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From madness to genius: The Openness/Intellect trait domain as a paradoxical simplex

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ABSTRACT

A novel theory of Openness/Intellect is proposed, which integrates intelligence and positive schizotypy (or apophenia, false detection of patterns or causal connections) within the Big Five. Openness/Intellect comprises a simplex of subtraits arrayed along a single scaling dimension. Openness traits fall in one half of the simplex, bounded by apophenia; Intellect traits fall in the other half, bounded by intelligence. The simplex is paradoxical because intelligence and apophenia are negatively correlated despite both loading positively on the general Openness/Intellect factor. The model was supported in two samples and organizes theories of (1) the relation of intelligence and schizotypy to personality, (2) the psychological and biological mechanisms involved in Openness/Intellect, and (3) the costs and benefits of Openness, proximally and evolutionarily.

> Men have called me mad; but the question is not yet settled, whether madness is or is not the loftiest intelligence—whether much that is glorious—whether all that is profound—does not spring from disease of thought—from moods of mind exalted at the expense of the general intellect. They who dream by day are cognizant of many things which escape those who dream only by night. In their gray visions they obtain glimpses of eternity, and thrill, in waking, to find that they have been upon the verge of the great secret.
>
> Edgar Allan Poe (1848/1975, p. 649)

1. Introduction

Genius has long been associated with madness in the popular as well as the artistic imagination. What do madness and genius have in common, and what separates them? We believe these questions may be related to two seemingly more mundane questions from personality psychology and psychometrics: What is the relation of intelligence to personality? and What is the relation of schizotypy to personality? The theory we present here addresses the latter two questions by suggesting that their solutions are linked and that the existence of each as a problem is due in part to the solution of the other. Our theory is designed to explain the nature of Openness/Intellect (one of the "Big Five" personality traits), which is the basic dimension of personality most related to many psychological phenomena that are quintessentially human, including art, imagination, creativity, and intellectual curiosity.

Central to the theory is a novel model of the structure of Openness/Intellect as a domain of personality traits, locating both intelligence and the positive symptoms of schizotypy as facets within this domain. This may at first seem unlikely. Surely, schizotypy and intelligence should be inversely related (the empirical evidence suggests as much), let alone conceived as part of the same broad trait dimension. Nonetheless, madness and genius may be similar in their association with unconventional perspectives on the world. Both the negative and the positive associations between schizotypy and intelligence are intuitively plausible, and this creates a puzzle. Even Poe, in our epigraph, vacillates between linking madness to the "loftiest intelligence" and suggesting that it comes at the expense of "general intellect". Which is it? Can this paradox be resolved?

We propose that the full extent of the Openness/Intellect domain forms a paradoxical simplex, extending from intelligence at one end to apophenia at the other. Apophenia is the perception of patterns or causal connections where none exist. (We discuss below why this construct may be a desirable replacement for the construct of *positive schizotypy* in the context of personality theory.) Extreme apophenia might be seen as the epitome of madness. It is, at least, one important form of madness and the defining feature of psychosis. A simplex is an arrangement of variables along a single dimension, with those closest together most related and those farthest apart least related. (Note that this is not a trait dimension, which represents variability in a population, but a

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scaling dimension describing the magnitudes of relations among variables.) In this case, the simplex is paradoxical in that its opposite ends are hypothesized to be unrelated or even negatively related, despite the fact that all of its elements load positively on the same latent trait. This situation would imply that intelligence and apophenia may share some cause in common related to Openness/Intellect, though some other force drives them apart.

A key motive for developing this theory is desire for a structural model that can integrate the growing literature on the psychological and biological mechanisms that may be causes of traits in the Openness/Intellect domain (e.g., DeYoung, Peterson, & Higgins, 2005; DeYoung, Shamosh, Green, Braver, & Gray, 2009; Jung, Grazioplene, Caprihan, Chavez, & Haier, 2010; Kaufman et al., 2010; Peterson, Smith, & Carson, 2002). The hierarchical organization of personality traits indicates that causes need to be considered at multiple breadths (DeYoung, 2010a). Some causal forces will influence Openness/Intellect as a whole, whereas others will be specific to lower-level traits within this domain. This principle has been demonstrated in behavior genetics, where lower-level traits in the Big Five hierarchy are found to be influenced by specific genetic factors that are independent of the genetic factors influencing the entirety of each Big Five domain (Jang, McCrae, Angleitner, Riemann, & Livesley, 1998; Jang et al., 2002). The Openness/Intellect domain appears likely to have a particularly complex array of causal sources because of the diversity of traits it encompasses, and its structure needs to be modeled in a manner reflecting this complexity.

The incentive for integrating intelligence and apophenia with the Big Five model stems from two premises. First, the Big Five can provide a reasonably comprehensive taxonomy for all broad categories of variability in psychological function in which there is substantial variation (e.g., reward sensitivity for Extraversion, cognitive exploration for Openness/Intellect; DeYoung, 2010b; Van Egeren, 2009). Given this premise, important traits such as intelligence and positive schizotypy must be integrated with the Big Five or else deemed to be unique to more specific categories of psychological function, unrelated to those represented by the Big Five. Second, personality traits should be explained mechanistically as variation in the functional parameters of the brain (DeYoung, 2010a). Because the brain is a single system of interacting elements, mechanistic theories for all specific traits should be compatible and ultimately unified. Both intelligence and apophenia are linked to Openness/Intellect not only through psychometrics but also through overlapping biological substrates (DeYoung et al., 2009; Jung et al., 2010). A unified, mechanistic theory of personality is therefore likely to require the conceptual integration of these two traits with Openness/Intellect. Note that the proposed integration does not require any radical reconceptualization of the Big Five (our model considers intelligence and apophenia to be relatively peripheral facets of the Openness/Intellect domain) but offers clarification of two important traits for which both conceptual and empirical difficulties have hitherto prevented integration with general models of personality.

In what follows, we first situate our theory in the relevant literature on Openness/Intellect, intelligence, and schizotypy. Next, we turn to data to test the model. Finally, we utilize our structural model to organize hypotheses regarding the likely mechanisms and processes, both proximal and evolutionary, involved in the traits encompassed by the Openness/Intellect domain and responsible for creating the paradoxical simplex structure of this domain.

1.1. The two aspects of Openness/Intellect

Openness/Intellect is one of the Big Five personality traits identified through factor analysis of ratings of adjectives from the lexicon and scales from personality questionnaires (John, Naumann, & Soto, 2008; Markon, Krueger, & Watson, 2005)—with the other four being Extraversion, Neuroticism, Agreeableness, and Conscientiousness. The Big Five model captures most of the covariance among more specific personality traits. Although some argument exists as to whether a six factor model might be more appropriate in lexical research (Ashton et al., 2004; Saucier, 2009), the five and six factor models are very similar and both include Openness/Intellect as one broad domain including traits related to imagination, curiosity, creativity, intellectual interests, perceived intelligence, artistic and aesthetic interests, and unconventionality. Given the goal of a comprehensive taxonomy and the content of Openness/Intellect, it is reasonable to investigate whether intelligence and schizotypal traits can be incorporated within this domain.

As reflected in its compound label, the Openness/Intellect domain has been the most difficult of the Big Five for which to provide an adequate concise description. One early suggestion, *Culture*, has been deemed clearly inadequate, and the two most common labels currently are *Openness to Experience* and *Intellect*. The trend toward a compound label reflects the recognition that Openness and Intellect reflect two equally important aspects of the broader trait, which are separable despite being correlated (DeYoung, Quilty, & Peterson, 2007; Johnson, 1994; Saucier, 1992, 1994). In the hierarchical organization of personality, Openness and Intellect can be considered distinct traits below the Big Five, whereas the Big Five domain itself (Openness/Intellect) reflects the shared variance of these two lower-level traits. Saucier (1992, 1994) has proposed that "Imagination" might be a good single label for the domain as a whole, given the existence of both intellectual and aesthetic forms of imagination. However, we maintain the more common, compound label "Openness/Intellect," when referring to the domain as a whole, because colloquially "imagination" has specific connotations that are too narrow to capture the full extent of this complex trait domain. Whenever we refer to "Openness" or "Intellect" alone, we are referring to a subtrait that constitutes one aspect of this domain.

The psychological function that appears to be common to all of the traits encompassed by the Openness/Intellect domain is cognitive exploration of the structure of both inner and outer experience, with cognition understood broadly to include both reasoning and perceptual processes (DeYoung, 2011; DeYoung et al., 2005; Van Egeren, 2009). Individuals high in Openness/Intellect display the ability and tendency to seek, detect, comprehend, and utilize more information than those low in Openness/Intellect. Intellect appears to reflect engagement primarily with abstract or semantic information, whereas Openness appears to reflect engagement primarily with perceptual or sensory information. Intellect is represented in lexical studies by adjectives like, "intellectual," "intelligent," "clever," and "philosophical," whereas Openness is represented by adjectives like, "artistic," "perceptive," "poetic," and "fantasy-prone." The lexicon also includes adjectives representative of both Intellect and Openness, such as "imaginative," "original," "curious," and "innovative."

Distinct descriptors of Openness and Intellect can be found not just in adjectives from the lexicon but also in personality questionnaires. A factor analysis of 15 lower-level facet scales in the Openness/Intellect domain found evidence for exactly two factors, which clearly represented Openness and Intellect (DeYoung et al., 2007). These two factors were characterized by correlating them with over 2500 items from the International Personality Item Pool (IPIP; Goldberg, 1999a). Intellect was related to intellectual engagement (e.g., "Avoid philosophical discussions" – reversed) and perceived intelligence (e.g., "Am quick to understand things"), whereas Openness was related primarily to aesthetics (e.g., "See beauty in things that others might not notice") and fantasy (e.g., "Seldom daydream" – reversed).

The existence of Openness and Intellect as two distinct aspects of a broader trait offers an approach to understanding how apophenia and intelligence might belong to the same trait domain. Importantly, like all traits, the Big Five are probabilistic entities: a high score on Openness/Intellect indicates an increased likelihood of high scores on its various subtraits but is not deterministic. Thus, people scoring high in Intellect will, on average, score higher in Openness than people scoring low in Intellect. However, the correlation between Openness and Intellect is far from perfect, so some people will score high in Intellect but only moderate or low in Openness, and vice versa. Some narrower subtraits within Openness and Intellect could even be relatively unrelated to each other. Our model incorporates the hypothesis that apophenia is the facet of Openness that is least related to Intellect, whereas intelligence is the facet of Intellect that is least related to Openness.

1.2. Intellect and intelligence

Intelligence is typically measured by ability tests with objectively correct answers. Intelligence test scores correlate with Openness/Intellect at around $r = .3$ (Ackerman & Heggestad, 1997; DeYoung, 2011). However, intelligence tests are more strongly related to Intellect than to Openness, and when Intellect and Openness are used as simultaneous predictors (thereby examining their unique rather than shared variance), only Intellect is associated with general intelligence (DeYoung, 2011; DeYoung, Quilty, Peterson, & Gray, in press). Given that the average intercorrelation among facets of Openness/Intellect is only about .3 (Costa & McCrae, 1992b), and that intelligence tests and questionnaires do not share method variance, these results suggest that intelligence has the potential to be considered at least a peripheral facet of Openness/Intellect, located specifically within the Intellect aspect of this domain. Some have argued that the association of Openness/Intellect with intelligence is merely due to its association with verbal (or "crystallized") intelligence, resulting from greater learning due to intellectual curiosity (e.g., e.g., Ashton, Lee, Vernon, & Jang, 2000; Bates & Shieles, 2003). However, unlike Openness/Intellect, Intellect is associated equally strongly with verbal ("crystallized") and nonverbal ("fluid") intelligence (DeYoung et al., in press).

Considering intelligence as a facet of Intellect is consistent with evidence from factor analysis showing that lexical and questionnaire descriptors of intelligence fall within Openness/Intellect in the Big Five (DeYoung et al., 2007; Goldberg, 1990; Saucier, 1992). Nonetheless, considerable debate has taken place regarding whether intelligence, as measured by ability tests, is validly considered part of Openness/Intellect (e.g., Costa & McCrae, 1992a; McCrae & Costa, 1997; for more complete review of this debate see DeYoung, 2011). Clearly, self- or peer-ratings of intelligence should not be used as a proxy for tests of intelligence, given their correlation of about .3 with the latter (DeYoung, 2011; Paulhus, Lysy, & Yik, 1998), but this limitation indicates the presence of error in self-reports of intelligence, not that intelligence must be external to the Big Five conceptually. To argue the latter is to confuse method with construct; the goal of questionnaire research is typically to understand actual patterns of behavior, motivation, emotion, and cognition, not just to understand how people answer questionnaires, and we should not categorically distinguish behavioral from questionnaire measures of personality in our structural models.

Some have argued against including intelligence in personality on the grounds that personality traits should reflect typical behavior rather than maximal ability (Cronbach, 1949). However, the lexical studies that led to the Big Five model have almost always included descriptors of abilities as well as typical behavior, and personality is a broad enough concept to cover both. Nor is Openness/Intellect the only domain that might include abilities; for example, empathy (within Agreeableness) and self-control (within Conscientiousness) can both be measured with ability tests (DeYoung, 2011; Mischel, Shoda, & Rodriguez, 1989; Nettle & Liddle, 2008).

The major piece of empirical evidence used to argue against the inclusion of intelligence in the Big Five is that, if multiple intelligence tests are factor analyzed with personality questionnaires, they typically form a sixth factor, rather than loading on a factor with questionnaire variables reflecting Openness/Intellect (McCrae & Costa, 1997). Two artifacts may account for this finding, however (DeYoung, 2011). First, questionnaires and ability tests have different sources of method variance. All of the questionnaires share method variance that they do not share with any ability test, and vice versa. Shared method variance inflates intercorrelations among measures of the same type, relative to their correlations with the other type, and inclines the two types of measure to form separate factors, regardless of what they share substantively. The second possible artifact resembles what Cattell (1978) called a "bloated specific factor." If multiple measures of a single lower-level trait are present among the variables to be factor analyzed, their intercorrelations may be strong enough to cause them to form a separate factor, even when the other factors recovered are at a higher level of the trait hierarchy and one of them should subsume the lower-level trait in question. Intelligence is often considered a broad trait, but, in a hierarchy based on the Big Five, intelligence would make up just a facet of Openness/Intellect (though it might nonetheless be subdivided into more specific traits, like verbal ability and perceptual reasoning, at a still lower level of the trait hierarchy). Integrating intelligence into the Big Five thus remains a viable possibility and one we believe may be achieved by a theory that captures the structural complexity of the Openness/Intellect domain.

1.3. Openness, schizotypy, and apophenia

Schizotypy is a construct that has been conceived both as liability for schizophrenia-spectrum disorders and as a trait reflecting subclinical levels of symptoms of schizophrenia-spectrum disorders in the general population. We emphasize the latter conception, although the two are not incompatible, as disorder may be likely with a sufficiently high level of the trait. Additionally, however, we would argue that the construct of schizotypy may not be ideal in research on normal personality variation because of its heterogeneity and because it implies dysfunction. Our primary interest is in characterizing the Openness/Intellect trait domain in normal personality, rather than informing research on schizophrenia-spectrum disorders.

Schizotypy is a complex construct, composed of multiple subfactors that probably stem from different sources. Factor analyses have suggested potential subfactors including positive schizotypy, negative schizotypy, cognitive disorganization, paranoia, asocial schizotypy, and nonconformity (Kwapil, Barrantes-Vidal, & Silvia, 2008; van Kampen, 2006; Vollema & van den Bosch, 1995). The best validated of these subfactors are positive and negative schizotypy. Positive schizotypy comprises magical ideation, perceptual aberration, and overinclusive thinking. Negative schizotypy primarily reflects anhedonia, lack of pleasure in both social and sensory experience. Previous research shows that positive schizotypy is positively related to Openness/Intellect, whereas negative schizotypy is negatively related to Openness/Intellect (Kwapil et al., 2008; Ross, Lutz, & Bailley, 2002).

In our theory, we replace the label "positive schizotypy" with "apophenia," a term coined by the German neurologist Klaus Conrad in 1958 (Brugger, 2001). Apophenia is the tendency to perceive meaningful patterns and causal connections where none in fact exist. This terminological substitution has two advantages for our

purposes. First, apophenia is a much more common phenomenon than may be implied by relying on the constuct of schizotypy. In essence, apophenia simply reflects the general human propensity to Type I error—identifying a pattern as meaningful when in fact the observation is attributable to chance. Seeing faces in random visual patterns, mistaking random sounds for the calling of one's name, committing the gambler's fallacy (expecting that alternation is more likely than repetition in a random sequence), and believing that something may bring good or bad luck are common examples of mild apophenia. Apophenia is a useful construct because it highlights the fact that these mundane cognitions have something fundamental in common with more dramatic cognitive processes like magical ideation (e.g., belief in telepathy). Second, "apophenia" is a word specifically descriptive of the phenomenon in question, whereas the term "positive schizotypy" inherently contrasts the relevant trait with "negative schizotypy." This contrast implies a coherence to schizotypy that may be illusory and also necessitates reference to the more complex construct of schizotypy, even when only apophenia is of interest.

The complexity of schizotypy may explain why it has been difficult to reach consensus about its relation to the Big Five. A significant push to describe the symptoms of personality disorders (PDs) in dimensional terms has resulted in much consensus regarding the ability to map PD symptoms onto four of the Big Five (Markon et al., 2005; O'Connor, 2005; Watson, Clark, & Chmielewski, 2008; Widiger & Mullins-Sweatt, 2009). However, Openness/Intellect is the one Big Five trait not involved in this consensus, and diagnoses of Schizotypal PD tend to be associated primarily with high Neuroticism and low Extraversion, rather than high Openness/Intellect (O'Connor, 2005; Samuel & Widiger, 2008). This may result from the fact that positive schizotypal symptoms, those involving apophenia, are not well represented in standard PD assessment, which entails that diagnoses of schizotypal PD often reflect primarily negative schizotypy (Tackett, Silberschmidt, Krueger, & Sponheim, 2008).

Attempts have been made to conceptualize and measure "Oddity" (Watson et al., 2008), "Peculiarity" (Tackett et al., 2008), or "Experiential Permeability" (Piedmont, Sherman, Sherman, Dy-Liacco, & Williams, 2009) as a fifth domain of PD symptoms related to positive schizotypy. In these studies, this fifth domain was always marked by scales measuring magical ideation, unusual perceptual experiences, and other forms of apophenia, which have been shown to be associated with Openness/Intellect in other studies (Kwapil et al., 2008; Miller & Tal, 2007; Ross et al., 2002). A recent effort to demonstrate the link between schizotypy and the Big Five more directly involved creating schizotypy scales derived specifically from individual facets of the Revised NEO Personality Inventory (NEO PI-R; Costa & McCrae, 1992a, 1992b); this project utilized three facets from Openness to derive positive schizotypy scales labeled "Aberrant Perceptions," "Aberrant Ideas," and "Odd and Eccentric" (Edmundson, Lynam, Miller, Gore, & Widiger, 2011).

However, the studies just mentioned have come to very different conclusions about whether PD symptoms involving apophenia are subsumed within Openness/Intellect (Edmundson et al., 2011; Piedmont et al., 2009) or whether they are distinct from Openness/Intellect (Watson et al., 2008). Because our theoretical position is that apophenia should be subsumed within Openness/Intellect, it is worth considering the research of Watson et al. (2008) in more detail. We note first that when Watson et al. (2008) extracted five factors from their Study 1 data, Openness/Intellect and oddity scales jointly formed a single factor, which is consistent with our model. However, when they extracted six factors, the oddity scales and the Openness/Intellect scales formed separate factors. The latter finding may reflect the fact that this study did not distinguish clearly between Openness and Intellect. We suspect that with a sufficient number of separate markers for Openness and Intellect, a six-factor solution would be more likely to produce distinct Openness and Intellect factors (with measures of apophenia loading on Openness) than distinct oddity and Openness/Intellect factors. We were able to test this hypothesis in one sample.

Interestingly, in their third study, Watson et al. (2008) did derive separate Openness and Intellect factors, and found that an oddity factor was not related to either. This result is particularly important for the current research because it was found in one of the two samples on which we report below (the Eugene–Springfield community sample; ESCS; Goldberg, 1999a). Three facts convinced us that this finding should not discourage us from testing our hypotheses in the ESCS.

First, Watson et al. (2008) used a restricted set of Openness/Intellect markers, particularly for Openness, which they labeled "Culture" and for which they included only three facets, all describing aesthetic interests. They excluded facets related to fantasy-proneness, which clearly mark Openness (Costa & McCrae, 1992a; DeYoung et al., 2007), and which we would expect to be related to apophenia.

Second, Watson et al. (2008) included constructs other than apophenia within oddity. We do not claim that apophenia is the only way to be odd, but we do suspect that, of the various ways one can be odd, only apophenia is primarily related to Openness. In their factor analysis, Watson et al. (2008) utilized total scores for inventories that contain distinct subscales, rather than utilizing each subscale separately. This approach juxtaposes constructs that clearly reflect apophenia (e.g., magical ideation) with others that do not (e.g., dissociative amnesia)—and the latter may be primarily associated with Big Five domains other than Openness/Intellect. They also included a scale measuring obsessive–compulsive symptoms, which seems inadvisable, given that obsessive–compulsive symptoms are associated with Conscientiousness in the consensus dimensional model of PD symptoms (Markon et al., 2005; O'Connor, 2005; Widiger & Mullins-Sweatt, 2009). Because our hypothesis was simply that Openness is associated with apophenia, we did not form hypotheses regarding the association of Openness with dissociation, negative schizotypy, or any other subfactor of oddity or schizotypy, and we included only measures of apophenia in our analyses.

Third, Watson et al. (2008) performed their factor analysis on ESCS measures of Openness/Intellect and oddity in isolation. A better strategy would have been to include facets from all of the Big Five domains, in case some of the oddity scales had primary or strong secondary loadings on domains other than Openness/Intellect. Failure to do so, in conjunction with failure to separate measures of apophenia from other types of oddity, renders it impossible to conclude from their study that measures of apophenia do not have important loadings on an Openness factor.

1.4. Testing the paradoxical simplex model

In two existing samples, we tested the hypotheses (1) that measures of Openness, Intellect, intelligence, and apophenia would load positively on the same factor, in analysis of many Big Five facets (though because measures of intelligence and apophenia are expected to be at least weakly negatively correlated, their loadings should be suppressed and thus relatively low), and (2) that multidimensional scaling analysis would show that traits within this factor form a simplex, with intelligence at one end, adjacent to other measures of Intellect, and apophenia at the other, adjacent to other measures of Openness.

In our factor analyses, one might assume that a confirmatory approach would be desirable, given clear hypotheses about structure and the possibility of method artifacts related to intelligence tests. However, two considerations led us to the conclusion that exploratory factor analysis should be used in this case. First, when

carrying out factor analysis on a highly diverse set of facet-levels traits, confirmatory analysis typically fails because of the fact that personality lacks simple structure (Costa & McCrae, 1992b; Hofstee, de Raad, & Goldberg, 1992). The number of cross-loadings necessary (from each latent Big Five trait to facets with a primary loading on a different Big Five trait) renders their *a priori* specification practically impossible. Well-fitting confirmatory models are therefore generally not possible in this context. Second, the method variance associated with intelligence tests cannot readily be separated from substantive variance by modeling a latent method factor. This difficulty is due to the fact that the shared variance of all such tests represents *g*, the general intelligence factor, as well as method variance. Shared substantive variance and shared method variance would thus be confounded if we included multiple intelligence tests in our factor analyses. Our strategy for avoiding the artifacts that may cause intelligence tests to form a separate factor was simply to include only one intelligence score in exploratory factor analyses, treating intelligence as a single facet-level trait.

2. Study 1

2.1. Method

2.1.1. Participants

This study used a sample of 175 participants (119 female, 56 male), described by DeYoung et al. (2005), who completed assessments of intelligence as well as personality, in a single laboratory session. All were university students in Toronto, Canada, ranging in age from 18 to 38 years (M = 21.2, SD = 2.9). Ethnically, the sample was 59% White, 19% East Asian, 9% Black, and less than 5% each for South Asian, Hispanic, or other. Although DeYoung et al. (2005) analyzed associations between the Big Five and intelligence, data from the measure of schizotypy utilized in the current study have not been previously analyzed.

2.1.2. Measures

2.1.2.1. Big Five. The Big Five were assessed with two well-validated instruments, the NEO PI-R (Costa & McCrae, 1992a, 1992b) and Goldberg's (1992) Trait Descriptive Adjectives (TDA). The NEO PI-R comprised 240 items on a 5-point Likert scale and provided scores for 30 facet-level traits, six for each of the Big Five. Alpha coefficients for the facets ranged from to .60 to .87. The TDA assessed the Big Five by means of 100 adjectives (20 for each scale), using a 7-point Likert scale (range of α = .87–.93). The TDA uses some different labels for Big Five traits than the NEO PI-R—for example, "Intellect" instead of "Openness to Experience." Bear in mind, however, that the TDA Intellect scale contains content reflecting the general Openness/Intellect factor, not just its Intellect aspect (DeYoung et al., 2005).

2.1.2.2. Intelligence. Participants completed Raven's Advanced Progressive Matrices (RAPM; Raven, Raven, & Court, 1998) and five subtests from the WAIS-III (Wechsler, 1997). One subtest, Digit Symbol Coding, was not used in the calculation of intelligence scores because its loading on the first unrotated factor for the intelligence tests (*g*) was negligible, .13 (DeYoung et al., 2005). Loadings for all included tests were in the range of .51–.74. Intelligence scores were created by standardizing then averaging scores from the RAPM and the Vocabulary, Similarities, Arithmetic, and Block Design subtests of the WAIS. One participant did not complete the WAIS due to time constraints and for this participant intelligence was estimated by standardized RAPM score alone.

2.1.2.3. Apophenia. Participants completed the Schizotypal Personality Scale (Claridge & Hewitt, 1987), a commonly used measure of schizotypy consisting of 37 yes/no items. Hewitt and Claridge (1989) reported a factor analysis of these items revealing three distinct factors, Magical Ideation, Unusual Perceptual Experiences, and Paranoid Ideation and Suspiciousness. A three factor solution in our data (maximum likelihood factor analysis with oblimin rotation) yielded very similar factors to those found by Hewitt and Claridge, and we created three subscales by combining items that had loadings of .4 or higher on one and only one of the three factors. To assess apophenia, we utilized only scales for Magical Ideation (5 items; sample item: "Do you believe in telepathy?"; α = .67) and Unusual Perceptual Experiences (15 items; sample item: "Do everyday things sometimes seem unusually large or small?"; α = .83). Paranoia might be considered a form of apophenia when it involves misperceptions of hostility; however, most of the items in this factor merely describe mistrust and alienation. In the Big Five, mistrust and alienation are associated primarily with low Agreeableness and high Neuroticism (Costa & McCrae, 1992a, 1992b; DeYoung et al., 2007; Markon et al., 2005). Additionally, paranoia has been found to be more associated with negative than positive schizotypy (Miller & Tal, 2007).

2.2. Results

Table 1 shows correlations among the measures of Openness/Intellect, intelligence, and apophenia. As predicted, all were positively correlated except for intelligence and apophenia. Unusual Perceptual Experiences was uncorrelated with intelligence, and Magical Ideation was negatively correlated with intelligence.

Table 2 shows the results of a maximum likelihood factor analysis with oblimin rotation (delta = 0) of all Big Five scales, plus intelligence and apophenia. (The full correlation matrix for this analysis is available as online Supplementary material) The first 10 eigenvalues were 8.43, 5.30, 3.46, 3.29, 2.46, 1.45, 1.11, 0.98, 0.91, and 0.82. As predicted, when five factors were extracted, Openness/Intellect, intelligence, and the apophenia scales all loaded positively

Table 1
Correlations among assessments of Openness/Intellect, intelligence, and apophenia in Study 1.

	O1	O2	O3	O4	O5	O6	TDA-I	Int.	UPE	MI
NEO PI-R										
O1 fantasy	–									
O2 aesthetics	.43	–								
O3 feelings	.31	.51	–							
O4 actions	.41	.32	.22	–						
O5 ideas	.39	.41	.25	.26	–					
O6 values	.32	.41	.35	.32	.35	–				
TDA intellect	.41	.50	.46	.24	.59	.28	–			
Intelligence	.25	.21	.16	.15	.30	.31	.26	–		
Unusual perceptual experiences	.23	.26	.27	.14	.25	.12	.15	-.01	–	
Magical ideation	.22	.15	.21	.17	.18	.13	.19	-.15	.39	–

Note: N = 175. TDA = Trait Descriptive Adjectives.

Table 2
Five factor solution for Study 1.

	N	A	C	E	O/I
TDA emotional stability	−.89	.25	.14	.07	−.05
N1 anxiety	.83	−.08	−.19	−.22	−.04
N2 angry hostility	.76	−.55	−.19	−.12	−.04
N3 depression	.80	.01	−.37	−.31	-.04
N4 self-consciousness	.71	.03	−.20	−.37	−.05
N5 impulsiveness	.54	−.23	−.49	.09	.09
N6 vulnerability	.78	−.10	−.44	−.20	−.20
TDA agreeableness	−.36	.73	.34	.35	.15
A1 trust	−.39	.37	.05	.40	.29
A2 straightforwardness	−.13	.56	.19	−.19	−.02
A3 altruism	−.15	.71	.33	.38	.18
A4 compliance	−.22	.72	.01	−.10	−.04
A5 modesty	.17	.34	.04	−.28	−.08
A6 tender-mindedness	−.01	.61	.00	.09	.15
TDA conscientiousness	−.32	.17	.84	.09	−.10
C1 competence	−.43	.16	.77	.26	.18
C2 order	−.05	−.07	.66	.03	−.14
C3 dutifulness	−.23	.25	.78	−.04	−.07
C4 achievement striving	−.13	.03	.70	.07	.09
C5 self-discipline	−.37	.17	.78	.05	.05
C6 deliberation	−.13	.29	.63	−.28	−.06
TDA surgency	−.33	−.16	.13	.79	.17
E1 warmth	−.17	.33	.14	.76	.19
E2 gregariousness	−.10	.04	−.07	.76	−.02
E3 Assertiveness	−.26	−.22	.31	.54	.25
E4 activity	−.19	−.12	.39	.60	.25
E5 excitement seeking	−.10	−.19	−.19	.60	.14
E6 positive emotions	−.26	.14	.06	.80	.36
TDA intellect	.07	.06	.19	.14	.72
O1 fantasy	−.04	−.07	−.38	.33	.63
O2 aesthetics	.16	.08	−.08	.17	.67
O3 feelings	.37	.07	.03	.40	.55
O4 actions	−.24	.09	−.21	.41	.45
O5 ideas	−.14	.08	.14	.01	.72
O6 values	−.03	.12	.02	.24	.54
Intelligence	−.08	−.04	−.05	−.04	.37
Unusual perceptual experiences	.32	−.03	−.25	−.01	.32
Magical ideation	.05	.10	−.07	.20	.28

Note: N = Neuroticism, A = Agreeableness, C = Conscientiousness, E = Extraversion, O = Openness/Intellect, TDA = Trait Descriptive Adjectives. $N = 175$. Maximum likelihood factor analysis with oblimin rotation (delta = 0); structure matrix.

on one factor. Unusual Perceptual Experiences had a loading of equal magnitude on the Neuroticism factor, which is consistent with the link between apophenia and psychopathology.

Because this dataset included a relatively small number of facets for each Big Five domain, and because only one NEO PI-R facet (Ideas) is a good marker of the Intellect aspect of Openness/Intellect (DeYoung et al., 2007), we did not expect that extracting six factors would lead to separate Intellect and Openness factors. However, we did extract six factors to see whether measures of apophenia would be the primary markers of a sixth factor. This was not the case; the sixth factor was a second Conscientiousness factor, with loadings from most Conscientiousness facets, and the other five factors remained essentially unchanged.

Because factor analysis showed all Openness/Intellect scales, intelligence, and apophenia loading positively on the same factor, we subsequently performed a multidimensional scaling analysis to determine whether these 10 variables would define a simplex. A one dimensional solution fit the data well, yielding a stress value of .25, which is less than the value of .29 that marks the first percentile of stress values for a one dimensional solution for 10 random variables only related at chance levels (Sturrock & Rocha, 2000). The resulting simplex is depicted in Fig. 1. The distances shown accounted for 83% of the variance in the matrix of variables. As expected, measures of intelligence and apophenia anchored opposite poles of the simplex, with Openness/Intellect scales arranged between them.

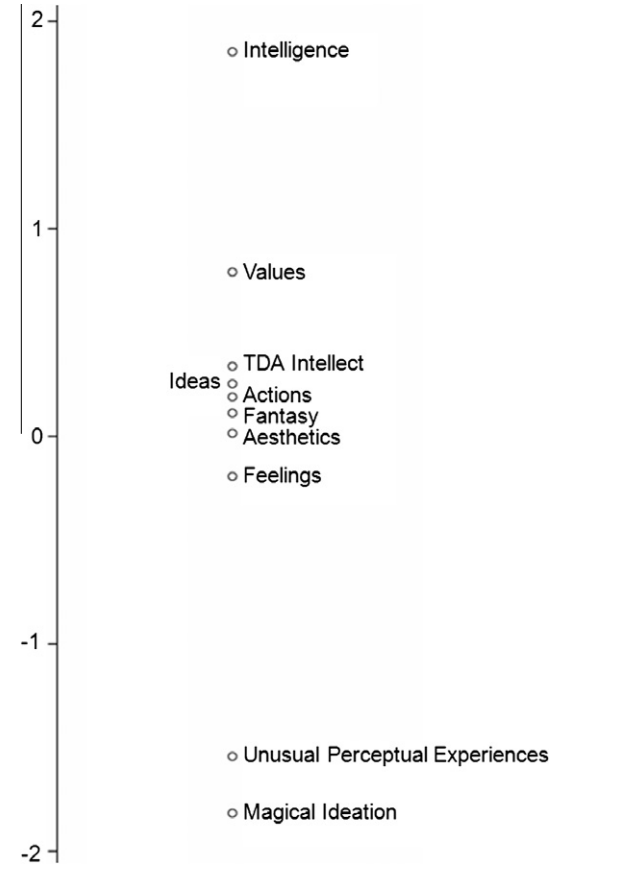

Fig. 1. Simplex arrangement of variables in the Openness/Intellect domain, Study 1. TDA = Trait Descriptive Adjectives scale (Goldberg, 1992).

2.3. Discussion

Both of our hypotheses were supported. Intelligence and apophenia both loaded on the Openness/Intellect factor of the Big Five, and variables in that factor formed a simplex with intelligence and apophenia at opposite ends. The Openness/Intellect simplex can be considered paradoxical because the outermost variables (Magical Ideation and Intelligence) were negatively correlated, despite both loading positively on the same factor.

One notable feature of the simplex depicted in Fig. 1 is the amount of empty space between the Openness/Intellect questionnaire variables in the center and the apophenia and intelligence measures at the ends. The gap between the Openness/Intellect questionnaires and intelligence is likely to be due to the paucity of scales assessing Intellect (as opposed to Openness) in our measures. The NEO PI-R contains only one good marker of Intellect (the Ideas facet). (Previous research suggests that the Values facet, which falls between Ideas and intelligence in Fig. 1, is not a particularly good marker of Intellect (DeYoung et al., 2007), probably because it assesses a liberal sociopolitical worldview, which is associated with Conscientiousness and with Openness about as much as with Intellect (Carney, Jost, Gosling, & Potter, 2008; Goldberg & Rosolack, 1994; Hirsh, DeYoung, Xu, & Peterson, 2010)) Despite being labeled "Intellect," the TDA scale in fact assesses the general Openness/Intellect factor, rather than Intellect specifically (DeYoung et al., 2005). We hypothesized that the inclusion of more Intellect scales would lead to better coverage of the space in the simplex between intelligence and the more central variables.

We suspected that the space between the Openness/Intellect questionnaires and apophenia might be filled by scales measuring

traits reflecting a strong engagement with patterns of experience that are highly subjective, even if they do not constitute the strongest form of apophenia (i.e., confusion about reality). The NEO PI-R Openness scales describe attention to aesthetics, feelings, and fantasies, but at a relatively low level of intensity. In our second study, we attempted to identify variables that might fill in the emptier portions of the simplex in Fig. 1.

3. Study 2

We turned to the ESCS to provide a more extensive sampling of the domain of traits in question. The remarkable breadth of assessments available in the ESCS enabled us to include Big Five measures of Openness/Intellect that better represented the Intellect aspect of this domain, as well as several other measures that were not originally designed to assess the Big Five. In addition to various measures of apophenia and a measure of intelligence, these included measures of Need for Cognition and Absorption.

Need for Cognition is a construct reflecting the "tendency to engage in and enjoy thinking" (Cacioppo & Petty, 1982, p. 116). A considerable body of research has been carried out on Need for Cognition, but rarely has this been integrated with larger models of personality (Cacioppo, Petty, Feinstein, & Jarvis, 1996; Fleischhauer et al., 2010). Need for Cognition is not identical with the general Openness/Intellect dimension, but based on its strong correlation with the Ideas facet of the NEO PI-R, it seems likely to be an excellent marker of Intellect specifically (DeYoung, 2011). Although one study reported a structural model suggesting that the Ideas and Need for Cognition scales were measuring slightly different things (Fleischhauer et al., 2010), nonetheless the two latent variables were correlated at .89, which is equivalent to loadings of .94 on a single higher-order factor. Given that the Big Five model appears to describe the structure of any sufficiently large and comprehensive pool of trait measurements (e.g., Markon et al., 2005), it seems most parsimonious to conclude that Need for Cognition is another measure of Intellect.

The construct of Absorption is closely linked to Openness conceptually. Indeed, the article introducing Absorption as a personality trait began its title with the phrase "Openness to absorbing and self-altering experiences" (Tellegen & Atkinson, 1974). Further, Absorption was a good marker of the Openness factor in Markon et al.'s (2005) factor analysis of scales from normal and abnormal personality inventories. We hypothesized that Absorption would fall between traditional measures of Openness and measures of severe apophenia in the Openness/Intellect simplex. Although Absorption does not necessarily represent apophenia strong enough to produce magical ideation, it may involve at least a temporary suspension of metacognitive critique of fantasies or sensations, and it often involves unusual perceptual experiences (Tellegen & Atkinson, 1974). Consistent with this observation, Absorption was found to correlate at $r = .52$ with a self-report measure of thought disturbance (Tellegen & Waller, 2008).

In addition to our two primary hypotheses, in this sample we were also able to test the hypothesis that Intellect and Openness would form separate factors when six factors were extracted, with intelligence loading on Intellect and apophenia loading on Openness.

3.1. Method

3.1.1. Participants

We included 423 members of the ESCS (249 female, 174 male) who had completed all of the measures used in our analyses. This is a subset of the sample described by DeYoung et al. (2007)—which is itself a subset of the full ESCS (Goldberg, 1999a, 1999b). They ranged in age from 20 to 85 years ($M = 52.4$, $SD = 12.5$). Ethnically, almost all participants (98%) identified as White, with less than 1% identifying as Hispanic, Asian American, or Native American. ESCS participants were recruited by mail from lists of homeowners in the US municipalities of Eugene and Springfield, Oregon, and agreed to complete questionnaires, delivered by mail, for pay, over a period of many years, beginning in 1994. (Note that this entails that correlations may be slightly attenuated between measures that were completed at different times.) The sample spanned all levels of educational attainment, with an average of 2 years of post-secondary schooling.

3.1.2. Measures

3.1.2.1. Big Five. Two instruments were used to assess facets of the Big Five. Unless otherwise noted, all instruments in the ESCS utilized 5-point Likert scales. The NEO PI-R (see Study 1) was administered to the ESCS in the summer of 1994. Alpha coefficients for the facets ranged from .61 to .85. The IPIP version of the Abridged Big Five Circumplex (AB5C-IPIP; Goldberg, 1999a) contains 485 items and breaks each of the Big Five down into 9 facets (range of $\alpha = .66–.86$). The AB5C-IPIP facets were derived from the AB5C lexical model (Hofstee, de Raad, & Goldberg, 1992), which is based on the observation that almost all trait-descriptive adjectives can be represented as a blend of two Big Five dimensions. Each of the 10 possible pairs of Big Five dimensions can therefore be used to define a circumplex, or circular arrangement of traits, with Big Five axes at 0° and 90°. Facets were defined by dividing each of these 10 circumplexes with six axes, located at 15°, 45°, 75°, etc., thus defining 12 sections of 30° each. Adjectives falling within each section or its polar opposite represent a facet. There are two "factor-pure" facets in each circumplex, spanning the *x* and *y* axes, plus four facets that represent a positive primary loading on one of the Big Five and a positive or negative secondary loading on the other. Across all 10 circumplexes, nine facets are thus defined for each of the Big Five domains—one factor-pure and eight with secondary loadings. They are identified using Roman numerals to indicate primary and secondary loadings and "+" and "−" to indicate positive and negative loadings. Neuroticism is reversed to indicate Emotional Stability. Each of the AB5C-IPIP facets targeted the content of the adjectives in one of the AB5C lexical facets, using short descriptive phrases, which are more consistently interpreted than single adjectives (Goldberg, 1999a). The items used to create the AB5C-IPIP were administered between 1994 and 1996. The AB5C-IPIP is publicly available on the Web at http://ipip.ori.org/.

Note that we changed the label of one AB5C-IPIP facet from "Creativity" to "Intellectual Creativity" because it would be misleading to think of this scale as assessing the kind of artistic creativity that is often associated with Openness. In fact, most of its items describe intellectual ability and engagement (e.g., "Like to solve complex problems," "Know the answers to many questions").

The Big Five Aspect Scales (BFAS; DeYoung et al., 2007) were not included in our factor and scaling analyses, despite being specifically designed to distinguish between Intellect and Openness factors, because they were constructed from many of the same items as the AB5C-IPIP and therefore comprise partially redundant data. However, we did utilize them for two supplemental regression analyses, designed to examine the unique associations of Openness and Intellect with intelligence and apophenia. The BFAS Openness ($\alpha = .78$) and Intellect ($\alpha = .84$) scales were created by selecting 10 IPIP items that were strongly and differentially correlated with the Openness and Intellect factors identified in factor analysis of the 15 Openness/Intellect facets from the NEO PI-R and AB5C-IPIP (DeYoung et al., 2007).

3.1.2.2. Need for cognition. Participants completed a 10-item version of the short-form Need for Cognition scale (Cacioppo, Petty, & Kao, 1984) in 1999 ($\alpha = .81$).

3.1.2.3. Intelligence. Participants completed Cattell's 16 Personality Factor Questionnaire (16PF; Conn & Rieke, 1994) in 1996. The 16PF includes a 15-item intelligence test (Factor B) that includes knowledge and reasoning problems with multiple-choice answers (α = .73).

3.1.2.4. Absorption. Participants completed the Multidimensional Personality Questionnaire (MPQ; Tellegen & Waller, 2008) in 1999. The 34-item MPQ Absorption scale (α = .90) has two subscales: Sentience (reflecting heightened awareness and positive emotion in response to sensory information) and Proneness to Imaginative and Altered States.

Another measure of Absorption was taken from the Curious Experiences Survey (CES; Goldberg, 1999b), a revision of the Dissociative Experiences Scale, which was administered to the ESCS in 1997. Only the Absorption subscale was used from this survey (α = .81). It was square-root transformed to reduce skewness. The Amnesia subscale was excluded as conceptually unrelated to apophenia. Items from the Depersonalization subscale are arguably related to apophenia (e.g., "Had the experience of feeling as though I was standing next to myself, or watching myself as if I were looking at a different person"); however, scores on this subscale remained heavily skewed even after logarithmic transformation (and thus were in violation of the assumptions of our statistical analyses). Very few individuals in this sample reported having any experiences of depersonalization.

3.1.2.5. Fantasy. Proneness was assessed using the Creative Experiences Questionnaire, which was previously found to correlate at r = .61 with the Schizotypal Personality Questionnaire used in Study 1 (Merckelbach, Horselenberg, & Muris, 2001). In computing Fantasy Proneness scores, we excluded 8 items that specifically assess fantasy proneness in childhood, to maintain the focus on adult personality (leaving 17 items; α = .77). The ESCS completed the CEQ in 2000.

3.1.2.6. Magical Ideation. Two instruments were used to assess magical ideation. In 2000, the ESCS completed the 30-item Magical Ideation scale (Eckblad & Chapman, 1983), one of the most widely used and well-validated measures of positive schizotypy (α = .92). Scores on this scale were logarithmically transformed to reduce skewness. In 1999, the ESCS completed a 19-item version of the Revised Paranormal Belief Scale (α = .93; Tobacyk, 1988; Tobacyk & Milford, 1983), which excluded two redundant items and several items that assess traditional religious beliefs (e.g., "I believe in God"; "There is a heaven and a hell"). Because education may disabuse people of particular superstitious or magical beliefs, without necessarily affecting an underlying tendency toward apophenia, we partialled out education from scores on Magical Ideation and Paranormal Beliefs. Indeed, education was significantly, though weakly, negatively correlated with both of these scales (r = .10 for both, p < .05), but was not correlated with the three Absorption scales or with Fantasy Proneness.

3.2. Results

Table 3 shows correlations among intelligence, apophenia, Absorption, and Need for Cognition, as well as their correlations with standard measures of Openness/Intellect subtraits from the NEO PI-R, AB5C-IPIP, and BFAS. Almost all correlations were positive, but a few were negative, especially among correlations involving intelligence and apophenia. Consistent with Study 1, the strongest negative correlation was between intelligence and Magical Ideation.

Table 4 shows the results of a maximum likelihood factor analysis with oblimin rotation (delta = 0) of all measures. (The full correlation matrix for this analysis is available as online Supplementary material) The first 10 eigenvalues were 15.26, 11.23, 8.93, 6.55, 5.63, 2.50, 1.78, 1.59, 1.48, 1.41. As predicted, when five factors were extracted, Openness/Intellect, Need for Cognition, Absorption, intelligence, and measures of apophenia

Table 3
Correlations of intelligence, apophenia, and related measures with each other and with standard measures of Openness/Intellect in Study 2.

	Int.	NFC	MPQ1	MPQ2	CES	FP	PB	MI
Intelligence	–							
Need for cognition	.30	–						
MPQ absorption (PIAS)	−.06	.12	–					
MPQ absorption (sentience)	−.03	.20	.70	–				
CES absorption	.02	.04	.25	.43	–			
Fantasy proneness	−.08	.16	.49	.65	.42	–		
Paranormal beliefs	−.07	−.03	.30	.40	.28	.35	–	
Magical ideation	−.13	.01	.34	.47	.42	.59	.60	
NEO PI-R								
O1 fantasy	.18	.27	.29	.41	.24	.39	.21	.16
O2 aesthetics	.07	.24	.62	.49	.08	.29	.25	.17
O3 feelings	.02	.16	.48	.42	.18	.28	.26	.18
O4 actions	−.05	.26	.33	.27	−.02	.11	.22	.11
O5 ideas	.31	.62	.24	.31	.15	.26	.04	.14
O6 values	.17	.24	.18	.17	.04	.06	.24	.14
AB5C-IPIP								
V + V + Intellect	.40	.52	.24	.24	.05	.16	.07	.04
V + I + Ingenuity	.17	.49	.13	.22	−.02	.17	.09	.06
V + II + Reflection	−.04	.15	.55	.38	.05	.25	.21	.09
V + III + Competence	.25	.47	.00	.09	−.08	−.02	.05	−.03
V + IV + Quickness	.32	.60	.09	.17	−.04	.11	.01	−.01
V + I − Introspection	.24	.28	.18	.29	.18	.26	.08	.08
V + II − Intellectual Creativity	.39	.61	.16	.22	.08	.15	.00	.06
V + III − Imagination	.13	.40	.51	.49	.14	.39	.23	.19
V + IV − Depth	.17	.38	.33	.40	.30	.37	.18	.23
BFAS								
Intellect	.38	.65	.13	.18	−.01	.11	−.01	−.02
Openness	.11	.30	.59	.52	.18	.43	.26	.23

Note: N = 423; MPQ = Multidimensional Personality Questionnaire, PIAS = Proneness to Imaginative and Altered States, CES = Curious Experiences Survey; See Supplementary material for full correlation matrix.

Table 4
Five factor solution for Study 2.

	N	A	C	E	O/I
N1 anxiety	.75	.07	−.13	−.14	−.07
N2 angry hostility	.74	−.35	−.05	.02	.02
N3 depression	.76	−.04	−.30	−.28	−.07
N4 self-consciousness	.60	.04	−.19	−.40	−.20
N5 impulsiveness	.54	−.10	−.37	.16	.11
N6 vulnerability	.73	.02	−.38	−.21	−.16
IV + IV + Stability	−.85	.15	.13	−.02	.08
IV + I + Happiness	−.81	.10	.29	.36	.17
IV + II + Calmness	−.75	.40	.05	−.03	.01
IV + III + Moderation	−.69	.18	.55	.01	−.01
IV + V + Toughness	−.78	−.04	.23	.10	.31
IV + I − Impulse control	−.59	.23	.27	−.48	−.08
IV + II − Imperturbability	−.58	−.36	.18	−.21	−.04
IV + III − Cool-headedness	−.36	.26	−.28	.04	.18
IV + V − Tranquility	−.74	−.08	.13	−.12	−.26
A1 trust	−.51	.41	.04	.29	.07
A2 straightforwardness	−.14	.54	.09	−.23	−.17
A3 altruism	−.27	.67	.22	.20	−.01
A4 compliance	−.37	.59	−.05	−.22	−.15
A5 modesty	.18	.44	−.12	−.35	−.22
A6 tender-mindedness	.00	.51	−.14	.06	.09
II + II + Understanding	−.07	.74	.13	.23	.26
II + I + Warmth	−.14	.73	.08	.46	.26
II + III + Morality	−.25	.57	.44	−.10	−.17
II + IV + Pleasantness	−.50	.71	.03	.05	.01
II + V + Empathy	−.01	.59	.14	.23	.44
II + I − Cooperation	−.20	.63	.19	−.29	−.09
II + III − Sympathy	.08	.74	−.12	.32	.17
II + IV − Tenderness	.32	.62	−.03	.41	.08
II + V − Nurturance	−.15	.80	.12	−.05	−.22
C1 competence	−.53	.02	.63	.19	.16
C2 order	.00	.01	.70	−.08	−.16
C3 dutifulness	−.21	.22	.62	−.07	−.13
C4 achievement striving	−.19	−.10	.62	.22	.19
C5 self-discipline	−.37	.05	.76	.09	−.04
C6 deliberation	−.32	.12	.53	−.22	−.04
III + III + Conscientiousness	−.15	.10	.84	−.01	−.02
III + I + Efficiency	−.29	.10	.82	.20	.08
III + II + Dutifulness	−.27	.45	.56	−.07	−.10
III + IV + Purposefulness	−.42	.08	.80	.07	.08
III + V + Organization	−.21	.10	.74	.10	.38
III + I − Cautiousness	−.19	−.03	.52	−.42	−.25
III + II − Rationality	−.11	−.29	.71	−.09	−.09
III + IV − Perfectionism	.29	−.14	.60	.01	−.06
III + V − Orderliness	.02	.14	.70	−.08	−.29
E1 warmth	−.18	.55	.04	.64	.14
E2 gregariousness	−.09	.22	−.02	.59	−.06
E3 assertiveness	−.21	−.23	.31	.64	.32
E4 activity	−.08	−.06	.34	.48	.21
E5 excitement seeking	.07	−.20	−.09	.34	.13
E6 positive emotions	−.26	.37	.01	.60	.25
I + I + Gregariousness	−.06	.02	.01	.85	.19
I + II + Friendliness	−.24	.40	.12	.74	.08
I + III + Assertiveness	−.31	−.09	.56	.51	.32
I + IV + Poise	−.56	.20	.20	.64	.25
I + V + Leadership	−.23	−.09	.29	.74	.45
I + II − Provocativeness	.04	−.54	.04	.54	.37
I + III − Self-disclosure	.05	.13	−.22	.68	.32
I + IV − Talkativeness	.23	−.31	−.09	.67	.12
I + V − Sociability	.03	.04	−.04	.45	−.21
O1 fantasy	.08	.04	−.30	.22	.61
O2 aesthetics	.04	.36	−.19	.20	.61
O3 feelings	.26	.37	−.02	.42	.50
O4 actions	−.10	.15	−.15	.31	.48
O5 ideas	−.10	−.07	.03	.09	.76
O6 values	−.17	.07	−.25	.17	.42
V + V + Intellect	−.13	.04	.09	.23	.77
V + I + Ingenuity	−.29	−.10	.20	.43	.67
V + II + Reflection	.09	.52	−.07	.18	.52
V + III + Competence	−.33	−.05	.46	.16	.56
V + IV + Quickness	−.32	−.06	.28	.17	.71
V + I − Introspection	.02	−.13	−.04	−.24	.52
V + II − Intellectual creativity	−.10	−.25	.11	.24	.77
V + III − Imagination	.09	.20	−.26	.20	.74
V + IV − Depth	.27	.03	.03	.16	.65
Need for cognition	−.15	−.15	.13	.10	.62
Intelligence	−.13	−.18	.03	−.03	.32
MPQ absorption (PIAS)	.17	.34	−.19	.12	.44
MPQ absorption (sentience)	.24	.17	−.21	.14	.51
CES absorption	.39	−.09	−.25	.02	.21
Fantasy proneness	.25	.08	−.24	.07	.38
Paranormal beliefs	.15	.17	−.17	.16	.22
Magical ideation	.23	−.02	−.21	.12	.21

Note: N = Neuroticism, A = Agreeableness, C = Conscientiousness, E = Extraversion, O = Openness/Intellect, MPQ = Multidimensional Personality Questionnaire, PIAS = Proneness to Imaginative and Altered States, CES = Curious Experiences Survey. $N = 423$. Maximum likelihood factor analysis with oblimin rotation (delta = 0); structure matrix.

all loaded positively on one factor. However, the CES Absorption scale loaded more heavily on Neuroticism than Openness/Intellect, and the Magical Ideation scale loaded almost equally on Neuroticism, Conscientiousness, and Openness/Intellect.

When six factors were extracted, measures of Intellect formed one factor, including Need for Cognition and intelligence, and measures of Openness formed a separate factor, including Absorption and apophenia (Table 5). Notably, in this factor analysis, both CES Absorption and Magical Ideation had larger loadings on Openness than on any other factor.

Following factor analysis, we performed a multidimensional scaling analysis to determine whether the 23 variables in the Intellect and Openness factors would define a simplex. A one dimensional solution fit the data well, yielding a stress value of .27, which is less than the value of .47 that marks the first percentile of stress values for 23 random variables (Sturrock & Rocha, 2000). The resulting simplex is depicted in Fig. 2. The distances shown accounted for 78% of the variance in the matrix of variables. As expected, measures of intelligence and apophenia were at opposite poles of the simplex, with Openness/Intellect scales arranged between them. Need for Cognition fell in the Intellect region with Intellect facets from the AB5C-IPIP. The MPQ Absorption scales fell between conventional Openness facets and measures of magical ideation, and the CES Absorption scale fell at the far end of the simplex with measures of magical ideation.

Finally, we used the Openness and Intellect scales from the BFAS as simultaneous predictors in regressions of intelligence and apophenia. Apophenia scores for this analysis were creating by standardizing and averaging values for the three scales falling at the low end of the simplex in the previous analysis, Magical Ideation, Paranormal Beliefs, and CES Absorption. Consistent with previous research (DeYoung et al., in press), only BFAS Intellect predicted intelligence independently (Intellect: $\beta = .39$, $p < .001$; Openness: $\beta = -.03$, $p = .57$). In contrast, BFAS Openness predicted apophenia positively ($\beta = .33$, $p < .001$), but BFAS Intellect predicted apophenia negatively ($\beta = -.14$, $p < .01$). This was the case despite the fact that BFAS Intellect was not correlated with apophenia at the zero order ($r = -.02$, $p = .68$), which indicates that only the variance in Intellect not shared with Openness is negatively associated with apophenia.

3.3. Discussion

Again, both of our primary hypotheses were supported. Measures of intelligence and apophenia both loaded positively on the Openness/Intellect factor of the Big Five (despite weak

Table 5
Six factor solution for Study 2.

	N	A	C	E	I	O
N1 anxiety	.74	.05	−.09	−.16	−.18	.18
N2 angry hostility	.76	−.37	−.02	−.02	−.02	.12
N3 depression	.75	−.07	−.26	−.31	−.20	.21
N4 self-consciousness	.59	.01	−.16	−.41	−.32	.13
N5 impulsiveness	.53	−.14	−.35	.13	.01	.26
N6 vulnerability	.73	−.01	−.36	−.23	−.27	.14
IV + IV + Stability	−.86	.17	.10	.01	.16	−.12
IV + I + Happiness	−.81	.12	.26	.39	.28	−.12
IV + II + Calmness	−.77	.41	.02	.01	.05	−.08
IV + III + Moderation	−.68	.24	.51	.05	.13	−.29
IV + V + Toughness	−.77	.01	.19	.11	.43	−.13
IV + I − Impulse control	−.59	.28	.23	−.46	−.01	−.23
IV + II − Imperturbability	−.55	−.31	.15	−.19	.10	−.33
IV + III − Cool-headedness	−.38	.26	−.30	.04	.15	.09
IV + V − Tranquility	−.74	−.08	.11	−.08	−.16	−.29
A1 trust	−.55	.40	.03	.31	.07	.06
A2 straightforwardness	−.15	.57	.06	−.20	−.18	−.12
A3 altruism	−.31	.67	.21	.23	−.05	.07
A4 compliance	−.40	.59	−.07	−.19	−.19	−.03
A5 modesty	.13	.40	−.09	−.34	−.35	.13
A6 tender-mindedness	−.06	.47	−.11	.06	−.04	.32
II + II + Understanding	−.10	.76	.12	.24	.20	.20
II + I + Warmth	−.19	.72	.08	.47	.18	.29
II + III + Morality	−.26	.62	.41	−.06	−.12	−.20
II + IV + Pleasantness	−.55	.71	.01	.08	−.03	.05
II + V + Empathy	−.05	.60	.14	.22	.36	.33
II + I − Cooperation	−.20	.70	.14	−.26	−.06	−.20
II + III − Sympathy	.04	.73	−.11	.32	.06	.29
II + IV − Tenderness	.27	.57	.01	.41	−.07	.37
II + V − Nurturance	−.19	.80	.12	−.01	−.28	.00
C1 competence	−.51	.08	.60	.21	.30	−.21
C2 order	.00	.04	.72	−.06	−.10	−.13
C3 dutifulness	−.20	.27	.61	−.05	−.04	−.23
C4 achievement striving	−.18	−.07	.63	.22	.27	−.01
C5 self-discipline	−.37	.08	.76	.11	.07	−.18
C6 deliberation	−.29	.18	.50	−.20	.06	−.25
III + III + Conscientiousness	−.13	.16	.85	.01	.08	−.19
III + I + Efficiency	−.28	.14	.83	.21	.18	−.12
III + II + Dutifulness	−.26	.51	.53	−.04	−.02	−.24
III + IV + Purposefulness	−.40	.13	.79	.09	.20	−.20
III + V + Organization	−.19	.17	.73	.10	.47	−.02
III + I − Cautiousness	−.14	.06	.48	−.39	−.10	−.47
III + II − Rationality	−.06	−.22	.70	−.08	.07	−.34
III + IV − Perfectionism	.30	−.13	.63	.00	−.03	−.03
III + V − Orderliness	.02	.16	.72	−.05	−.24	−.17
E1 warmth	−.23	.52	.05	.66	.08	.25
E2 gregariousness	−.11	.19	−.01	.60	−.06	.06
E3 assertiveness	−.18	−.22	.31	.63	.42	.03
E4 activity	−.08	−.07	.36	.48	.24	.10
E5 excitement seeking	.04	−.26	−.05	.32	.07	.26
E6 positive emotions	−.31	.31	.04	.61	.18	.35
I + I + Gregariousness	−.07	−.01	.02	.85	.21	.15
I + II + Friendliness	−.25	.39	.11	.77	.10	.06
I + III + Assertiveness	−.30	−.06	.56	.51	.42	.01
I + IV + Poise	−.57	.19	.19	.66	.30	.07
I + V + Leadership	−.21	−.08	.28	.72	.53	.11
I + II − Provocativeness	.04	−.57	.07	.50	.39	.22
I + III − Self-disclosure	.00	.07	−.18	.66	.23	.41
I + IV − Talkativeness	.25	−.35	−.07	.65	.14	.12
I + V − Sociability	.02	.00	−.03	.46	−.22	−.01
O4 actions	−.13	.12	−.14	.28	.40	.37
O5 ideas	−.09	−.04	.02	.04	.76	.29
O6 values	−.19	.06	−.25	.15	.38	.26
V + V + Intellect	−.11	.10	.05	.19	.82	.20
V + I + Ingenuity	−.29	−.08	.19	.40	.71	.23
V + III + Competence	−.30	.02	.42	.15	.67	−.01
V + IV + Quickness	−.30	.01	.24	.14	.80	.09
V + I − Introspection	.01	−.11	−.04	−.29	.48	.25
V + II − Intellectual creativity	−.07	−.20	.08	.19	.85	.17
V + IV − Depth	.26	.04	.04	.11	.57	.44
Need for cognition	−.13	−.10	.11	.07	.67	.15
Intelligence	−.08	−.12	−.02	−.05	.42	−.12
O1 fantasy	.04	.01	−.28	.17	.50	.50
O2 aesthetics	−.02	.33	−.16	.16	.45	.60
O3 feelings	.21	.33	.02	.39	.37	.53
V + III − Imagination	.04	.17	−.24	.14	.59	.60
V + II + Reflection	.03	.50	−.04	.15	.37	.52
MPQ absorption (PIAS)	.08	.26	−.12	.07	.22	.73
MPQ absorption (sentience)	.16	.09	−.13	.08	.28	.79
CES absorption	.34	−.15	−.19	−.03	.06	.46
Fantasy proneness	.17	−.01	−.16	.01	.17	.69
Paranormal beliefs	.09	.09	−.11	.13	.06	.50
Magical ideation	.16	−.11	−.14	.07	.03	.58

Note: N = Neuroticism, A = Agreeableness, C = Conscientiousness, E = Extraversion, O = Openness/Intellect, MPQ = Multidimensional Personality Questionnaire, PIAS = Proneness to Imaginative and Altered States, CES = Curious Experiences Survey. $N = 423$. Maximum likelihood factor analysis with oblimin rotation (delta = 0); structure matrix.

negative correlations between them), and variables in that factor formed a simplex with intelligence and apophenia at opposite ends. An additional hypothesis was also supported: with adequate coverage of content across the extent of the Openness/Intellect simplex, a six factor solution yielded separate Intellect and Openness factors.

Need for Cognition appears to be an excellent marker of Intellect, and Absorption (at least as measured by the MPQ) appears to be an excellent marker of Openness. In the five factor solution, the CES Absorption scale loaded more heavily on Neuroticism than on Openness/Intellect; however, in the six factor solution this scale loaded more heavily on Openness than on Neuroticism. The stronger association with Neuroticism for this Absorption scale relative to MPQ Absorption may reflect its origin in a measure of dissociative experiences, which are likely to be associated with psychopathology. The relatively weak loadings for CES Absorption and measures of apophenia in the five factor solution, despite sizable loadings in the six factor solution, suggest the degree to which loadings on Openness/Intellect may be suppressed for constructs that fall near the ends of the simplex. This phenomenon directly reflects the paradoxical negative correlation between variables loading positively on the same factor.

One limitation of both studies presented above is that the distribution of scores for intelligence is likely to be somewhat restricted relative to the general population. Both Canadian undergraduates and relatively well-educated middle-class Americans are almost certain to be above average in intelligence relative to the population as a whole. They may also be below average in apophenia; presumably few if any are suffering from schizophrenia-spectrum disorders in which apophenia might be particularly severe. Nonetheless, all variables used in our analyses were close to normally distributed (following transformations of Magical Ideation and CES Absorption in Study 2), suggesting the presence of adequate variance for our results to be meaningful.

Despite the link between apophenia and schizotypy, we do not believe that the absence of a disordered population in these studies is problematic. Although our theory has implications for the manner in which extreme Openness may relate to risk for schizophrenia-spectrum disorders, it is primarily a theory of normal personality, not a theory of disorder. We view apophenia as a normal and common feature of human functioning, and the fact that our structural model accurately characterized two relatively highly functioning but demographically quite different samples suggests its utility for describing normal personality variation. Nonetheless, future research could usefully extend the present work by testing our model in more varied populations.

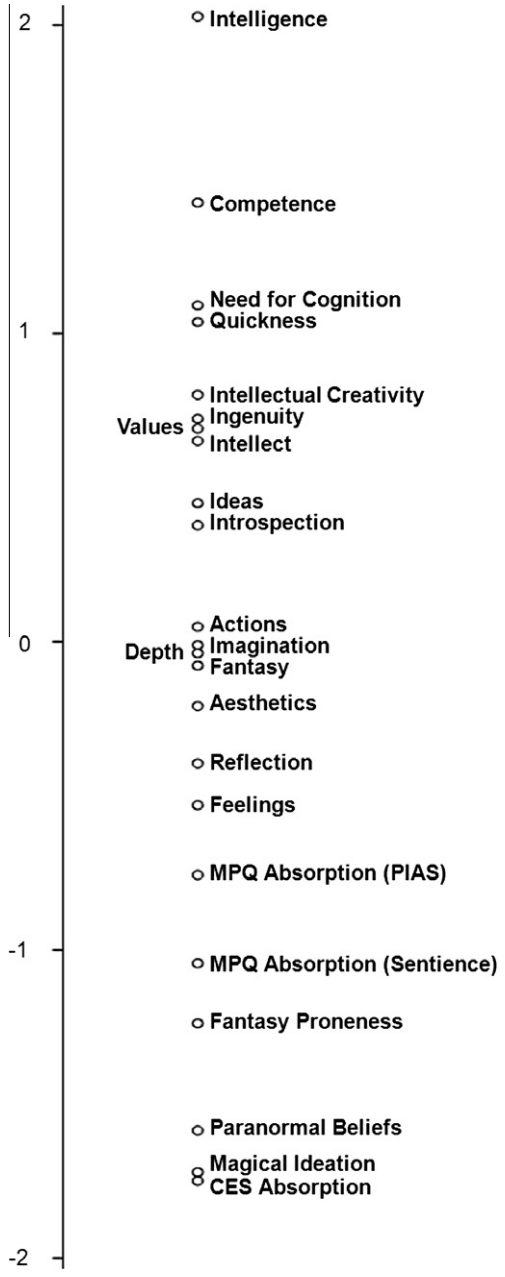

Fig. 2. Simplex arrangement of variables in the Openness/Intellect domain, Study 2. CES = Curious Experiences Survey (Goldberg, 1999b), MPQ = Multidimensional Personality Questionnaire (Tellegen & Waller, 2008); PIAS = Proneness to Imaginative and Altered States.

4. General discussion

In two studies, we demonstrated that the Openness/Intellect domain can be well described as a simplex, an arrangement of variables along a single dimension according to distances reflective of how strongly the variables are related to each other. The opposing ends of the simplex were occupied by intelligence and apophenia. The fact that this pattern replicated using different measures of intelligence and apophenia suggests it is likely to be robust, not simply due to the idiosyncracies of particular measures. In both samples, intelligence and apophenia were weakly negatively correlated, despite loading positively on the same factor, producing a situation we have described as a paradoxical simplex. Some causal forces (implied by the underlying factor) cause intelligence and apophenia to vary together positively, whereas other forces cause them to vary inversely. As indicated by the zero-order correlation, the negative covariation is stronger than the positive covariation. Nonetheless, both groups of forces will be important to explore for a full explanatory model of Openness/Intellect.

Another way to describe the situation is that scores on variables in the Openness/Intellect simplex tend to covary, but the relative balance of Intellect and Openness is likely to be important in predicting whether people score high on intelligence (associated with relatively high Intellect) or high on apophenia (associated with relatively high Openness), as people do not tend on average to score high on both intelligence and apophenia together. The importance of the balance between Intellect and Openness was further emphasized by our supplemental regressions in Study 2, using the BFAS Intellect and Openness scales, which showed that, when controlling for Openness, even a questionnaire measure of Intellect (rather than an ability test of intelligence) was negatively related to apophenia. Nonetheless, it is important to remember that, given the relatively weak associations between apophenia and intelligence or Intellect, many people may be found who score high on both or neither.

Our model has implications for both measurement and conceptualization of Openness/Intellect. With regard to measurement, we can now question what region of the simplex any particular measure of Openness/Intellect might be assessing. Note that, in Fig. 2, some Big Five facets measuring Intellect fall between 0.5 and 1.5 on the simplex scale, fairly close to intelligence. Big Five facets measuring Openness, however, fall much more centrally, with none extending beyond about −0.5 in the direction of the apophenia pole. This pattern suggests that, whereas standard Big Five measures can assess Intellect fairly far along the simplex toward its intelligence pole, they assess Openness more centrally, far from outright apophenia. In contrast, scales such as MPQ Absorption assess a more dramatic form of Openness, which might be useful for some research, or might lead to an expansion of Big Five measures of Openness.

Future research could usefully attempt to integrate additional measures related to positive schizotypy and apophenia into the simplex model. Two constructs that should be included are referential thinking (Lenzenweger, Bennett, & Lilenfeld, 1997) and aberrant salience (Cicero, Kerns, & McCarthy, 2010; Kapur, 2003). Pleasant referential thinking (e.g., the idea that people play songs on the radio just for you) has been associated with Openness/Intellect (Cicero & Kerns, 2011). Aberrant salience, the tendency to assign significance to stimuli that are otherwise unimportant, is a particularly important constuct here because it constitutes a potential source of apophenia in general. Having one's sense of meaning or salience triggered at a very low threshold, or when it should not be, may constitute an important factor predisposing one to perceive patterns or causal connections where none exist. A number of items from the MPQ Absorption scale describe aberrant salience, suggesting that a specific measure of aberrant salience would be likely to fall in the same general region of the simplex.

Conceptually, our findings should simultaneously broaden and clarify models of Openness/Intellect. First, they highlight the importance of distinguishing between Intellect and Openness as related but separable aspects of a single broad domain (DeYoung et al., 2007), while allowing the additional insight that facets within each aspect vary systematically in the strength of their relation to the other aspect. Making the distinction between Intellect and Openness facilitates the integration of intelligence and apophenia into general taxonomies of personality. Descriptors of intelligence as an ability already appear in questionnaire measures of Intellect (e.g., "Am quick to understand things"; "Have difficulty understanding abstract ideas" – reversed), so including intelligence as measured by performance tests within the broader construct of Intellect is not a far stretch. In contrast, items explicitly assessing

apophenia tend not to appear in Openness questionnaires, but apophenia is not far semantically from Openness items that describe an unusual sensitivity to patterns (e.g., "See beauty in things that others might not notice"). Strong apophenia, such as that seen in magical ideation, involves believing such patterns to be objectively real without sufficient evidence. (One might describe apophenia as "openness to implausible patterns.") Perhaps, therefore, distance along the simplex within its Openness half reflects the degree to which people with those traits are metacognitively aware of the subjectivity of the patterns perceived.

In addition to highlighting the distinction between Openness and Intellect, our results provide motivation to clarify the unifying features of the Openness/Intellect domain as a whole. Part of why it has been difficult to figure out where intelligence and apophenia or positive schizotypy should be located in general taxonomies of personality is that they are related to the same broad trait domain, despite being negatively related. Locating both within Openness/Intellect suggests that they share some characteristic. We believe what they have in common is cognitive exploration of the structure of experience (DeYoung, 2011; DeYoung et al., 2005; Van Egeren, 2009), with intelligence and other traits related to Intellect emphasizing exploration of abstract information, and apophenia and other traits related to Openness emphasizing exploration of perceptual information. Potentiating this broad tendency toward cognitive exploration would tend to increase both Intellect and Openness, despite the fact that some traits within Intellect and Openness are negatively related.

One objection that might be raised to including intelligence and apophenia in the Openness/Intellect domain is their relatively weak loadings on the general Openness/Intellect factor (see Tables 2 and 4). Note, however, that our model specifies these traits as relatively peripheral facets of the domain (which is consistent with weaker loadings), and thus does not force a reconceptualization of the central qualities of Openness/Intellect involving innovation, curiosity, and imagination. Additionally, note that multiple reasons exist for their loadings to be suppressed, including (1) their negative correlation with each other, (2) the relatively weak correlations of intelligence with Openness and apophenia with Intellect, and, (3) in the case of intelligence, method variance. The relative weakness of loadings for apophenia on Openness/Intellect may explain why, in studies that do not include a sufficiently broad range of variables related to both Intellect and Openness, measures of apophenia may split off with other measures of oddity to form a separate factor that does not include Openness (Watson et al., 2008). That we found apophenia to join an Openness factor, with reasonably high loadings, when six factors were extracted in Study 2, provides additional support for integrating apophenia or positive schizotypy with established personality dimensions, as suggested by Edmundson et al. (2011) and Piedmont et al. (2009). However, because we were not attempting to investigate oddity broadly and were focused only on apophenia, our results do not provide a strong empirical case against the existence of a separate oddity factor (nor were they intended to).

Nonetheless, we see at least one good theoretical reason to prefer integrating apophenia (and intelligence as well) into the Big Five, rather than assigning it to a novel trait dimension: namely, the desirability of a unified mechanistic account of traits as variation in the parameters of an adaptive system (Block, 2002; DeYoung, 2010b; Van Egeren, 2009). The Big Five model represents an important empirical achievement but currently offers little in the way of explanation for the existence of these particular five traits. The development of explanatory models requires identification of the psychological functions and brain systems that produce the patterns of emotion, motivation, cognition, and behavior that are described by the Big Five. Several preliminary versions of such models have been proposed (DeYoung, 2010a, 2010b; Nettle, 2006a, 2007; Van Egeren, 2009), and they rest on the premise, noted in our introduction, that the Big Five offer a reasonably comprehensive list of major categories of psychological function in which there is substantial variation. Within an individual (considered as an adaptive, goal-directed system), the psychological mechanisms responsible for these functional categories must operate together to produce behavior and experience. Given this premise, characteristics related to psychopathology should be explicable in terms of extremity or dysfunction of this integrated set of mechanisms, without reference to entirely new categories of psychological function. Apophenia, for example, can be seen as an extreme form of Openness, stemming from the functioning of at least some of the systems that produce cognitive exploration.

4.1. Substrates of the Openness/Intellect simplex

The theoretical perspective just described invites consideration of the psychological and biological systems that might be responsible for producing the functions encompassed by the Openness/Intellect simplex. The following section demonstrates the utility of the simplex model for the development of a mechanistic theory of Openness/Intellect, including hypotheses that may be tested in future research. The primary advantage of the simplex model in organizing theories of the substrates of Openness/Intellect is its implication that certain mechanisms will influence both Openness and Intellect, whereas others will differentiate them, and some of the latter may even influence them in opposite directions, thereby producing the negative correlation between intelligence and apophenia.

One system likely to influence Openness/Intellect as a whole is the dopaminergic system (DeYoung et al., 2005). Dopamine potentiates exploration in behavior and cognition (Depue & Collins, 1999; Kang et al., 2009; Panksepp, 1998). The role of dopamine in Extraversion is better established than the role of dopamine in Openness/Intellect (Depue & Collins, 1999; Wacker, Chavanon, & Stemmler, 2006; Wacker & Stemmler, 2006), but these two traits are correlated and form a higher order Plasticity factor that appears to reflect the general tendency to explore and engage actively with possibilities (DeYoung, 2006, 2010b). Whereas Extraversion appears to reflect the effects of dopamine on approach-oriented behavior and affect, Openness/Intellect may reflect its effects on cognition (DeYoung et al., 2005). Some evidence suggests that variation in two genes involved in the dopaminergic system is related to Openness/Intellect (DeYoung, Cicchetti, Rogosch, Gray, & Grigorenko, 2011; Harris et al., 2005).

Intellect specifically is likely to be influenced by dopaminergic projections to prefrontal cortex, as dopamine is crucial for working memory and other cognitive functions of that brain region. Considerable evidence implicates working memory in general intelligence (Conway, Kane, & Engle, 2003; Gray, Chabris, & Braver, 2003), and working memory appears to be a unique substrate of Intellect rather than Openness. In an fMRI study, working memory capacity and activity of prefrontal cortex during a working memory task were associated with Intellect but not Openness, and brain activity in two prefrontal regions mediated the association of Intellect with performance on the task (DeYoung et al., 2009). Similarly, general intelligence and nonverbal or fluid intelligence are independently associated with Intellect but not Openness (DeYoung et al., in press). Verbal intelligence, in contrast, was found to be associated independently with both Intellect and Openness.

If working memory is uniquely associated with Intellect, what psychological functions might be specific to Openness? One candidate is the ability to detect covariance patterns in sensory information automatically, a phenomenon known as implicit learning. One study demonstrated a double dissociation, in which Intellect was associated with working memory but not implicit learning,

whereas Openness was associated with implicit learning but not working memory (Kaufman et al., 2010). Additionally, implicit learning was uniquely associated with verbal intelligence, independently of general intelligence. This latter association may represent the contribution of implicit learning to language acquisition and could explain the relation of Openness to verbal intelligence (Kaufman et al., 2010). At the end of the simplex associated with apophenia, the tendency to detect covariance patterns automatically may lead to overinterpretation of coincidences and sensory noise as meaningful patterns. Indeed, the tendency toward magical ideation is positively correlated with identification of meaningful patterns in noisy or random visual stimuli (Blackmore & Moore, 1994; Brugger et al., 1993).

Dopamine appears to potentiate implicit learning, much as it potentiates working memory, thus influencing psychological mechanisms specifically associated with Openness as well as those specifically associated with Intellect (Wilkinson & Jahanshahi, 2007). This fact is consistent with the hypothesis that dopamine levels may contribute to the general Openness/Intellect factor and illustrates the kind of causal hierarchy that might correspond to the trait hierarchy. Some mechanisms (working memory, implicit learning) should contribute to particular lower-level traits specifically, whereas other mechanisms (dopamine) should contribute to broader traits by influencing multiple lower-level mechanisms.

In the case of Openness/Intellect, there may be additional biological forces that influence Intellect and Openness in opposite directions, potentially accounting for the negative correlation between intelligence and apophenia. At least three such mechanisms present themselves as possibilities. First, although dopamine may generally potentiate both Intellect and Openness, leading them to share variance, dopamine's effect on the functions of prefrontal cortex exhibits an inverted U-shaped function, with both too low and too high levels of dopamine impairing cognitive function (Arnsten & Robbins, 2002). Additionally, some degree of antagonism exists between levels of dopamine in the prefrontal cortex and levels in the striatum, such that elevated striatal dopamine is often associated with reduced dopamine in the prefrontal cortex (Winterer & Weinberger, 2004). At sufficiently high levels, dopamine may increase apophenia while disrupting cognitive functions like working memory that underlie intelligence. The positive schizotypal symptoms (including magical ideation, unusual perceptual experiences, and aberrant salience) that characterize the prodromal symptoms of schizophrenia are associated with elevated striatal dopamine function (Howes et al., 2009; Kapur, 2003). Further, schizophrenia, schizotypy, and Openness are all associated with reduced latent inhibition (i.e., a reduction in the automatic tendency to exclude previously ignored stimuli from consciousness), and latent inhibition is reduced by increases in dopamine (Peterson et al., 2002).

Second, intelligence and apophenia appear to be associated in opposite directions with the integrity of white matter tracts (Chiang et al., 2009; Jung et al., 2010; Nelson et al., 2011). White matter consists of axons, which communicate between different regions of the brain, and their surrounding myelination (fatty insulation). Studies of white matter structure in health and disease, using diffusion tensor imaging in MRI, find that healthy white matter tracts exhibit increased coherence and myelination relative to those seen in various pathologies (Le Bihan, 2003). White matter integrity is highly heritable and shares considerable genetic variance with intelligence (Chiang et al., 2009). Intelligence and working memory have been found to correlate positively with white matter integrity in tracts within prefrontal and parietal cortices (Charlton et al., 2006; Chiang et al., 2009). In schizophrenia, by contrast, white matter tracts in the frontal lobes exhibit reduced integrity, which may partially account for the cognitive deficits associated with psychosis (McIntosh et al., 2008; Sussmann et al., 2009). Similarly, a measure of positive schizotypy has been found to correlate negatively with frontal white matter integrity in the normal population (Nelson et al., 2011).

Interestingly, in a sample of normal subjects with relatively high intelligence, both Openness/Intellect and divergent thinking (the ability to generate multiple creative responses) were associated with decreased white matter integrity in the same areas that exhibit white matter changes in schizophrenia (Jung et al., 2010). Because this analysis controlled for intelligence statistically, variance in Openness/Intellect was presumably due primarily to variance associated with Openness rather than Intellect. These findings indicate that, although reduced white matter integrity is often a sign of damage, deficit, or reduced intelligence, some attenuation of frontal white matter integrity may be associated with flexible and innovative cognition in normal individuals. They further suggest that frontal white matter integrity may be a factor predisposing individuals toward one end of the Openness/Intellect simplex or the other.

A third biological factor that may influence Intellect and Openness in opposite directions is related to the lateralization of functions in the brain. In general, the brain's left hemisphere shows specialization for functions that involve close associations and serial logical operations, whereas the right hemisphere shows specialization for functions that involve remote associations and holistic or global pattern recognition (Heller, 1994; MacNeilage, Rogers, & Vallortigara, 2009; Peterson, 1999). For this reason, the semantic functions of language are largely lateralized to the left hemisphere, whereas the right hemisphere is more strongly involved in processing imagistic information and spatial relations. Intelligence is associated with structure and function in many brain regions in the frontal and parietal lobes, but considerably more associations are found in the left hemisphere than the right (Jung & Haier, 2007). In contrast, schizophrenia has been associated with reduced left hemisphere dominance for language (Crow, 2000), as have apophenia and divergent thinking (Mohr et al., 2005; Weinstein & Graves, 2002). Further, elevated levels of dopamine in the right hemisphere specifically have been hypothesized to produce the magical ideation and loose associations associated with positive schizotypy (Mohr, Bracha, & Brugger, 2003). None of this is to suggest, simplistically, that Intellect is somehow located exclusively in the left hemisphere and Openness in the right, but rather that a bias toward dominance of left- or right-hemisphere function might predispose individuals toward expressing traits at one end of the simplex or the other.

An association of Openness with right-hemisphere function, together with its association with dopaminergic function, might help to explain the association of Openness with dreaming. Individuals high in Openness/Intellect (but none other of the Big Five) report having more dreams and more vivid dreams than those low in the trait (Watson, 2003). Evidence that dopaminergic projections to the cortex are necessary for dreaming suggests that dreaming may be, at least in part, dopaminergically driven cognitive exploration similar to that associated with Openness/Intellect in waking (Peterson & DeYoung, 2000; Solms, 2000). Additional support for this speculation comes from studies showing that sleep and dreaming facilitate creative insight (Cai, Mednick, Harrison, Kanady, & Mednick, 2009; Wagner, Gais, Haider, Verleger, & Born, 2004). Tasks that require creative insight and divergent thinking draw preferentially on right hemisphere function (Bowden & Beeman, 2003; Carlsson, Wendt, & Risberg, 2000; Fiore & Schooler, 1998). Intriguingly, the left hemisphere typically shows an advantage in speed of reaction to stimuli during waking, but the right hemisphere gains the advantage during sleep, suggesting a switch from left- to right-hemisphere dominance during sleep (Casagrande & Bertini, 2008). Taken together, the findings reviewed here suggest that both dreaming and Openness may be preferentially supported by right

hemisphere functions potentiated by dopamine. In our epigraph, Poe characterizes the mad genius as someone who dreams by day as well as by night. Perhaps those high in Openness, which encompasses fantasy-proneness and apophenia, really do engage in cognitive processes akin to dreaming while awake.

4.2. Costs and benefits of Openness

The inclusion of apophenia within the domain of Openness/Intellect invites consideration of the costs and benefits of Openness. Many traits entail potential trade-offs; for example, high Extraversion may be associated with greater positive emotion and acquisition of rewards but also with greater risk-taking and injury (Nettle, 2006a). We assume that there are no serious costs to Intellect, but the association of Openness with traits entailing risk for schizophrenia suggests that Openness carries a serious potential cost and begs consideration of its associated trade-offs. The costs and benefits of Openness can be considered both proximally and in terms of their evolutionary significance.

Proximally, the danger of apophenia is clear: to misidentify the structure of reality can lead to maladaptive behavior and consequent suffering. One notable pattern in the results of the factor analysis in Study 2 that revealed distinct Intellect and Openness factors (Table 5) was that facets of Neuroticism tended to show modest negative loadings on Intellect but modest positive loadings on Openness. This was by far the most consistent set of secondary loadings differentiating the Intellect and Openness factors. To the degree that Openness involves apophenia, and apophenia causes maladaptation, Openness might cause higher levels of Neuroticism (which reflects the tendency to experience negative emotion). Further, to the degree that Openness, even without full-blown apophenia, involves heightened sensitivity to the detection of patterns and a reduced threshold for bringing information into awareness, it increases the range of stimuli available to worry about. Neuroticism involves detection of error, conflict, and uncertainty—functions attributed to the behavioral inhibition system (DeYoung, 2010a, 2010b; Gray & McNaughton, 2000; Van Egeren, 2009). This system compares a model of desired or expected sensory inputs to actual inputs, and generates anxiety in response to any mismatch. High Openness appears to entail that a wider range of perceptions would be available as actual inputs, which, *ceteris paribus*, should lead to a higher rate of mismatch detection.

The positive association of Openness with Neuroticism may help to explain the association of artistic creativity with certain forms of psychopathology, especially mood disorders (Nettle, 2006b). Additionally, however, the association of Openness with creativity, measured both in terms of actual creative achievement and as divergent thinking ability, draws attention to the potential benefits of Openness (Feist, 1998; McCrae, 1987; Nelson & Rawlings, 2010). Heightened sensitivity to the detection of patterns may lead to apophenia, but it may also lead to innovation and discovery. The trade-off for Openness, then, is similar to that which has been postulated for positive schizotypy: a decrease in Type II errors at the cost of an increase in Type I errors (Brugger & Graves, 1997).

The identification of apophenia as a facet of Openness additionally may help to clarify evolutionary theories designed to explain the prevalence of schizophrenia. Schizophrenia itself is associated with reduced reproductive success and hence reduced fitness (Avila, Thaker, & Adami, 2001; Bassett, Bury, Hodgkinson, & Honer, 1996), a fact which makes its continued presence in the population puzzling, unless one posits the existence of selection for traits that create risk for schizophrenia. Openness has been hypothesized to be such a trait (Nettle, 2006a). The relation between Openness and fitness might therefore be described by an inverted U (Nettle & Clegg, 2006), or even a "fitness cliff," in which adaptive advantage increases up to a certain threshold after which fitness falls off precipitously (Nesse, 2004). This threshold would be the point of apophenia severe enough to render behavior maladaptive and psychosis likely. Prior to that point, Openness may increase reproductive fitness by producing higher levels of creativity, with fitness benefits attendant on increased detection of rewarding possibilities and innovative solutions to problems. More directly, increased fitness might be due to increased sexual attractiveness; one study found that apophenia was positively related to number of sexual partners for both men and women, and that this association was mediated by artistic creative activity (Nettle & Clegg, 2006).

Note also that the paradoxical simplex model implies that forces increasing levels of Openness/Intellect generally should increase fitness benefits associated with both Openness and Intellect. In conjunction with high levels of Openness/Intellect, however, a shift along the simplex away from intelligence toward apophenia could be catastrophic if sufficiently great. This suggests an additional hypothesis regarding the adaptive advantage of Openness, namely that it is moderated by intelligence (Eysenck, 1993; Nettle, 2006a). Intelligence may compensate for the overinclusive pattern recognition associated with apophenia, diminishing the attendant risk for schizophrenia. In fact, it may be precisely high Openness with insufficient intelligence that produces severe apophenia. It might even be that Intellect and Openness covary in part because Intellect has been selected by evolution to occur with high Openness, so as to avoid the maladaptive drift into severe apophenia.

Seen another way, one of the main benefits of Openness may be to increase the level of creativity associated with a given level of intelligence. Individuals high in Openness who are also highly intelligent should be sensitive to potential patterns and causal connections, without lapsing into the magical ideation that occurs in the absence of sufficient metacognitive awareness and logical reality testing. Creativity requires both novelty and appropriateness of the creative product (Amabile, 1996; Csikszentmihalyi, 1999), and intelligence may provide the ability to determine the appropriateness of the novelty stemming from Openness (Carson, Peterson, & Higgins, 2003).

5. Conclusion: madness and genius

The Openness/Intellect domain can be described as a simplex ranging from intelligence to apophenia. This model allows both psychometric and theoretical integration of a surprisingly large number of phenomena into a coherent framework. (We hope our integrative endeavor will not be seen as an instance of apophenia.) Returning to our initial question regarding the relation of madness to genius, we can now suggest that madness (as apophenia) may indeed be both the antithesis and the complement to genius, as Poe implied. Genius requires penetrating insight into reality, whereas madness is confusion about reality. Nonetheless, both madness and genius appear likely to be positively related to the broad trait of Openness/Intellect. We have not studied madness or genius directly in this research, and our goal was an improved understanding of personality variation in the normal population, rather than in clinical samples or among the highest levels of genius. However, we suspect that future research might be able to extend our model to those groups. Without the tendency to perceive patterns that is fundamental to Openness, Intellect may by unlikely to lead to the creativity required for genius. Perhaps, then, genius is most likely to emerge given the combination of high Intellect and high Openness, and one must risk madness to achieve genius.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jrp.2011.12.003.

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