Variables

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Behavioural AT													
2. TfA	.02												
3. MSTAT	.04	.66											
4. Uncertainty Intolerance	-.05	-.56	-.79										
5. Intelligence	-.16	.12	.14	-.15									
6. Extraversion	.05	.29	.45	-.41	-.10								
7. Negative Emotionality	-.01	-.23	-.48	.60	-.02	-.52							
8. Conscientiousness	-.02	.10	.24	-.27	.03	.33	-.53						
9. Agreeableness	.05	.15	.27	-.31	.07	.35	-.43	.46					
10. BFI-2 Open M	.06	.40	.50	-.34	.18	.37	-.24	.33	.43				
11. BFAS O/I	-.01	.43	.55	-.38	.25	.37	-.32	.39	.50	.85			
12. BFAS Openness	.03	.32	.34	-.17	.14	.25	-.07	.24	.49	.81	.85		
13. BFAS Intellect	-.01	.41	.60	-.46	.29	.37	-.46	.43	.36	.64	.86	.46	
14. Plasticity	.07	.42	.57	-.45	.05	.84	-.46	.40	.47	.82	.73	.63	.61

Note: $r_s > .18$ are significant at $p < .05$, and $r_s > .23$ are significant at $p < .001$, Holm-Bonferroni corrected for multiple comparisons. $p_s < .001$ are bolded. Behavioral AT = Behavioral Ambiguity Tolerance, TfA = Tolerance for Ambiguity Scale, MSTAT = Multiple Stimulus Types Ambiguity Tolerance Scale-II, BFI-2 Open M = BFI-2 Open Mindedness, BFAS O/I = BFAS Openness/Intellect. Plasticity is computed by averaging scores for BFI-2 Open Mindedness and BFI-2 Extraversion.

We speculated that participants' responses may have followed a different pattern for our fourth and fifth behavioral tasks, which both employ second-order probabilities. However, reliability for the first, second, and third items was even worse ($\alpha = .29$, $\omega_h = .03$, $\omega_t = .32$). As noted in our preregistration, drawing inferences from unreliable measures would be unwise. Thus, although we will present results as per our hypotheses, we consider these of descriptive rather than inferential value, and will not use them to derive evidence for or against our stated hypotheses.

Although our self-report measures demonstrated acceptable reliability, there were some interesting discrepancies between the ω_h and ω_t values across some of the variables (e.g., TfA $\omega_h = .40$ vs. $\omega_t = .83$; and Openness/Intellect $\omega_h = .53$ vs. $\omega_t = .93$). In one sense, it is unsurprising that omega hierarchical would produce a smaller internal consistency measure than omega total, as the former is the proportion of variance accounted for by the general factor only, whereas the latter includes the proportion of variance accounted for by the group and general factors (Zinbarg, Revelle, Yovel, & Li, 2005). Indeed, the large discrepancies between these measures may indicate the existence of a secondary factor structure. This is not surprising in the case of Openness/Intellect, subscales of which were designed to maximally distinguish between each of its two aspects (DeYoung et al., 2007). For TfA, however, this may imply a currently unknown multifaceted structure of ambiguity tolerance than as measured by the MSTAT.

3.2 Correlations

The zero-order correlation matrix depicted in Table 2 revealed that each measure of ambiguity tolerance was correlated with each measure of openness to experience at $r \geq .40$. Additionally, ambiguity tolerance was significantly correlated

with extraversion and neuroticism.⁶ Correlations between ambiguity tolerance and each of openness to experience, extraversion, and neuroticism appeared stronger when measured with the MSTAT than the TfA. We used a Fisher r -to- z transformation to test whether MSTAT produced significantly stronger correlations, and found that this was the case for extraversion ($z = -2.30, p = .021$) and neuroticism ($z = 3.57, p < .001$), but not for Openness to Experience (Open Mindedness $z = -1.55, p = .061$; Openness/Intellect $z = -1.96, p = .05$). Unsurprisingly, given its lack of reliability, behavioral ambiguity tolerance did not significantly correlate with any variable.

3.3 Regression Analyses

3.3.1 Self-report measures. In a linear regression, openness to experience significantly predicted ambiguity tolerance, $\beta = 0.56, t(306) = 11.75, p < .001$, accounting for 31% of the variance in ambiguity tolerance; and continued to predict ambiguity tolerance even controlling for intelligence, $\beta = 0.55, t(305) = 11.31, p < .001$. (Intelligence did not significantly predict ambiguity tolerance in this model; $\beta = 0.02, t(305) = 0.48, p = .631$.)

Extraversion also significantly predicted ambiguity tolerance, $\beta = .43, t(306) = 8.41, p < .001$. Interestingly, this relation held when including openness to experience in the multivariate regression (extraversion, $\beta = 0.25, t(305) = 5.06, p < .001, 95\% \text{ CI } [0.14, 0.37]$; versus openness, $\beta = 0.46, t(305) = 9.20, p < .001, 95\% \text{ CI } [0.36, 0.55]$).

Although openness appeared a stronger predictor, CIs between openness to experience and extraversion just overlapped, indicating that there was not a

⁶ In our preregistration, we mentioned that we would conduct two one-sided equivalence tests, setting $-.17$ and $.17$ as our equivalence bounds (Lakens, 2017) for the associations between self-report openness to experience, extraversion, plasticity, and ambiguity/uncertainty tolerance. As we found very strong correlations between all of these variables, it was unsurprising that when testing equivalence between these measures, the relationships were statistically not equivalent to zero.

statistically significant difference in the size of the predictors. However, extraversion contributed only 5% of unique variance to this model ($R^2 = .36$).

We expected that openness to experience would negatively predict uncertainty intolerance, even controlling for intelligence; but that the effect would be weaker than for ambiguity tolerance, as the items in the Intolerance of Uncertainty scale seem on face value to be more conceptually related to neuroticism. Openness to experience did significantly negatively predict uncertainty intolerance, $\beta = -.37$, $t(304) = 6.74$, $p < .001$, $R^2 = .15$; and when neuroticism was added as a predictor to this model, this trait was the stronger predictor, with the absolute value of CIs not overlapping (neuroticism $\beta = 0.54$, $t(303) = 11.70$, $p < .001$, 95% CI [0.46, 0.62]; versus openness to experience $\beta = -0.20$, $t(303) = 4.12$, $p < .001$, 95% CI [-0.28, -0.12]). The percentage of variance accounted for rose substantially to $R^2 = .41$; and the model with added neuroticism was significantly better fit than the model with only openness to experience and intelligence, as measured by an analysis of variance, $f(1) = 136.83$, $p < .001$.

Analyses presented here employ observed variables or, for openness to experience and ambiguity tolerance, latent factor scores. As inferences concerning incremental validity can be misleading when using observed variables (Westfall & Yarkoni, 2016), the supplementary materials also includes a version of these analyses using structural equation modelling. Inferences were the same as presented here, and beta weights were highly similar or identical.

3.3.2 Behavioral ambiguity tolerance. Originally, we planned to test our predictions for behavioral ambiguity tolerance by computing a behavioral ambiguity tolerance index combining all five tasks. However, given the very poor internal consistency of our behavioral ambiguity tolerance measure, it was not appropriate to

compute a combined index. Instead, we present a summary of analyses for each item in the supplementary materials (Table S1), and exploratory latent variable regressions to assess whether accounting for measurement error would provide additional insight (Table S2). Note that these analyses are included for completeness rather than for value in inferential conclusions, as the poor reliability casts serious doubt on our measurement of behavioral ambiguity tolerance. None of the variables listed above (openness to experience, extraversion, plasticity, and neuroticism) predicted behavioral ambiguity tolerance, either with any of the five behavioral ambiguity tolerance tasks, or with a latent variable approach. It therefore made no sense to test our third behavioral hypothesis (controlling for intelligence) or our exploratory research question (extraversion predicting behavioral ambiguity tolerance controlling for openness to experience).

3.4 Exploratory Network Analyses

An exploratory graph analysis produced three dimensions for the MSTAT ambiguity tolerance and two for Intolerance of Uncertainty (TfA was not included in the network analysis due to confusion surrounding its component structure). Supplementary materials Section S.3 contains further details of the exploratory graph analysis procedure. Assessing the item content within these dimensions, MSTAT included one dimension seemingly related to ambiguity *avoidant* items (M1; e.g., *I don't tolerate ambiguous situations well*), a second dimension related to ambiguity *tolerant* items (M2; e.g., *I am tolerant of ambiguous situations*) and a third that seemed to involve appreciation of complex problem solving (M3; e.g., *I would rather avoid solving a problem that must be viewed from several different perspectives*). For intolerance of uncertainty, the suggested dimensions were the same as the factors defined in the original scale by Carleton et al. (2007): prospective anxiety (IoU1; e.g.,

I always want to know what the future has in store for me) and inhibitory anxiety (IoU2; e.g., *when it's time to act, uncertainty paralyses me*).

Figure 1 displays the partial correlation network of averaged scale sub-components, conditioning on all other nodes in the network. Importantly, the spatial arrangement of nodes is not directly interpretable, as this is a function of the plotting algorithm's attempt to derive a visually appealing graph with minimal overlap of nodes (Jones, Mair & McNally, 2018). The reader should instead focus on the size of the edge connecting nodes, which confer information concerning the size of the partial correlation. A companion to this graph is Table S5 in the supplementary information, which includes exact values for partial correlations, including 95% bootstrapped CIs around edge weights.

Figure 1. A partial correlation network between sub-dimensions of openness to experience, extraversion, neuroticism, and ambiguity tolerance. Nodes are averaged subscale scores for each measure, and correlations between nodes are depicted by the line (or “edge”) between items. Positive edges are blue, whereas negative edges are red. The size of the edge corresponds to the strength of the correlation. Items from a given scale or subscale are represented by different colors according to the legend. OAes = Open-Mindedness–Aesthetic Sensitivity; OCre = Open-Mindedness–Creative Imagination; OCur = Open-Mindedness–Intellectual Curiosity; Open = Openness/Intellect–Openness; Intel = Openness/Intellect–Intellect; NegDep = Negative emotionality–Depression; NegAnx = Negative emotionality–Anxiety; NegVol = Negative Emotionality–Emotional Volatility; ExEnergy = Extraversion–Energy levels; ExSoc = Extraversion–Sociability; ExAssert = Extraversion–Assertiveness; Mx = MSTAT Dimension x; IoUx = Intolerance of Uncertainty Dimension x.

The strongest partial correlation was between BFI-2 aesthetic sensitivity and BFAS openness, $r = .61$, 95% CI [.52, .69]. Following this in strength were sub-dimensions of scales, such as extraversion (sociability and assertiveness), $r = .39$, 95% CI [.27, .50]; and neuroticism (depression and anxiety), $r = .38$, 95% CI [.29, .47]. A large partial correlation could also be observed between M1 (ambiguity avoidance) and IoU1 (prospective anxiety), $r = -.38$, 95% CI [-.46, -.30]. This between-scale association is of a similar magnitude to within-scale relations, supporting the view that these scales measure highly similar phenomena; and specifically, suggesting that the common thread between the scales is intolerance for ambiguity.

The strongest connection between sub-domains of personality traits and ambiguity tolerance was between openness to experience—specifically, the intellect aspect—and M3, representing appreciation of complex problem-solving, $r = .23$, 95% CI [.13, .33]. Intellectual curiosity (the BFI-2 equivalent to intellect) also correlated with M3, $r = .15$, 95% CI [.07, .24]. All other sub-domains were only related to ambiguity tolerance via their connection with intellect (small connections remaining between openness to experience and ambiguity tolerance that are visible in Figure 1 have CIs that encompass zero, and thus may not be accurate). To explore this pattern of associations further we conducted a traditional regression analysis predicting the MSTAT from openness and intellect. This found converging results, with intellect the only significant predictor of the MSTAT (intellect $\beta = 0.56$, $t(305) = 10.85$, $p < .001$, 95% CI [0.45, 0.66]; compared to openness, $\beta = 0.08$, $t(305) = 1.57$, $p = .117$, 95% CI [-0.03, 0.19]).

For neuroticism, the strongest correlation was between depression and IoU2 (inhibitory anxiety), $r = .21$, 95% CI [.12, .29]. Anxiety and volatility were also

weakly negatively related to IoU2, but the CIs for both encompassed zero, indicating uncertain accuracy. No relation between neuroticism and MSTAT existed where the CI did not encompass zero.

Finally, extraversion (assertiveness) was connected to ambiguity tolerance, and specifically to M2, the sub-component concerning positively-valenced attitudes towards ambiguity, $r = .14$, 95% CI [.05, .23]). Sociability and energy levels were only connected to ambiguity tolerance via their connections with assertiveness (except for a small relation between energy levels and M2 with CIs that encompassed zero, $r = .08$, 95% CI [-.01, .16]).

As we employed two measures of openness to experience, it is possible that strong relations between similar subdomains (e.g., the high correlation between openness and aesthetic sensitivity) could obscure any meaningful associations with other measures. Thus, we also created versions of the network models with either BFI-2 Open-Mindedness or BFAS Openness/Intellect. These can be found in the supplementary material (Figures S2 and S3; Table S6). Promisingly, these alternative models yielded broadly similar results. We found identical $r = .14$ correlations between depression and M2 as for the main analysis, with only small variations in the CIs. For neuroticism, depression was correlated with IoU2 at $r = .19$ for the network with only BFI-2 Open-Mindedness, and $r = .22$ for the network with only BFAS Openness/Intellect, within $r = .02$ of the original effect size. Indeed, with only one measure of openness to experience, the associations between either intellect facets and M3 were *stronger* (intellect and M3 $r = .35$, 95% CI [.24, .45]; and intellectual curiosity and M3 $r = .28$, 95% CI [.19, .37]). For the network including only BFI-2 Open-Mindedness, aesthetic appreciation and creative imagination did not correlate with ambiguity tolerance. For the network considering BFAS Openness/Intellect,

openness did weakly correlate with M3 ($r = .09$, 95% CI [.01, .17]), but this effect was far smaller than that linking intellect and M3, and included CIs that almost encompassed zero.

In summary, each of these Big Five traits were characterized by distinct relations to ambiguity tolerance, with neuroticism most related to emotive avoidant responses to ambiguity, openness to experience most related to complexity of problem solving, and extraversion most related to a positive attitude towards ambiguity tolerance. We additionally found, with our re-analyses including solely Open-Mindedness or Openness/Intellect, that the network was relatively stable to small changes in item content.

4. Discussion

In the present study, we investigated links between ambiguity tolerance and the traits openness to experience, extraversion, and neuroticism. We employed a comprehensive selection of ambiguity tolerance measures, encompassing multiple self-report and behavioral choice methods. In support of our hypotheses, we found that openness to experience and extraversion correlated positively, whereas neuroticism negatively correlated, with ambiguity tolerance. We also found that openness to experience continued to predict ambiguity tolerance even controlling for intelligence, and that extraversion continued to predict ambiguity tolerance controlling for openness to experience. Surprisingly, despite decades of research employing the Ellsberg paradigm as a behavioral index of ambiguity tolerance, this demonstrated very poor reliability in the form of low consistency of responding across the five variants of this paradigm used in the present study.

In a set of exploratory network analyses we examined how sub-dimensions of openness to experience, extraversion, and neuroticism related to ambiguity tolerance

while controlling for all other variables. These results suggested that openness to experience was related to ambiguity tolerance via intellectual curiosity rather than aesthetic appreciation; that extraversion was most connected to ambiguity tolerance via assertiveness rather than sociability or energy levels; and that neuroticism had a strong connection to uncertainty intolerance, with no remaining reliable connections to any sub-dimensions of ambiguity tolerance.

4.1 Implications for Psychological Entropy Theories of Personality

One key aim of the current study was to assess the degree of support for predictions implied by the psychological entropy theories of personality (Hirsh et al., 2012; DeYoung, 2013). DeYoung (2013) suggested that openness to experience and extraversion share variance because they both reflect a tendency to explore the unknown, either for sources of reward (in the case of extraversion) or information (in the case of openness to experience). Insofar as exploration of the unknown necessitates entering a more ambiguous state (the correspondence of which we outlined in Section 1.2), this theory predicts that extraversion and openness to experience will be related to tolerance for ambiguity. Conversely, individuals scoring highly on neuroticism would be more likely to anticipate potential threats lurking in the unknown, indicating that these persons would be more likely to display aversive attitudes toward ambiguity. We maintained that it was possible to test the initial stages of entropy theories of personality by measuring the relation between ambiguity tolerance and these basic domains of personality. Although prior studies provided suggestive evidence of the association between ambiguity tolerance and openness to experience, extraversion, and neuroticism, these associations emerged from secondary analyses and often involved scales with poor psychometric properties. However, the current study found strong evidence at the level of self-report that extraverts and those

open to experience are more tolerant of ambiguity, and that those high in neuroticism are intolerant of ambiguity, thus supporting the assumptions inherent in the entropy theory of personality.

Note that the current study does not address other elements of entropy theory of extraversion and openness to experience outlined by DeYoung (2013): namely, that extraverts are motivated by rewards and that those higher in openness to experience are motivated by the reward value of any information, and that both of these drives are underpinned by dopaminergic mechanisms. We simply take the predictions that this hypothesis naturally evokes—that exploration necessitates engagement with ambiguity—and find that this is consistent with our empirical results. However, if extraverts *are* indeed motivated to explore by the potential for rewards, and individuals higher in openness to experience are motivated to explore for the rewarding value of information, then how might ambiguity tolerance assist these goals? We suggest that a greater tolerance for ambiguity may make it easier for these individuals to pursue these rewards, because it reduces any negative psychological burden involved in entering the unknown. This makes the exploration process more inherently enjoyable, and thereby, more positively reinforcing.

Testing mechanistic theories is a slow process, and we believe that it makes sense to first grasp the low hanging fruit. In other words, the connection between ambiguity tolerance and personality traits was something easily testable, where failing to find associations in the expected direction would call into question fundamental principles of the theory. Having now found evidence that supports the foundations on which entropy theories of personality are based, our study lays the groundwork for future researchers to test further predictions of this theory, such as the expectation that openness to experience relates to a greater motivation to obtain information.

4.2 Exploratory Network Analysis

The results of the exploratory network analysis offer some additional—if preliminary—insights, by allowing us to assess how individual facets of personality traits relate to particular dimensions of ambiguity tolerance. These analyses were intended to assess whether similar patterns of associations are uncovered as were previously reported by Lauriola et al. (2016), and to explore new patterns of associations that may not yet have been discovered, which may assist future confirmatory investigations.

For openness to experience, we found that holding constant all other nodes, the only relations between ambiguity tolerance and openness to experience were the intellect aspect and the intellectual curiosity facet; and that these connected to an empirically-derived factor representing appreciation of complex problem-solving. All other sub-domains were only related to ambiguity tolerance via their connection with intellect. Interestingly, this converges with Lauriola and colleagues' (2016) finding that openness to experience was most strongly correlated with the component of ambiguity tolerance representing need for complexity and novelty. This finding has two key implications. First, it implies that those who tend to appreciate beauty and art (individuals higher in openness) are only more tolerant of ambiguity because they are also more likely to engage with abstract information and ideas. Furthermore, it implies that those higher in intellect are more tolerant of ambiguity primarily because they like to think about complex problems, which necessitates engaging with ambiguity.

Why might openness to be unrelated to ambiguity tolerance conditional on intellect? To speculate, it is possible that higher ambiguity tolerance permits individuals who are open to experiences to engage in deep intellectual musings

without being burdened by the uncertainty of not uncovering an answer. Conversely, ambiguity tolerance may not influence an individual's openness to the same extent, because one can still appreciate art, literature, and poetry in a variety of forms, some which are more ambiguous (e.g., abstract art) than others (e.g., portraits). In this case, ambiguity tolerance would be a pre-condition for high intellectual curiosity, but not high openness. This would indicate that it is only when high openness is paired with high ambiguity tolerance that we would expect to find open individuals appreciative of ambiguous art. This is a prediction that could be tested in future research.

Extraversion demonstrated a contrasting pattern of results: assertiveness was the only facet that reliably related to ambiguity tolerance, and this was onto M2, the sub-component reflecting a general ambiguity-tolerant factor. This indicates that individuals who are enthusiastic or sociable are not primarily tolerant of ambiguity due to these factors; but rather, because they are also more likely to be bold, dominant, and socially powerful. Regarding the link to M2 that is apparent for extraversion but not openness to experience, this dovetails with Lauriola et al. (2016), who found that the general ambiguity tolerance sub-component was more strongly connected to extraversion than openness to experience (although note that formal comparisons of the strength of effect sizes were not conducted, meaning this difference may not be statistically significant).

Why do we find a link between ambiguity tolerance and assertiveness, but not sociability or energy levels? Perhaps higher ambiguity tolerance allows extraverts to display their bold, dominant tendencies with an optimistic expectation of positive outcomes and rewards. However, this would imply a similarly strong correlation between sociability and ambiguity tolerance, as extensive social engagement seems to necessitate a comfort with ambiguous scenarios (e.g., uncertain body language;

misunderstood messages; shifting social hierarchy). It is possible that the high inter-correlations between assertiveness and sociability (zero-order $r = .60$; partial correlation $.39$) are obscuring any existing relation between sociability and ambiguity tolerance. To assess this, it may be useful to measure extraversion with a personality scale that maximally distinguishes between facets, such as the BFAS.

Finally, neuroticism had its strongest connection with intolerance of uncertainty (inhibitory anxiety) consistent with the theory that those higher in neuroticism will find ambiguity strongly aversive. This also fits with our regression analyses, in which we found that neuroticism was a stronger predictor of uncertainty intolerance than openness to experience. Thus, although we view ambiguity tolerance and uncertainty intolerance as conceptually interchangeable, it seems likely that individuals higher in neuroticism respond more strongly to the more negatively valenced items that characterize uncertainty intolerance scales.

4.3 Unreliability of Behavioral Ambiguity Tolerance

One unexpected observation in this study was the very low reliability we observed for the well-established behavioral measures of ambiguity tolerance included in our study (Ellsberg, 1961). Interestingly, when revisiting the relevant literature we discovered that this has been previously documented, but the seriousness of this problem appears to have been overlooked. Stahl (2014) found that more than 60% of 101 individuals responded near randomly to 12 two-choice ambiguity tasks, with only 12% consistently choosing an ambiguity-averse response. Despite observing “significant heterogeneity and confusion” using these tasks (p. 97), Trautmann and Kuilen (2015) justified the continued use of the measure based on the fact that individuals were, on average, ambiguity averse. A similar pattern of ambiguity aversion was evident in our study (Table 1), but the lack of consistency

across different behavioral measures makes it nearly impossible to establish convergent validity with survey measures of personality, or indeed, ambiguity tolerance. In addition, if the Ellsberg Paradigm does measure ambiguity tolerance, it is likely capturing a much narrower aspect of ambiguity tolerance than is measured in self-report surveys, specific to decision-making for reward under risk. This may tap into different cognitive and emotional processes than the MSTAT or TfA scale: for example, a calculated reward assessment, rather than any comfort with exploring the unknown.

Why are responses to behavioral ambiguity tolerance so unreliable? These tasks require individuals to choose between, for example, a risky but unambiguous 50% chance of winning, versus an equally risky but *completely unknown* probability of winning. Thus, in this task economists define ambiguity as an *unknown probability* (Trautmann & Kuilen, 2015), and this can be distinguished from risk in computational terms. However, there is no guarantee that individuals perform the same computations, and as a result *perceive* ambiguity separately from risk. A risky gamble means that the outcome is unknown—and unknown outcomes are also ambiguous outcomes. Thus, participants could view risky options as ambiguous. This would result in more random responding to behavioral gambles, providing an explanation for why we have observed poor reliability between the items. Future studies might directly investigate this possibility by having participants rate the perceived ambiguity of a series of gambles that differ in risk, holding constant ambiguity. If participants rate increasingly risky options as increasingly ambiguous, this would demonstrate that decision-makers do not differentiate ambiguity from risk.

If the Ellsberg tasks are not optimal for assessing individual differences in ambiguity tolerance, it would be valuable to identify an alternative behavioral

paradigm to triangulate against self-report measures. One option could be to harness principles from marketing that exist on Internet websites. For example, some travel websites offer individuals the chance to stay in an unknown establishment for a slightly cheaper price—an inherently more ambiguous option. It could be possible to experimentally manipulate the degree of information available about these “unknown” travel options (e.g., star rating, number of bedrooms, closeness to nature or a beach, etc.) and observe whether individuals higher in openness to experience and extraversion were more likely to choose a more unknown alternative.

A complementary approach could be to retain the Ellsberg paradigm, but to vastly increase the trial numbers from 5 to 50 or beyond. Behavioral choices are inherently noisy data, and experiments from cognitive and mathematical psychology tend to manage this noise by running trial numbers in the hundreds or thousands, statistically aggregating these to account for noise in single observations. Given we did observe some consistency in responding ($\omega_t = .47$) one could conceive that a task in which participants made repeated decisions between an ambiguous and unambiguous option over the course of a 30-minute experiment might shed light on the relation between personality traits and behavioral ambiguity tolerance.

4.4 Strengths, Limitations, and Constraints on Generality

By directly addressing the question of relations between ambiguity tolerance and personality traits, and by employing two newer measures of ambiguity tolerance with acceptable psychometric properties—in addition to a measure of uncertainty intolerance—we provide compelling support for the relations between these traits and ambiguity tolerance at the zero-order level. Further, by finding that openness to experience predicted ambiguity tolerance even controlling for intelligence, this alleviates concerns that the relation observed between openness to experience and

ambiguity tolerance may be driven by more intelligent individuals reasoning more meticulously about their choices when options are ambiguous, and thus being less affected by aversive properties in ambiguity.

Intriguingly, correlations between personality traits and ambiguity tolerance measured by TfA were uniformly smaller effects than for ambiguity tolerance measured by MTSAT. This is consistent with the poor omega hierarchical reliability observed for TfA, indicating that this form of ambiguity tolerance may tap a wide array of sub-traits. When computing separate TfA dimensions using exploratory graph analysis, it was unclear what the model suggested sub-domains might represent, and how they were related to ambiguity tolerance. This led us to drop TfA as a measure included in the network analysis. Thus, although TfA seems an adequate measure when considered as a unitary scale—and could be preferable for analyses of cross-cultural studies, for which it was originally designed (Herman et al., 2010)—we would not recommend this scale for assessing relations with personality traits and sub-domains of ambiguity tolerance.

We aimed to comprehensively measure ambiguity tolerance with different measures that tap different sub-components. However, it is possible that our measures were not sufficiently broad. For example, Lauriola et al. (2016) found three factors representing distaste for ambiguity, need for complexity, and moral absolutism. None of our chosen ambiguity tolerance measures assessed this final moral absolutism component, and thus it would be valuable to assess whether moral absolutism displays the same pattern of correlations with personality traits as for our current scales.

As may be clear from Section 4.3 above, we do not think that our non-significant findings related to behavioral ambiguity tolerance tasks are likely to generalize beyond the Ellsberg paradigm. It is highly possible that different

behavioral measures could be devised that would better tap this construct, and would better assess relations with personality traits.

Within our sample, we had a reasonably wide distribution of income and age brackets, indicating that results may generalize across these groups. We also used a sample of United States participants from Amazon Mechanical Turk. There is no reason to expect that ambiguity tolerance would not generalize across cultures, so it is possible that conclusions are not limited to individuals in western countries—though of course, future studies would be necessary to confirm this intuition.

Finally, given the exploratory nature of the network analysis, our inferences drawn from this analysis should be followed up by a confirmatory analysis attempting to replicate the network structure.

5. Conclusions

Life presents us with many unknown possibilities and interpretations. Those who are open to experiences, or who are more extraverted, are more likely to tolerate the ambiguities inherent in life. Conversely, those higher in neuroticism are more likely to find ambiguity aversive and fear-provoking. Our findings may provide a basis for future research to propose mechanistic explanations for personality traits, such as the support that we have found for the psychological entropy theories of Hirsh et al. (2012) and DeYoung (2013). The current study extends current understanding of how different people react to the unknown—an inevitable consequence of fully engaging with life.

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