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The Tower of Hanoi in Dynamic Creative Problem Solving

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THE TOWER OF HANOI IN DYNAMIC CREATIVE PROBLEM SOLVING

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The Tower of Hanoi in Dynamic Creative Problem Solving

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Creativity and emotions are well-studied constructs, and there is much work on their interrelations. However the empirical application of dynamical systems analysis to them is still relatively rare. For these reasons, a study was conducted on the dynamics and interrelationships of creativity, emotion, and psychopathology using state space grids (SSG) in 33 young adult participants assessed for autism spectrum and negative schizotypy traits, using a computerized Tower of Hanoi (ToH) creative problem-solving task. An overview of the dual importance of convergent and divergent thinking styles to creativity is provided as a context for the experiment. The hypothesis that participants with subclinical autism (AS) or negative symptom schizotypy (SZ) traits would obtain higher creativity scores, as defined by 1/(moves∗min), than controls on the ToH tasks, even after statistically controlling for participants' IQ and task experience was not supported. The hypothesis that AS/SZ individuals tend to stay in negative moods longer and more frequently than controls was also not supported. There is marginal support for the connection between type of college major (science vs. nonscience) and subclinical schizotypy traits with science majors tending to score higher on subclinical traits ($t[106.32] = 1.63$, $p = .053$). SSGs plotting frequency of move and emotion ratings of selected participants were analyzed for possible emotional attractors, repellors, and other dynamical characteristics.

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Studying Divergent and Convergent Thinking and Psychological "Spectra"

Creativity has been conceptualized by many researchers as a product of primarily divergent thinking (Brophy, 1998). Divergent thinking involves generating multiple ideas for a given situation or task, linking seemingly unrelated ideas, and combining familiar elements into novel new products (Cropley, 2006). However, as will be discussed shortly, some researchers suggest that many types of creativity also include convergent thinking processes. Divergent thinking is important to creativity as generation of many differing ideas is likely to lead to unique products (Runco, 2008). Many tests that purport to measure creativity, such as the Torrance Test of Creative Thinking, are fundamentally tests of divergent thinking tendencies and primarily tap constructs such as fluency, flexibility, originality, and elaboration (Baer, 2011; Benedek, Koenen, & Neubauer, 2012; Glazer, 2009). Although some tests of Divergent Thinking or ideational fluency, such as Alternate Uses (Guilford et al, 1978), take into account the "quality" as well as the number of the new ideas produced, a result of the emphasis on number of ideas produced is that the concept of creativity has in some respects become reduced to the fluent generation of wild or unusual ideas with greater volume implying greater creativity instead of accounting for an evaluative component that is considered to be central to creativity (Baer, 2011).

In contrast, convergent thinking considers effectiveness and other qualities such as problem evaluation and specification (Brophy, 1998; Lubart, 2000). Convergent thinking is directed towards finding the optimal solution to a problem by using correctness, accuracy, logic, and reapplying existing techniques/knowledge. Interest in convergent thinking is growing as a consequence of some researchers questioning the validity of defining creativity solely by divergent thinking tasks (Baer, 2011; Cropley, 2006; Lubart, 2000; Moneta, 1993; Prentky, 2000). Divergent thinking is often directed towards generating multiple equally valid answers to a problem by making unusual connections or combinations, being unconventional, and taking risks (Cropley, 2006). Although divergent thinking is critical in the initial phases of creative thinking, convergent thinking may be just as critical in latter stages when one engages in the evaluative component (Cropley, 2006).

However, this emphasis on divergent thinking is not in alignment with some other definitions of creativity. For example, Russ (1993) states that for a product to be creative it must be "(a) unique, original, novel; (b) good, that is adaptive, useful, aesthetically pleasing, according to the standard of the particular discipline." (p. 1) Included in Russ's definition is an "evaluative" component that somewhat dissolves the notion that ideational fluidity (rapid generation of ideas) and uniqueness fully determine creativity. During the evaluative phase, one considers the effectiveness or quality of a particular product. Many creativity researchers assert that novelty is necessary but not sufficient for creativity; a product must also be deemed good (Russ, 1993; Runco, 2008). As Runco (2008) suggests, divergent thinking is not equivalent to creativity, as not all ideas produced from this process are useful or valuable.

Various forms of psychopathology have been studied by researchers as important factors associated with creativity (Acar & Runco, 2012; Schuldberg, 2000-2001). Extensive research has been done on creativity in individuals with disorders such as schizophrenia, depression, and bipolar disorder (Guastello, Guastello, & Hanson, 2004;

Rybakowski & Klonowska, 2008). The current study investigates convergent thinking in relation to two types of "spectrum" disorders, the autism spectrum and negative symptom schizotypy in a non-clinical sample.

Distinguishing convergent and divergent thinking. Cropley (2006) suggests that, although convergent and divergent thinking have historically been thought of as being completely distinct, they are actually intimately related in creativity. He proposed that creative thinking involves these two components: "generation of novelty (via divergent thinking) and evaluation of the novelty (via convergent thinking)" (p. 391). Brophy (1998) conceptualized the creative process as resulting not just from these two discrete processes, but also from the alternations between periods of convergent and divergent thinking and the ability to determine when each should be used. In particular, Brophy suggests that effective creative problem solving is achieved when both convergent and divergent thinking styles are used together, as both thinking styles uniquely contribute to the creative process. This notion is similar to Guilford's (1957) point that convergent and divergent thinking may occur simultaneously and furthermore, often occur in problem solving. It is possible the dialectical coordination of both divergent and convergent thinking leads to an original, useful, and ideal solution that is found in a reasonably efficient manner.

Nevertheless, despite the seemingly distinct nature of convergent and divergent thinking, they tend to become somewhat muddled in descriptions of creativity. Guilford (1968) proposes that there are two essential cognitive abilities in creativity: divergent thinking and transformation abilities. Guilford defines divergent thinking as "a matter of scanning one's stored information to find answers to satisfy a special search model." (p

105) Implied in Guilford's definition of divergent thinking is also a convergent process of applying existing techniques and knowledge. This notion is also suggested in Guilford's proposed creative process/operation of transformation, which is generally the ability to transform or update previous knowledge or configurations into something new. Again, the idea of transformation suggests convergent elements of interaction with preexisting ideas, and the use of potentially logical thinking. Something may appear to be new, but without careful consideration of the product's elements in comparison to the existing model, such a determination is difficult.

The distinction between convergent and divergent thinking is further blurred in Wallas' (1926) stages of creativity: preparation, incubation, illumination, and verification. Stage 4 of verification of novelty and usefulness is difficult without using the convergent property of referencing past methods and stores of knowledge. Furthermore, Wallas suggests that critical and logical thinking, aspects of convergent thinking, are essential to this stage as assessment of usefulness and uniqueness are dependent on such cognitive abilities. Even creative outputs attributed to serendipity or insight still require convergent thinking qualities, such as contextualizing combined associative elements with knowledge about appropriateness of a given solution. After all, a person provided with a key element to a problem's solution may not appreciate its significance if he or she has no understanding of how it is related to the problem at hand. In other words, something may appear novel or unique; but, without logical evaluation of the product's merit or comparison of the product to past creations, it is perhaps impossible to truly assess if something is creative in terms of either quality or uniqueness.

To illustrate how convergent and divergent thinking are both important to creativity, consider novelty – a hallmark requirement of creativity. Convergent thinking (logical comparisons between the idea and known prototypes) is needed to determine if something is novel. However, divergent thinking is also critical because otherwise an ideal creative solution or answer may not be found if a person limits him or herself purely to the conventional. If one is unwilling to explore the unknown, then only lesser quality solutions may be found. This fine balance between being open to new ideas and synthesizing the disparate along with ability to contextualize novelty in a useful framework has been proposed to be essential to creativity (Brophy, 1998; Cropley, 2006; Moneta, 1993).

The current study investigates convergent thinking in relations to two types of "spectrum" disorders: the autism spectrum and negative symptom schizotypy in a non-clinical sample.

Types of creativity in different domains and tasks. Creativity is not limited to the arts, and several researchers incorporate science and technology into their definitions of creativity. For example, Russ (1993) notes that a good creative product may be "an accurate solution to a scientific problem" or a "useful invention for consumers." This idea is mirrored in Vernon's (p. 94) definition of creativity: "Creativity means a person's capacity to produce new or original ideas, insights, restructuring, inventions, or artistic objects, which are accepted by experts as being of scientific, aesthetic, social or technological value." Unfortunately, one weakness of purely divergent thinking theories of creativity is that they incompletely account for creativity displayed by scientists (Moneta, 1993). Scientific creativity may depend much more overtly on convergent thinking than perhaps the creativity displayed by artists, as it is critical for scientists to draw upon past knowledge amassed in their discipline and use skills such as logic and assessment of accuracy (Guilford, 1957). However, as will now be explored, scientific creativity still necessitates use of both convergent and divergent thinking styles. As nicely stated by Prentky (2000), "Creativity may derive from either thinking style and may do so with little or no regard to profession (e.g., artists and scientists may be divergent or convergent)." (p. 97)

Hu et al. (2002) define scientific creativity "as a kind of intellectual trait or ability producing or potentially producing a certain product that is original and has social or personal value, designed with a certain purpose in mind, using given information." Although Hu et al. are specifically referring to scientific creativity, these components are strikingly similar to those proposed for creativity in general as earlier outlined by Russ and Guilford. This similarity may allude to commonalities between artistic and scientific creativity. Hu et al. propose a model for scientific creativity called the Scientific Structure Creativity Model (SSCM). The SSCM is a three-dimensional model with the axes of process (imagination, thinking), trait (fluency, flexibility, originality), and product (technical product, science knowledge, science phenomena, science problem). The fact that divergent thinking (trait) and convergent thinking (product) are both featured prominently in this model of scientific creativity again points to the seeming dual importance of these connected cognitive processes. This multidimensional model highlights how scientific creativity, and potentially creativity in general, is a highly complex phenomenon that depends on several processes that are sometimes opposing –

such as divergence and convergence along with the relevant aforementioned driving process elements.

Another influential theory of scientific creativity was proposed by Rothenberg (1996). He suggested that the Janusian process of “actively considering multiple opposites or antitheses simultaneously” underlies scientific creativity (p. 207). The Janusian process is inspired by the Greek god Janus who has two faces looking in opposite directions. This physical embodiment of polarized states underlies the proposed process of simultaneously engaging seemingly opposite ideas. The Janusian process is not synonymous with the dialectical process, as it resolves opposing ideas simultaneously as opposed to sequentially (Rothenberg, 1996). Furthermore, in the Janusian process, opposing ideas are not treated as things to be resolved, but instead equally valued distinct entities.

The four Janusian phases thought to underlie scientific creativity are: motivation to create; deviation or separation; simultaneous opposition or antithesis; and construction of theory, discovery, or experiment. To describe Phase 1, Rothenberg supplies the quote by Einstein discussing his motivation to resolve the Maxwell-Lorentz and Faraday laws: “The thought that one is dealing here with two fundamental different cases was, for me, unbearable” (p. 211). One driving force Rothenberg proposes to be important in the initial creativity process displayed by scientists is the desire for “aesthetic beauty” and “elegance.” As an illustration, Rothenberg (1966) looks to Jules-Henri Poincare “Beauty and elegance...[give] a presentiment of a mathematical law” (p. 212) In the second phase, Rothenberg proposes that scientists “deviate” or “separate” themselves from preexisting bodies of work to consider conflicting ideas that will be considered simultaneously in

Phase 3: simultaneous opposition or antithesis. These conflicting ideas may already be recognized by the scientific community; however, the exact way the ideas will be united is a creative act that the individual scientist contributes in the later phases of the Janusian process. As example of Phases 2 and 3 Rothenberg notes how Einstein was able to develop the theory of general relativity by considering the opposing ideas of a body simultaneously at rest and in motion. In alignment with Phase 4, Einstein proposed extending his special theory of relativity by mapping it to a four dimensional coordinate system with three space axes and one time axis. Einstein also extended his special theory of relativity by incorporating the effects of gravity; the result was his general theory of relativity.

Rothenberg stresses that it is in this last phase (which in many ways mirrors the evaluative phase proposed in other creativity theories) that convergent abilities such as skills in mathematics, deductive and inductive logic, and knowledge of a particular area become focal. This is in contrast to Phase 2 where it appears that divergent thinking takes more precedence as Rothenberg suggests that it is here that scientists break away from the mold and entertain new or unusual thoughts. Phase 3 also incorporates divergent thinking as consideration of opposites can be seen as an exercise in remote associations.

Mednick (1962) was the first to propose that formation of remote associations, such as unusual or opposite word pairings, is a hallmark of creativity. There is some support that ability to see unexpected connections can underlie or improve creativity (Benedek, Konen, & Neubauer, 2012; Kenett, Anaki, & Faust, 2014). Even the late Steve Jobs suggested that "creativity is just connecting things" and that the products of creative individuals results from their ability to "connect experiences they've had and synthesize new things." Rawlings and Locarnini (2008) found support for the presence of Phase 3 (antithesis) in their sample of scientists and artists; physical scientists/mathematicians were found to suggest more opposite word pairings than artists. Thus, from these steps outlined, Janusian scientific creativity can be conceptualized as both a byproduct of convergent and divergent thinking processes.

Gooding (1996) suggests the same cognitive processes underlie both creative artistic and creative scientific pursuits. In particular, he posits that creative scientists are able to attune sensitively to many perceptual experiences, usefully refine their experiences, and maintain openness to new possibilities in a manner very similar to creative artists. Specifically, the process of transforming and consulting stores of past knowledge is critical in developing something that is novel and useful in the sciences. Convergence on foundational strategies and methods that have worked in the past often lays the groundwork for creative divergent transformations. It is reasonable to suggest that no impactful scientific discovery has been made without consideration of past innovations and theories. Theories of relativity, gravity, and electricity would have been difficult, if not impossible, to develop without the language and tools of mathematics. Creativity is not manifested in a vacuum, and this notion is captured in Isaac Newton's quote "If I have seen further, it is by standing on the shoulders of giants." Furthermore, scientists must use logic and accuracy to find the best or optimal solution.

Although scientists more overtly use convergent thinking, creative artists may also employ this thinking style (Moneta, 1993). Creative artists may hone and expand their skills from apprenticeships, attending art schools, or even admiring the works of others. Again, artists do not live in a vacuum either, and thus new forms of expression are often influenced by external factors and methods developed by predecessors. This idea is furthered by Csikszentmihalyi (1998) who suggested that if an individual has no access to the foundational principles and resources others in the field have provided, then the individual will be incapable of making further creative contributions to that field no matter the inherent creativity or genius of that individual.

One possible implication from Gooding's work is that we perceive artistic creativity to be more creative than scientific creativity because the prior is a celebration of the artist's personal expression whereas the latter is meant to further a particular field. Consequently, the creativity of the scientist is perhaps masked because the functionality of the discovery or theory is not for beauty or enjoyment, but for advancement of current understanding. Sass (2011) also comments on how our notions of creativity have been culturally romanticized to include only a narrow image of the tormented artistic type. Becker (2000-2001) furthers this notion by suggesting that some artists may intentionally offer evidence of "madness" during psychological evaluations, as they believe such traits are congruent with culturally sanctioned notions of creative individuals. However, it perhaps seems silly to suggest that scientific creativity is less creative than artistic creativity because we do not expressly produce it for creative enjoyment or because it does not fit into our unnecessarily stringent schemas of creativity.

This perhaps romanticized conceptualization of creativity is demonstrated in Ludwig's (1992) study of individuals typically associated with creativity, such as musical composers, artists, poets, and individuals not typically associated with creativity, such as physicists and social scientists/academicians. Ludwig expected that individuals classified in the creative arts group would score higher than individuals not in the creative arts group on the Creative Achievement Scale (CAS). The CAS provides an estimate of overall creativity and has scales that measure level of public recognition, impact of contributions, expertise of a domain, and ability to be creative in nonvocational areas. Ludwig found that musical composers, physical scientists, artists, and architects/designers scored significantly higher on the Creative Achievement Scale (CAS) than other examined professions such as museum/film curators and explorer/adventurers. Although physical scientists were not included in Ludwig's “creative arts” group, they actually scored the second highest on the CAS measurement. Another surprising finding was that as a group, social scientists/academicians scored higher on CAS than expository writers, musical performers, poets, and theater individuals. These results underscore how creativity is not limited to professions such as art, architect/design, musical composition, theater, writing, etc. but instead extend to highly systematic and convergent thinking dependent fields such as physics and social science/academia.

Although the creativity displayed by artists and by scientists appears to share some common bases, Guilford (1957) suggests that there is an imperfect overlap between the creative abilities of artists and scientists. For example, Guilford indicates that the general ability to see relationships among numbers, letters, and symbols is more central to mathematics than to the arts.

Admittedly not all scientific endeavors are creative nor are all artistic endeavors creative (e.g. paint by numbers). As suggested by Moneta (1993), scientific creativity hinges on the balance between problem finding and problem solving; here, convergent and divergent thinking are used to promote both problem exploration and ideation.

Moneta draws the distinction between scientists who are only problem solvers versus those who are only problem finders. Creative potential is maximized when an individual is motivated equally by satisfying the constraints of a problem and by desire to extend possible valid solutions. Additionally, some creativity researchers suggest that the ability to understand, logically engage, and find problems in existing methods or products is itself a creative ability (Guilford, 1957). It is this dissatisfaction and drive to improve, innovate, and transform existing ways that may also separate the merely good from the truly creative. In support of these ideas, Zhang-Jinghuan and Jin-Shenghua (2007) found that the most important factors for scientific creative achievements were having a solid knowledge base and personal initiative to further explore problems beyond a satisfying point.

In summary, some current theories of creativity may overemphasize divergent qualities, such as fluency and originality, at the cost of examining the role of convergent thinking qualities such as meeting well-defined problem constraints and using technical skills in creativity. This tendency may render some of the theories less able to account fully for scientific creativity, or even possibly artistic creativity. Hence, it is suggested that convergent thinking be more explicitly included in theories of creativity so as to provide a more robust picture of various types of creativity.

Creativity and Psychopathology

The current study investigates one type of creativity, convergent thinking, in relation to two types of psychopathological "spectrum" symptoms, those of autism and negative symptom schizotypy. Additionally, this study explores how having some symptoms of spectrum disorders may actually enhance or be positively associated with creativity.

In support of this idea, participants with bipolar disorder have been shown to score higher on the BIS creativity scale in a measure of some dimensions of schizotypy than controls (Rybakowski & Klonowska, 2008). Carson (2011) suggests that higher levels of dopamine and serotonin in the prefrontal and subcortical region may improve creativity, as these neurotransmitters, may weaken or decrease the boundary between various altered states of consciousness. Interactions with less accessible altered states may promote creativity by affording unusual experiences to complement the mundane. However, if levels of dopamine and serotonin are too high, psychotic symptoms emerge. According to Carson's (2011) shared vulnerability model, schizophrenia and creativity share common genetic heritability. Genetic studies support the psychopathology-creativity connection as close relatives of those with schizophrenia exhibit greater creativity than controls (Karlsson, 1984).

The schizotypy and autism spectra. Schizotypy represents the degree of psychosis-proneness a person may exhibit, with increasing schizotypy indicating more symptoms of schizophrenia (Fisher et al., 2004). The schizotypy spectrum (SZ) extends from mild subclinical cases of psychosis to the extreme end with schizophrenia. Positive schizotypy symptoms include magical thinking and unusual perceptual experiences, while negative symptom schizotypy symptoms include introvertive withdrawal and anhedonia (Rawlings & Locarnini, 2008).

Primary autism spectrum (AS) disorder characteristics include poverty of emotion, repetitive behaviors, preservation, and hypersensitivity (LeBlanc, & Fagiolini, 2011). The AS ranges from mild to severe with some individuals exhibiting profound impairments in multiple functional domains (e.g. social, academic) and others relatively little impairment.

The negative symptom schizotypy and autism relationship. The relationship between autism and the negative symptoms of schizophrenia was first formally explored by Frith and Frith (1991). Crespi and Badcock (2008) suggest that autism spectrum and psychotic spectrum disorders probably lie on the same continuum, as there may be similar social and genetic mechanisms influencing the development or expression of these full-blown or symptoms disorders. Claridge and McDonald (2009) found support for the connection between negative symptom schizotypy and autistic traits in that symptoms of both disorders include introversion, social deficits, anhedonia, and narrow-focus styles. They also found that college students who scored higher on schizotypy and autism measures tended to perform better on convergent thinking tasks than those who with less spectrum traits. Additionally, poverty of speech, flattened affect, and rigidity are also characteristic of both spectra (Sass, 2001; Baron-Cohen et al., 2001).

In support of the cognitive connection between negative symptom schizotypy and autism, Rawlings and Locarnini (2008) found that the Introvertive Anhedonia scale of the O-LIFE significantly correlates with the full scale AQ autism score. This finding was replicated by Claridge and McDonald (2009) who also found partial support for the connection between traits of autism and negative symptom schizotypy and convergent thinking tendencies. Individuals with subclincial schizotypal and autism symptoms also tend to exhibit greater cognitive inhibition (Davison-Jenkins, 2003). To possibly confirm these previous findings of a relationship between schizotypy and autism spectrum score traits, I will correlate participant negative symptom schizotypy scores as measured by the Chapman Physical Anhedonia scale and the Autism Quotient scale with a measure of convergent thinking developed here.

Autism and schizotypy spectrum symptoms and creative thinking styles. Convergent thinking is expected to be a characteristic of autism in that a narrow focus is taken and perseveration on a single idea can occur (Liu, Shih, & Ma, 2011; Nettle, 2006). This feature may allow these individuals to perform better on creative problem solving tasks than individuals with a more "overinclusive" or less cognitively inhibited style, as irrelevant information are not as efficiently filtered and triaged. In fact, Claridge and McDonald (2009) failed to find the often cited connection between divergent thinking and the "overinclusive" processing tendencies of positive symptom schizotypy. They argue that although overinclusive thinking may promote divergent thinking, and thus creativity by making unusual or novel connections, it can also lead to lack of inhibition of inappropriate responses and detrimental levels of impulsivity.

For example, Stoneham and Coughtrey (2009) found that individuals low on schizotypy (i.e., negative symptom schizotypy) on average entertained fewer strategies to solve a creative problem solving task than individuals high on schizotypy (i.e., positive schizotypy). Additionally, the individuals with negative symptom schizotypy tended to offer high quality ideas (in that they were more effective at solving the problem) than individuals with positive schizotypy. From these results, it appears that individuals with negative symptom schizotypy who engaged in more convergent thinking were more effective at offering useful high quality solutions than individuals with positive schizotypy who tended to offer more solutions in general. Individuals with subclinical autism in general tend to also perform better on convergent thinking tasks. For example, Claridge and McDonald (2009) found that individuals with subclinical autism or schizotypy traits tended to complete the Tower of Hanoi task faster than individuals without subclinical traits. Although not stated by the authors, it is possible that the faster time completion could possibly indicate that these individuals attempted fewer illegal moves than non-spectrum individuals, hinting at a possibly less inclusive cognitive processing style.

Some support also exists for the proposition that both individuals with autism and negative symptom schizotypy tend to focus on the details instead of on the larger picture. While this cognitive bias may lead some individuals to "miss the forest for the trees," it may help individuals hone in on hidden details or patterns. Frith and Happe (1994) suggest that individuals with autism in addition to exhibiting weak theory-of-mind (predicting others' thoughts, emotions, intentions), may also have weak central coherence. They conceptualize central coherence as the ability to integrate information at different levels into a comprehensive holistic whole.

One example of central coherence is ability to recall the gist of a story while forgetting specific details. Shah and Frith (1993) provided empirical support for this central coherence deficit in relation to autism; they found that the performance advantage individuals with autism have on the Block design portion of the WISC is likely due to superior ability to segment the block designs into constituent parts (detail-focused) instead of overall superior spatial ability. In other words, individuals with autism tend to identify and use the micro-details of the design whereas individuals without autism tend to focus more on the overall block design instead of the constituent features.

Interestingly, Prentky's (2000) C-type personality, that he associates with schizophrenic symptomology, aligns well with this detached, detail focused, convergent thinking style picture of autism. In particular, Prentky proposed that the C-type is "characterized by a microscopic dissectional focus on the separate constituent elements of a problem. The hypothesized C-type approach to problem solving is to zero in on detail, observing critical relations or unexpected but meaningful anomalies." (p. 100) The C-type is also characterized by low to normal distractibility and strong attentional focus.

Individuals with autism or negative symptom schizotypy tend to also have impaired "theory of mind" or "mentalizing" ability (Baron-Cohen, 1995; Sprong et al., 2007), which may lead to "mindblindness" or difficulty predicting and guessing the state of mind of another. Baron-Cohen et al. (1998) suggested that this might lead to an impaired sense of "folk psychology," or social understanding, but enhanced sense of "folk physics," or object understanding. Such an enhanced "folk physics" understanding may be useful for scientific understanding as many scientific problems revolve around understanding patterns and relationship among objects as opposed to people.

There is also evidence that negative symptom schizotypy and autism traits are more common in scientists versus nonscientists (Claridge & McDonald, 2009; Nette, 2006). Furthermore, Baron-Cohen et al. (1998) found that autism tended to run more often in families of students who were physics, engineering, and mathematics majors compared to families of students who were literature majors. These results are not surprising, as the sciences often capitalize on the cognitive hallmarks of these clinical conditions such as logical, convergent, and detached style of information processing. In *Madness and Modernism*, Sass (1992) draws parallels between the detached, fragmented, and analytical creativity celebrated by modernists and postmodernists and symptoms common to the schizophrenia spectrum. Additionally, attention to detail, high frustration tolerance aided by low affect and strong attentional focus, and tendency to parse information effectively into relevant categories makes these individuals especially well suited to scientific creativity.

Based on the evidence that individuals with AS and SZ share some similar symptomatology and perform comparably on creativity tasks, I jointly evaluate how subclinical and autism traits may be associated with enhanced performance on a creative problem-solving task.

Creativity and spectrum symptomatology: A fine balance. Creativity may exhibit an inverted-U shape relationship with psychopathology where maximal creativity is achieved with moderate psychopathology or various different spectra or symptom dimensions. For example, Kinney et al. (2000-2001) found that creativity was greatest for individuals who had a genetic predisposition for schizophrenia as compared to individuals who did not have a predisposition or who exhibited the disorder. This finding is in alignment with two-factor models of creativity suggesting that creativity is maximized when both symptoms of health and psychopathology are present in an individual (Barron & Harrington, 1981; Schuldberg, 2000-2001). Barron and Harrington (1981) point out that complexity, ideational fluency, and an "overinclusive" tendency are traits that are often present in the schizotypal disorders and that are relevant to creativity. While overinclusive thinking can help promote more associative links and thus, widen the net of possible creative ideas (Acar & Sen, 2013), it can also lead to inefficiency, as improbable and less useful ideas are more often entertained than with a more logical, focused type of thinking (Glazer, 2009). An overinclusive thinking style is also conceptually related to cognitive disorganization, a thinking style that has been negatively correlated with creativity in some work (Batey, 2008).

As noted by Prentky (2000), high levels of true creativity are rarely found in individuals who exhibit full schizophrenia, as they are usually unable to synthesize necessary elements to create a useful and pleasing product. Hence, Barron and Harrington (1981) suggest that while some mild symptoms of schizophrenia can improve or be associated with elevated levels of creativity, markers of health must also be present for creativity to emerge or be maximized (Barron, 1972). This juxtaposition of health and mild psychopathology in promoting creativity appears to be supported by Kinney et al. (2000-2001); they found that creativity was highest in those who displayed a few symptoms of schizotypy as opposed to those who displayed none, or several.

Along these lines, Keefe and Marago (1980) argue that if one thinks of schizophrenia as a way of thinking, then the factors that lead to schizotypal thinking may also be the factors that promote creativity. This is one of a number of models linking creativity and psychopathology described by Richards (1981). Carson (2011) provides a more biological interpretation of this general two-factor model, and in his shared vulnerability model posits that the interplay and ratio of vulnerability and protective factors, such as working memory and cognitive flexibility along with the genetic predispositions, determine whether creativity or psychosis manifest. Furthermore, Carson (2011) notes that creativity is harmed or inhibited by the presence of severe mental disorders, such as schizophrenia and bipolar spectrum disorders.

The current literature on the balance and coexistence of health and subclinical symptomology in the manifestation of creativity supports the idea that one can possibly view creative ability and predisposition on a spectrum, just as one can do so for spectrum psychopathology. In particular, Glazer (2009) proposes that science and art domain creativity lie on one axis, while eminent and everyday creativity lie on a perpendicular axis. These axes then define to characterize subtle qualitative changes or variations in creative output and creative potential. The probability that an individual will exhibit some signs of subclinical psychopathology increases as the quality of the creative output increases from everyday to eminent. Glazer is careful, though, to note that eminent creativity does not imply that the producer has psychopathological traits; rather, there is increased probability for at least small doses of unusual traits.

Based upon the findings that creativity may be maximal with small doses of psychopathology, it appears that there is a fine balance between markers of health and psychopathology. In particular, note that full-blown psychopathology is unlikely to result in recognizable creativity as severe symptoms such as psychosis, disorganization of thought, and catatonic behaviors are likely to obscure coherency and meaningful contributions (Prentky, 2000). Thus, while some subclinical traits such as associative and divergent thinking style, detail-focused convergent thinking, and introvertive anhedonia – a facet of negative symptom schizotypy -- may enhance creativity, extreme levels of psychopathology will likely result in production of incoherent flight of ideas. The idea that creativity is maximal with influence of both the unusual (subclinical traits) and usual (congruence with reality) is consistent with current definitions of creativity that stress both originality and usefulness. Originality may stem from departing from the norm, and this may be enhanced by, or associated with subclinical traits. However, a product is unlikely to be recognized as useful or even creative (required to achieve "eminence"), if severe symptoms of psychopathology completely sever an individual from the grounded current cultural norms others use to assess creativity.

Finally, a balance of subclinical traits and health may represent the most optimal usage of both convergent and divergent thinking. As already explored, creativity is likely a product of both cognitive thinking styles. While certainly some of the traits of autism and negative symptom schizotypy -- such as tendency to engage in convergent thinking, attention to detail, and parsimony of thought -- may help performance on creative problem solving tasks, too many of these traits have also been known to impair creativity performance. There is a good deal of research supporting the poverty of imagination present in individuals high on the autism scale, as they have difficulty adopting flexible strategies, engaging in the pretend, and engaging in activities with others indicative of theory of mind (Frith, 1972; Frith & Happe, 1994). Additionally, an individual with severe autism or negative symptom schizotypy may be sufficiently withdrawn and isolated from the reality others share as to be unable to produce products that are useful or appreciated as creative by others. In essence, creativity can be seen to be a well-balanced dish that has just the right amount of ingredients from both health and pathology to help the individual create ideas that depart from the mundane and yet also soar with recognizable utility and capability of being communicated to or understood by others. Some researchers suggest that shared insight of originality and utility is one quality that distinguishes the divergent thinking patterns of psychotic thinking from that of eminent creativity. In addition to utility, elegance can be a motivating force in creative production as one may wish to maximize some criteria to make it aesthetically or conceptually pleasing.

From the above-presented literature it appears that possessing a few symptoms or low levels of psychopathology can enhance creativity. Therefore it is hypothesized that in this research individuals who possess a greater degree of subclinical AS/SZ symptoms will tend to achieve higher creativity scores on the ToH creativity task than controls, as they potentially possess clinical attributes and traits that enhance creativity.

Affect and creativity

The relationship between mood and creativity is at present unclear, as positive mood and negative mood seem both at times to improve creativity (Davis, 2009). Positive mood is thought to facilitate creative problem solving by promoting connection of remote associations and idea generation (Isen et al., 1987). Conversely, negative mood may facilitate creativity by prompting individuals to focus attention and strive for better answers instead of adopting an easier or more immediately satisfying approach, which is more common with positive mood. Kauffman and Vosburg (2002) suggest that negative and positive mood may both be relevant in a creativity task depending on the particular stage of the task (early vs. late).

In support of the facilitating effects of positive affect, the broaden-and-build theory (Fredrickson, 1998) suggests that positive mood may enhance creativity by widening the scope of attention thus facilitating idea generation. Fredrickson and Branigan (2005) found that positive mood helped to increase the number of thought-action repertoires as assessed by a Twenty Statements Test and a global-local visual processing task relative to both neutral and negative mood. Positive mood may also enhance intrinsic motivation to work on an enjoyable task and has been associated with successful outcomes (Lyubomirsky et al., 2005; Isen & Reeve, 2005).

However, support has also been found for the inhibitory effects of positive mood and the facilitating effects of negative mood on creativity. Kauffman and Vosburg (1997) found that negative mood facilitated creative problem solving over neutral and positive mood on creative insight tasks. Martin and Stoner (1996) initially demonstrated that individuals in positive mood produced more unusual word associations than individuals in negative mood. However, when asked if they would like to supply further word associations, individuals in negative mood provided more unusual word associations than those in positive mood. Additionally, positive mood seemed to inflate individuals' estimates of quality of ideas whereas negative mood led to more realistic evaluations. These results suggest that individuals in positive mood were more satisfied with their initial responses and thus did not feel compelled to exert as much effort as those in negative mood to provide further unusual associations. Although the property of being unusual is associated with divergent thinking, which -- as noted earlier in this paper -- is not sufficient for creativity, I have above explored how it appears to be a necessary ingredient for creativity.

Negative mood may prompt individuals to process and evaluate the problem on a deeper level than positive mood, thus leading to possibly superior problem solutions: a component of convergent creativity, as described earlier (Sinclair & Mark, 1995). In support of this idea, de Vries et al. (2012) found that positive mood tends to promote decisions that depart from logical rules. Hence, increases in idea production facilitated by positive mood may be offset by idea quality and utility. The case has also been made for a link between clinical depression and creativity (Haynal, 1985).

These results are congruent with theories that propose negative mood may be a necessary ingredient for creative problem solving (Mumford & Gustafson, 1988). In essence, creative problem solving requires some degree of dissatisfaction, as one is actively looking for the "best" solution to a potentially challenging problem. The very nature of this situation likely induces some negative affect, as an individual must reject the conventional and contemplate possibly several competing strategies/approaches. Positive mood tends to promote complacency and satisfaction with current affairs whereas negative mood promotes a driving tension to find something "better."

Thus, negative mood may ultimately enhance creativity better than positive mood as it leads individuals to evaluate more clearly their creative products and spurs them to continue to find better ideas instead of being satisfied with initial efforts.

Affect and spectrum disorders and symptoms in relation to creativity

Some researchers have proposed that mood disorders may spur individuals to channel dysphoria into creative outputs (Guastello, Guastello, & Hanson, 2004). Depressed mood tends to foster rumination and this may promote creative interests and outputs by increasing motivation and efforts in creative endeavors (Verhaeghen et al., 2005). Additionally Schuldberg (2000-2001) proposes that negative schizotypal cognitive symptoms, negative schizotypal affective symptoms (flat affect and physical anhedonia), and depression may all be traits linked to normal creativity.

As noted earlier, Sass (2011) suggests that the affective disorders have been perhaps overly valued and linked with creativity at the cost of overlooking how schizophrenia spectrum disorders can also be associated and promote creativity. While the conceptualizations of creativity characteristic of the movement of romanticism tend to be linked to a regressive, highly emotional creative prototype, Sass argues that creativity has been more commonly linked historically with a more detached and analytical prototype that was prominent during the modernist and postmodernism eras. The negative symptoms of schizotypy characterized by symptoms or traits such as flattened affect, apathy, withdrawal, and indifference, as well as positive schizotypy symptomology, may be related to creativity (Sass, 1992). These symptoms are not unlike the characteristics held to be ideals by artists typical of the modernist era -- such as Warhol and Duchamp, as opposed to the more emotionally driven and liable artists associated with the romanticist era. The following are some features of the modernist era that Sass suggests overlap topologically with the schizophrenia spectrum: “a certain fragmentation and passivization of the ego,” “loss of the ‘worldhood of the world’,” and “extreme and pervasive detachment or emotional distancing” (p. 9). As implied by these modernist features, traits of schizotypy appear to actually drive and promote creativity typified in the modernist era.

Depressive ruminations may be a byproduct of the unusual hyperconnectivity, greater than seen in typical neuronal connections, that is exhibited by some depressed individuals (Berman et al., 2011). Hyperconnectivity has been proposed to be both instrumental and helpful in creative outputs. For example, individuals with synesthesia are often highly creative and one suggested explanation is that the hyperconnectivity characteristic of synesthesia allows these individuals to engage in metaphorical thinking and make more novel associations and combinations (Carson, 2011).

The connection between certain creative professions and affective disorders was explored by Ludwig (1992) when he examined the biographies of 1,005 individuals who were either in the creative arts profession or not. He found that those who were in the creative arts professions (e.g. artists, composers, poets etc.) were significantly more likely to suffer from affective disorders. Furthermore, creative arts professionals also suffered from affective difficulties earlier and over longer periods than noncreative professionals. The case has also been made for a link between clinical depression and creativity (Haynal, 1985).

Affect, the autism spectrum, and creativity. In addition to cognitive features, autism spectrum disorders and schizotypy share common affective features that may be conceptually linked together to enhanced creativity. Also, as noted earlier, autism has been shown to be similar to negative symptom schizotypy in that they both involve social withdrawal, anhedonic avolition, and flat affect (Claridge & McDonald, 2009; Fisher et al., 2004). Note that this "flat" affect is partially distinct from both the negative affect and depression discussed above. Similar to schizophrenia, autism is often comorbid with depression, bipolar and anxiety disorders (Lainhart, 1999). Furthermore, chances of depression increase with relatedness to an individual with autistic characteristics (Lainhart, 1999). Sass (2011) notes that schizotypal features, particularly negative symptoms such as ability to detach oneself and critically examine situations, may be closely associated with creativity in the domains of physics, architecture, and engineering and the arts.

Using a self-report online survey, Samson, Huber, and Gross (2012) found that high-functioning individuals diagnosed with autism and Asperger's syndrome experienced overall more negative emotions than typically developing individuals. Surprisingly, the amount of positive emotion experienced by both groups was comparable. Tani et al. (2011) found that individuals with Asperger's syndrome experienced significantly more depressed affect and anxiety than controls.

The literature connecting mood, creativity, and AS/SZ leads to the second hypothesis of this paper, that individuals in the AS/SZ group will tend to spend more time in a negative mood than controls. Because negative mood is associated with enhanced creativity on tasks that require more convergent thinking, I proposed that individuals who posses a greater number of subclinical schizotypy or autism traits will tend to gravitate to negative mood and consequently will perform better on the ToH task than individuals with fewer symptoms, as they will be more apt to critically evaluate their creative performance and continue to strive for better solutions.

Creativity Definition Revisited In Relation to Dynamics and Psychopathology

Individuals with autism or negative symptom schizotypy are often experimentally found to be less creative than controls and artistic groups (Craig & Baron-Cohen, 1999). However, one problem with such studies is that they typically only include divergent thinking tests to measure creativity. Such a divergent thinking task may be listing all the possible things one can do with a brick. However, as mentioned before, divergent thinking tests fail to measure usefulness or practicality – a stipulation often included in creativity definitions. Individuals with AS/SZ may exhibit more convergent thinking; hence, such purely divergent thinking creativity tests are most likely underestimating their creative abilities. This paper takes a position that is consistent with the work of the aforementioned creativity researchers who suggest that creativity is best characterized as a dynamic process where convergent and divergent thinking are used in alternating and sometimes overlapping cycles (Cropley, 2006; Lubart, 2000).

Dynamical System Approaches

A dynamical system (DS) is a system that is time dependent (Strogatz, 1994). Creativity and emotions are inherently dynamic, as they change with time. As described in the creativity and affect section, creativity appears to fluctuate with mood. Although it is unclear whether either positive or negative mood universally enhances creativity, it is fairly clear that mood can influence creativity and there is some connection between them. For example, Richards and Kinney (1990) found that creativity tended to follow participants' subclinical bipolar cyclic mood swings. For these high functioning individuals, periods of elevated mood were associated with enhanced creativity. A nice result of examining participants with subclinical symptoms is that these results have implications for everyday fluctuations of creativity. Hence, dynamical concepts traditionally used in the physical sciences are conducive to studying these psychological constructs as they allow qualitative and quantitative analysis of time dependent phenomena. Schuldberg (2001) argues for use of a dynamical system approach to understanding the ever-changing landscape of creativity as he asserts that such an approach possibly allows for a more complex and rich understanding of the creative process than merely tracing linear trajectories of the creative process from point A to point B.

In particular, the variables of affect, subclinical schizotypy and autism spectrum traits are explored in this paper as possible factors of creative performance over time.

Additionally, we are interested in the dual roles of convergent and divergent thinking in the creative process of solving the three and four disk ToH tasks.

Dynamical Principles. Dynamical systems can be modeled by linear or nonlinear equations depending on the phenomena studied. Typically, the output of linear systems is an additive function of the inputs, whereas it is not for nonlinear systems. Linear systems need only be linear in the parameters. In other words, outputs from linear systems are strictly proportional to the changes to the input variable; this relationship is not true for nonlinear systems. An example of a nonlinear system in biology is the response of a confined population to increased resources; here, growth initially increases with the addition of new resources but eventually levels off as time increases. Dynamical nonlinear systems are termed chaotic if they are sensitive to initial conditions and exhibit a number of other characteristics (Smith, 1999). Psychological initial conditions include factors such as affect and arousal. In dynamical systems, attractors are nodes such that all states tend towards those points, and furthermore tend to stay there (Granic & Hollenstein, 2003; Lewis, 2005). In psychological terms, one can think of attractors as being similar to recurring patterns of behaviors or thoughts that individuals return to time after time.

Repellors are unstable nodes that push the system away (Aligood, Sauer, & Yorke, 1996). A psychological example of a repellor may be neutral mood. Pure neutral mood is difficult to maintain and is often transformed into the more stable positive or negative moods. Thus, in this example both negative and positive mood are attractors and neutral mood is a repellor as it is an unstable existence. Equilibria are steady state points such that attractive and repellant forces on the system are in balance (Gottman et al., 2002).

Dynamic Data Analytic Techniques

State space grids. This study uses state space grids as an easy method to visually examine how mood during the ToH (Tower of Hanoi) task changes as a function of time, and frequency of moves. State space grids (SSG) are 2-dimensional plots that allow one to dynamically visualize the interaction between two variables indicative of the state of a system (Howerter et al., 2012). Each axis is defined as a variable, and levels of the variable are defined along the axes (see Figure 1). The plot is broken into a grid consisting of states, which denote the number of possible combinations of levels of the variables, like those in factorial experiment diagrams. States occurring during the experiment contain circles circumscribed within the grid, and transitions between states are denoted by directional lines. Some SSG indicate time spent in a state by setting circle diameters proportional to duration. Each state represents a possible attractor (Granic & Hollenstien, 2003). Attractors are found by looking at where the system tends to go, or in the particular method proposed here, the duration of time spent in a state (Granic & Hollenstien, 2003). The larger the diameter of a circle in a state, the more likely that state is an attractor. Additionally, the smaller the diameter of the circle, the more likely that state is a repellor.

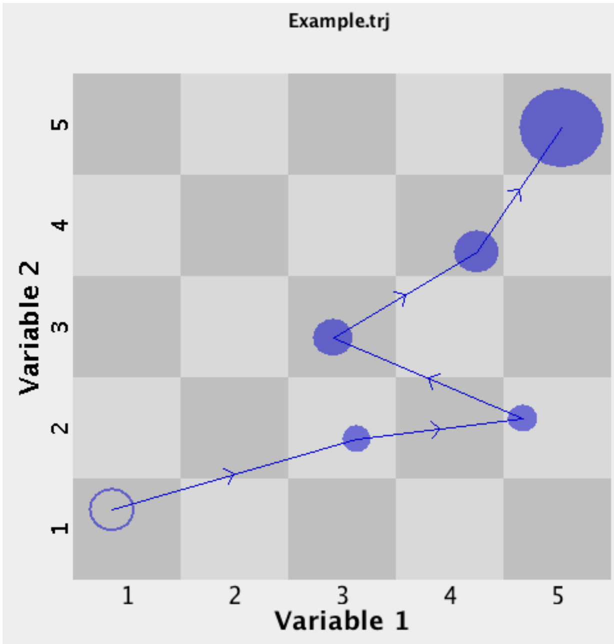

Figure 1. Example SSG showing two variables with five levels plotted against each other. The circles represent nodes of states where a state is the intersection of a variable level with another variable level. Larger nodes indicate longer duration in a state. Temporality and direction of realized nodes are indicated with arrows and connected lines.

SSGs are typically used to examine interactions within dyads. Some examples include studies of parent-child interactions (Hollenstein et al., 2006), athlete-coach interactions (Erickson et al., 2011), and adolescent friendship (Dishion, Nelson, Winter, & Bullock, 2004). However, they have also been used to examine dynamical changes within one system on various levels of two variables. In the paper by Granic et al. (2003b), types of interactions (hostile, negative, neutral, positive) were plotted on both the abscissa and ordinate axes so that patterns of interactions within a family, such as hostile-negative or neutral-positive could be easily seen. Additionally, Ribeiro et al (2010) examined changes in narrative style for a client engaged in psychotherapy treatment. I used SSGs to illustrate the natural dynamical emotional forces within individuals as they play the ToH game and how that may be related to frequency of moves in a given time period. Frequency of moves was chosen because based upon the affect and creativity literature presented earlier, negative mood appears to promote more careful and strategic thinking than positive mood. Hence, I predicted that negative mood would be associated with participants engaging in lower frequency of moves than when in a more positive mood. One can visually inspect for this relationship by examining the diameter of the circles corresponding to frequency of game moves (low, medium, high) and the associated mood. Larger circle diameters correspond to a longer duration in that state (e.g. low frequency, negative mood).

Tower of Hanoi as a creativity task

Guilford (1957) notes that "creative steps are necessary in problem solving" and furthermore, "we can hardly say there is a problem unless the situation presents the necessity for new production of some kind." (p. 112) Isaken et al. (2010) conceptualize problem solving as a process where one decreases the distance between current and desired states. They note how problem solving involves knowledge contextualization, understanding of current parameters, and potentially the pursuit of one correct answer. To them, the defining feature that separates ordinary problem solving and the creative variety is the degree of imagination and intelligence used in tackling an ambiguous problem.

Based upon the creative problem solving definitions given above, we seek to investigate whether the ToH task indeed involves imagination (via divergent abilities), evaluation (via convergent abilities), uniqueness, and usefulness. The ToH problem-solving task appears to be more related to scientific creativity than artistic creativity as it mirrors the constraints, logic, and focused utility primary in creative scientific achievements as before described. Admittedly, solving the ToH task is far from the scope and beauty of proposing evolutionary theory, general relativity, or the structure of DNA. However, it is a well studied psychological task (Ahonniska, 2000) that can provide a glimpse into the process of scientific creativity: the ToH task involves both convergent and divergent thinking bounded by task constraints with a well defined optimal solution.

The ToH task relies heavily on convergent thinking, as one must find the optimal path in order to complete the puzzle in the minimum number of moves. In finding the optimal path, evaluative abilities such as logic, prior knowledge or experiences with similar problems, and reflection of problem satisfaction become critical. As noted by Rothenberg, a scientifically inclined individual might desire to optimally solve the ToH problem as the resulting solution would be more “elegant” than other alternatives. Finding the optimal path also involves divergent thinking, as this process requires synthesizing and discerning distant connections between current, future, and final problem spaces. This process is similar to Isaken et al. (2010), whose definition of problem solving involves closing the distance between current and desired states. While optimal problem completion necessitates careful logic, an ingredient of convergent thinking, it also requires divergent thinking, in that individuals must learn to abandon suboptimal strategies quickly. This abandonment of suboptimal strategies again captures the spirit of parsimony and speed that are implicit in the evaluation of elegance and creativity in many scientific products as observed by Rothenberg (1996).

Hence, in alignment with definitions of creativity, the optimal solution to the ToH task is unique and must be “converged” on, requires consideration of multiple possible paths (divergent thinking), and assessment of performance (evaluation and convergent thinking to identify that optimal solution has been achieved). Similar to elegantly solving a mathematical proof, one may be required to recast the ToH problem in a new light and break conventionality of thought in order to efficiently complete the task.

In sum, we propose that a purely divergent task such as the “brick task” (one of Guilford’s “Alternate Uses” tasks) fails to satisfy criteria for true creativity, whereas solving the ToH task does since it involves both divergent thinking (synthesis of seemingly unrelated concepts) and convergent thinking (funneling to an optimal solution using logic). While the ToH spatial problem can be completed in many ways, it is reasonable from the above arguments to suggest that finding the optimal sequence of steps that minimizes the path length from the beginning tower state to the end tower state requires the most creativity as this process symbiotically maximizes use of convergent and divergent thinking and evaluation to achieve the required solution space.

Finally, the ToH task satisfies criteria of uniqueness and usefulness as there is only one set of moves that solves the puzzle in the fewest number of moves, as such the optimal solution is unique. Additionally, finding a solution to the ToH task is useful as it completes the puzzle. An individual who solves the puzzle in fewer moves and in less time may perhaps be deemed more creative as s/he is likely enacting a more “clever” or “elegant” solution than brute force or trial and error. The ToH task is certainly solvable through mindlessly moving the disks until the desired state is achieved. However, most would agree this “strategy” is not very creative.

Computer-administered creativity task

In the current experiment, a computerized ToH task was used to assess creativity. To the best of our knowledge, the ToH task has not previously been considered a creativity task. However, it has long been considered a problem-solving task (Ahonniska, 2000). Many researchers suggest that certain types of problem solving are indeed creative (Isaksen et al., 2010) and furthermore, some propose that creativity itself is just an extension of problem solving (Guilford, 1977; Newell, Shaw, & Simon, 1962).

A computerized version of the ToH task allows real time dynamical analysis of the creative process. In the ToH task (Simon, 1975), there are typically 3 pegs with *n* number of disks of decreasing size stacked on the leftmost peg. The goal of the spatial puzzle is to move all disks to the rightmost peg while following the rule that no larger disk may be placed upon a smaller disk. While in theory the puzzle seems simple, the optimal number of steps to complete the puzzle rapidly increases with each additional disk. Specifically, the number of moves to solve the puzzle with n disks is 2^n-1. The ToH task can be optimally played by following these routinized steps: "(a) move the largest disk to its goal first; (b) move the smaller disks out of the way; (c) build a "mini-tower" on the "open" peg; and (d) repeat the process to completion" (Welsh & Huizinga, 2005, p. 284). The optimal solution is unique, and thus a clear best solution can be achieved. Although creativity is arguably lost once this optimal strategy is found, I argue in the next few paragraphs that before this point, one must think creatively to solve this problem.

To incorporate the elements of both convergent and divergent thinking, the quantity 1/(moves∗min) was chosen to measure creativity. Convergent thinking is represented in this measurement because one is rewarded for funneling to the correct solution in a timely and efficient manner. Additionally, divergent thinking is incorporated because one is also rewarded for flexibly abandoning inefficient strategies instead of perseverating on suboptimal strategies.

Based upon the outlined literature review, I here proposed a dynamical study on creative problem solving using a computerized version of the Tower of Hanoi (ToH) game. Below are the experimental hypotheses. Intelligence and experience with the task will be controlled statistically in testing both of the two hypotheses.

Hypothesis 1. Individuals possessing higher scores on a psychometric measure of AS/SZ traits will tend to exhibit higher creativity, as measured by higher 1/(moves∗min), on the ToH task than individuals possessing lower levels of AS/SZ traits even when statistically accounting for intelligence and prior task experience.

Hypothesis 2. Individuals possessing higher scores on a psychometric measure of AS/AZ traits will tend to spend more time in a negative mood than controls when performing the creativity task. It is predicted that this differential mood preference will be correlated with creativity scores and AS/SZ symptomology.

Exploratory Analyses. SSGs were analyzed for presence of attractors. Attractors will be determined by both diameter of nodes and number of nodes in various states (such as high frequency moves and negative mood). Based upon the literature connecting negative mood and AS/SZ, I predicted that the SSGs would show negative mood as being an attractor. Additionally, I predicted the SSGs would show that low frequency of moves and negative mood will be an attractor as the mood and creativity literature shows that negative mood tends to promote careful and evaluative thinking. Thus, it is possible that individuals in negative mood will tend to make fewer moves, as they are taking more time to plan out moves. In addition, exploratory analyses were conducted regarding other correlates of PA and AQ scores.

Method

Participants

A total of 33 participants (26 F, 7 M) completed the ToH task. The average age of participants was 20.36 with the range being 18-36 years. Potential participants were recruited from 335 college-age students from the PSYX 100 test pool. In the Fall 2014, 219 potential participants were screened and an additional 116 were screened Spring 2015. To achieve a power of .75 with an effect size of .35, a total sample size of approximately 60 participants was needed. As obtaining 60 participants who meet the criteria as specified in the methods was difficult to achieve, with approval from the thesis committee, I modified procedures to include all participants from the Spring 2015 screening pool who were not excluded for reasons described below. Subclinical symptoms were investigated as varying along on a continuum instead of being used to form two extreme groups, as was initially desired.

A *t*-test on correlation with effect size .35, power .75, and alpha .05 required a sample size of 40 participants. The effect size of .35 between control and subclinical schizotypal groups on creativity tasks was chosen based upon personal communication with Dr. Schuldberg. This suggestion is consistent with other estimates of effect size in the creativity literature. For example, Burch et al. (2006) found that Cohen's *d* for the magnitude of the difference between divergent thinking (uniqueness) is .43 between non-artists and visual artists. Cohen's *d* for divergent thinking (totals) was .22. A meta-analysis by Ma (2009) shows that the mean effect sizes of the variables of divergent and convergent thinking with creativity are respectively .43 and .20.

Measures

Demographic information. Information about major, time in major, age, and gender was collected during the initial screening process via a paper and pencil questionnaire.

Negative symptom schizotypy. The degree of negative symptom schizotypal characteristics of the participants was measured with the Chapman scale of Physical Anhedonia (Chapman, Chapman, & Raulin, 1976). The connection between physical anhedonia as a manifestation of negative symptom schizotypy symptoms and creativity has been previously made (Schuldberg, 2000-2001). The Physical Anhedonia scale is composed of 40 true-false questions that tap into one's longstanding lack of ability to enjoy physical pleasure. Some sample questions include "The beauty of sunsets is greatly overrated;" "I have seldom cared to sing in the shower;" and "I have always loved having my back massaged" (keyed False). This measure was developed on 371 college students, and was later tested on 505 typical adults and 123 males with schizophrenia. Coefficient *alpha* (Kuder-Richardson formula 20) was .74 for the Physical Anhedonia scale.

Each question scored in the keyed direction is worth one point. The mean Physical Anhedonia score was 7.0 (sd = 3.9) for male college students and 5.6 (sd = 3.5) for female college students. The mean Physical Anhedonia score for males with schizophrenia was 10.6 (sd = 6.1). In order to form extreme groups used in the SSG analyses, the procedures developed by the Wisconsin investigations and employing local Montana norms, male and female participants from the Fall 2014 test pool were placed in the high SZ group if they scored at least 1.5 sd above the mean (based on Montana norms for males and females) on the Physical Anhedonia scale. The use of 1.5 sd instead of the more common 2 (or 1.75 sd) is a reflection of our desire better to capture subclinical symptoms. The raw score cutoffs for the high Anhedonia group were thus > 17 for males and > 14 for females. For the fall participants only, a low scoring comparison group consisted of males who scored < 7 and females who scored < 6.

Placement of participants into high and low SZ groups was not completed for spring participants to allow for gathering a larger sample. For the spring, all participants who scored less than 2 on an Infrequency scale designed to detect spurious responding were invited to participate, instead of only those who scored 1.5 SD above the mean or higher or .5 above the mean and lower on the Chapman Physical Anhedonia scale.

Autism spectrum traits. Autism spectrum characteristics were measured by the Autism-Spectrum Quotient (AQ) developed by Baron-Cohen et al. (2001). The AQ adult version was designed for individuals 16 and older. The adult AQ version has been shown to be a valid measurement of autistic traits in the general population (Baron-Cohen et al., 2001) and is composed of 50 questions that are answered with "Definitely agree," "Slightly agree," "Slightly disagree," or "Definitely disagree." Note that the first 9 participants tested from the fall were given a version of the AQ, which was not standard due to the following error. Instead of the one of the options being "Slightly agree" the option was "Strongly agree." However, it seems reasonable to suggest that AQ results should in general be unchanged from that arrived with the original format as there is ambiguity between if "Definitely" or "Strongly" is more certain, and because participants likely relied on spatial layout of the responses as opposed to reading the options each time. The areas assessed are social skills, attention switching, attention to detail, communication, and imagination.

Cronbach's α coefficients for each scale were: Communication = .65, Social Skills=.77, Imagination = .65, Attention to Detail = .63, and Attention Switching = .67. Cronbach's for the overall AQ – adolescent measure is .79. Test-retest reliability $r = .7$. The authors argue that the AQ has reasonable face validity because 80% of the AS/HFA individuals score above their suggested cut score of 32 compared to none of the controls and interpret this to mean that the questionnaires is using questions that resonate with autistic individuals. The authors also suggest that the test has reasonable construct validity because the five domains tested have high coefficients. The mean AQ score for autism spectrum/high functioning autism (AS/HFA) participants is 35.8 with a standard deviation of 6.5. The mean AQ score for controls is 16.4 with a standard deviation of 6.3. Baron-Cohen et al. (2001) recommend a cut score of 32 to identify possible AS/HFA in adults. All participants who met the infrequency criteria on the Chapman scales were invited to complete the second portion of the study, which included the AQ questionnaire and the creativity task.

Intelligence. It is possible that intelligence rather than creativity could explain ToH task performance. According to Ma (2009), the effect size associated with creativity and cognitive abilities is .3 with a standard deviation of .36. Although the effect size is medium, the associated error is relatively large. Hence, cognitive abilities may or may not be a significant covariate in the experiment. Furthermore, creativity as assessed by various methods such as divergent thinking tasks and self-ratings of creativity was not related to intelligence in correlational and regression analyses as measured by the

Wonderlic Personnel Test (Furnham & Bachtiar, 2008). This somewhat surprising result can possibly be explained by the possibility that after a certain general level of intelligence (IQ =100), intelligence has no direct affect on creativity. In other words, while having adequate intelligence is necessary for creativity, above a certain threshold, it may make very little difference. However, general cognitive ability information was collected in case it is significantly correlated with our dependent outcome of creativity operationalized as 1/(moves∗min).

General intelligence was measured using the Vocabulary scale of Shipley-2, a brief test of cognitive functioning (Shipley, Gruber, Martin, & Klein, 2009). The Shipley-2 taps into fluid (logic and problem-solving based) and crystallized (education and experienced based) abilities and has three subscales: Vocabulary, Abstraction, and Block Patterns. This test, normed on a sample of 2,826 individuals, is appropriate for ages 7-89 with separate norms for children 7-19 and for adults 17-89. The Vocabulary scale is composed of 40 questions where the test-taker must select the answer that most closely matches the given word. Each correctly chosen answer is scored a point and each wrong or blank answer is scored a zero. The Vocabulary scale can be administered in about 10 minutes and takes less than 5 minutes to score. The median internal consistency for the Shipley-2 as a whole was .92 with subscale consistencies ranging from .77-.91. Test-rest reliability ranged from .87-.94. Test administration was via paper and pen. There was no cut off score for inclusion in the study.

Mood. Participants were asked to indicate their mood on a Likert scale from 1 – 7 with 1 (very negative) to 7 (very positive) approximately every 30 s during the computerized ToH task. Mood ratings ≤2 were defined to be negative mood ratings, and mood ratings ≥4 were defined as positive mood ratings. Ratings of 3 were considered as neutral mood. A similar 7-point Likert scale for measuring mood has been used by Kaufmann and Vosburg (2002) in creativity experiments. Mood scores were averaged over the ratings in the task to supply an overall mood score.

Prior task experience. Participants were given a questionnaire asking if they have ever seen the ToH task before and if so, how many times. A picture of the ToH three tower task was provided in case some participants only know the task by sight.

Apparatus

Creativity, as defined by 1/(moves∗min), was assessed by a computerized ToH task. Participants could select and drag the desired disk by using a computer mouse. Illegal moves were not allowed in the game; attempts at illegal moves sent the most recently moved disk back to its original location. Illegal moves include moving more than one disk at a time and placing a larger disk on top of a smaller disk. The number of moves and time spent on the three and four disk tower tasks were recorded by the computer game.

One may be concerned that the simple progression from the three to four tower task may lead to automatic problem insight for participants. However, a study by Welsh and Huizinga (2005) found that completing the ToH task in increasing tower disk number does not lead to superior performance even when 60 ToH tasks are performed. The authors hypothesize that individual differences in problem solving abilities is what most likely accounted for differences in performance. Welsh and Huizinga also suggested that other factors that may improve ToH performance include formal operational thinking, working memory, and inhibition.

Higher levels of creativity will be defined by higher creativity scores 1/(moves∗min) on the ToH problem-solving task. The measurement 1/(moves∗min) was selected to capture both features of convergent and divergent thinking. A convergent thinking approach would promote parsimony of moves and efficiency, thus minimizing both number of moves and duration needed to successfully complete the task. Additionally, divergent thinking is needed to help minimize number of moves and time as if one only perseverates on one strategy, more optimal strategies may be missed. The inverse quantity was used so that higher values would naturally map onto higher levels of task "creativity." An optimal ToH solution is defined as achieving the goal state in as few moves as possible without violating the cardinal rule of ToH: no larger disk can be placed on a smaller disk. Hinz (1992) mathematically proved that for any ToH task beginning and ending in tower states, there is only one optimal solution. Furthermore, the two, three, and four tower problem can be respectively solved optimally in 3, 7, and 15 moves.

Procedure

Participants were initially recruited during screening day in the Psychology Department Fall 2014 and Spring 2015. During screening day, potential participants were provided a demographic form and the Chapman Physical Anhedonia Scale. All participants from the spring semester were invited to participate in the study and complete the AQ and ToH task. Only participants who either scored 1.5 sd above and an equal number of individuals who scored less than or equal to 1 SD above the mean were invited via email to participate from the fall. On testing day, invited participants completed the paper-pencil AQ and then the Shipley vocabulary test. Upon completion, participants were introduced to the computerized ToH game.

After completing the questionnaires and the vocabulary test, participants were required to complete ToH puzzles with two (practice), three, and four disks. Participants first performed the two disk tower task to gain familiarity with the computerized interface and the rules of the game. After participants could successfully complete the two disk tower task and made a mood rating, they were directed to respectively complete the three and four disk tower tasks. Previous literature on the ToH task indicates that the three and four tower tasks are appropriate even for adolescent children; hence, it is reasonable to assume that college-age students should be able to complete these puzzles (Welsh, 1991).

The survey on mood appeared on the computer screen every 30 s. Participants indicated their mood rating on the 7-point Likert by using the virtual mood slider on the computer screen. A virtual slider format for the mood survey was chosen to maintain consistency with the type of physical action required on the ToH task. Participants were entered into a lottery to possibly win one of two Amazon gift cards (each valued at $20). Additionally, individuals were given research credits if applicable. Debriefing letters were e-mailed after all participants had been tested.

Analyses

The first hypothesis that individuals with higher levels of subclinical traits would tend to exhibit higher creativity [1/(moves∗min)] was tested by computing the partial correlation between AQ (Autism Quotient) and PA (Physical Anhedonia) scales with the creativity scores, accounting for intelligence and task experience. The second hypothesis, that individuals with subclinical traits tend to be in a more negative mood, was tested by correlating average mood during the creativity task with AQ and PA scales while partialling out intelligence and experience with the task. To account for the possible individual affects of completion time and number of moves, (1/moves) and (1/min) were also added to the quantity 1/(moves∗min) in selected analyses. This additional index [1/moves + 1/min + 1/(moves∗min)] will be referred to as the extended creativity index. For both creativity indices, the total number of moves and time were divided by their respective standard deviations to place these quantities on the same scale.

SSGs were created using GridWare, software created by Lamey, Hollenstein, Lewis, and Granic (2004). From the state space plots, we can determine which mood ratings individuals endorsed the most. The diameter of the circles corresponds to duration of time spent in the cell. Additionally, the directional arrows indicate temporal order of reported mood. The largest circles on the grids represent attractors. The SSG analyses were conducted as within-subjects analyses and were largely used to illustrate the utility of this method. Separate SSGs were created for each of the 9 high- and low-schizotypy participants selected from the fall screening. Frequency of moves and associated mood ratings were plotted against each other to illustrate how mood might influence or be related to the frequency of game moves. Frequency of moves (number of moves in a 30 s window) were categorized as Low, Medium, or High and then plotted against mood ratings ranging from 1-7. A 15 s window before and after the mood rating was used to determine the frequency of moves associated with that mood rating. Number of moves in that 30 s window was totaled and then categorized as either being Low (0-5 moves), Medium (6-11 moves), or High (12+ moves). I predicted negative mood would be associated with lower frequency of game moves as prior literature has found that negative mood tends to promote more careful and convergent thinking styles. Consequently, individuals may make fewer overall and less frequent moves, as they may be more strategic in the moves they make.

To evaluate some of the research finding a connection between negative symptom schizotypy and AQ traits (e.g. Claridge & McDonald, 2009), the Chapman Physical Anhedonia and AQ scores were correlated. Prior research suggests that degree of subclinical symptoms might be related to profession and one's college major. In particular, Nettle (2006) found that mathematicians tended to score higher on introvertive anhedonia than poets and visual artists.

Additionally, Nettle found differences in degree of schizotypal scores depending on engagement with a profession (e.g., non-poet, hobby, serious, professor). Claridge and McDonald (2009) found that science majors tended to score higher on the AQ than nonscience majors. Thus, to attempt replication and extension of these results in the current sample, a *t* test was performed on science vs. nonscience majors (following criteria outlined in Baron-Cohen et al, 2001) using the PA scores. For example, science majors included physics, chemistry, biological sciences, mathematics, medicine and engineering. I included social science majors in with science majors as this sample only contained a few pure science majors. Some of the social science majors included psychology, communication disorders, human and health performance, and exercise science. Additionally the PA scores for science majors were correlated with years in major to assess if engagement with field was related to the degree of subclinical symptoms.

Results

Main Hypotheses

The following analyses pertaining to the main hypotheses were performed on only the 33 participants who completed the entire experimental procedures, including the ToH task, as the creativity index could only be calculated for these individuals. The numerical summaries for the experimental variables are summarized in *Table 1.* The mean Shipley raw and standardized scores respectively were 30.06 (sd =3.75) and 108.3 (sd = 8.98). The Standardized Shipley scores are raw scores transformed to a distribution with $\overline{X}$ = 100, sd = 15. The mean Shipley standardized score is slightly above average, and this is consistent with what one would believe to be the average IQ of college students. Participants on average had only been exposed to the ToH task once before (sd = 1.04). This is an encouraging finding as this suggests the ToH task was relatively novel to participants and thus likely required participants to actually think through how to solve the puzzle as opposed to using an already learned solution.

The mean PA score was 9.76 (sd = 6.44) and the mean AQ score was 18.12 (sd = 5.09). The average creativity score 1/(moves∗min) was .016 (sd = .009). The average combined completion time for both the 3 and 4-disk task was 2.41 min (sd = 1.159). The very rapid time for completion suggests this task was not too difficult, and was perhaps even a little too easy, introducing a possible ceiling effect into this study.

Variable	Min	Q1	Median	Mean	Q3	Max
Age	18	18	19	20.36	20	36
Shipley Raw	21	27	30	30.06	32	37
Shipley Std	87	102	108	108.3	113	123
Task Exposure	0	0	1	1.03	2	3
PA	0	6	9	9.76	13	26
AQ	9	14	18	18.12	21	31
Creativity	0.03	0.14	0.29	0.26	0.34	0.66
Ext. Creativ.	.36	.90	1.37	1.26	1.52	2.35

Note: All these values were computed on the 33 participants who completed the entire experimental procedures, including the ToH task.

Table 1: Descriptive statistics for the variables. Q1 and Q3 represent the first and third quartile (25th and 75th percentile).

The distributions for the experimental variables are shown in *Figure 1*. The distributions of participant Shipley, AQ, and extended creativity scores appear to be roughly normal. Task experience is skewed to the right, indicating only a few individuals had had substantial prior exposure to the task. The distribution for PA is also right skewed, suggesting that most college students do not have subclinical negative schizotypy scores.

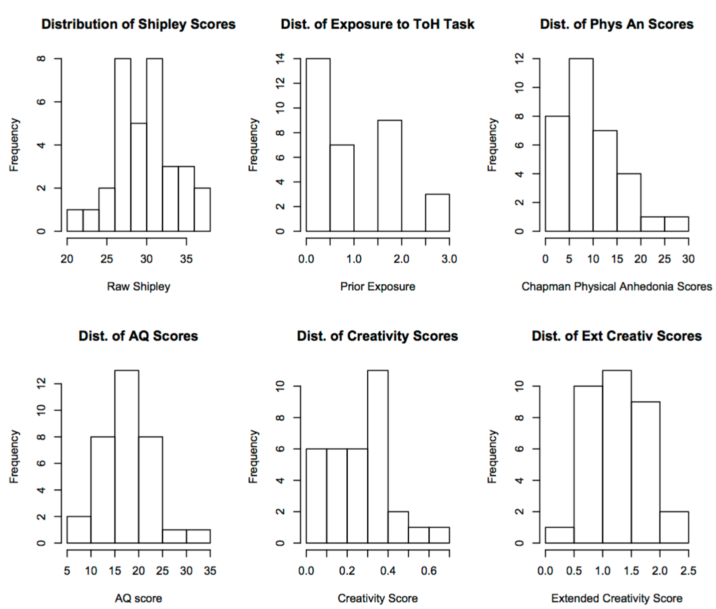

Figure 1: Distribution plots of variables.

The correlations between the predictors and covariates are shown in *Table 2.* It appears that none of the variables are highly correlated ($p > .05$). It is noteworthy (and somewhat surprising; see Discussion) that the correlation between PA and AQ scores is quite small ($r = .152$, $r(31) = .86$, $p = .40$), as prior researchers have noted that individuals who score high on negative symptom schizotypy traits tend to also score high on autism traits. However, this small correlation may be a reflection of the sample containing very few subclincial traits, thus making associations at the extreme difficult to measure. Additionally, as the sample size is small, unusual observations gain possibly undue influence. For example, removal of Observation 4 increases the association between PA and AQ ($r = .31$, $t[30] = 1.77$, $p = .09$).

	Shipley	Prior.Ex	Phys.An	AQ
Shipley	1			
Prior Ex.	0.167	1		
Phys.An	-0.197	0.307	1	
AQ	0.011	-0.141	0.152	1

Note: These values were computed on the 33 participants who completed the entire experimental procedures, including the ToH task.

Table 2: Correlation table of predictor (Phys.An, AQ) and the covariates (Shipley, Prior Experience with task).

Hypothesis 1, that individuals who scored higher on subclinical traits would tend to perform more creatively on the ToH task (as assessed by 1/(moves∗min), was not supported. As can be seen in Table 3, creativity was not significantly related to either AQ or PA, after accounting for the effects of prior experience and intelligence. Furthermore, the extended creativity index [1/moves + 1/min + 1/(moves∗min)] was also not significantly related to either AQ or PA ($p > .5$). Refer to Table 5 for partial correlations of the two creative indices and their partial components with PA, AQ, and mood. It is interesting that creativity appears to have a slight negative (albeit non-significant) relationship with PA. This is counter to expectations that these variables would be positively related to each other. However, the fact we see this slight non-significant negative relationship may be due to random noise arising from a very small sample. As shown in *Figure 2,* there does not appear to be any visual relationship between PA and the creativity index.

	Creativity	*t*	*p* (one-sided)
Chapman	-0.198	-1.12	0.87
AQ	-0.013	-0.073	0.53

Note: These values were computed on the 33 participants who completed the entire experimental procedures, including the ToH task.

Table 3: Partial correlations between creativity scores and subclinical symptoms accounting for prior task exposure and intelligence.

Hypothesis 2, that individuals who scored higher on subclinical traits, would tend to be in a more negative mood during the ToH task, accounting for prior exposure and intelligence, was also not supported. Additionally, it appears there is no connection between mood and creativity score as assessed in this experiment. The lack of these associations in regards to both Hypothesis 1 and 2 mirrors the scatter plots of the data as shown in *Fig 2.* Note that the plots using the regular or extended creativity indices are quite similar. This suggests that the regular and extended creativity indices are fairly strongly related ($r[31] = .99$), and thus it does not come as a surprise that the results using either the regular or extended creativity indices are relatively unchanged.

	Mood
Chapman	-0.023
AQ	-0.078
Creativity	0.002

Note: These values were computed on the 33 participants who completed the entire experimental procedures, including the ToH task.

Table 4: Partial correlations between subclinical traits, and creativity with mood accounting for prior exposure and intelligence.

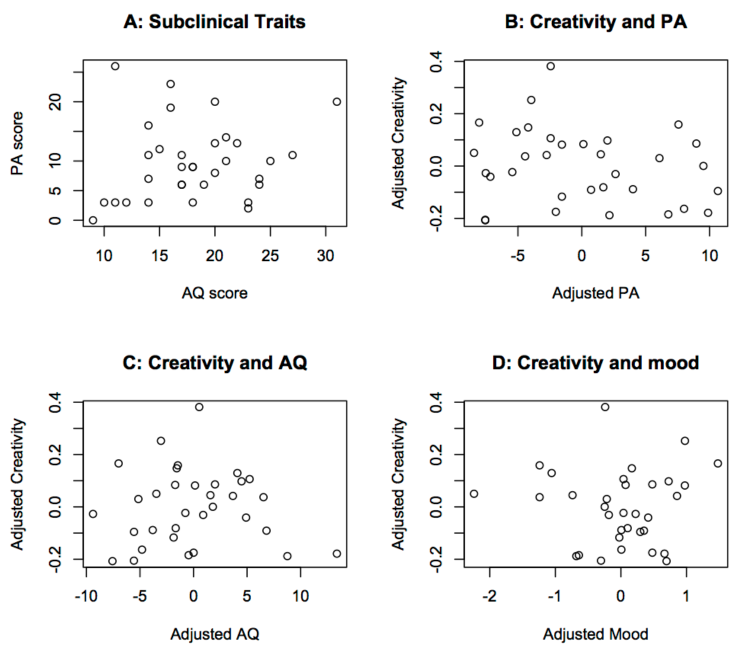

Figure 2. A shows the relationship between the subclinical traits. B and C show the subclinical traits against creativity adjusted for prior experience and intelligence. D shows mood against creativity adjusted for prior experience and intelligence.

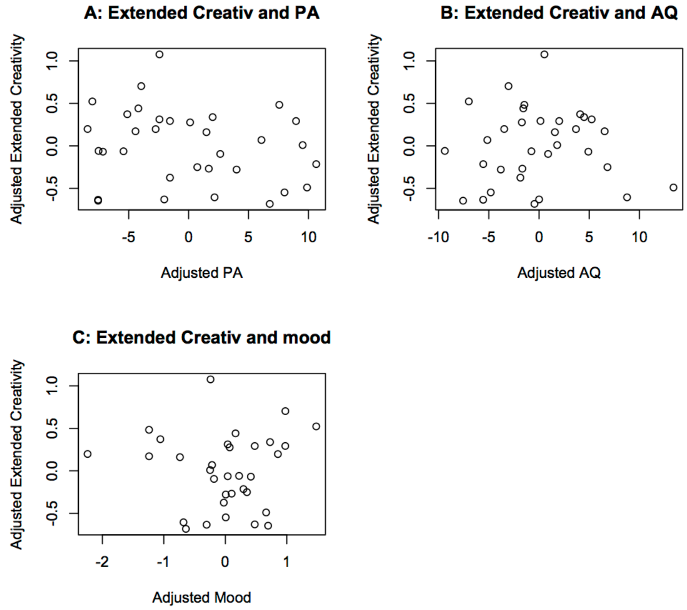

Figure 3. A, B, and C show the relationships between the extended creativity score and variables subclinical traits or mood once prior experience and intelligence have been adjusted for. Note that these plots are virtually identical to those in Figure 2, except for the scale of the axes.

	Creativity	Extended Creativity	1/time	1/moves
Chapman	-0.198	-.199	-.173	-.212
AQ	-0.013	.009	.067	-.055
Mood	.002	.012	.101	-.117

Note: These values were computed on the 33 participants who completed the entire experimental procedure, including the ToH task.

Table 5: Partial correlations between subclinical traits, mood, and creativity scores and components, accounting for prior exposure and intelligence.

Additional Analyses

The additional analyses were conducted on the entire spring screening pool participants as computing creativity score was not necessary here. Hence, the additional analyses sample size was $n = 114$. Two participants were dropped due to Infrequency scores > 2. Note that these analyses do not examine presence of subclinical autism traits as only individuals who returned for the ToH task after screening day completed the AQ questionnaire. Hence, AQ analyses were limited to the 33 tested participants, and are described above in section Main Hypotheses. Based upon the reported major information from the demographic questionnaire, majors were classified as either Science or Non-science (Baron-Cohen et al., 2001). Note that pure sciences and social sciences were grouped together to equalize group sizes as pure science majors were rare in the psychology screening sample. Table 6 shows the categorization of majors as science or Non-Science. Based on the below classifications, there were 62 Science majors and 52 Non-Science majors.

	Majors
Science (*n* = 62)	Non-Science (*n* = 52)
Exercise Science	Athletic Training
Psychology	Business Management
Nursing	Elementary Education
Political Science	Marketing
Human and Health Perf.	Undeclared
Environmental Studies	Social Work
Nursing	Management
Human Biology	Arabic
Psychology	Media Arts
Wild Life Biology	Creative Writing
Mathematics	Parks and Recreation
Technology	Philosophy
Pharmacy	History
Communication Sciences	
Ecology	
Physical Therapy	
Computer Science	
Ecology	
Chemistry	
Cell and Molecular Biology	

Table 6. Shows the reported majors by participants and the classification them as Science or Non-science.

There is marginal support for the hypothesis of a relationship between college majors and degree of subclinical schizotypal symptoms (t[1.63, 106.32] = 1.63, p = .053,

$\overline{X}_S = 12.21$, $\overline{X}_{NS} = 10.26$). Thus, it appears that subclinical negative symptom schizotypy traits tended to be more common those who pursue Science vs. Non-science majors. However, the hypothesis that years in major (proxy for engagement with field) would be associated with subclinical traits was not at all supported ($r[59] = -.39$, $p = .65$).

State Space Grid Analyses

SSGs for nine participants who scored either low or high on negative symptom schizotypy as measured by Chapman's Physical Anhedonia scale are shown in Figure 3 (High schizotypy) and Figure 4 (Low schizotypy). Mood ratings from 1-7 are plotted on the abscissa and frequencies of moves are plotted on the ordinate axis. It appears that for Participant 436, negative-neutral mood was a possible overall attractor whereas for Participant 413, neutral-positive mood was an overall attractor. For Participant 56, Mood = 2 and Medium frequency of moves was an attractor, as this individual spent the most time in this state. Participant 288 appeared to take time to think about or consider the task and made few moves before starting to make frequent moves and adopting a more positive mood.

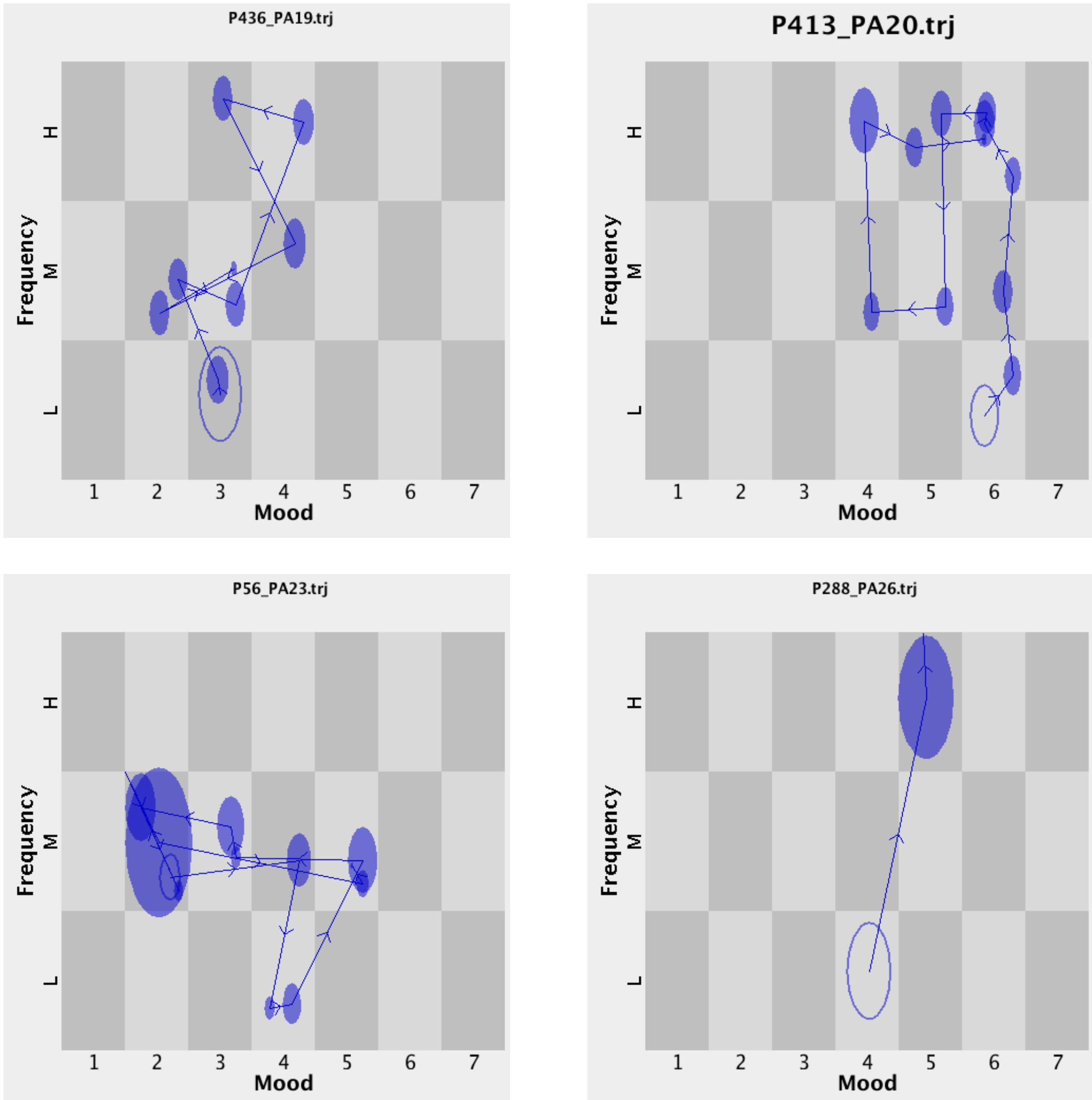

Figure 3. State space grids of mood vs. frequency of moves during the ToH task for participants with high Chapman Physical Anhedonia scores. Figure headings code participant identification number and PA score [example: P436_PA19 codes for Participant 436, PA score = 19].

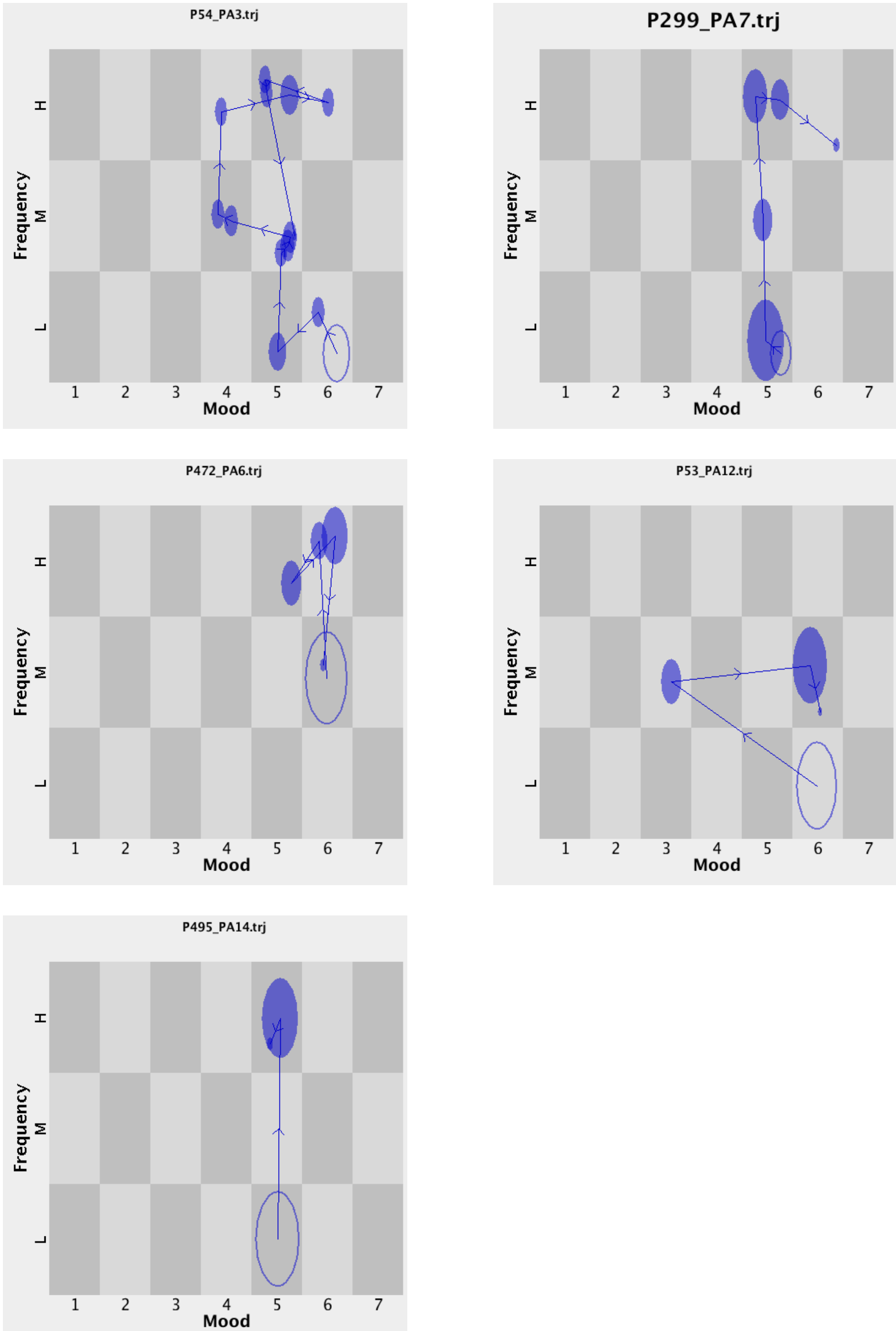

Figure 4. State space grids of mood vs. frequency of moves during the ToH task for participants with low Chapman Physical Anhedonia scores.

In general, participants with low schizotypy scores appear to spend more time in positive mood than in negative mood. However, it is difficult from these data to determine if individuals with a greater number of subclinical symptoms tend to stay in negative mood longer and more frequently than individuals with fewer subclinical symptoms. Note that Participant 495 appears to start in a relatively neutral-positive mood and engages in very few moves before transitioning to high frequency of moves for the remainder of the task. Interestingly, this participant received a very high creativity score. Thus, this pattern could suggest this participant was first thinking about the task and engaging in careful preparation for the task before gaining insight and rapidly completing the task. Note, while Participant 288 also demonstrated a similar SSG profile, his/her creativity score was much lower. Thus, the utility of SSG to shed insight on the phase of creativity needs to be accompanied with other information, such as asking participants their experience during the task and their strategy.

Discussion

One major limitation of this study was only a very small number of participants actually completed the ToH task (n = 33). Consequently, this study was underpowered, and this made it difficult to detect a significant effect even if one existed between the hypothesized variables. In the future, it would be useful to double or even triple sample size. Additionally, it would be useful to block participants based upon subclinical traits. This would again increase power as the difference between the means for these groups on the independent variable would be increased.

It is also noteworthy that subclinical traits as measured by PA and AQ appeared to be slightly negatively correlated with creativity as measured by the ToH task, which is counter to Hypothesis 1. However, it is important to keep in mind that this result may be due to noise and or unusual observations that gain weight from being analyzed in such a small sample.

Additionally, although the computerized ToH task allowed one to have real-time insight into the creative process, it may have been too easy or short to fully model the creative solving problem process. Most participants finished the both the 3 and 4-disk task in less than 3 minutes. This short completion time suggests that one may not need to think creatively on this task as the brute force solution of just moving the disks until the desired state is achieved works fairly effectively as well. Hence, it might be useful in the future to either increase the disk number of this task or consider another convergent thinking task that might require more overt planning and evaluation.

Furthermore, the index of creativity $1/(\text{moves} * \text{min})$ utilized here may not have been a very good measure of the creativity constructs I wished to measure. Although it measures convergent thinking in the sense that a person who has "converged" or "funneled" to an optimal strategy should solve the puzzle in fewer moves and in less time, it may not be as useful as some other indices. A possibly better way to determine convergent and divergent processes would have been to look at the type of moves made in the game. In particular, it might be informative to determine number of illegal/legal moves, number of incorrect moves, and number of repeated move patterns.

As the ToH game is easily solvable by a computer, it is possible to determine the optimal set of moves to complete the game given any disk setup. Hence, errors could be defined to be any move made that deviates from the set of optimal moves determined by the computer for that particular game setup. Time and move latency until a person reaches and stays on the optimal path for the given disk setup at any particular time could also be determined so as to approximate when a person finally has the "Aha!" or insight moment. Future administrations of the game could also incorporate a pause button so that individuals who are incubating, but then solve the puzzle perfectly can be distinguished from others who simply take a long time to figure out the problem and do not experience insight. During pauses, the game would halt so that moves cannot be played. It would not be too difficult to modify the current computerized ToH game to compute these measurements of creative problem solving strategy or lack of strategy in future administration of this task.

Two possible other tasks might be the Missionaries and Cannibals task (Claridge & McDonald, 2009) or the Egg problem (Karimi et al., 2007). The Missionaries and Cannibals task involves moving three missionaries and three cannibals across a river on a boat. However, the boat can only carry two people at a time and the number of missionaries must be greater than the number of cannibals on either side of the bank. The minimum number of moves to solve this problem is 11. The Egg problem involves figuring out how to use a 7 min and an 11 min timer to time the boiling of an egg for exactly 15 min. It might also be useful to ask participants to think aloud about their thought process or ask them how they arrived at their solution.

The finding that there was only marginal support for the connection between major and subclinical traits was surprising. However, the lack of strong evidence may be due to small number of pure science majors in the sample. As participants were drawn from a psychology testing pool from an introductory level psychology course, not many participants were mathematics, physics, or other pure science majors. Consequently, social science and other applied science majors were collapsed with the pure science majors in analyses. However, this may have masked or decreased the strength of connection between science majors and subclinical traits. Future studies could recruit participants who squarely fell in either the pure or non-sciences to increase power.

The SSGs may in part have yielded little insight into the dynamics of creativity, problem solving, and mood because the ToH task was generally completed very quickly; in addition, this task is also amenable to brute force strategy of just moving the disks mindlessly until the desired conformation is achieved as opposed to insight or planning. Hence, the SSGs may be more illuminating about the creative process if one of the creative problem solving tasks described above is used. For example, a researcher could code both mood and creative strategy phase (preparation, incubation, illumination, and verification) as a person progresses through the problem solving process. The more deliberate and interactive nature of the procedures described above may allow better discrimination between creative process versus noise due to guessing or lack of effort.

Conclusions

Although none of the main findings from this project were significant, this project still adds to the existing body of creativity research literature by calling for researchers to incorporate more dynamical and multidimensional techniques to assess creativity. As previously discussed, creativity research has historically focused on divergent thinking tasks as a measure of creativity. Unlike some creativity measures, the computerized ToH task as outlined in this study may allow measurement of both convergent and divergent thinking processes. However, given the findings from this study, appropriate modifications to the index of creativity would need to be made. For suggestions, refer to the Discussion section.

Additionally, the computerized ToH task allows dynamical creative and affective data collection. This feature allows a potentially richer understanding of how creativity changes as a function of time and mood. Although the SSGs method did not shed much light on the ToH task in this study, I believe SSGs still hold promise as being a useful way to visualize the dynamics of an evolving process, such as creativity.

Furthermore, this study adds to the chorus of researchers who suggest a balance of both health and psychopathology may maximize creativity instead of looking at full blown disorders as giving arise to creativity. If this study was repeated with any of the modifications previously suggested, it is possible the results would be in alignment with the outlined hypotheses. If such an outcome were to occur, it would give provide support for how subclinical schizotypy may actually be associated with both convergent and divergent thinking as opposed to just more divergent processes that are closely tied to positive schizotypy. Finally, significant results would help create the case for how subclinical traits can affect and interact with mood to shape creativity on an everyday problem solving level.

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