

THE COGNITIVE NEUROSCIENCE OF CREATIVE THINKING IN THE SCHIZOPHRENIA
SPECTRUM: INDIVIDUAL DIFFERENCES, FUNCTIONAL LATERALITY
AND WHITE MATTER CONNECTIVITY

By

Bradley S. Folley

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Approved:

Professor Sohee Park

Professor Adam W. Anderson

Professor Steven D. Hollon

Professor Andrew J. Tomarken

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TABLE OF CONTENTS

	Page
DEDICATION	ii
ACKNOWLEDGMENTS	iii
LIST OF TABLES	vii
LIST OF FIGURES	viii
 Chapter	
I. OVERVIEW OF THE DISSERTATION	1
II. THE CREATIVITY CONSTRUCT: ITS RELATIONSHIP WITH PSYCHOPATHOLOGY AND NEUROCOGNITION	4
Creativity as a Psychological Construct	5
Divergent Thinking	5
Associative Hierarchies	6
Blind Variation and Selective Retention	9
Insight, Problem-Solving and Allusive Thinking	10
Neurobiological Bases of Creative Thinking	12
The Genetic Bases of Creative Ability	12
Heritability	13
Emergenesis	14
Functional Neuroimaging Studies of Creative Thinking	14
Psychopathology and Behavioral Investigations of Creativity	17
Schizophrenia	17
Schizotypy	19
Bipolar Disorder and Cyclothymia	22
Summary	24
III. INDIVIDUAL DIFFERENCES: CREATIVE THINKING ABILITY IN SCHIZOPHRENICS, SCHIZOTYPES, AND NORMAL CONTROLS	26
Aims	29
Method	30
Participants	30
Design and Material	31
Procedure	32
Measuring Creative Personality and Achievement	33
Validity and Reliability of the Divergent Thinking Task	34
Schizotypal Personality	35
Handedness and Neuropsychological Measures	36
Results	36
Scoring	36
Number of Singular Uses	37

	Number of Combinatory Uses	38
	The Effect of Intelligence	38
	Rate	40
	Associations with Schizotypy Factors	40
	Associations between Divergent Thinking Scores and Handedness	41
	Discussion	42
IV.	HEMISPHERIC CONTRIBUTIONS TO DIVERGENT THINKING: A DIVIDED VISUAL FIELD ‘HALO’ TASK BETWEEN SCHIZOPHRENICS, SCHIZOTYPES AND NORMAL CONTROLS	47
	Aims	51
	Method	52
	Stimuli	52
	Verbal Stimuli	52
	Non-Verbal (Graphic) Stimuli	54
	Pilot Study	54
	Subjects	54
	Method	54
	Results	55
	Divided Visual Field Experiment	55
	Participants	55
	Tachistoscopic Presentation	56
	Results	58
	Trial Performance	58
	“Halo”	59
	Response Time	60
	External Creativity	61
	Relationships with Schizotypy	61
	Relationships with Divergent Thinking Variables	63
	Relationships with Creative Achievement and Personality	63
	Discussion	64
V.	PREFRONTAL NEURAL SUBSTRATES OF CREATIVITY: A NIRS INVESTIGATION OF DIVERGENT THINKING IN SCHIZOPHRENICS, SCHIZOTYPES, AND NORMAL CONTROLS	68
	Aims	72
	Method	73
	Participants	73
	Cognitive Paradigm	74
	NIRS Measurement	75
	Hemispheric Localization	77
	Results	77
	Behavioral Analyses	77
	Associations with External Measures of Creativity	78
	Near Infrared Chromophore Analyses	79
	Data Processing	79
	NIRS Analyses	79
	NIRS Analyses for Temporal Normalization	83
	Discussion	84

VI.	WHITE MATTER COHERENCE AND DIRECTIONALITY IN RELATION TO CREATIVE THINKING: DTI CORRELATES OF DIVERGENT THINKING IN SCHIZOPHRENICS AND NORMAL CONTROLS	90
	Candidate Neuroanatomic Regions Important for Creative Thinking	92
	Corpus Callosum	92
	Cingulum Bundle	94
	Uncinate Fasciculus	95
	Diffusion Tensor Imaging	95
	Goals	97
	Method	98
	Participants	98
	Apparatus and Image Acquisition Parameters	99
	Data Analysis and Region of Interest Measurements	100
	The Corpus Callosum	100
	The Genu	100
	The Cingulum Bundle	100
	The Uncinate Fasciculus	102
	Creative Thinking Measures	103
	Results	103
	Descriptive Results	103
	Comparative Results	104
	Associations with Creative Personality Traits and Achievement	105
	Hemispheric Differences	106
	Discussion	107
VII.	GENERAL CONCLUSIONS	113
	Limitations	115
	Future Directions	116
	REFERENCES	120

LIST OF TABLES

Table	Page
1. Investigations of schizotypy and creative thinking or achievement	21
2. Demographic and clinical characteristics of the sample for the behavioral study	31
3. External validity of divergent thinking measurements with creative achievement and personality	35
4. Relationships between psychometric intelligence and divergent thinking variables	39
5. Correlations between divergent thinking scores and SPQ total and factor scores	41
6. Correlations between divergent thinking scores and handedness scores from the Edinburgh Handedness Inventory	42
7. Stimuli used in the divided visual field experiment	53
8. Demographic and clinical characteristics of the divided visual field sample	55
9. Associations between halo performance and schizotypal traits including the Active and Withdrawn subtypes	62
10. Relationships between halo scores and divergent and convergent thinking	63
11. Demographic and clinical characteristics of the NIRS creativity study sample	73
12. Hemispheric results from the NIRS study based on contrasts for each chromophore	81
13. Demographic and clinical characteristics of the sample for the DTI study	99
14. FA and λ_1 of white matter tracks in relation to creativity and intelligence measures	104

LIST OF FIGURES

Figure	Page
1. Associative hierarchies proposed by Mednick.....	8
2. Conventional and ambiguous stimuli used in the divergent thinking task.....	32
3. Number of singular uses generated by subjects for different object types.....	37
4. Number of combinatory uses generated by subjects for different object types	38
5. Divided visual field presentation	57
6. Schematic diagram of the tachistoscopic presentation paradigm used in the divided visual field experiment.....	58
7. ‘Halos’ obtained by presentation of either words or graphics to either hemifield in each group.....	60
8. Cognitive paradigm used in the NIRS creativity study.....	74
9. Placement of the NIRS optodes on the forehead	76
10. Number of responses given by subjects for different conditions in the NIRS study	77
11. Oxyhemoglobin results from the NIRS creativity study.....	82
12. Locations of major white matter pathways	93
13. Structure of the diffusion tensor	96
14. Placement of ROIs for DTI measurements	101
15. Laterality indices for FA and λ_1 values in the uncinate fasciculus and the cingulum bundle	106

CHAPTER I

OVERVIEW OF THE DISSERTATION

Although attempts to explain the relationship between creativity and mental illness have existed since man has been keeping written records, the scientific study of this relationship began in the first half of the nineteenth century (Becker, 2001). Efforts to explain the existence of creative thought processes and novel outcomes in human cognition and achievement have varied from purely biological to entirely social rationales (Sass & Schulberg, 2001). Indeed, creativity is a multifaceted construct that includes a process and a context as well as a novel outcome or product. Forces from atavism (Lombroso, 1910) to cultural periodicity (Martindale, 1990) have been linked to creativity and, at its extreme end, genius (Eysenck, 1995). Although broad, these theories have failed to provide a descriptive or predictive basis for the presence of creativity as part of the corpus of human abilities. Attempts to define the construct of creativity have been equally divergent, and so comprehensive accounts of human creativity are absent from the literature. Historiometric and biographic data from individuals with psychotic illnesses and from their relatives have clearly supported the association between creativity and mental illness; however, few studies to date have used experimental approaches to examine the causal influences that are common to creativity and psychopathology.

The research presented in this dissertation has sought to investigate the neurocognitive components of creative thinking and their relation to the schizophrenia spectrum, combining studies that address the behavioral manifestations and functional and connective neuroanatomy of creative thinking. A major goal of this research is to understand the neural processes that facilitate creative thinking and to understand how degrees of psychoses may enhance creative thoughts. A key thematic question that runs throughout series of investigations is: *are individuals who are either at increased risk for schizophrenia or who have subclinical schizophrenia-like traits (compared to psychotic patients themselves) more likely*

to be creative thinkers (addressed by Chapter III)), and if so what inherent neurocognitive components facilitate these thought processes (addressed by Chapters IV, V and VI)?

Chapter III, forming the behavioral basis for the subsequent experiments in the dissertation, addresses the utility of a new type of creative thinking task and its appropriateness in probing differences between groups along the schizophrenia continuum. This experiment was undertaken in order to replicate and to expand upon previous studies indicating that trait schizotypy is positively associated with creative, divergent thinking (Abraham et al., 2005; Eysenck, 1993; O'Reilly et al., 2001; Rawlings et al., 1997; Woody et al., 1977). However, to date, no single comprehensive investigation has been performed assessing divergent thinking abilities in schizophrenics, schizotypes, and normal controls within the same study. This experiment used divergent thinking to assess creative ability between these three groups because it has been shown to correlate well with multidimensional conceptualizations of creativity (personality, achievement, profession) and because it is a measure of the creative thinking process.

Chapter IV employs a tachistoscopic paradigm using words and graphics to assess conceptual boundaries and divergent thinking between schizophrenics, schizotypes, and normal controls in order to bridge the individual differences data from Chapter III with the structural and functional neuroimaging investigations presented in later chapters. To date, no known experiments have assessed the relative contribution of both hemispheres to verbal and nonverbal creativity in the same paradigm. Differential hemispheric contributions to creative thinking indicate that both the left and right cerebral hemispheres contribute to the creative thought process (Boden, 2004; Carlsson, Wendt, & Risberg, 2000). However, most psychophysiological research in the functional laterality of creativity has been performed using verbal stimuli, finding that the right hemisphere makes an important contribution to ambiguous or subordinate verbal meanings (Atchley, Keeney, & Burgess, 1999). Because the creative thinking process is not simply a verbal one, it is important to assess differential hemispheric contributions to nonverbal stimuli as well. In addition, the relationship between schizophrenia and schizotypy to these lateralized nonverbal contributions has not been assessed.

In Chapter V, the neural correlates of creative thinking processes have been examined using EEG, PET, and fMRI techniques in non-psychiatric populations; however several flaws using these modalities can be identified, particularly by employing uniform time constraints and inappropriate control tasks. The NIRS technique, being relatively new to the neuroimaging field, has also not been used to date to examine creative thinking, and investigations of the neural bases of creative thinking have not examined schizophrenics, normal controls, and schizotypes. Chapter V examines the use of NIRS to measure blood oxygenation properties during divergent thinking compared to a cognitive control task between schizophrenics, schizotypes, and normal controls.

Connectivity has been an important research issue for creativity, as creative people connect ideas in new ways in order to form unique solutions or products. Chapter VI asks the question: is there a concrete neural basis for this ideational connectivity? Both creativity and psychosis-proneness may be associated with increased synaptic connectivity and functional integration (Crow, 1995b; Horrobin, 1998). Diffusion tensor imaging (DTI) can be used to examine physical white matter connectivity in vivo and to calculate indices concerning the strength and integrity of these connections. Using region of interest (ROI) analyses, diffusivity and fractional anisotropy were examined in specific neuroanatomic regions implicated in bi-hemispheric integration, cognitive inhibition, and semantic associations in order to elucidate white matter characteristics that may be associated with creative ability. As this was the first investigation of its kind, the experimental design was goal-directed in an attempt to identify associations between creative behavior and its neuroanatomic substrates.

The relationship between creativity and psychosis, although studied for centuries, has been difficult to specify. The following series of studies has taken a step towards developing reliable tools for the empirical study of creativity and psychosis. This approach may help to bridge the gap between anecdotal evidence for the creativity-psychosis relationship and its underlying neural mechanisms.

CHAPTER II

THE CREATIVITY CONSTRUCT: ITS RELATIONSHIP WITH PSYCHOPATHOLOGY AND NEUROCOGNITION

The argument that creativity and psychoses may be related is the basic theme of the experiments presented in this dissertation. Although this relationship has been addressed previously, only a minority of studies have addressed the question experimentally. Nonetheless, the road has been paved thus far with several tantalizing links that, taken together, help to point out several links that may be responsible for the underlying mechanisms bridging creative ability and observed psychotic traits. These links will be expanded in the following sections. The primary concept to be introduced is an operational definition of creativity. Because this series of investigations has intended to show that the positive relationship between creativity and schizophrenia can be explained, at least partially, through neurobiological means, the genetics of creativity will be discussed in order to provide an impetus for addressing other neurobiological mechanisms in creativity. The conclusions that have already been drawn based on previous studies of schizophrenic phenomenology and creativity will be addressed in addition to the studies that have adopted schizotypy as a more favorable link to the relationship between creativity and psychoses. Schizotypy has shown strong, replicated positive relationships with creative thinking ability. If a link between psychoses and creativity does exist, it may be expressed more saliently in this group, as they display the sub-clinical positive, negative, and disorganized traits of schizophrenia without the debilitating cognitive dysfunction that characterizes psychoses. Finally, the neurocognitive link between creativity and schizophrenia will be addressed translationally by examining the elements that may constitute the cognitive bases of creative thinking and the ways in which there may be a similarity in information processing between schizotypes and creative thinkers. Thus, if creativity requires a broad conceptual expansion, a wide attentional focus, and enhanced associational linking, addressing these elements may direct the next stages in creativity research. Although the roadmap has certainly not yielded a well-defined destination thus far, previous research has been careful to document the directions that

have already been taken and to trace the divergent path that has allowed this series of experiments to be initiated. It is the goal of the present research to further refine to the quest, with the intent of bringing the journey closer to its destination.

Creativity as a Psychological Construct

To some extent all individuals retain the ability to be creative (Raven, 2002), however traditional subparceling of the creativity construct has identified the person, the process, the products, and the environment as distinct elements that contribute to what is commonly called “creativity” (Rhodes, 1987). The creative person can be described based on affective and personality variables; and creative products can be identified based on their novelty and utility. In its broadest sense, creativity is the capacity for original thinking and the production of novel and useful products and solutions. The temporal process of creative thinking can be subdivided into the preparation, incubation, illumination (or inspiration), and verification (or elaboration) stages (Wallas, 1926). Additionally, several investigators in the social sciences have identified environmental contextual characteristics that either enhance or limit the likelihood of being creative or arriving at a creative result (Amabile, 1983; Berry, 1999; Csikszentmihalyi, 1988; Niu & Sternberg, 2001; Raven, 2002; Rhodes, 1987).

Divergent Thinking

J.P. Guilford (1959) distinguished between *divergent* and *convergent* thinking in relation to his Structure of Intellect model defining the operations, content, and products of thought. These two modes of thinking are conceptualized as being distinctly related to memory ability because success depends on accurately accessing existing memory of facts and knowledge. Convergent thinking is defined by a narrowing of possible responses when the correct answer is made of few possibilities. Alternatively, divergent thinking involves the culmination of flexible ideational processes to generate responses to problems that are open-ended and multifaceted. Convergent thinking works best with well-defined

problems that have singular response possibilities that are arrived at based on a logical process, while divergent thinking is best suited for poorly defined or unstructured problems.

According to Guilford, divergent thinking provides the foundation for creative production because it requires ideational searching without directional boundaries, and it is operationalized primarily by his concepts of *fluency*, *flexibility*, and *originality*, and secondarily by *redefinition* and *elaboration*. *Redefinition* and basic fluency are also related to convergent thinking, while *sensitivity to problems* is separated as a component of creativity that is particularly important in developing creative solutions while thinking divergently. Although several definitions use strictly verbal examples, it should be noted that Guilford also addressed the utility of these concepts in symbolic and figural processing and in behavioral and interpersonal applications according to the Structure of Intellect model (Guilford, 1959).

Wallach and Kogan posited that ideational fluency was the main criterion of interest (Wallach & Kogan, 1965). They emphasized the context of the creative process, and asserted that the process would yield its greatest effects if given under game-like conditions (Wallach, 1971). Their battery uses tests of instances, alternate uses, similarities, and pattern and line ideation (using Guilford-like components to tap associative processing), and scores on these tests are independent of intelligence, aptitude, and achievement (Wallach et al., 1965). Like the Wallach and Kogan tests, the Torrance Tests of Creative Thinking were initially developed in an educational context to provide the field with a creativity battery that incorporated normative data into the assessment process. However, they are essentially an extension of the Guilford divergent thinking tests (Torrance, 1974) with the additional benefits of providing predictive and discriminant validity (Torrance, 1988). They include verbal (generating uses, questions, and guesses) and nonverbal (drawing elaboration, drawing completion, and shape ideation) subtests that can be scored according to fluency, flexibility, and originality.

Associative Hierarchies

Mednick's approach to defining the creative thinking process emphasized the divergent production of new ideas that came from combining "associative elements" into a novel product that was

useful (Mednick, 1962), or that met certain requirements (Mednick, 1969). Although not stated explicitly, one cannot ignore the influence of Guilford's theory on the production of remote associations, as he states that originality in divergent thinking is a result of infrequent and clever responses and "remote associations" (Guilford, 1959, p.150). This theory also arose as a result of distilling accounts from highly creative people (e.g. Einstein, Coleridge, and Poincaré) concerning their discovery processes, and it concluded that a creative solution could be achieved in one of three ways: serendipity, similarity, and mediation. With *serendipity*, elements just happen to appear simultaneously (X-rays and penicillin were discovered this way); *similarity* refers to one element eliciting another because they are similar (verbal elements such as rhymes, alliteration, and homonyms are emphasized); and *mediation* is the linkage of two elements through a third bridging factor (especially important in creating symbolic associations in math and science and in purely creative thinking). Although Mednick uses the term "associative elements" to describe the rudiments that comprise the final combinations (Mednick, 1962), his description clearly indicates that these elements are knowledge, memories, and information without which associations could not be produced. Mednick (1962) suggests that the *mediation* process becomes significantly important among the more remote associates in developing truly creative responses.

Each individual's associative hierarchy determines the probability and speed of reaching a creative response (Mednick, 1962). Similarly, the likelihood of producing a creative response increases as the number of associations between ideas increases. The easiest way to conceptualize these associative hierarchies is through a graph (Figure 1) of possible associations for a given solution showing the hierarchy for a creative and non-creative person. A non-creative person will show a relatively steep associative hierarchy (higher response rate with fewer responses) because they do not associate the more unique elements with the product, so their web of responses will drop precipitously after the common responses are generated. Also, their subjective association strength with the most common response will be quite strong. The creative person, however will show a flat associative hierarchy (slow, steady responding) that includes the more commonly produced elements (at lower subjective strength) and the

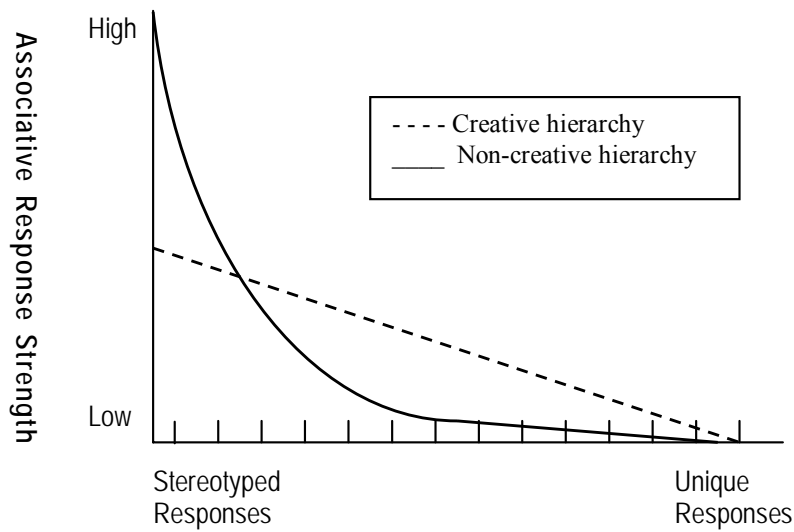


Figure 1. Associative hierarchies proposed by Mednick.

more unique, or “remote”, associates as well because they do not become fixated on the over-used response. In fact, the likelihood of producing a creative response was shown to be inversely related to the familiarity with the associative relationships for a given solution (Mednick, 1958).

The Remote Associates Test (RAT) (Mednick, 1962) was developed to measure creative process and ability according to Mednick’s theory of mediation. The RAT consists of 30 items, each containing three disparate words, and the subject must find a fourth word that associatively links the other three as a mediating factor (e.g. rat, blue, cottage → *cheese*). It has shown excellent reliability and validity (based on expert judgments of creativity and research ability), it is negatively correlated with grades and not correlated with general intelligence, it is positively associated with anagram problem-solving, and it is positively associated with creative personality and teacher’s ratings of creativity (Mednick, 1962). Other studies have found that the preparation (Mednick, Mednick, & Jung, 1964a) and incubation (Mednick, Mednick, & Mednick, 1964b) stages of the creative process are also implicated in successful RAT performance, implying a similarity in process among other theories of creativity.

Blind Variation and Selective Retention

The ability to create random non-sequential ideas may be a necessary but insufficient substrate of divergent thinking and remote mediation, and true randomness exists in association generation when each individual element has the same probability of being selected. However, the culmination of ideas into creative solutions cannot be governed by entirely random principles (the complete absence of order or structure) (Boden, 2004). This would rapidly evolve into chaotic thinking and disconnection from original problems, as is seen in thought disorder. Boden has asserted that the element of randomness that is essential in creative thought is “relative” randomness. Here, thought elements are random relative to existing knowledge, but they are subject to top down constraints.

Campbell was the first to suggest that randomness and blind variation are important elements in the creative thought process (Campbell, 1960), and Simonton has characterized this process as a “constrained stochastic behavior” (Simonton, 1999a, 2003) or “chance-configuration theory” (Simonton, 1993). Campbell theorized that creative ideas are achieved through a process of “blind variation and selective retention.” After behavioral and cognitive experimentation with ideas have proven to be insufficient for a truly creative response, the process turns to random generation and recombination. Random thoughts are generated, and some survive a process of “asymmetric transition”. The asymmetric transition phase requires consistent selection criteria in order to make stable combinations. The most successful, or stable, elements left over from the asymmetric transition process are then selectively retained in this iterative process for further cogitation and elaboration. Campbell’s theory offers a Darwinian perspective to thinking and knowledge, and, similar to Boden’s conceptualization, it provides a useful framework for understanding how random thoughts can become productive after a selection process that discards unstable combinations.

Simonton (1999a, 1999b, 2003) has applied Campbell’s original theory to the divergent thinking and associative hierarchy models because perseverative associations restrict the generation of ideas that are completely unrelated to initially conceived ideas. According to Mednick, an extremely flat gradient would suggest that elements have an almost equal probability of being included, and this increases the

likelihood that the associations will be truly random. At the far end of the gradient, “rare” associations exist because they become almost unpredictable. Rather uncreative associations, represented by a steep associative gradient, are selected commonly, and they are therefore predictable and non-random. In divergent thinking, elements depart from commonality (*flexibility* and *originality*) as their numbers increase (*fluency*). After the most common responses have been given, subsequent responses are more likely to be unpredictable, and using random generation becomes more important. The ideas that are sequentially generated can also be randomly combined within their own sets to arrive at novel solutions (Simonton, 1993). Being able to form associations between seemingly random elements will increase the number of responses, and by their unpredictable nature, they will also be more original.

Insight, Problem-Solving and Allusive Thinking

Other processes that are likely to be involved in neuropsychologically defined models of creative thinking are insight, problem solving, and allusive thinking. Sudden cognitive reorganizations that result in creative responses or solutions are identified as *insight* phenomena. This process is what distinguishes a “eureka” event from a well-defined conscious process of problem-solving (Schooler & Melcher, 1995). Although divergent thinking is thought to be primarily a conscious process associated with creativity, insight has emerged as an unconscious process that likewise results in creative solutions even though the solution is not subjectively determined incrementally (Metcalf & Weibe, 1987; Sternberg & O'Hara, 1999). Mental imagery has been studied as an important contributor to creative production, however a meta-analysis of the contribution of mental imagery to divergent thinking found that only 3% of the variance in divergent thinking task performance was accounted for by mental imagery ability (LeBoutillier & Marks, 2003).

Inductive reasoning has also shown a positive correlation with divergent thinking measures such that individuals who tend to approach a creative problem from a bottom-up approach as opposed to a top-down approach show higher divergent thinking ability (Vartanian, Martindale, & Kwiatkowski, 2003). Creative problem solving can refer to the use of divergent thinking to arrive at solutions to difficult

problems, but a more selective definition involves a departure from *functional fixedness*, which is a rigid reliance on the over-associated use for an object or applicability of a concept (Duncker, 1945). Functional fixedness can inhibit the production of new ideas from familiar experiences (German & Defeyter, 2000). It is often tested using the candle problem (Duncker, 1945) and the two-string problem (Maier, 1931) which require subjects to solve problems using common objects in novel contexts.

The concept of “*allusive thinking*” has also been studied as a measure of concept divergence and breadth of categorization in reference to recognizing and establishing proximal and distal associations, and it is therefore a type of divergent thinking (Armstrong & McConaghy, 1977). Allusive thinking tests have generally been verbal semantic measures of subjective boundaries for related meanings. The idea behind these tests is to measure divergent thinking through lateral conceptualization by presenting subjects with concepts that are objectively related on a continuum and asking them to decide which concepts form a related set (Tucker, Rothwell, Armstrong, & McConaghy, 1982). Because allusive thinking requires thought divergence rather than a combination of primary divergence and secondary convergence to arrive at a single “correct” answer, it has been used previously as a measure of verbal divergent thinking (Kyriacou, Weniger, & Brugger, 2003).

Divergent thinking has emerged as an internally, externally, and conceptually valid element in the creative process (Bartlett & Davis, 1974; Bennet, 1973; Cropley, 1972; Drevdahl, 1956; Harrington, Block, & Block, 1983; Hocevar, 1980; McRae & Costa, 1987; Milgram & Milgram, 1976; Runco, 1984, 1986, 1992; Torrance, 1988; Wallbrown & Huelsman, 1975; Zegas, 1976), however alternate data have appeared addressing problems using divergent thinking to define and predict creative achievement and creative personality (cf. Brittain & Beittel, 1964; Gough, 1976; Kogan & Pankove, 1974; Skager, Klein, & Schultz, 1967). These studies have been used in the literature to support the assertion that divergent thinking should not be used as a measure of creativity. Although these alternative data provide valuable information about the possible inappropriateness of divergent thinking tests for predicting creative achievement, it should be noted that creative achievement has been established as a higher-level construct that requires affective components (motivation, drive) and social resources as well as creative thinking

skills. The creative thinking process, however, is thought to be subsumed by basic processes tapped by divergent thinking, and its value as a tool in studying real-time cognitive components of creativity, including its biological bases, cannot be discounted.

Neurobiological Bases of Creative Thinking

Creativity research has been divided in terms of approaching a consensus on where to search to further understand creative behavior. The majority camp has approached creativity through social and educational research; however those who have considered a reductionist approach have treated creative thinking similarly to other thought processes that have a neurocognitive basis. Consider the position of Csikszentmihalyi who wrote:

Many psychologists develop a vocational inability to perceive the true systemic nature of phenomena and insist on looking at them as if they were caused by individual processes. They keep searching for creativity inside the head—or in the DNA, or in the hormones. But this quest is doomed to failure, because one cannot discover a relation by analyzing only one of its components (Csikszentmihalyi, 1993, p. 189).

Owing to the complexity of the construct and its varied manifestations, both lines have resulted in substantial support for their positions. Although creative performance is affected substantially by social and educational factors (Amabile, 1983; Boden, 2004), this research has not been able to sufficiently explain the bases of the creative thinking process. In order to address the commonalities between the requisite factors that allow creative thinking and the attributes of psychosis or psychosis-proneness that give rise to enhanced creativity, the creative thinking *process* must be studied. The first step in approaching the neurobiological basis of this process would be to determine whether a requisite heritable component exists for creative thinking.

The Genetic Bases of Creative Ability

Genetics plays an important role in partially validating neurobiological theories of creativity. If the assumption is that an underlying neurobiological mechanism exists that is responsible for enhanced creativity and that this mechanism could be passed from parent to child, then a genetic component to

either creative thought or creative achievement should exist. In one of the first investigations characterizing genetic components of creativity, performance in a specific type of divergent thinking ability (allusive thinking) was found to be similar in college students and their parents (McConaghy & Clancy, 1968), suggesting that there may be a genetic bias for creative thought processes. In addition, there is evidence that parents of creative writers are more externally creative (assessed through ratings) than relatives of non-creative writers (Andreasen & Canter, 1974). Other studies addressed the environmental influence and the effects of genetics by using twins or adoption studies to address the heritability of creative thinking. Interestingly, the first adoption studies of gene-environment interactions in schizophrenia revealed anecdotal evidence of enhanced ability in the biological children of schizophrenic mothers who had been reared away (Hammer & Zubin, 1968; Heston, 1966; Heston & Denney, 1968). Another adoption study found that rates of mental illness in biological parents and in adoptees themselves, but not in adoptive parents or siblings, were positively related to creative achievement in adulthood (McNeil, 1971). Unfortunately, this study failed to measure creativity in the biological relatives of the adoptees in addition to rates of mental illness.

Heritability: Heritability estimates ($h^2 = 2(r_{MZ} - r_{DZ})$) for creative ability have been calculated from twins for divergent thinking and for creative personality by specifying the phenotypic variance attributable to the genetic variance. For divergent thinking, ten twin studies represented an average r_{MZ} of 0.61 and r_{DZ} of 0.50, resulting in an h^2 estimate for divergent thinking at 0.22 (reviewed in (Nichols, 1978)). An additional study that examined several cognitive variables including divergent thinking in monozygotic (MZ) and dizygotic (DZ) twins reported h^2 for the Torrance Tests of Creative Thinking (a validated and normed psychometric test of divergent thinking) at 0.43, which was higher than the heritability estimate for Wechsler FSIQ ($h^2 = 0.29$) from the same twins (Grigorenko, LaBuda, & Carter, 1992). In one of the first investigations characterizing genetic components of creativity, allusive thinking ability was found to be similar in college students and their parents (McConaghy et al., 1968), suggesting that there may be a genetic basis for this type of creative thought processes. These, along with the adoption studies previously mentioned, provide converging evidence that there is at least a moderate

genetic influence on creative ability, and that this may be subsumed by the ability to think divergently. However, it is difficult to integrate these data into several historical accounts of creative achievement that have shown that “creativity” per se does not run in families, especially at the level of genius (Eysenck, 1995). McNeil’s (1971) study also showed that creativity and rates of mental illness were not correlated among biological siblings.

Emergenesis: This apparent contradiction, that creativity is at least somewhat genetic but does not appear at high levels within families (Rothenberg & Wyshak, 2004), has been explained by emergensis, and has received some empirical support. Gough’s Creative Personality Scale from the Adjective Checklist, which significantly predicts creative achievement (Kaduson & Schaefer, 1991), was given to MZ and DZ twins in the Minnesota Twin Study (Waller, Bouchard, Lykken, Tellegen, & Blacker, 1993). The h^2 obtained separately for MZ twins was 0.54, but for DZ twins it was small and *negative* (-0.06). With a similar twin sample, subjective reports of art interest and ability yielded an h^2 estimate of 0.63 for MZ twins and 0.07 for DZ twins (Lykken, McGue, Tellegen, & Bouchard, 1992). These results support the idea of creativity being an emergent trait. As such, creativity requires the culmination and integration of several other lower-level traits, and it is unlikely that these phenotypes would exist simultaneously within individuals in families given the significant variation that exists among family members (Waller et al., 1993). Furthermore, the theory of emergensis also stipulates that the unique gene combinations that result in the expression of emergenic traits are highly heritable (Lykken, 1981). Together, these data indicate a genetic basis for both creative thinking ability and creative personality, and they support the investigation of biological mechanisms that may result from genetic influence.

Functional Neuroimaging Studies of Creative Thinking

The earliest neuroimaging studies that have reported lateralized (mostly right hemisphere) contributions to creative thinking only examined a single hemisphere, a circumscribed brain region, or a limited spectral range of EEG frequencies (Martindale & Greenough, 1973; Martindale & Hasenfus, 1978; Martindale & Hines, 1975; Martindale, Hines, Mitchell, & Covell, 1984). This finding was

generally not supported during later investigations that took advantage of bilateral or full brain coverage. Interestingly, the shifts in attention and concentration measured by low frequency EEG that occur in creative thinking are similar to those experienced by unmedicated schizophrenics prior to hallucinations, providing further support for the similarity in mental processing that characterizes creativity and psychosis (Whitton, Moldofsky, & Lue, 1978).

EEG coherence analyses, measuring synchronous connectivity, support successful creative production by involving diverse and distal cortical regions that are connected by long cortico-cortical fibers (Bhattacharya & Petsche, 2002; Jausovec, 2000; Jausovec & Jausovec, 2000a; Molle et al., 1996; Molle, Pietrowsky, Fehm, & Born, 1997; Petsche, 1996; Petsche, Kaplan, von Stein, & Filz, 1997; Razoumnikova, 2000). There is also converging evidence that creative thinking requires integration *between* both frontal lobe hemispheres (Bekhtereva, Dan'ko, Starchenko, Pakhomov, & Medvedev, 2001; Bekhtereva et al., 2000; Carlsson et al., 2000; Jung-Beeman et al., 2004; Starchenko, Vorob'ev, Klyucharev, Bekhtereva, & Medvedev, 2000), especially in very creative thinkers, while intelligence may be related to facilitated integration *within* hemispheres (Jausovec, 2000; Jausovec et al., 2000a; Jausovec & Jausovec, 2000b). Gender differences have also been observed indicating that male subjects are more likely to show greater binding (coherence) bilaterally, while performance for females was characterized by unilateral (local) coherence of lower amplitude (Razumnikova, 2004).

EEG complexity, an estimate of individual cortical cell complexes that contribute to a signal, has also elucidated some of the neuronal bases of creative thinking and intellect. The “efficiency hypothesis” of intelligence was generally supported by several studies that found decreased cortical and subcortical involvement in problem solving tasks for highly intelligent subjects (Berent et al., 1988; Haier, Siegel, Tang, Abel, & Buchsbaum, 1992; Haier et al., 1988; Jausovec, 1998, 2000; Jausovec et al., 2000a, 2000b; Jausovec & Jausovec, 2001). Creative thinking, however is best served by *increased* cellular complexity in individual networks (Bekhtereva et al., 2000; Molle et al., 1996; Molle, Marshall, Wolf, Fehm, & Born, 1999; Molle et al., 1997; Starchenko et al., 2000). Although attentional resources are more variable in divergent thinking and less focused compared to convergent thinking, increased individual cellular

complexes are needed to arrive at creative solutions. To summarize these findings, intelligent subjects recruit fewer neural elements and utilize greater ipsilateral processing, while successful creative thinking involves greater recruitment of specialized cellular complexes and greater coherence between bilateral cortical regions.

More recently, MRI studies have revealed some of the neuroanatomic substrates of creative thinking styles, and they have allowed better temporal parcellation of the creative thought process in reference to different stimulus conditions. However, since a single operational definition of creative thinking has not been established, differential results must be taken into account in reference to the thinking paradigm that was used. Using an event-related fMRI paradigm, a recent study investigated the neural correlates of solving analogies, finding bilateral neural activation widely distributed in the frontal cortex and in the anterior cingulate cortex (Geake & Hansen, 2005). In an fMRI task that involved creative story generation, the investigators examined BOLD response to related and unrelated word sets while instructing subjects to be either creative or 'uncreative'. The right prefrontal cortex showed significant activation in the creative instruction condition while using unrelated words (Howard-Jones, Blakemore, Samuel, Summers, & Claxton, 2005). In a simultaneous fMRI/EEG study, increased BOLD activation was seen bilaterally in the frontal lobes and in the right temporal lobe during creative insight solution development, while EEG suggested that the right temporal activation (Jung-Beeman et al., 2004), and fMRI investigations have supported the role of the right hemisphere in processing novel metaphors (Mashal, Faust, Hendlar, & Jung-Beeman, in press).

One study that has bridged the differential data obtained from divergent and convergent thinking studies (Jausovec, 2000) has shown that convergent thinking arrives at logical goal based on a series of formal steps, recruiting a limited network that is specialized for determining the needed answer (Haier et al., 1992; Jausovec, 1998; Jausovec & Jausovec, 2000c). On the other hand, divergent thinking employs a greater number of neuronal complexes in specified regions that are well-connected to contralateral regions for direct bihemispheric processing. Successful convergent thinking involves being globally efficient, but creative thinking appears to engage selective circuits at higher levels. In particular, future

research should address the distinctions between bilateral integration and right hemisphere activation that are consistently seen in neuroimaging studies of creative thinking across various paradigms. These neuroimaging results support the idea of the creative process being distinguished by specific functional markers.

Psychopathology and Behavioral Investigations of Creativity

What kind of person is creative? Early human attempts to answer this question relied upon explanations that equated the creative temperament with psychopathology, but after the Second World War a growing interest in the human capacity for industry, exploratory science, and social change provided a context for examining individual differences in creative ability and the previously incongruous idea that mental illness may be associated with such high mental capacity (Vernon, 1970). Using the Five Factor Model of personality traits, there is much convergence regarding Openness: it is consistently associated with creative thinking and ability measures, which is not surprising since it is measuring facets of fantasy, aesthetics, feelings, actions, ideas, and values (King, Walker, & Broyles, 1996; McRae, 1987; Soldz & Valliant, 1999). Neuroticism is inversely related to creative thinking and ability, while Agreeableness and Conscientiousness were found to be unrelated (King et al., 1996; McRae, 1987). How does the substantiated link between creativity and psychopathology fit into this model of general personality? What incremental evidence can psychopathology add to understanding the bases of creative thinking beyond the traditional personality models?

Schizophrenia

In the first modern systematic study relating creativity and genius to madness and degeneration, Cesare Lombroso (1910) concluded that creativity was related to a psychotic subtype of mental degeneration, and subsequent studies found no definable relationship between psychiatric diagnoses and creativity (Juda, 1949). Additional theories have arisen linking creativity to schizophrenia through primary process thinking (Arieti, 1979), overinclusiveness (Hasenfus & Magaro, 1976), and the creative

use of schizophrenic language for poetry and song (Buck & Kramer, 1977). Experimental investigations of the schizophrenia-creativity relationship have generally not found support for enhanced creative ability in schizophrenics except for the similarities in conceptual style (Hasenpus et al., 1976). Unlike creative individuals, schizophrenics tended to have reduced tolerance for incongruous information (Cropley & Sikand, 1973), they showed concrete responses in divergent thinking tests similar to non-creative controls (Shimkunas & Murray, 1974), and they showed a greater propensity for pathology in states that otherwise enhance creativity (Kreitler, Kreitler, & Wanounou, 1988). One study suggested that these negative results could be due to diagnostic subtype, as non-paranoid (but disorganized) schizophrenics displayed superior performance to controls on divergent thinking tests (Keefe & Magaro, 1980). Andreasen and Powers (1975) compared the performance of creative writers, schizophrenics, and manic phase bipolar patients on an object sorting test scored for behavioral overinclusiveness and conceptual quality. The bipolar patients, rather than the schizophrenics, resembled the creative writers in behavioral and conceptual overinclusiveness. It is unclear how these results can be generalized beyond creative writing as a definition of creative ability.

Although these behavioral data may tell one story, the genetic and familial studies paint a different picture. Considering that the concordance rate for schizophrenia is significantly greater in MZ (50%) twins than in DZ (10%) twins, Scandinavian studies have sought to elucidate the genetic relationship between creativity and mental illness using retrospective analyses of birth and medical records. Defining high creative achievement as being listed in the *Who's Who* of Iceland, first and second degree relatives of psychotic patients were twice as likely to be listed compared to the general population (Karlsson, 1970). Extending the sample and using more precise definitions based on profession, close relatives of schizophrenic patients were more successful in scholarly and academic professions (Karlsson, 1983) and they were more likely to become successful in professions that emphasized art and scholarship (published authors, honors graduates, doctorates, professors, clergymen) rather than leadership (parliamentarians, lawyers, physicians, and engineers). The relatives studied in these samples represented 1/20 of the total population in Iceland, but 1/10 of the honor students in writing and poetry, and these

qualitative differences appeared to be equally related to family history of either schizophrenia or manic depressive psychosis (Karlsson, 1984). Although this relationship between psychotic relatives and academics and authors was confirmed 16 years later, it was also found to be true of mathematicians and of general school performance (Karlsson, 2001). In fact, excellent school performance was retrospectively linked to developing schizophrenia in a Finnish cohort (Isohanni, Jarvelin, Jones, Jokelainen, & Isohanni, 1999), providing evidence that overall intellectual ability, including creativity, is associated with schizophrenia (Karlsson, 1978).

Given these compelling familial studies, it is relatively easy to believe that frank schizophrenia, associated with executive dysfunction, sensory gating abnormalities, thought disorder, and cerebral abnormalities may comprise a neuropsychological profile that is systematically distinct from the metacognitive abilities associated with creativity. So why do predicted associations between schizophrenia and creativity still exist reinforced by genetic and familial studies? Schizophrenics also display attentional disinhibition (Park, Lenzenweger, Püschel, & Holzman, 1996), remote semantic associational networks (Spitzer, Braun, Maier, Hermle, & Maher, 1993b), and overinclusive thinking (Hasenfus et al., 1976). Individuals who display the schizophrenic-like qualities associated with creativity but without the debilitating features of schizophrenia that impair cognitive function may provide the key to this hypothesized relationship (Eysenck, 1993; Karlsson, 1970) that has not yet been sufficiently studied.

Schizotypy

Schizotypy (Eysenck & Eysenck, 1976; Meehl, 1962) describes a constellation of traits that is phenomenologically and genetically related to schizophrenia, and increased schizotypal traits represent a latent liability for schizophrenia (Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994; Lenzenweger, 1991; Tyrka et al., 1995a; Tyrka, Haslam, & Cannon, 1995b). Most factor analytic and clinical conceptualizations of this constellation of traits support a tridimensional model of schizotypy: traits that cluster along the *positive*, *negative*, and *disorganized* symptoms of schizophrenia (Claridge & Beech,

1995). Although a substantial amount of research in schizotypy has concentrated on the deficit model, especially in relation to schizophrenia, it is equally important to examine the factors that may protect schizotypes from progressing into schizophrenia. Although others have shown a relationship between trait schizotypy and creativity, Venables (1989) has argued that schizotypes with high IQ may be able to direct their cognitive abnormalities toward creative, rather than dysfunctional, cognitive output. Indeed, the data suggest evidence in support of these concepts, as divergent thinking and creative achievement measures have generally shown positive relationships with schizotypy measures. However, studies have not sufficiently addressed how psychometric intelligence could be mediating this relationship. Several studies (Getzels & Jackson, 1962; Taylor, 1960; Wallach et al., 1965) have determined that intelligence plays a secondary role in creativity (Andreasen, 1987) behind divergent thinking, personality, and motivational factors. The generally accepted view is that a minimal level of intelligence is a necessary, but not sufficient, trait for creative thought (Schubert, 1973), and that creativity and intelligence both represent optimal mental ability, however the distinctions between them have not been sufficiently defined.

To date, many studies (see Table 1) have investigated the relationship between schizotypy and creative thinking or achievement. Eysenck and Eysenck's (1976) conceptualization of Psychoticism purportedly measures aggressive, cold, egocentric, impersonal, impulsive, antisocial, unempathic, creative, and tough-minded traits. Therefore, many of the earlier studies investigated the Psychoticism-creativity relationship because Psychoticism is inherently defined by creativity. Although conceptually different from "schizotypy," Psychoticism may be measuring more schizoid or psychopathic traits; however it has also shown a genetic relationship with schizophrenia (Maziade et al., 1995). Thus, the relationship between creativity and Psychoticism may be non-specific (Schulberg, 2005). Overall, these studies have asserted a positive relationship between Psychoticism/schizotypy (a theoretical latent vulnerability for schizophrenia), divergent thinking variables, and some forms of creative productivity separate from divergent thinking ability. However, few investigations have sought to examine the causes of this relationship between trait schizotypy and creativity experimentally.

Table 1. Investigations of schizotypy and creative thinking or achievement

Study	Creative Thinking			
	Schizotypy Defined as	Creativity Defined as	Variables with a + Relationship	Variables with No or - Relationship
(Woody & Claridge, 1977)	P	W & K	P; fluency; originality	
(Kline & Cooper, 1986)	P	DT tests	P; word fluency	P; ideational fluency, flexibility; unique (-)
(Rust, Golombok, & Abram, 1989)	P	DT tests	“+” schizotypy; originality, fluency	schizotypy and flexibility (no)
(Rushton, 1990)	P	W & K	fluency	originality (-)
(Ward, McConaghy, & Catts, 1991)	P; PAb; PsAn	word halo test	P; word halo test fluency	
(Eysenck, 1993)	P	word assoc., Art Scale	P; DT originality, art complexity, fluency (non-verbal)	
(Poreh, Whitman, & Ross, 1994)	STA; Mid, Per Ab	TTCT		
(Stavridou & Furnham, 1996)	P	W & K	originality	fluency (-)
(Rawlings & Toogood, 1997)	P; STA	TTCT, W & K	P, STA; originality	P, STA; fluency (-)
(Zanes, Hatfield, Houtler, & Whitman, 1998)	P & DSM-III	RAT	suspiciousness	Mid; PAb (-)
(Merten & Fischer, 1999)	P	word assoc.	P; originality	
(Gianotti, Mohr, Pizzagalli, Lehmann, & Brugger, 2001)	Paranormal belief	word assoc.	Paranormal belief; originality of associations	
(O'Reilly, Dunbar, & Bentall, 2001)	O-LIFE: UnEx, Int Anh, CD, IN	TTCT	Un Exp; originality, flexibility; fluency	
(Weinstein & Graves, 2001, 2002)	Mid; PAb; SocAn	RAT, Uses	Mid; PAb; RAT	SoAn; RAT and Uses (-)
(Abraham, Windmann, Daum, & Güntürkün, 2005)	P	original, useful, imagery	conceptual expansion, originality	usefulness, practicality
(Folley & Park, 2005)	SPQ	DT	DT fluency,	
Creative Achievement				
(Götz & Götz, 1979a, 1979b)	P	professional artists	P; Male + Female artists ↑ P	
(Schuldberg, French, Stone, & Heberle, 1988)	Mid; PAb; IN; PsAn	figure pref.; DT; Gough	Mid; PAb; Imp Non; figure pref., biography	DT(Alternate Uses) or Gough (no)
(Schuldberg, 1990)	IN; hypomania	creative attitude, activity	Hypomania; Imp Non; attitudes, activities	
(Rushton, 1990)	P	publications	P; publication quantity	
(Eysenck & Furnham, 1993)	P	Barron-Welsh Art Scale	P; art complexity	
(Rawlings, Hodge, Sherr, & Dempsey, 1995)	P	music pref.	P; dissonance, heavy metal music	
(Merten et al., 1999)	P	Profession (writer, actor)	P; creative profession,	
(O'Reilly et al., 2001)	O-LIFE: UnEx, Int Anh, CD, IN	TTCT		College major (humanities vs. creative arts) (-)
(Kinney, Richards, Lowing, LeBlanc, & Zimbalist, 2001)	DSM-III SCT & schizoid traits	Lifetime Creativity	SCT & schizoid traits	schizophrenia (-)
(Nettle, in press)	UnEx, CD, IntAnh, IN	Poetry, visual arts, math	UnEx, CD	IntAnh

PAb: Perceptual Aberration; PsAn: Physical Anhedonia; Mid: Magical Ideation; UnEx: Unusual Experiences; Int Anh: Introverted Anhedonia; CD: Cognitive Disorganization; IN: Impulsive Non-conformity; SoAn: Social Anhedonia; DT: Divergent Thinking, TTCT: Torrance Tests of Creative Thinking, O-LIFE: Oxford-Liverpool Inventory, P: Psychoticism

Schuldberg (2001b) investigated traits associated with schizotypy and subclinical affective disorders in relation to creativity. In this diagnostically comprehensive study, creativity was defined in terms of figural preference, personal biography, everyday achievement, creative personality, and divergent thinking. Results indicated a positive relationship with hypomania, positive symptoms, thought disorder, and impulsivity, and a negative relationship with depression and negative symptoms. Thus, there is integrative evidence for relating “positive” symptoms, and not “negative” ones, to creative achievement and creative personality. The study employed thinking process measures of creative thinking in addition to creative achievement. These variables are equally important to understanding the relationship between creativity and schizotypy in reference to motivation and productivity (Schuldberg, 2001a), and they may provide discriminant data for comparing creative thinking to creative achievement in psychopathology.

Although these studies have generally found overwhelming support for a positive relationship between creativity and various conceptualizations of schizotypy, the Schizotypal Personality Questionnaire (SPQ(Raine, 1991)), based on the nine syndromes of schizotypal personality disorder as defined by DSM-III-R, has not been investigated at all in relation to creativity. Both Mednick’s and Guilford’s assertions that creativity is associated with few common responses and many more unique responses were supported in relation to schizotypy, strengthening the specific relationship between ideational fluency and schizotypy. These divergent thinking variables, in addition to creative achievement, appear to be positively related to either the positive or disorganized factors of schizotypy rather than the negative or “schizoid” ones. Even with this substantial convergence of descriptive studies, the causes for the positive relationships have not been adequately explained. Thus, the SPQ has the potential to provide both incremental and additive evidence to the body of research that already exists.

Bipolar Disorder and Cyclothymia.

Unlike theories linking creativity to schizophrenia and psychosis-proneness, the association between creativity and bipolar disorder lacks a possible unifying explanation (Eysenck, 1995). Even so, much of the biographical data linking creativity to “madness” has shown that several eminent artists,

statesman, musicians, poets, and the like have suffered from what appears to be an affective psychosis (Jamison, 1989, 1993, 1995). Individual examples, like that of composer Robert Schumann (Jamison, 1995), have shown a clear positive association of creative productivity with manic episodes, and a negative association with depressive episodes (Weisberg, 1995). The common link between creativity and bipolar disorder and schizophrenia may be through a conceptual expansion of the current nosology, going back to the roots of the *Einheitspsychosen* theory (Neumann, 1859) that equates many of the features of bipolar and schizophrenic psychoses into one unitary concept (Eysenck, 1995) that may be operating in a latent phase before the full expression of each disorder (Crow, 1990).

Studies of creative achievement assessment in individuals with bipolar disorder have not provided support for these biographical accounts (Rothenberg, 2001), and very little experimental work has been done in an effort to elucidate the cognitive, behavioral, or neural mechanisms that may be operating in association with bipolar disorder and creativity. However, there is some evidence that first degree relatives of bipolar patients are more likely to be involved in creative professions (Ludwig, 1998). Limited familial data suggests that bipolar disorder is more prevalent in creative writers, and family history of affective illness is positively correlated with creative occupations (Andreasen, 1987). In addition, one study found that creative writers have a higher history of diagnosed alcoholism combined with affective disorder diagnoses compared to individuals not involved in creative arts (Andreasen et al., 1974). Results from experimental manipulations assessing lithium use on creativity did not support the anecdotal evidence (Jamison, 1993; Phillips, 1982) that lithium disrupts the creative energy experienced during a manic episode, as more than half of the creative individuals reported an increase in creative productivity while they were taking lithium while less than 20 percent decided to discontinue using lithium because of its adverse effects on their subjective creative production (Judd, Hubbard, Janowsky, Huey, & Attewell, 1977; Judd, Janowsky, Huey, & Takahashi, 1977; Marshall, Neumann, & Robinson, 1979; Schou, 1979).

Considering these tempting results in the face of previous limitations, one well-designed study (Richards, Kinney, Lunde, Benet, & Merzel, 1988) compared creative accomplishments between bipolar

disorder patients, cyclothymes, non-affected relatives, and normal controls using the Lifetime Creativity Scales (Richards, Kinney, Benet, & Merzel, 1988). This study confirmed that cyclothymes and first degree relatives of cyclothymes and bipolar disorder patients (all representing increased genetic liability for bipolar disorder without expressing full symptoms) had higher creative achievement compared to normal controls, affective controls, or bipolar disorder patients themselves. Similar to findings in schizophrenia, it appears that creativity may in fact be linked to this form of psychosis as well, but in its milder, genetically predisposed variants compared to the acutely ill probands.

Thus, much of the literature investigating the creativity/psychopathology link has asked, ‘is schizophrenia or is bipolar illness related to enhanced creativity?’ However, this question may be inappropriate as the link may reside in a common factor to both. This factor, psychosis-proneness, is thought to be operating in both taxometric and dimensional conceptualizations of schizophrenia.

Summary

Creativity is a definable and measurable construct of interest, and proper operational definitions of creativity warrant more comprehensive behavioral science research. Although full conceptualizations of creativity encompass personality traits, interests and abilities, motivation and need in addition to the distinct processes that characterize creative production, it is the creative thinking process that can best be understood by cognitive neuroscience. Because it is one of the more concretely operationalized definitions of creativity, divergent thinking has been widely studied. It encompasses a thinking style that underlies the process of creative productivity, and it is positively associated with creative personality, interests, and abilities. It forms the basis of a multidimensional construct, and it has the power to uncover a much broader series of cognitive and behavioral elements that are subsumed by this distinct style of thinking. Studying the processes that underlie or enhance creative thinking ability in psychiatric populations is an efficient method of psychological inquiry because it has the potential to extract bidirectional explanations. That is to say, that if processes inherent in creative thinking are enhanced in psychiatric populations, then studying these populations may elucidate elements of the creative process

common to all individuals. In addition, studying the creative thinking processes may indicate cognitive processes or neurobehavioral elements that may be operating in the pathogenesis of mental illness. A sufficient foundation has been established regarding this relationship, and future research should concentrate on elucidating the specific mechanisms responsible for it.

CHAPTER III

INDIVIDUAL DIFFERENCES: CREATIVE THINKING ABILITY IN SCHIZOPHRENICS, SCHIZOTYPES, AND NORMAL CONTROLS

Since the presentation of the idea, “schizophrenia paradox” (Huxley, Mayr, Osmond, & Hoffer, 1964), efforts to explain the stable existence of schizophrenia in spite of reduced fecundity (Larson & Nyman, 1973) and increased mortality (Brown, 1997) have proposed a compensatory advantage for the genes associated with schizophrenia (Brune, 2004). Crow (1995a, 1995b) has asserted that the origins of schizophrenia and language are linked through cerebral asymmetry. Thus, language disturbance and thought disorder, as is seen in schizophrenia, may be the result of incomplete hemispheric specialization; and there is evidence to suggest that individuals with schizophrenia, their relatives, and those with schizotypal personality traits have anomalous cerebral lateralization. The benefit of incomplete hemispheric specialization could result in increased interhemispheric communication, associative processing, and ideational flexibility (Crow, 1997).

Complementing Crow’s view from a neurochemical perspective, Horrobin (1998, 2001) has also proposed an evolutionary theory linking changes in lipid biochemistry to increased microconnectivity and plasticity that may lead to psychoses and creativity at the same time. Horrobin (2001) proposed that alterations in fatty acid metabolism may have produced changes in synaptic connections that lead to enhanced divergent thinking, schizophrenia, bipolar disorder, and possibly dyslexia which is also associated with phospholipid abnormalities (Richardson et al., 1999), schizotypy and mixed handedness (Richardson, 1994), and enhanced creative ability (Wolff & Lundberg, 2002). These two theories converge in: (1) emphasizing the importance of cognitive flexibility and neural plasticity; (2) conceptualizing psychoses on a continuum; and (3) providing theoretical links for connecting the schizophrenia spectrum to creativity (Folley, Doop, & Park, 2003).

There is little support for enhanced creative ability in schizophrenics themselves (Andreasen et al., 1975; Cropley et al., 1973; Keefe et al., 1980; Shimkunas et al., 1974), yet several studies have sought

to elucidate the relationship between creativity and psychosis using retrospective analyses of birth records. These studies supported the theory of increased creativity in the relatives of schizophrenic individuals, rather than the probands themselves (Karlsson, 1970, 1984), suggesting that enhanced creativity may be masked by the psychotic illness in the probands but can be detected in those individuals who share latent liability for psychosis. Many studies have provided overwhelming support for a positive relationship between creativity and schizotypy (cf. Eysenck et al., 1993; Gianotti et al., 2001; Kline et al., 1986; Merten et al., 1999; O'Reilly et al., 2001; Poreh et al., 1994; Rawlings et al., 1997; Rushton, 1990; Rust et al., 1989; Weinstein et al., 2001, 2002; cf. Woody et al., 1977; Zanes et al., 1998).

Divergent and creative thinking may be characterized by increased cooperation of both hemispheres (Atchley et al., 1999; Bekhtereva et al., 2000; Carlsson et al., 2000), and reduced hemispheric dominance has also been linked to creativity (Claridge & Broks, 1984). Musicians, a particularly creative group, are more likely to be left-handed on average than the general population (Hassler, 1990; Jäncke, Schlaug, & Steinmetz, 1997), and this may be an effect of non-dominant hand specialization that is required with musical training, especially in string players (Christman, 1993; Hassler & Gupta, 1993). In a series of three very large studies, Coren (1995) demonstrated that left-handedness was positively associated with divergent thinking, although this effect was gender-dependent.

There is robust evidence for the more frequent occurrence of mixed handedness in schizophrenia (Cannon et al., 1995; Crow, Done, & Sacker, 1996; DeLisi et al., 2002) and in schizotypes (Annett & Moran, in press; Chapman & Chapman, 1987; Claridge, Clark, Davis, & Mason, 1998; Kim, Raine, Triphon, & Green, 1992; Richardson, 1994) rather than pure left-handedness (Shaw, Claridge, & Clark, 2001). Mixed handedness is associated with decreased cerebral lateralization, schizotypy and enhanced creativity (Claridge et al., 1984). However, several neuroimaging and lesion studies had also reported specific right hemisphere correlates of creative thinking (Bowden & Beeman, 2003; Jung-Beeman et al., 2004; Martindale et al., 1984; Miller & Tippett, 1996b; Razumnikova, 2004), although such unilateral functional preference may also be an outcome of *intra*hemispheric cooperation (Petsche, 1996;

Razoumnikova, 2000). However, a direct comparison of these studies is problematic because definitions of “creativity” vary wildly.

Past studies with schizophrenics have generally relied on biographical records rather than on empirical tasks to assess creativity; and few examined handedness or laterality despite the relationship between hemispheric asymmetry, psychosis, and creative thinking. Because psychosis may also mask enhanced creativity, the relationships between creativity, handedness, and psychosis may be more clearly observed in healthy individuals who carry the latent liability for schizophrenia. Examining a clearly-defined aspect of creativity in schizotypal individuals in relation to brain laterality is warranted.

Existing psychometric tests measure creativity according to Guilford’s (1959) and Mednick’s (1962) theories of divergent thinking and associative processing according to the use of generative, flexible responses that redefine or elaborate upon an existing product or idea, emphasizing the generation of novel associations. The Wallach and Kogan test (Wallach et al., 1965) includes instances, alternate uses, similarities, and pattern and line ideation. The Torrance Tests of Creative Thinking (Torrance, 1974) measure verbal and figural creativity in addition to a general ‘creativity index’. The Remote Associates Test (Mednick, 1962) examines the ability to recognize remote verbal associations, and it has been viewed primarily as a test of convergent, rather than divergent thinking (Kyriacou et al., 2003). There are particular drawbacks to using these tests in laboratory studies of creativity. Although they have shown excellent predictive validity (Cropley, 2000; Millar, 2002; Wallbrown et al., 1975) and are therefore useful in educational settings, many have questioned their external validity (Yamada & Tam, 1996).

Understandably, psychometric assessment tools must balance several issues including validity and reliability in addition to ease of administration in order to achieve appropriate normative data. However, experiments can circumvent these issues while creating paradigms that are specific representations of operational definitions. What is particularly absent from these tests is specifying goal-oriented versus exploratory creativity, internal controls for creative cognition (the absence of concurrent stimuli), and probing conceptual combinations based on tangible, rather than theoretical standards (Ward, Smith, & Finke, 1999). Accordingly, a more powerful paradigm would address a specific, goal-directed

approach to creative thinking that would present subjects with tangible “problems”. It would also be attentive to time while allowing subjects to produce solutions according to their own associative hierarchy rates (Wallach, 1971). Therefore, there is much need for new “creativity” tests.

The Schizotypal Personality Questionnaire (SPQ) (Raine, 1991) was developed based on DSM-III-R symptoms of schizotypal personality disorder, which is a well-known predisposing factor to schizophrenia (Lenzenweger, 1991; Tyrka et al., 1995a). No other investigations appearing in the literature prior to this proposal have used the model suggested by Raine to address the relationship between creativity and schizotypy, thus investigating this relationship may provide incremental validity to the 20 or so studies that have already investigated the relationship between schizotypy and creativity according to other theoretical models. Factor analysis of the SPQ suggests a three factor structure including cognitive-perceptual deficits (odd beliefs/magical thinking, unusual perceptual experiences, paranoid ideation), interpersonal deficits (social anxiety, loneliness, constricted affect, paranoid ideation), and disorganized traits (odd speech, odd behavior) (Raine et al., 1994). This structure arising from the SPQ converges quite well with other measures of schizotypy. The one notable exception is the one proposed by Eysenck (Psychoticism) which may also include traits associated with borderline and psychopathic personality rather than with purely “schizotypal” personality.

Aims

The principal aim of the following studies was to examine the relationship among divergent thinking and creativity in relation to schizophrenia and schizotypy. The investigation had two major goals: (1) to provide incremental support for the association between enhanced creative thinking ability and schizotypal traits using the DSM criteria for schizotypal personality as contained in the SPQ; and (2) to determine if there is evidence for a relationship between divergent thinking, schizotypy, and reduced dextrality as an impetus to progress with a neuroimaging study of hemispheric group differences in divergent thinking among schizotypal, schizophrenic, and normal control subjects. A novel behavioral task was chosen instead of one used in the literature because, although several divergent thinking tasks in

present use have been shown to have high internal and external validity, they rely a great deal on creative imagery and representational inference (Finke, 1996). The novel task was chosen because it removed this inferential step (“Imagine you have a brick and think of all of the uses for the brick”) so that the subjects would be presented with the actual object(s) that they were supposed to use in the creative process. Although this difference may be relatively minor, it was a step towards using a more clearly defined divergent thinking test in psychological research.

Method

Participants

Demographics and clinical characteristics for subjects in the normal control, schizotypal, and schizophrenic groups are presented in Table 2. Overall, fifty-one subjects participated in the study (17 schizophrenic, 17 schizotypal, and 17 control subjects). Outpatient schizophrenic subjects were recruited from a local mental health cooperative. Control and schizotypal subjects were recruited from the community using posted signs and flyers. These individuals were recruited as a single group, and then they were assigned to group inclusion in this study based on their SPQ score (described below). All subjects were screened for the following criteria: substance abuse, neurological disorders, and history of head trauma. All patients were taking atypical antipsychotic drugs (clozapine, risperidone or olanzapine) at the time of testing, and were stable on medication. Schizophrenic subjects were assessed for symptom severity using the Expanded Brief Psychiatric Rating Scale (BPRS;(Lukoff, Nuechterlein, & Ventura, 1986)) and the Scales for the Assessment of Positive (SAPS) and Negative (SANS) Symptoms (Andreasen, 1982; Andreasen & Olsen, 1982). As shown in Table 2, there were no significant group differences in sex ($\chi^2(2, N=51) = 1.43, ns$); years of education ($F(2,48)=2.36, ns$); handedness ($F(2,48)=0.27, ns$); design fluency ($F(2,48)=2.67, ns$); letter fluency ($F(2,48)=2.37, ns$); or FSIQ intelligence ($F(2,48)=3.03, ns$). Of note, schizophrenia patients had lower category fluency scores than schizotypal or control participants ($F(2,48)=9.28, p<.001$). The study was reviewed and approved by the

Vanderbilt University Institutional Review Board, and informed consent was obtained from all participants. The testing session lasted approximately two hours, and subjects were compensated for their participation.

Table 2. Demographic and clinical characteristics of the sample for the behavioral study

Demographic Variable	Group		
	Normal Control N=17	Schizotypal N=17	Schizophrenic N=17
% female	47%	47%	29%
Age	35.2 (3.1)	22.8 (1.8)	39.5 (2.6)
Years of Education	12.9 (0.3)	13.9 (0.3)	13.0 (0.5)
Laterality Score	60.3 (15.2)	45.9 (13.3)	54.7 (13.4)
SPQ	20.9 (1.8)	44.7 (2.1)	-
BPRS	-	-	25.0 (3.9)
SANS	-	-	28.5 (3.9)
SAPS	-	-	27.3 (5.7)
WASI FSIQ	101.6 (3.4)	111.1 (3.5)	100.4 (3.2)
Letter Fluency	41.5 (2.6)	42.5 (3.0)	34.7 (2.8)
Category Fluency	36.8 (1.7)	40.0 (1.5)	31.2 (1.2)
Design Fluency	8.4 (0.8)	10.8 (0.9)	8.6 (0.7)

Values are given as mean (SE).

Design and Material

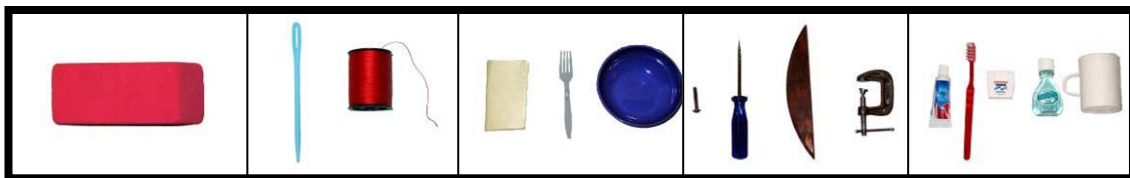
The novel divergent thinking task was developed to examine creativity in outpatients with schizophrenia, healthy psychometrically-ascertained schizotypal individuals and healthy normal control subjects. The task that that was devised follows the theoretical structure and instructions given to subjects that other well-validated divergent thinking tasks have followed (Guilford, 1959; Torrance, 1974; Wallach et al., 1965). In particular, this task has been set up as an “alternate uses” task, employing two

notable exceptions to those already in use: (1) the objects that subjects are asked to use in their creative thinking are present and accessible to all sensory modalities at the time of testing (unlike traditional divergent thinking tests where objects are verbally presented or described to subjects); and (2) in order to experimentally determine the effect of context on divergent thinking productivity, both conventional and ambiguous objects have been included in our task with an equal trial load for each type in order to determine the differential effect this provides for divergent idea production.

Procedure

There were two types of divergent thinking conditions (see Figure 2). In the conventional object conditions, subjects were presented with common, familiar objects in their customary context. In the

Conventional Stimuli



Ambiguous Stimuli



Figure 2. Conventional and ambiguous stimuli used in the divergent thinking task. Context was manipulated using conventional and ambiguous objects. The combinatory load was manipulated using between one and five objects on each trial. Subjects determined uses for each trial (Total = 10), giving either uses for individual (singular) items in a trial, or by describing how the items within a trial could be used together (combinatory).

ambiguous object conditions, ambiguous, unfamiliar objects were presented. Each trial contained 1-5 objects. The task was to generate ‘uses’ for the objects. For each condition, the task demand was varied by asking subjects to generate uses for a combination of the objects that were presented. Both sets of trials employed an increasing “combinatory load”, as each of the five trial types for each set of objects contained between one and five different objects. This combinatory load was manipulated because combining and juxtaposing ideas through trial and error processes has been thought to be a hallmark of creativity (Boden, 2004; Campbell, 1960; Simonton, 2003). During the divergent thinking task, subjects were presented with each of the ten trials separately in pseudorandom order. They were asked to use their imaginations in order to determine uses for the objects. They were told that these uses could be for separate objects or for combinations of objects within a trial, and a set of instructions including several examples of singular and combinatory uses were given for sample sets of objects. There was no time limit, and responses were recorded verbatim in test booklets. Subjects notified testers when they felt that they had exhausted all possibilities on a trial, at which point the next trial began. Singular responses were those that included a single object from the trial in a use description, and combinatory responses were uses that had been given for multiple (2 or more) objects together within a trial.

Measuring Creative Personality and Achievement

The Gough Creative Personality Scale (Gough, 1979) derived from the Adjective Checklist (Gough & Heilbrun, 1965) has been widely used to measure personality traits associated with increased creativity. The subset of items taken from the Adjective Checklist that have become part of the Creative Personality Scale consists of 30 items, 18 of which are strongly endorsed by creative individuals and 12 of which are almost never endorsed by creative individuals. Therefore, an individual score derived from the Creative Personality Scale items can range from -12 to +18. Items on the Creative Personality Scale with positive factor loadings include resourceful, insightful, individualistic, and reflective. Examples of those with negative factor loadings include conservative, conventional, narrow interests, and

commonplace. The Creative Personality Scale significantly predicts creative achievement (Kaduson et al., 1991) and is sensitive to inherited components of creative ability (Waller et al., 1993).

Recently, the Creative Achievement Questionnaire (Carson, Peterson, & Higgins, 2005) has become available for assessing real-life creative achievements that can be assessed outside of abilities on laboratory tests of creative ability. The Creative Achievement Questionnaire is a self-report measure of creative achievement that assesses achievement across 10 domains of creativity. Its test-retest reliability was $r = .81$, and internal consistency was $\alpha = .96$. The ability of the Creative Achievement Questionnaire to predict creative product ratings was $r = .59$. Convergent validity with other measures of creative potential was: divergent thinking tests ($r = .47, p < .0001$); Gough Creative Personality Scale ($r = .33, p = .004$); Intellect ($r = .51, p < .0001$); and Openness to Experience ($r = .33, p = .002$). Factor analysis identified a two-factor solution labeled as Arts and Science.

Validity and Reliability of the Divergent Thinking Task

Convergent and discriminant validity of the novel divergent thinking task were examined by comparing performance with a widely used test of verbal creativity, the Remote Associates Test (RAT) (Mednick, 1962), which was completed by all subjects. The scoring method proposed by Mednick (“correct” solutions; convergent thinking) was used in addition to an association score produced by having subjects list individual associations to each word triad on the RAT (divergent thinking). As expected, the total number of uses score on the alternate uses task was significantly correlated ($n = 49$) with the number of associations produced on the RAT ($r_s = .48, p < .001$). Correlations were strong for RAT associations with number of uses for conventional objects ($r_s = .39, p < .01$) and number of uses for ambiguous objects ($r_s = .52, p < .001$). However, measures of convergent thinking assessed by number of correct responses on the RAT were *not* associated with total, conventional, or ambiguous alternate uses scores ($r_s = .11$ to $.16, p = ns$). This lack of a significant correlation between the novel task’s divergent thinking variables and a different task’s (RAT) convergent thinking variables provides an initial measure of discriminant validity.

External validity was examined using measures of creative personality traits and of real-life creative achievement. A subset of the subjects (N=28; n_{SZ}=12, n_{SCT}=8, n_{NC}=8) in this experiment were given the Gough Creative Personality Scale and the Creative Achievement Questionnaire. External creative achievement in several ability domains was assessed using the Creative Achievement Questionnaire. Both creative achievement and creative personality traits were significantly associated with divergent fluency measures from the alternate uses task, as seen in Table 3. These data indicate a positive relationship between divergent thinking ability and creativity that exists outside of laboratory tests of creative thinking. In addition, these data provide converging evidence that the complex construct of creativity can be validly measured by laboratory tests of creative thinking abilities and that these tests are strongly associated with other facets of creativity that may be related to a more complex construct.

Table 3. External validity of divergent thinking measurements with creative achievement and personality

Creativity Measure	Divergent Thinking Variable				
	Conventional Uses	Ambiguous Uses	Total Uses	Conventional Combinatory	Ambiguous Combinatory
CAQ	.69*	.68*	.76*	.72*	.64*
Gough CPS	.47‡	.51*	.49*	.48*	.40*

CAQ: Creative Achievement Questionnaire; CPS: Creative Personality Scale

All correlations are Spearman's rho (r_s).

Significance: ‡ = $p < .05$; * = $p < .01$

Schizotypal Personality

Subjects (normal controls and schizotypes) completed the SPQ (Raine, 1991), which assesses schizotypal personality traits obtained from a total score, subscale scores (*Ideas of reference, Excessive social anxiety, Odd beliefs or magical thinking, Unusual perceptual experiences, Odd or eccentric behavior, No close friends, Odd speech, Constricted affect, and Suspiciousness*), and factor scores (*Cognitive-perceptual, Interpersonal, and Disorganized*). To date, over 100 individual subjects were screened for elevated schizotypal traits using the SPQ (N = 116; 59 males, 56 females). The average SPQ

total score is 21 within our total sample (SD = 11), and the “high” range (1.5 SDs above the mean) is a total SPQ score of 37 or above. This is approximately equivalent to the data obtained in the original normative sample for the SPQ (Raine, 1991). Therefore, subjects in our ‘normal control’ group had a total SPQ score < 21, and the ‘schizotypal’ group had a total SPQ score > 37.

Handedness and Neuropsychological Measures

Laterality scores (range -100 to +100) were calculated for each subject based on the Modified Edinburgh Handedness Inventory (Oldfield, 1971; Schachter, Ransil, & Geschwind, 1987), which was used to assess hand preference. In order to control for the effects of psychometric intelligence and non-creative fluency, verbal fluency (lexical fluency using F, A, and S (Spreeen & Strauss, 1998), category fluency (semantic fluency using animal and boys’ names categories) (Spreeen et al., 1998), and design fluency (non-verbal fluency using the Five Point Test) (Regard, Strauss, & Knapp, 1982) were used to estimate fluency in relation to frontal lobe functioning. Psychometric intelligence was estimated using the WASI (Wechsler Abbreviated Scales of Intelligence, The Psychological Corporation, 1999).

Results

Scoring

Three dependent variables were examined for trials involving generating uses for conventional and for ambiguous items: number of singular uses, number of combinatory uses, and time spent. For each of the ten divergent thinking trials, responses were summed after examination to exclude repeated responses. Singular uses were calculated by summing the responses within each stimulus set that were comprised of a use given to one of the objects in a set. Combinatory responses were calculated for each trial by summing the number of responses that included a use for at least two objects within the stimulus set. In addition, a total response time for each trial was calculated. Interrater reliability for the divergent thinking task administration and scoring of number of uses was high ($r_{ICC} = .94$).

Number of Singular Uses

Using a repeated measures ANOVA with number of singular responses as the dependent variable, group as the between subjects factor, and object type (conventional, ambiguous) as the repeated measures factor (Figure 3), the main effect of group was significant, $F(2,48) = 6.39$, $p < .01$, $r_{\text{effect size}} = .49$.

¹Schizotypes ($M = 120.59$, $SE = 22.43$) generated more uses than normal controls ($M = 67.24$, $SE = 5.9$) ($p < .05$) and schizophrenics ($M = 55.18$, $SE = 5.56$) ($p < .01$). The main effect for object type was significant, $F(1,48) = 5.73$, $p < .05$, $r_{\text{effect size}} = .47$. Subjects gave more responses to ambiguous items ($M = 43.14$, $SE = 4.84$) compared to conventional items ($M = 37.86$, $SE = 4.16$). The interaction between group and object type was not significant, $F(2,48) = .44$, $p = ns$.

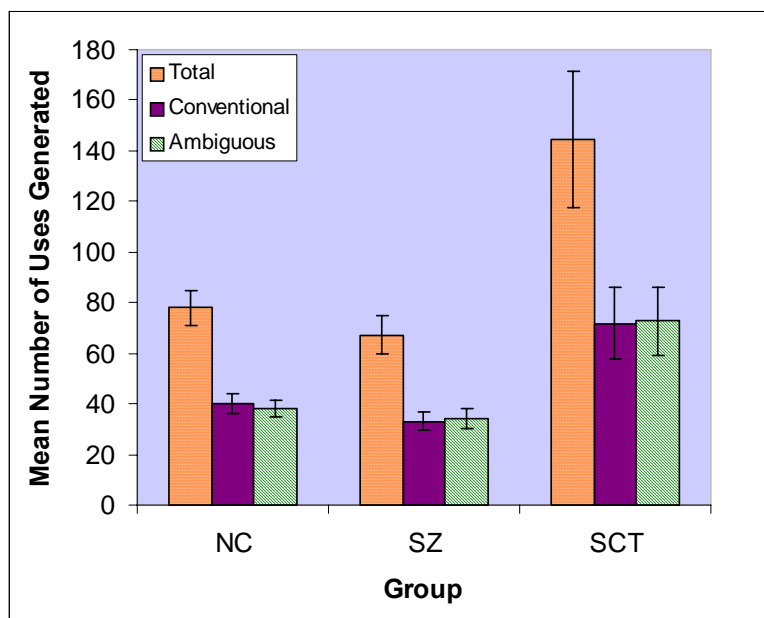


Figure 3. Number of singular uses generated by subjects for different object types.

¹ For these and subsequent analyses, assumptions of the general linear model have been tested. When Levene's test for variance homogeneity is not significant, analyses are followed by Dunn or Sidak post-hoc tests for multiple comparisons. When Levene's test is significant, the GLM is still used, however the Games-Howell post-hoc test is employed because it uses a pooled variance term to correct for unequal variance components.

Number of Combinatory Uses

With regard to the dependent variable, number of combinatory responses, data were analyzed using a repeated measures ANOVA with group as the between subjects factor and object type (conventional, ambiguous) as the repeated measures factor (Figure 4). The main effect for group was significant, $F(2,48) = 4.26$, $p < .05$, $r_{\text{effect size}} = 0.40$. Schizotypes gave more combinatory responses ($M = 24.0$, $Se = 5.37$) compared to schizophrenics ($M = 12.0$, $SE = 2.46$) ($p < .05$), and compared to normal controls ($M = 10.82$, $SE = 1.61$) ($p < .05$). The main effect of object type was also significant, $F(1,48) = 19.16$, $p < .001$, $r_{\text{effect size}} = .72$; indicating that overall, subjects made more combinatory responses to conventional items ($M = 10.39$, $SE = 1.54$) compared to ambiguous items ($M = 5.22$, $SE = 0.82$). The interaction between group and object type was not significant, $F(2,48) = .686$, $p = ns$.

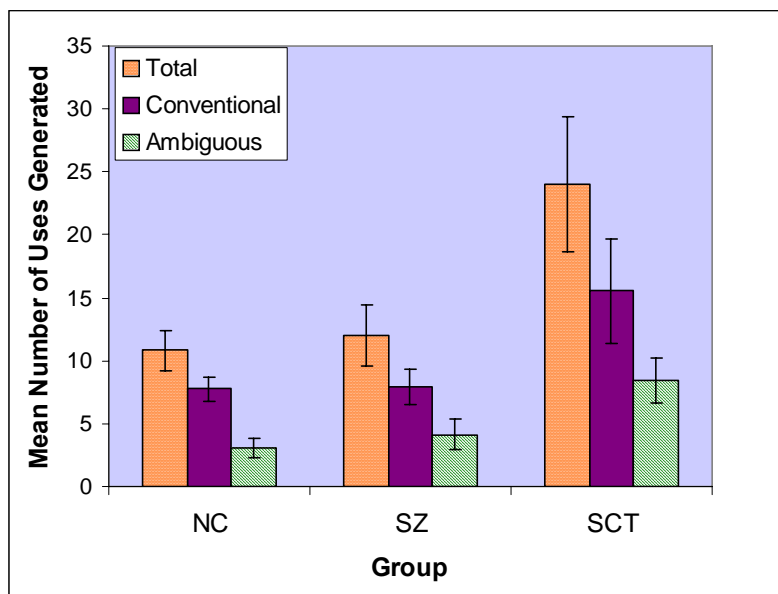


Figure 4. Number of combinatory uses generated by subjects for different object types

The Effect of Intelligence

One of the problematic methodological issues in creativity research is disambiguating the effect of psychometric intelligence from creative ability. Because a new divergent thinking task has been

presented in this experiment, and because it forms the structure for the construct being studied in the following series of investigations, the data were re-analyzed partialing out the effect of intelligence. The relationships between psychometric intelligence and divergent thinking can be seen in Table 4. An ANCOVA was performed with psychometric intelligence (FSIQ) as a covariate in the analysis. For the dependent variable, number of singular uses, the covariate, FSIQ, was significant, $F(1,47) = 4.0, p < .05$, $r_{\text{effect size}} = .39$ indicating that the effect of psychometric intelligence contributed significantly to group differences in the non-combinatory level of divergent thinking and intelligence (singular uses). The main effect of group was significant, $F(2, 47) = 3.97, p < .05$, $r_{\text{effect size}} = .39$. Means adjusted for the covariate explain this effect. Overall, schizotypal subjects ($M = 67.68, SE = 8.34$) generated more uses compared to

Table 4. Relationships between psychometric intelligence and divergent thinking variables

	Divergent Thinking Variable					
	Conventional Uses	Ambiguous Uses	Total Uses	Conventional Combinatory	Ambiguous Combinatory	Total Combinatory
Full Scale IQ (FSIQ)	.48	.43	.48	.49	.54	.53

Correlation is Spearman's rho (r_s).

Significance: all reported correlations significant at $p < .001$

schizophrenics ($M = 36.32, SE = 8.13$) ($p < .05$). The main effect of type, $F(1, 47) = 2.30, p = ns$, and the interaction between type and group were not significant, $F(1, 47) = 2.32, p = ns$. For the dependent variable, number of combinatory uses, the covariate, FSIQ, was significant, $F(1, 47) = 7.40, p < .01$, $r_{\text{effect size}} = .52$ indicating that there was a significant, positive relationship between psychometric intelligence and this combinatory level of divergent thinking in reference to group differences. However, the main effect of group was not significant, $F(2, 47) = 2.10, p = ns$, nor was the main effect of object type, $F(1, 47) = 0.59, p = ns$, nor the interaction between group and object type, $F(2, 47) = 0.23, p = ns$.

Rate

Using a repeated measures ANOVA with response rate (number of uses/second) as the dependent variable, group as the between subjects factor, and object type (conventional, ambiguous) as the repeated measures factor, the main effect of object type was significant, $F(1,48) = 46.72$, $p < .001$, $r_{\text{effect size}} = .85$. Subjects responded overall at a higher rate to the conventional object trials ($M = 7.1 \times 10^{-2}$, $SE = 3.6 \times 10^{-3}$) compared to the ambiguous object trials ($M = 5.9 \times 10^{-2}$, $SE = 3.3 \times 10^{-3}$). The main effect of group was not significant, $F(2,48) = 1.49$, $p = ns$. The interaction between group and object type was not significant, $F(2,48) = 0.465$, $p = ns$.

Associations with Schizotypy Factors

To examine the relationship between divergent thinking performance and schizotypal characteristics, non-parametric correlations (r_s) were calculated for associations between total uses generated, uses for ambiguous objects, uses for conventional objects, and total SPQ scores, SPQ factor scores, and the individual sub-factors that comprise the disorganization factor. All analyses were one-tailed due to the hypothesized positive correlation between schizotypal traits and divergent thinking scores. Corrections for multiple comparisons were not used.

Results from the analysis can be seen in Table 5. Total scores on the SPQ were significantly associated with each of the separate measures of divergent thinking fluency calculated, and all correlations were in the positive direction. The Disorganization cluster was particularly associated with each of the measures of creative fluency. Because the Disorganization cluster is a composite score based on responses investigating patterns of “odd speech” and “odd behavior”, correlations were calculated for these sub-factors separately. The odd speech factor was positively and significantly associated with each of the measures of divergent thinking fluency. Odd behavior was positively associated with each divergent thinking measure as well, but the association with conventional object type (singular and combinatory uses) was not significant. Overall, higher scores on the SPQ were associated with greater

creative use generation. This was especially true of the disorganization cluster, measuring factors related to language, communication, and non-verbal expression.

Table 5. Correlations between divergent thinking scores and SPQ total and factor scores.

Stimulus Type	SPQ Scores					
	Total	Positive	Negative	Disorganized	Odd Speech	Odd Behavior
Total Singular Uses	.44*	.31‡	.24	.46*	.45*	.43*
Conventional Objects	.35‡	.25	.20	.35‡	.35‡	.30
Ambiguous Objects	.44*	.35‡	.19	.49*	.47*	.48*
Total Combinatory Uses	.40*	.24	.34‡	.43*	.44*	.37‡
Conventional Combinatory	.37‡	.18	.37‡	.33*	.38‡	.34
Ambiguous Combinatory	.46*	.33‡	.28	.51*	.52*	.44*

Correlation is Spearman's rho (r_s). N = 51.

Significance: ‡ = $p < .05$; * = $p < .01$

Total SPQ score was inversely associated with handedness ($r_s = -.34$, $p = .06$). In particular, the disorganization factor was significantly associated ($r_s = -.51$, $p < .01$) with decreased dextrality. Endorsing items on the SPQ measuring odd patterns of speech and behavior were particularly associated with decreased dextrality. However, the relationship between all SPQ variables and handedness was in the inverse direction, even for the cognitive-perceptual ($r_s = -.27$, $p = ns$) and interpersonal ($r_s = -.14$, $p = ns$) factors, which did not reach significance.

Associations between Divergent Thinking Scores and Handedness

The relationship between Edinburgh scores and scores on each of the divergent thinking fluency variables were examined (Table 6). Laterality scores (range -100 to +100) were calculated for each subject based on the Modified Edinburgh Handedness Inventory (Oldfield, 1971; Schachter et al., 1987), which was used to assess hand preference. As can be seen from Table 6, there is an inverse relationship

between divergent thinking scores and handedness. Although two of the divergent thinking scores are significant, this did not pass a correction for multiple comparisons. Therefore, it is not the two significant correlations (total ambiguous object uses and combinatory ambiguous object uses) that are noteworthy, but that the direction of the relationship for all variables is in the inverse direction. This implies that anomalous laterality, or decreased dextrality, is associated with greater divergent thinking.

Table 6. Correlations between divergent thinking scores and handedness scores from the Edinburgh Handedness Inventory

Stimulus Type	Group			
	Normal Control (n = 17)	Schizotype (n = 17)	Schizophrenic (n = 17)	All Subjects (N = 51)
Total	-.26	-.26	-.16	-.21
Conventional Objects	-.20	-.02	-.14	-.15
Ambiguous Objects	-.24	-.40	-.24	-.26‡
Total Combinatory	-.18	-.22	-.20	-.21
Conventional Combinatory	-.01	-.26	-.14	-.14
Ambiguous Combinatory	-.33	-.25	-.20	-.27‡

Correlation is Spearman's rho (r_s). N = 51.

Significance: ‡ = $p < .05$

Discussion

To our knowledge, this is the first study to investigate relative divergent thinking ability in schizotypes, schizophrenics and normal controls. This study was undertaken in order to replicate previous experiments that have reported enhanced creative thinking ability in psychometric schizotypes with two added components. First, the utility of a new divergent thinking task was examined, and schizophrenics, schizotypes and normal controls were tested within the same experiment. Creativity was not defined by profession or hobby interests, rather the creative thinking process determined the final dependent variable, and creative thinking was further examined for its association with other “external” creative attributes.

These data compliment previous studies that have found evidence for enhanced divergent thinking in schizotypal individuals, and incremental validity for these findings has been provided by using the DSM criteria of schizotypy measured by the SPQ. This finding was not dependent on prior associative context among the stimuli used, as there was no interaction between group and stimulus type. Although previous behavioral studies of cognition in schizophrenia tended to find decreased ability compared to normal controls, this experiment found statistically equivalent performance in divergent thinking between these two groups. The measure of *combinatory responses* may be a more robust determinant of creative thinking due to the increased associative load, and schizotypes also performed better on this measure compared to the other two groups. There is evidence that divergent ideational fluency may differ in the way information is processed compared to semantic fluency. The finding that schizophrenia patients demonstrated lower category, but not phonemic, fluency compared to normal controls has been observed previously (Kremen, Seidman, Faraone, & Tsuang, 2003), however, both groups were equivalent in creative fluency measures. Creative thinking has been associated with frontal lobe function (Miller et al., 1996b), while semantic fluency may be more sensitive to temporal lobe function (Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998). This may indicate relative preservation in a specific frontal-mediated process in schizophrenia in spite of data suggesting executive dysfunction (Heinrichs & Zakzanis, 1998).

Divergent thinking ability was particularly associated with disorganized schizotypal traits; SPQ items that load onto this factor address slight abnormalities or oddities in speech and in non-verbal behavior. Because these traits are associated with social communication and transmission of ideas, this may imply an association between creative production and the ability to express unconventional ideas. Trait schizotypy may confer a preferential advantage to both. Handedness measures indicated that schizotypy and divergent thinking are both related to decreased dextrality. In order to address the neural components of these relationships, a subsequent experiment has been employed to monitor prefrontal hemispheric activity in a version of the divergent thinking task that was modified for functional brain imaging.

Phillips and Silverstein (2003) have asserted that disorganized symptoms in schizophrenia may be particularly related to abnormal cortical connectivity in schizophrenia. In the present series of investigations, Chapter III demonstrated that creativity was most strongly related to disorganized traits in schizotypy. Factor analytic studies have shown that cognitive disorganization is a unique factor contributing to the overall trait cluster (Gruzelier, 1996; Maziade et al., 1995; Raine et al., 1994). Future studies may aim to refine the neurobiological investigation of the relationship between creativity and schizotypy by concentrating on larger groups that exhibit largely disorganized traits.

This study included only right-handed individuals. It would be helpful to investigate the full range of handedness in relation to divergent thinking and schizotypy, as these data suggest that schizotypy and divergent thinking are both related to decreased dextrality. Our schizophrenia patients were chronic and medicated, but they were matched to controls for IQ and verbal fluency. What is remarkable is that this group of patients showed a range of cognitive deficits including memory (e.g. Park, Lee, Folley, Anderson, & Kim, 2004) and perception (Kim, Doop, Blake, & Park, in press), yet they perform as well as normal controls on divergent thinking.

One ongoing difficulty frequently encountered in creativity research is how to measure the construct. Subjecting the present paradigm to measures of convergent, discriminant, and external validity has identified an initially valid procedure that is relatively easy to administer in a laboratory setting on a variety of subject groups. The variation of alternate uses task used in this study can then be seen as an alternative for other tests of divergent thinking that have been criticized for lacking external validity and for requiring too much “imagination” that might not map well onto actual, non-laboratory scenarios where creative thinking must be applied and implemented. For the divergent thinking task used in this investigation, convergent and discriminant validity measures have been examined, and the task converges well with the general construct of ‘creativity’ that is of ultimate interest.

Although Eysenck’s factor structure of Psychoticism was not examined in this investigation, there was a strong positive relationship between divergent thinking and the SPQ Disorganization factor. As previously discussed, there are several reports of a strong positive association between divergent thinking,

creativity, and Psychoticism in the literature. Gruzelier (1996) has found that Psychoticism loads significantly onto the SPQ Disorganization factor, and future investigations may want to establish a more focused relationship between creativity and schizotypy by investigating the specific associations between Disorganization, Psychoticism, and creativity. In the most recent study published thus far examining the relationship between Psychoticism and creativity (Abraham et al., 2005), the investigators found that Psychoticism was related to creative thinking ability through associative thinking and conceptual expansion, similar to ideas of overinclusiveness and allusive thinking. Therefore, future investigations may serve to elucidate the relationship between schizophrenia, schizotypy, and normal controls in terms of allusive thinking ability, and determine if this thinking style is related to measures of 'alternate uses' divergent thinking tasks.

In terms of the internal purposes that this experiment was undertaken to support, the evidence indicates that schizotypes indeed evidence enhanced creative thinking, and in particular, a highly associative style of creative thinking as measured by the combinatorial uses variable. There is reason to undertake further studies investigating the neurocognitive bases of this enhancement. Prior research has indicated that anomalous cerebral lateralization may characterize psychometric schizotypes and that this type of cerebral organization may provide a venue for more efficient associative, unusual, and creative thinking. In fact, many studies have appeared in the literature reporting enhanced creative thinking in schizotypes, however few of them have investigated the possible neural substrates of this finding. Evidence from psychological and biological experimental investigations of creative thinking, creative achievement, and psychopathology can presently converge to approach a unified theory of the relationship between creativity and psychopathology. Research in the biological bases of creativity has, for the most part, ignored the available information concerning the biological bases of psychopathology. Likewise, basic process research in schizophrenia has not been sufficiently linked to available data in the biological bases of creativity. The cognitive neuroscience approach to investigating these types of questions must now be invoked in order to provide testable theories that can begin to establish the next phase of this line of research. Although linking creativity to psychopathology or to underlying

biochemical processes has helped to generate new theories and hypotheses, synthesizing and integrating these theories will increase their potential impact and power, and this will in turn guide future research. There are sufficient available data to begin to bridge the gaps in both theories and this coalescence will provide a meaningful link to expanding the biological bases of creativity and the ways in which these processes are inherently linked to the phenomenology of psychoses and subclinical spectrum disorders.

CHAPTER IV

HEMISPHERIC CONTRIBUTIONS TO DIVERGENT THINKING: A DIVIDED VISUAL FIELD 'HALO' TASK BETWEEN SCHIZOPHRENICS, SCHIZOTYPES, AND NORMAL CONTROLS

Although the functional neuroanatomy of the left hemisphere has become synonymous with language function, a similar categorical function for the right hemisphere has not been so clearly defined. Jaynes' (1976) theory of the "Bicameral Mind" opened the right hemisphere to more mysterious levels of cognition in human evolution, including hallucinations and communication with gods. In this way, a bicameral mind became associated with psychopathology and with before unexplained levels of consciousness. Maybe it has been the mystery, or complexity of function, that has led to the conception that the right brain is creative and expansive, while the left is autocratic and involved in rule-based strategies. However, it is useful to recall Lezak's (1995) objective reasoning when she wrote, "The bilateral integration of cerebral function is most clearly exhibited by creative artists who typically enjoy intact brains." Given that cerebral integration is undoubtedly important in creative thinking, what then is the precise role of the right hemisphere in creative thought? The present study attempts to elucidate some aspects of hemispheric processes in creative thinking associated with schizotypy, schizophrenia, and normal control subjects.

The right and left hemispheres are certainly functionally and anatomically different, and much research had been focused on their distinct properties including language, calculation, music, and humor (cf. Davidson & Hugdahl, 1995; Hugdahl & Davidson, 2003). The neurosurgeon, Joseph Bogen, who pioneered the commissurotomy procedure, was the first to address the neurological relationship between thinking styles and hemisphericity (Bogen, 1975) when he addressed the right hemisphere's *appositional*, or creative mind, in contrast to the *propositional* mind associated with left hemisphere's primary language functions. According to this conceptualization, intelligence tests are particularly targeted at measuring left hemisphere abilities, while it is the right hemisphere that provides the creative abilities that are difficult to

measure through conventional psychometric means. (cf. Gowan, 1979). Early studies of commissurotomy patients supported right hemisphere involvement in spatial and affective processing, and it was hypothesized that these patients would be impaired in creative thinking (Bogen & Bogen, 1969).

The concept that the right hemisphere alone contributes to creative thinking has persevered in the popular as well as in the scientific literature. However, there are no known experimental studies on creative thinking in split brain patients. Still, observational reports do suggest that many creative geniuses and professionals have been left-handed (Katz, 1980; Peterson & Lansky, 1974). In a series of three very large studies, Coren (1995) demonstrated that left-handedness was positively associated with divergent thinking (and not with convergent thinking). Divergent thinking scores were 28% higher among those who were most left-handed compared to right-handed subjects. Research in psychopathology has found substantial associations with left-handedness, as 28% of individuals with serious mental illness are left-handed, compared to 9% in the general population (Hicks & Barton, 1975).

Hormonal influences on the developing brain influence cortical dominance, as females are more likely to show diffuse lateralization and some left hemisphere dominance, and males often show strong asymmetries and some right hemisphere functional dominance (Wisniewski, 1998). Increased divergent thinking ability has been seen in males (Russ, 1988) and females (Richardson, 1986), and some studies have found no differences (Alpaugh & Birren, 1975). Similarly, significant gender differences have not been noted in regard to creative personality in the U.S. (Borod, Grossman, & Eisenman, 1971; Simpkins & Eisenman, 1968), but they have been noted in other cultures (Ibrahim, 1976). Although inconclusive, these studies suggest the possibility that sex could be interacting with environmental and cultural variables, but the question of sexual dimorphisms existing in creativity variables remains unanswered.

Flor-Henry (1969) and Crow (1990) have suggested that because left-handed individuals are more likely to have anomalous lateralization, schizophrenia may result from this anomalous laterality, which may also appear with increased incidence of left-handedness. Indeed, there is robust support for mixed handedness in schizophrenia (Cannon et al., 1995; Crow et al., 1996; Green, Satz, Smith, & Nelson, 1989; Malesu et al., 1996; Nelson, Satz, Green, & Cicchetti, 1993; Shimizu, Endo, Yamaguchi, Torii, & Isaki,

1985) and in schizotypy (Chapman et al., 1987; Claridge et al., 1998; Kim et al., 1992; Poreh et al., 1994; Richardson, 1994) rather than pure left handedness. In fact, pure left handedness is related to lower schizotypy scores (Shaw et al., 2001). Together, these data provide support for creativity and dimensions of schizophrenia being related to mixed handedness, and mixed handedness is associated with decreased cerebral lateralization (Claridge et al., 1984). Evidence from neuroimaging data suggests that creative thinking is characterized by increased cooperation of both hemispheres (Bekhtereva et al., 2001; Carlsson et al., 2000; Jausovec, 2000; Jausovec et al., 2000c; Orme-Johnson & Haynes, 1981; Razoumnikova, 2000; Starchenko et al., 2000), and reduced hemispheric dominance has also been linked to creativity (Claridge et al., 1984). However, investigations of the functional laterality of creativity in schizophrenic and schizophrenic-prone populations are absent in the literature.

Often, creative thinking uses language for thought generation and product expression, and divergent thinking models such as the one proposed by Mednick (1962) are intimately tied to the spread of information through semantic networks (Mednick et al., 1964a). The semantic network is generally conceptualized as a series of nodes (Collins & Loftus, 1975) that are connected by associational links, so nodes that are only indirectly related to the original stimulus are activated, then more original associations are made, and creative solutions are enhanced (Mohr, Graves, Gianotti, Pizzagalli, & Brugger, 2001; Pizzagalli, Lehmann, & Brugger, 2001). Schizophrenics (Spitzer, Braun, Hermle, & Meier, 1993a; Spitzer et al., 1993b; Weisbrod, Maier, Harig, Himmelsbach, & Spitzer, 1998) and schizotypes (Gianotti et al., 2001; Mohr et al., 2001; Pizzagalli et al., 2001) show increased indirect semantic priming, especially those with formal thought disorder (Moritz et al., 2001a; Moritz et al., 2001b) and mild language disturbances (Moritz et al., 1999). These data suggest that the spreading activation in semantic networks in schizophrenics and schizotypes is relatively fast and that the associative networks branch out to a greater degree, encompassing more indirectly related concepts. It also suggests that greater spreading activation could increase across hemispheres in individuals who have decreased or anomalous cerebral lateralization.

One study investigated semantic priming in relation to creativity (Atchley et al., 1999) using dominant and subordinate word meanings in a word priming task presented to either visual field. Priming for the dominant meaning was found regardless of divergent thinking ability; however the results indicated that only the group highest in divergent thinking ability showed priming for the subordinate words when presented to either the left or right visual fields. Groups lower in creative ability only showed subordinate priming when the stimuli were presented to the right visual field (left hemisphere), and some did not show subordinate priming at all. Like creative subjects, schizotypes are as efficient in lexical decision tasks when words are presented to the left hemisphere as when they are presented to the right hemisphere, unlike non-schizotypes who show a left hemisphere bias (Leonhard & Brugger, 1998). Studies examining similar phenomena without regard to subjects' creative ability have found that the left and right hemispheres may work synergistically processing both subordinate and distant (right hemisphere); and dominant and close (left hemisphere) word meanings (Faust & Lavidor, 2003; Rodel, Cook, Regard, & Landis, 1992). Evidence from ERP and fMRI have shown that the right frontal lobe is involved in generating unusual or distant verbal associations while the left frontal lobe is involved in generating "usual" associations (Kiefer, Weisbrod, Kern, Maier, & Spitzer, 1998; Seger, Desmond, Glover, & Gabrieli, 2000). Enhanced creativity, like schizotypy, may be associated with increased *interhemispheric* transfer (Miran & Miran, 1984), thereby making more efficient use of semantic networks to notice and generate close and distant associations.

Differential hemispheric dysfunction in schizophrenia has been shown using Gruzelier's (1984) conceptualization of the Active, Withdrawn, and Unreality syndromes. Accordingly, there is evidence for left > right hemisphere activity in the Active syndrome and right > left in the Withdrawn syndrome. This association has also been associated with schizotypal personality traits assessed using the SPQ (Gruzelier, Burgess, Stygall, Irving, & Raine, 1995) with 'positive' traits being associated with left temporo-parietal dysfunction, and 'negative' traits being associated with right temporo-parietal dysfunction. Additional evidence for this association indicates that individuals with the Withdrawn subtype show a right hemisphere face processing advantage, while the Active subtype is associated with a verbal report left

hemisphere asymmetry (Gruzelier & Doig, 1996). SPQ scales corresponding to the Active syndrome are the Odd Behavior and Odd Speech scales; while the Withdrawn syndrome is measured using the Constricted Affect, Social Anxiety, and Loneliness scales.

Because alternate uses divergent thinking tasks are not well-suited for tachistoscopic presentation, allusive thinking provides a way to present stimuli rapidly and to request immediate responses that can approximate the same type of concept divergence and conceptual boundary measurement inherent in other divergent thinking tasks. The Word Halo Test has been developed to measure allusive thinking ability, and high scorers are said to have allusive thinking because their subjective boundaries for related meanings include a greater number of concepts (Tucker et al., 1982). The Word Halo Test has been identified as a more “pure” measure of divergent thinking than other tasks because it only requires thought divergence (Kyriacou et al., 2003) rather than a combination of primary divergence and secondary convergence to arrive at a single “correct” answer. For the Word Halo Test, subjects are presented with 30 target words, each followed by five related words obtained from a thesaurus, and they are instructed to circle (hence “halo”) the words *most* related to the target (even though all words really are semantically related to the target word by design).

Aims

This experiment addressed hemispheric contributions to verbal and non-verbal creative thinking by assessing allusive thinking (pure thought divergence) for words and graphics presented to either visual hemifield. The primary question of this investigation was: *Which hemisphere (if either) would be specialized for non-verbal or verbal thought divergence, and did this hemispheric specialization interact with group membership or degree of schizotypy?* In order to investigate this question, words and non-verbal graphic stimuli were presented to individual hemispheres tachistoscopically and subjects responded by producing “halos” for individual target words and graphic stimuli as one would do on the Word Halo Test. For this, the Word Halo Test was modified for computerized administration and non-verbal stimuli were added. Schizophrenia patients, schizotypes, and normal controls were compared for

overall lateral thinking (between subjects effects) and thought divergence associated with each hemisphere (within subjects effects). The hypothesized effect was a significant interaction between the independent variables subject group, object type, and field/hemisphere such that schizotypes and schizophrenics would select more words or symbols (halo) when presented to either hemisphere (due to greater specialization in both hemispheres to correctly identify remote associates). On the other hand, normal controls would be expected to recognize remote associates in the left visual field/right hemisphere for symbols and in the right visual field/left hemisphere for words, although their conceptual “halos” should be reduced for words and symbols compared to both schizophrenic and schizotypal subjects.

Method

Because the original Word Halo Test was created to test allusive thinking using verbal stimuli only, it was necessary to create a non-verbal analog of the original stimuli. In addition, on the new version, careful consideration was made to select words based on word length and usage, which had not been considered on the original version. In order to select the best stimuli for the experiment, a pilot study was first conducted on a normal volunteer population in order to determine which letter and graphic sets provided the highest intersubject variance.

Stimuli (Table 7):

Verbal Stimuli. Each verbal target for the new Word Halo Test was a noun chosen for spoken word frequency in the English language (Leech, Rayson, & Wilson, 2001). Based on the occurrence frequency in one million words, each word chosen for the experiment had a frequency of between 0.0197% to 0.039%, and these fell in the 93.8% to the 98.6% cumulative percentage range for all nouns sampled. Each target word had 5 associated words that were gathered from Roget’s Thesaurus (Davidson, 2002) in the same way that the original Word Halo Test was created (Armstrong et al., 1977). This assured that each item contained a “target” word followed by five other semantically related words so that subjects could be instructed to select the words that were “nearly the same in meaning” as the target word.

Table 7. Stimuli used in the divided visual field experiment. 20 word and 20 graphic targets were presented in pseudorandom order. After each target presentation, one halo stimulus from the target set was presented, and subjects were instructed to decide if it was related to the target. Graphic targets based on (Li, 1994).

Target	Halo Stimuli				Target	Halo Stimuli			
Light	Beacon	Flare	Glow	Torch					
Land	Area	District	Region	Earth					
Order	Sequence	Peace	Calm	Decree					
Mind	Brain	Intuition	Power	Reason					
Road	Alley	Byway	Lane	Passage					
Paper	Tissue	Report	Journal	News					
Policy	Action	Approach	Course	Method					
Manager	Boss	Head	Officer	Organizer					
Society	Culture	Nation	People	Alliance					
Money	Bill	Cash	Finances	Payment					
Age	Maturity	Seniority	Epoch	Era					
Class	Branch	Rank	Clan	Pedigree					
Process	Course	Growth	Manner	Action					
Club	Baton	Hammer	Alliance	Fraternity					
Project	Activity	Design	Intention	Proposal					
Home	Dwelling	Residence	Nest	Hearth					
Back	Rear	Stern	Tail	Extremity					
Street	Route	Drive	Passage	Track					
Union	Blend	Fusion	Merger	Synthesis					
Use	Cause	Exercise	Habit	Practice					

When considering the effect of word length as presented to either hemifield, one study showed that there was no interaction between word length and hemifield in a divided visual field task (Fang, 2003). However, all words used were comprised of 4-7 letter strings.

Non-verbal (Graphic) Stimuli. For the non-verbal stimuli, logographic Chinese characters were chosen because they are not processed verbally by non-Chinese speakers (Ding et al., 2003) and because they could be used as a non-verbal correlate to the word halo paradigm. Because Chinese characters evolved from pictorial representations to more abstract patterns of strokes while retaining much of their original representational qualities, it is possible to arrange the logographs according to etymological evolution (see Table 7). Therefore, similar to word meanings, subjects can be asked to select stylized characters that look “nearly the same” or “most similar” to the original (etymologically earliest) characters. All characters were obtained from a corpus showing the etymological evolution of over 500 characters (Li, 1994). In order to control for spatial complexity (corresponding to word frequency control), only characters comprised of 4-6 strokes were used.

Pilot Study

Subjects. Thirty English-speaking normal control subjects not participating in the main experiment were chosen to participate. These individuals were given paper-and-pencil versions of the tasks that were later adapted for tachistoscopic presentation.

Method. The pilot session was conducted with all of the possible word and non-word combinations that could be used during the divided visual field experiment. Pilot subjects were given 70 verbal sets and 56 non-verbal sets of stimuli on paper. Although the instructions for the non-verbal stimuli (*circle the drawings that are most similar to the first drawing*) were created for this investigation, the verbal instructions were taken verbatim (*circle those words that are nearly the same in meaning as the first word given*) from the original Word Halo Test (Armstrong et al., 1977).

A verbal set consisted of a “target” word followed by four words that were semantically associated to the target. A graphic set consisted of a Chinese symbol “target” followed by four

etymologically related graphics. (See Table 7). For each target stimulus, participants were instructed to select those items that they considered to be most similar to the target stimulus (out of 5 possible choices). The items selected for inclusion in the final experiment were the 20 words and 20 graphics from the pilot study that had the greatest range of responses as measured by the variance.

Results. After subjects completed the paper-and-pencil versions of the verbal and graphic halo tasks, their responses were tabulated. The resulting sets for use in the lateralized presentation paradigm contained 20 target word sets and 20 target graphic sets. Overall, words and graphic targets were matched for word length ($M = 5.1$) and number of strokes ($M = 5.0$). The average word length of stimulus words was 6.2. The average variance for word halos was 1.7, and 1.8 for graphics. There was not a significant difference between halos derived from words compared to graphics ($t_{57} = 1.37, p = ns$).

Divided Visual Field Experiment

Participants. Overall, thirty subjects participated in the study (10 schizophrenic, 10 schizotypal, and 10 control subjects). Recruitment inclusion/exclusion criteria were the same as those for Chapter

Table 8. Demographic and clinical characteristics of the divided visual field sample

Demographic Variable	Group		
	Normal Control N=10	Schizotypal N=10	Schizophrenic N=10
% female	20	30	30
Age	35.2 (2.8)	22.3 (1.2)	31.4 (1.7)
Years of Education	13.3 (0.4)	14.9 (0.8)	13.6 (0.4)
Laterality Score	43.3 (24.8)	46.1 (18.9)	50 (18.4)
SPQ	14.9 (2.2)	43.2 (2.3)	-
BPRS	-	-	16.8 (4.9)
SANS	-	-	17.0 (4.9)
SAPS	-	-	12.3 (5.9)
WASI FSIQ	97.2 (5.6)	114.2 (4.1)	100.6 (6.3)

Values are given as mean (SE).

III. All patients were taking atypical antipsychotic drugs (clozapine, risperidone or olanzapine) at the time of testing. The study was reviewed and approved by the Vanderbilt Institutional Review Board, and informed consent was obtained from all participants. The testing session lasted approximately 1.5 hours, and subjects were compensated for their participation.

As shown in Table 8, schizotypes ($M = 22.3$, $SE = 3.7$) were younger, on average compared to schizophrenic ($M = 35.4$, $SE = 7.9$) or normal control ($M = 35.2$, $SE = 9.0$) subjects, $F(2,27) = 9.85$, $p < .01$. Subjects varied overall in psychometric intelligence (FSIQ), however this was not statistically significant, $F(2,27) = 2.72$, $p = .08$. Because all FSIQ scores fell within one standard deviation of the population mean (85-115), the possible increase in FSIQ for the schizotypal group compared to the normal control group was not meaningfully significant either. Amount of education ($F(2,27) = 2.59$, ns); sex ($\chi^2(2, N = 30) = 0.71$, ns); and laterality scores ($F(2,27) = 0.03$, ns) were matched across subjects.

Tachistoscopic Presentation. Tachistoscopic-like stimulus appearance was achieved by using rapid visual presentation on a computer display (Figure 5). Stimuli were presented by a PC on a 17 inch display using the E-Prime stimulus presentation software. Subjects were seated 50 cm. from the screen with their chins resting on a chinrest. Participants were instructed that they would see a target word or graphic in the center of the screen. They were told that after a delay and fixation they would see another stimulus word (for verbal targets) or stimulus graphic (for graphic targets) to either the left or right of fixation, but that it would appear very quickly. They were instructed to determine if the stimulus presented was related to the target or not and to press a key logging their response immediately after seeing the stimulus trial. Participants were further instructed to fix their gaze in the center of the screen at all times, and that response times and accuracy scores would be recorded. Therefore, they kept their index fingers positioned on the response keys at all times during the experiment to enable quick and accurate responses. The experiment was comprised of 2 runs. For $\frac{1}{2}$ of the trials, depressing the z key with the left hand logged a 'no' response and depressing the 3 number pad key with the right hand logged a 'yes' response. After half of the total trials were completed, subjects were given a break, and the responses were switched such that depressing the z key with the left hand logged a 'yes' response and depressing the

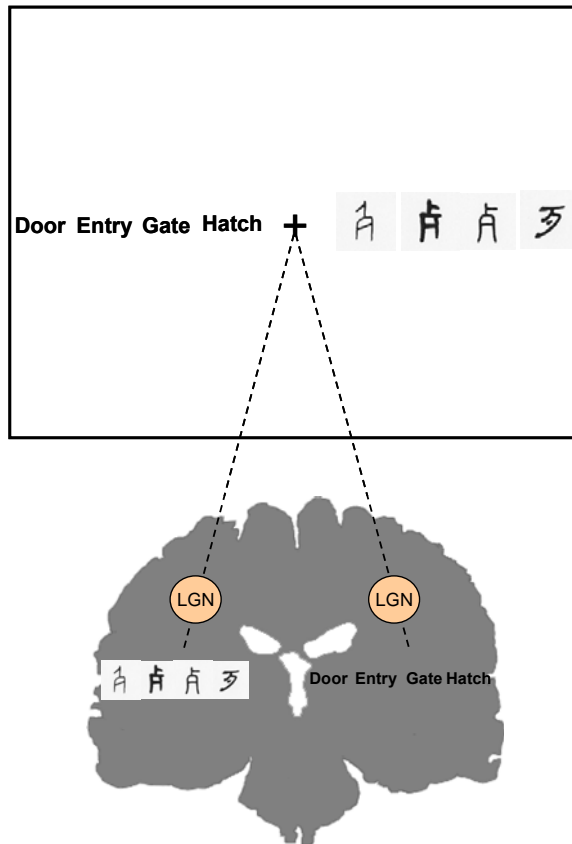


Figure 5. Divided visual field presentation. When subjects achieve foveal fixation immediately prior to receiving stimulus presentation to either the right or left visual fields; then stimuli presented to the left visual field are perceived in the right hemisphere, and those presented in the right visual field are perceived in the left hemisphere. In the present experiment, both words and graphic non-verbal characters were presented to both hemifields.

3 number pad key with the right hand logged a ‘no’ response. Each run was preceded by 15 practice trials with different stimuli balanced for visual field and target/stimulus type followed by 160 experimental trials. The order of stimulus presentation was counterbalanced across subjects. The practice trials verified instruction compliance and accustomed subjects to using their left and right hands to make appropriate responses. See Figure 6 for presentation details. Each trial began with the presentation of a target word or graphic for 3s. After a 350 ms. blank screen and a 500 ms. fixation, which directed subjects’ gaze to the center of the screen, the stimulus word or graphic appeared to the left or right of fixation for 150 ms. Following, a blank screen appeared for 1500 ms. signifying that subjects should log a ‘yes’ or ‘no’

response. A mask appeared for 2s. before the next trial began. Stimuli eccentricity was between 2.0° and 4.8° of visual angle. The stimuli subtended 0.6° by 0.6° of visual angle, as all words and graphics were presented in black superimposed on an identically sized white background. Overall, 20 verbal targets and 20 graphic targets were presented to subjects, and each target had four possible halo stimuli associated with it. Each stimulus was presented to the left and right visual fields for a total of 320 trials. Presentation to alternating visual fields was pseudo-randomized. Total time to finish the experiment was approximately 1 hour.

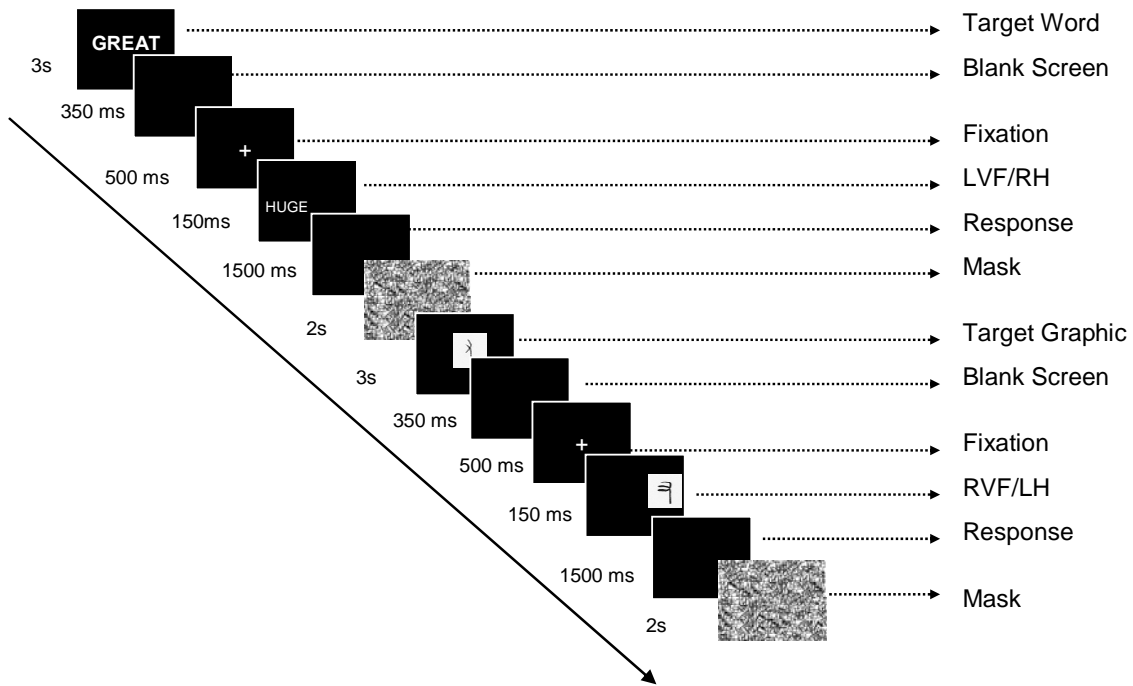


Figure 6. Schematic diagram of the tachistoscopic presentation paradigm used in the divided visual field experiment.

Results

Trial Performance

Overall, subjects gave valid responses to 92.4% of 320 possible trials (M=295.7, SE = 8.3). The number of total responded-to trials did not differ between groups $F(2,27) = 0.94, p = ns$; schizophrenia =

87.8% (M = 281.1, SE = 19.9), schizotypes = 96.1% (M = 307.4, SE = 8.6), NC = 94.2% (M = 301.3, S.E. = 8.8). In addition, there was no difference in total responded-to trials for stimuli presented to either the left (M = 148.1, SE = 4.2) or to the right (M = 148.5, SE = 4.2) hemifields; $F(1,27) = 0.20$, $p = ns$. However, subjects gave more overall responses to graphic stimuli (M=151.7, SE=3.9) than to verbal stimuli (M = 144.9, SE = 4.7); $F(1,27) = 8.74$, $p < .01$, $r_{\text{effect size}} = .66$. The two-way interactions between side and group $F(2,27) = 0.26$, $p = ns$; type and group $F(2,27) = 0.12$, $p = ns$; side and type $F(1,27) = 0.03$, $p = ns$; and the three way interaction between side, type, and group $F(2,27) = 0.02$, $p = ns$, were not significant.

Divided visual field experiments have been criticized for their test-retest reliability, where subjects showing a hemispheric advantage on one testing fail to show it on an identical task after a second testing. Because the experiment was completed using two runs, Cronbach's α was computed for responses to different stimuli types for each half of the experiment. For graphics, $\alpha = .95$; for words, $\alpha = .89$. This represented a high degree of consistency across testing runs.

“Halo”

The number of “yes” responses to verbal and non-verbal stimuli gives a direct measure of subjective boundary conceptualization and this is the variable that defines “allusive thinking”, which is the divergent thinking variable of primary interest in this task. By responding “yes” to a stimulus, a subject has essentially reported that they believe the stimulus to be related to the target, and the greater the number of “yes” responses, the more divergent the conceptual boundaries, since all stimuli used really were related to the associated targets. Because subjects varied in their responsivity to individual trials (missed trials), *percentage of ‘yes’ responses* was used as the primary dependent variable. This percentage is the proportion of responses given as ‘yes’ out of the number of responded-to trials in each category.

Data were analyzed using a repeated measures ANOVA with group (schizophrenic, schizotype, or control) as the within groups factor and side (left, right hemifield) and stimulus type (words, graphics)

as the within subjects factors (Figure 7). The main effect of group was not significant, $F(2,27) = 0.48$, $p = ns$. There was a main effect for stimulus type, $F(1,27) = 5.62$, $p < .05$, $r_{\text{effect size}} = .56$, indicating that overall, subjects found words ($M = 66.6\%$, $SE = 2.7\%$) to be related to their targets more often than they found graphics ($M = 59.1\%$, $SE = 2.8\%$) to be related to their targets in responded-to trials. The main effect for side (hemifield) was not significant, $F(1,27) = 0.38$, $p = ns$. The two way interactions between side and type, $F(1,27) = 0.001$, $p = ns$; group and type, $F(2,27) = 0.79$, $p = ns$; group and side, $F(2,27) = 0.11$, $p = ns$; and the three way interaction between side, type, and group $F(2,27) = 0.28$, $p = ns$, were not significant.

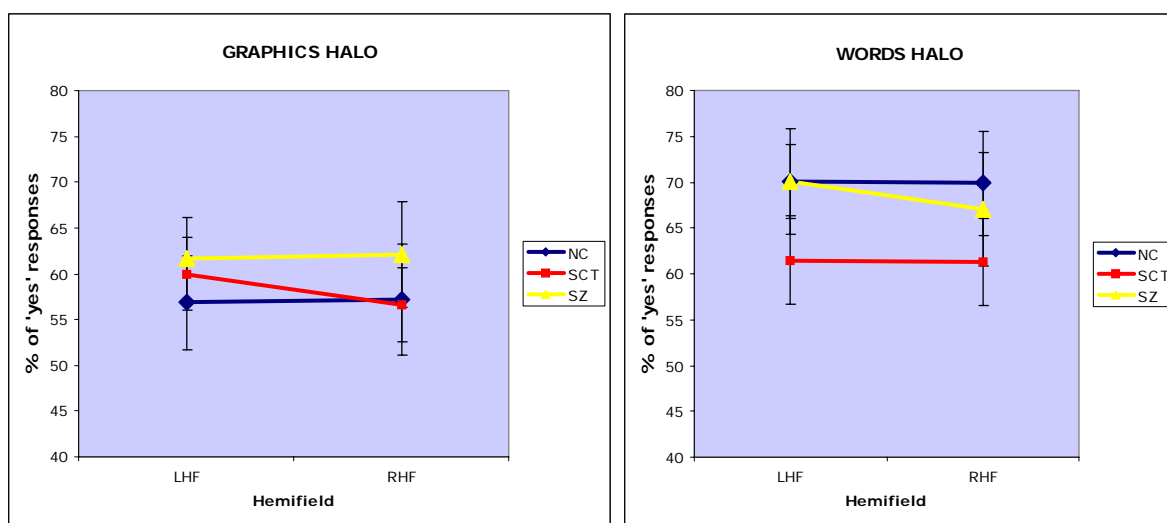


Figure 7. 'Halos' obtained by presentation of either words or graphics to either hemifield in each group. In order to control for an unequal number of overall responses made by subjects, results are reported as a ratio of 'yes' responses to total responded-to trials for that stimulus type. Error bars reflect ± 1 SE.

† NC=Normal Control; Schizotypes thinking=Schizotypal, schizophrenia= Schizophrenic; LHF=Left Hemifield; RHF= Right Hemifield

Response Time

For the dependent variable, response time, a repeated measures ANOVA with group (schizophrenic, schizotype, or control) as the between groups factor and side (left, right hemifield) and stimulus type (words, graphics) as the within subjects factors was conducted. There was a main effect for stimulus type, $F(1,26) = 52.48$, $p < .001$, $r_{\text{effect size}} = .92$, indicating that subjects responded more quickly to

graphic stimuli ($M = 698.0$ ms., $SE = 31.7$ ms.) compared to verbal stimuli ($M = 827.6$ ms., $SE = 27.5$ ms.). The main effect for presentation side was not significant $F(1,26) = 0.01$, $p = ns$, indicating similar response times for stimuli presented to the left or right hemifields. The two-way interactions between side and group $F(2,26) = 0.12$, $p = ns$; type and group $F(2,26) = 0.37$, $p = ns$; side and type $F(1,26) = 0.11$, $p = ns$; and the three way interaction between side, type, and group $F(2,26) = 0.68$, $p = ns$, were not significant.

External Creativity

Data from Chapter III have indicated that divergent thinking scores are positively associated with external creative personality and achievement variables. Because the precise relationship between ‘allusive thinking’ and divergent thinking has not been defined by previous research, it is important to note whether the participants in this experiment differed in their reported creative achievement or personality traits. Overall, there were differences in Gough Creative Personality Scale scores, $F(2,23) = 5.64$, $p < .01$; $r_{\text{effect size}} = .58$. Normal control ($M = 12.2$, $SE = 0.74$) subjects endorsed similarly high scores on the Creative Personality Scale as schizophrenic ($M = 8.6$, $SE = 1.34$) and schizotypal ($M = 13.43$, $SE = 0.78$) subjects, but schizotypal subjects endorsed more creative personality traits than schizophrenic subjects. No differences emerged between groups in creative ability as measured by the Creative Achievement Questionnaire, $F(2,21) = 0.36$, $p = ns$.

Relationships with Schizotypy

In order to determine if higher trait schizotypy is associated with conceptual overinclusion within this sample, and to examine the particular schizotypal traits associated with larger ‘halos’, Spearman’s rho was computed for each relationship. Total and factor scores from the SPQ were used in addition to the ratio of ‘yes’ responses to overall responded-to trials. This ratio was used rather than pure ‘yes’ responses in order to yield a more reflective score. Table 9 shows that overall, higher trait schizotypy was associated with lower halos. This was true particularly for halos to word stimuli.

Table 9. Associations between halo performance and schizotypal traits including the Active and Withdrawn subtypes

Hemifield	Stimulus Type	SPQ Score			
		Total	Cognitive Perceptual	<i>Gruzelier's Subtypes</i>	
				Interpersonal (<i>Withdrawn Subtype</i>)	Disorganized (<i>Active Subtype</i>)
LEFT	WORDS	-.46‡	-.34	-.54*	-.41†
	GRAPHICS	-.10	-.02	-.37	.01
RIGHT	WORDS	-.46‡	-.29	-.66*	-.31
	GRAPHICS	-.30	-.31	-.41†	-.09

Correlations are Spearman's rho (r_s).
 Significance: ‡ = $p < .05$; * = $p < .01$; † represents trend

The associations between 'halo' scores and trait schizotypy factors in this experiment were not as expected. Based on previous literature and on the findings presented in the series of experiments in this Dissertation, the strongest expected associations between creative thinking and schizotypal traits would be with the Disorganization factor. However, in the present experiment, the Interpersonal factor was most strongly associated with the 'halo' measure of lateral thinking. As an individual's conceptual halo increased, they tended to endorse fewer SPQ Interpersonal factor deficits.

According to Gruzelier's conceptualizations of the Active and Withdrawn subtypes in reference to differential hemispheric activation, the relationships between these subtypes and performance in the divided visual field task were examined. The Active subtype and SPQ Disorganization factors are identical as are the Withdrawn subtype and the SPQ Interpersonal factor. The Withdrawn subtype is associated with a decreased halo of responses in the left visual field, corresponding to right hemisphere processing, and for words in the right visual field, or left hemisphere.

Relationships with Divergent Thinking Variables

A subset of the subjects ($N = 22$; $n_{\text{schizophrenic}} = 10$, $n_{\text{schizotypal}} = 7$, $n_{\text{control}} = 5$) in this experiment also participated in the behavioral investigation of group differences in creativity (Chapter III). Across all subject groups, there was a tendency for the “halo” of graphics presented to the left visual field to be mildly associated with number of use scores from the divergent thinking task and with the number of associations made on the RAT, but not to correct scores on the RAT, the measure of convergent thinking (see Table 10). There were no associations between graphic halos presented to either hemifield or to verbal halos presented to the right hemifield and divergent or convergent thinking measures.

Table 10. Relationships between halo scores and divergent and convergent thinking

Hemifield	Halo Score	Divergent or Convergent Thinking Variable				Total Uses
		RAT Correct	RAT Associations	Uses for Conventional Objects	Uses for Ambiguous Objects	
LEFT	WORDS	.25	.23	.11	.31	.18
	GRAPHICS	.07	.39†	.32	.39†	.42‡
RIGHT	WORDS	.30	.24	.13	.28	.23
	GRAPHICS	.10	.29	.14	.15	.22

Correlations are Spearman’s rho (r_s).
Significance: ‡ = $p < .05$; † represents trend

Relationships with Creative Achievement and Personality

Investigating associations between creative personality traits, creative achievement, and variables from the halo task, there was a relationship between left visual field processing and halo (number of ‘yes’ responses). For word stimuli presented to the left visual field, halo was positively associated with creative achievement (Creative Achievement Questionnaire; $r_s = .45$, $p < .05$). In addition, there was a trend for a positive association between Creative Achievement Questionnaire scores and graphic stimuli presented to the left visual field ($r_s = .36$, $p = .07$). Of note, all correlation coefficients computed between questionnaire

variables (Creative Personality Scale, Creative Achievement Questionnaire) and response time were in the negative range, indicating that increased creative personality trait and achievement expression is associated with faster decision-making in the halo paradigm; however these coefficients did not reach statistical significance.

Discussion

In Chapter IV, hemispheric contributions to divergent thinking were examined behaviorally using the allusive thinking paradigm and a new conceptualization of the Word Halo Test between schizotypes, schizophrenics, and normal controls. Allusive thinking was used rather than an alternate uses task because of the difficulty involved in appropriately adapting an alternate uses task for tachistoscopic presentation. The hypothesis that schizotypes and schizophrenics would select more words or symbols (halo) when presented to either hemisphere (due to greater specialization in both hemispheres to correctly identify remote associates) was not supported. For halo scores, subjects found words to be related to their targets more often than they found graphics to be related to their targets, however there was no significant interaction between group, side, and type.

There are several possible reasons that the hypotheses were not supported. The first indication was from the data themselves. During the pilot phase of data collection, there was not a significant difference between halos derived from words compared to graphics when participants completed the paper-and-pencil version of the new halo task, thus the main experiment was completed under the indication that both types of stimuli were equivalent in terms of halo production. However, data from the lateralized presentation paradigm indicated that the stimuli may not have been equivalent in terms of halo responsivity. Subjects had larger ‘halos’ for words than for graphics. Future studies should be careful about equating verbal and nonverbal stimuli, as their associative properties may be inherently different. This caveat presents a challenge to future studies which may employ different methods to equate verbal and non-verbal stimuli for allusive thinking paradigms. Although this study employed a relatively small sample size, power estimates indicate that the differences seen in graphic and word halos were large.

The pattern between divergent thinking, schizotypy, and performance that was observed in Chapter III was not supported by the divided visual field experiment. There could be several reasons for these discrepant results. First, the underlying construct that has been measured until this point (creativity in terms of divergent thinking ability) may not be operating under this paradigm, and this assertion is supported by the lack of association between ‘halo’ scores and divergent thinking scores. Halo scores were not associated with convergent thinking ability either, indicating that the task may be tapping a different construct than associative production. Halo scores were not associated with the Disorganized schizotypy trait factor from the SPQ, however alternate uses scores were. In addition, external creativity measurements given by the Gough Creative Personality Scale and the Creative Achievement Questionnaire did not show the strong associations with halo scores that were seen with alternate uses divergent thinking scores. One can look at tasks such as this one and the Word Halo Task in terms of measuring either ‘lateral’ thinking, or conceptual expansiveness and overinclusion. The issue that overinclusion and divergent, or creative, thinking are not equivocal concepts has been addressed extensively elsewhere (cf. Harrington, 1993).

Divided visual field paradigms have been criticized for confounding neural mechanisms of perception and production when interpreting their results (Bryden, Free, Gagne, & Groff, 1991). This may be particularly important in the discussion of creating an appropriate experimental design for addressing hemispheric contributions to creative *production*. In the present experiment, the interest was in participants’ ability to produce conceptual boundaries for the target words and graphics. However, the task was implemented by asking subjects to perceive the relatedness between two stimuli. The hypotheses may not have been supported because divergent perception rather than divergent production may have been tested. In addition, the left and right hemispheres may contribute differently to visuospatial attention, and this may even differ between subjects (Liu, Banich, Jacobson, & Tanabe, in press; Spencer & Banich, 2005) such that individuals can show a strong bias to directing attention towards the visual field corresponding to the hemisphere dominant (or preferred) for attentional mechanisms. In the present experiment, individual differences in attentional biases may have contributed to a non-significant group

effect. Poor reliability on divided visual field experiment results (Hugdahl, 1995) may also indicate that as subjects change strategies that they bring to completing a divided visual field task, their hemispheric contributions change. This may represent transient differences in strategies rather than in hemispheric contributions to the proposed cognitive process in question.

Future experiments may benefit from the results reported here by using neuroimaging techniques to disambiguate the hemispheric contributions to different stimuli in terms of creative production. In this way, subjects can be given time to produce associative, creative products, and the thinking process can be monitored for lateralized contributions. It must still be noted, however, that investigating the differential contribution of verbal and non-verbal stimuli to associative thinking processes is still warranted as most studies in the literature have used verbal stimuli, presumably because the associative nature of semantic stimuli is inherent to the structure of language. If the same is not true for non-verbal stimuli, then the creative, associative process may well be different. Understanding these differences has important implications for different forms of creativity (for example, creative writing versus graphic art), and for the creative process in individuals who have a propensity for verbal or non-verbal creativity. Recently, Nettle (in press) has examined the relationship between different modalities of creative production in relation to schizotypy, finding that schizophrenia may be related to enhancement in art, poetry, and divergent thinking, while other forms of psychopathology may be related to mathematical creativity. These differences may be elaborated on further in experimental investigations that appropriately manipulate equivalent verbal and non-verbal stimuli to address creative production.

An inverse association was found between halo scores and interpersonal deficits on the SPQ, indicating that greater conceptual expansion was associated with fewer interpersonal deficits. Social cognitive problem-solving has been identified as an important aspect of social competence that identifies a creative approach to identifying and solving social and interpersonal problems (Donahoe et al., 1990). Social cognitive problem-solving has been posited to act as the social correlate of divergent thinking because it requires concept flexibility, the ability to see other viewpoints in order to keep successful relationships. Schizophrenia patients who show relatively preserved verbal memory and intact divergent

thinking abilities have also exhibited positive social problem-solving (Yamashita, Mizuno, Nemoto, & Kashima, 2005). Our results suggest a similar pattern that may be operating in schizotypy, that increased appreciation for social problem solving, indicated by fewer interpersonal deficits on the SPQ, may be associated with divergent thinking. Although this relationship is speculative at this point, it would be an important direction to take in terms of cognitive rehabilitation and in addressing the utility of creative thinking in schizophrenia. Chapter III has shown that schizophrenia patients have intact divergent thinking skills compared to normal controls. Although this group typically evidences neurocognitive deficits, the preservation of divergent thinking skills combined with data suggesting that divergent thinking and social problem-solving are positively associated has powerful implications for cognitive and social rehabilitation in schizophrenia.

Of the more than 20 studies to date that have investigated the relationship between creativity and schizotypy, most studies support the association between creative ability and the positive subclinical traits of schizotypy rather than the negative ones (Schulberg, 2001b). These positive traits include odd perceptual experiences and disorganization. The inverse association between halo and interpersonal deficits indicates that creating a halo, or conceptual boundary, to a stimulus may be a different construct than divergent thinking, as these map onto schizotypy differently. The concept of halo may be more directly related to overinclusiveness than to divergent thinking. Although overinclusiveness has also been studied in relation to psychoses (Andreasen et al., 1975), it does not involve the two seminal features requisite for creativity, i.e. novelty and usefulness. In spite of the finding that overinclusiveness may represent a novel boundary set, it does not serve a purpose or solve a problem.

Although this experiment attempted to study hemispheric contributions to verbal and non-verbal creativity, the verbal and non-verbal conditions were most likely not equivalent in their processing load, as exemplified by overall response time differences. In addition, the construct that was measured, allusive thinking, may be conceptually different from creative, divergent thinking.

CHAPTER V

PREFRONTAL NEURAL SUBSTRATES OF CREATIVITY: A NIRS INVESTIGATION OF DIVERGENT THINKING IN SCHIZOPHRENICS, SCHIZOTYPES, AND NORMAL CONTROLS

Traditionally, the neuropsychological literature has considered the prefrontal cortex to be the “creative brain” (Zangwill, 1966). Neuropsychological tests of generativity and flexibility have been addressed in terms of frontal lobe function with verbal flexibility deficits being associated with left hemisphere lesions (Milner, 1964) and non-verbal flexibility deficits with right hemisphere lesions (Jones-Gotman & Milner, 1977). When right frontal lobe lesion patients were compared to left frontal lobe lesion patients in divergent thinking and problem solving ability, the right frontal lobe lesion patients had the most difficulty generating solutions to problems (Miller et al., 1996b). This was not true for non-frontal lobe lesion patients with focal lesions of the right hemisphere that were either in temporal, parietal, or occipital cortices, and the results were interpreted as an effect of poor solution shifting among the right frontal lobe lesion patients. Not surprisingly, animal recordings (Birrell & Brown, 2000) and human neuroimaging studies (Rushworth, Passingham, & Nobre, 2002) have identified solution and set shifting as “frontal tasks” because of their demands on mental flexibility, and the link between mental flexibility and creativity has been established (Walker, Liston, Hobson, & Stickgold, 2002).

There is evidence that enhanced creative thinking also requires frontal lobe involvement through attention and working memory demands. The role of the prefrontal cortex in inhibition of selective attention with negative priming paradigms has been shown using fMRI (Steel et al., 2001), and in lesion studies (McDonald et al., 2005), with particular disruption in both induced by right frontal lesions (Stuss et al., 1999b). The substantial role of prefrontal cortical function in working memory has been shown in animals (Funahashi, Bruce, & Goldman-Rakic, 1989) and in humans (Smith & Jonides, 1999). If ideational fluency is enhanced, combined with adequate working memory capacity and decreased attentional inhibition that allows remote associations (Eysenck, 1995), then we may begin to approach a

neurocognitive model of creativity that is similar to certain forms of psychopathology (i.e. schizotypy). The inability to adequately inhibit, or filter out, irrelevant information and the inefficient allocation of attentional and working memory resources are implicated in creative thinking, schizophrenia, and in schizotypy.

Negative priming and latent inhibition have been investigated in relation to divergent thinking and creative achievement. Negative priming reflects inhibitory processes in selective attention shown by response latencies when ignored prime trials become attended-to probes (Tipper, 1985; Tipper & Cranston, 1985). Latent inhibition is an associative learning phenomenon that describes the delayed learning of an association to a stimulus after the stimulus has been pre-exposed without consequence (Lubow, 1989), and decreased latent inhibition (i.e. when the pre-exposed stimulus elicits an attentional response) is analogous to a decreased filtering mechanism that does not screen stimuli out of conscious awareness (Lubow, 1989; Lubow, Schnur, & Rifkin, 1976). There is strong evidence that creative subjects show decreased focused and selective attention in laboratory experiments, possibly because creative tasks benefit from attentional strategies that allow a greater amount of information to be potentially relevant (Dewing & Battye, 2004; Mendelsohn, 1976; Toplyn & McGuire, 1990). When divergent thinking tasks were scored for fluency, subjects who gave more responses showed less negative priming compared to those who gave fewer responses (Stavridou et al., 1996). These results indicate that creative subjects show reduced negative priming and therefore greater disinhibition than non-creative subjects. For latent inhibition, subjects higher in perceived originality of responses showed decreased latent inhibition, while those who showed greater fluency and flexibility of responses showed no effect (Carson, Peterson, & Higgins, 2003). High scorers on the Creative Achievement Questionnaire have attenuated latent inhibition compared to individuals with few creative achievements, and individuals with particularly strong creative achievements were seven times more likely to have reduced latent inhibition compared to non-creative individuals (Carson et al., 2003). The Five Factor Model traits of Openness (Peterson & Carson, 2002a) and Extraversion (Peterson et al., 2002a; Peterson, Smith, & Carson, 2002b), which were previously shown to be related to creativity, are negatively associated with latent inhibition,

indicating that individuals high in Extraversion and Openness who were pre-exposed to the non-reinforced stimulus took fewer trials to learn the association, indicating a greater degree of disinhibition. Low latent inhibition is also associated with higher scores on the Gough Creative Personality Scale, as those with decreased latent inhibition endorse more creative personality traits (Peterson et al., 2002b).

Sufficient working memory capacity may also be a necessary element in creative thinking (Dietrich, 2004). In fact, it would seem that the ability to maintain several mental representations at the same time while juxtaposing them in order to create combinations and solutions would require an intact working memory at the very least (Heilman, Nadeau, & Beversdorf, 2003). Only one study has looked at the simultaneous role of working memory and creative problem solving (Lavric, Forstmeier, & Rippon, 2000). In this study, employing a concurrent working memory task while solving problems disrupted analytical (close-ended), but not insight (creative) problem solving ability. Although this study found that working memory *interference* may not contribute to insight problem-solving, the question of working memory *capacity* while engaged in divergent thinking tasks has not been addressed directly. In developing an integrative theory of how cognitive systems interact to enhance creative thinking, working memory and cognitive inhibition may oppose each other. The greatest creative thinking ability may be expected among those who have sufficiently high working memory capacity combined with thought disinhibition and decreased selective attention.

This proposed model of increased disinhibition with a sufficiently intact working memory system is similar to what has been found in some schizotypes, and they perform well on creativity tasks. Schizotypes display reduced negative priming (Beech, Baylis, Smithson, & Claridge, 1989a; Beech, McManus, Baylis, Tipper, & Agar, 1991; Park et al., 1996), and greater disinhibition is related to increased positive symptoms of trait schizotypy (Ferraro & Okerlund, 1996; Moritz et al., 1999; Peters, Pickering, & Hemsley, 1994). Decreased latent inhibition has also been demonstrated in individuals with high trait schizotypy (Baruch, Hemsley, & Gray, 1988b; Braunstein-Bercovitz & Lubow, 1998; De la Casa & Lubow, 1994; De la Casa, Ruiz, & Lubow, 1993; Lubow & De la Casa, 2002; Williams et al., 1997) (especially in “positive” traits such as unusual experiences, impulsive non-conformity, and

cognitive disorganization (Gray, Fernandez, Williams, Ruddle, & Snowden, 2002). These data bring substantial confirmation that schizotypes have reduced cognitive inhibition (Moritz & Mass, 1997) and overly inclusive attentional responses (Lubow, 1989).

Schizophrenia patients show negative priming disinhibition as reflected by shorter response times in probe trials (Beech, Powell, McWilliam, & Claridge, 1989b; Park et al., 1996), and this is not related to thought disorder or course of disease (Roesch-Ely, Spitzer, & Weisbrod, 2003). However reduced negative priming in schizophrenia is associated with increased positive symptoms during acute psychosis and four months after initial negative priming testing (Park, Püschel, Sauter, Rentsch, & Hell, 2002). Schizophrenics (Baruch, Hemsley, & Gray, 1988a; Gray, Hemsley, & Gray, 1992; Gray, Pilowsky, Gray, & Kerwin, 1995; Lubow, Kaplan, Abramovich, Rudnick, & Laor, 2000; Rascle et al., 2001) and their first degree relatives (Martins, Jones, Toone, & Gray, 2001) show decreased or abolished latent inhibition. This effect is particularly strong in acutely ill patients as the latent inhibition effect reappears after several weeks with antipsychotic medication (Baruch et al., 1988a; Rascle et al., 2001), just as haloperidol enhances the latent inhibition effect in healthy controls (Williams et al., 1997).

Schizophrenics (Park & Holzman, 1992) and schizotypes (Park & McTigue, 1997; Tallent & Gooding, 1999) have reduced working memory ability compared to normal controls. Although reduced in schizotypy as well, the working memory deficits are not as profound as those displayed by schizophrenia patients (Park, Holzman, & Lenzenweger, 1995). Therefore, although both schizophrenia and schizotypy groups show greater disinhibition, schizotypes may have sufficient working memory ability to facilitate creative thinking in combination with broadened attentional mechanisms. Does this group, showing decreased inhibition with sufficient working memory, have increased creative ability? Answering this question would further enhance the model relating schizotypy, disinhibition, and working memory, and it would provide clues addressing the neural circuitry that facilitates creative thinking ability.

Previous studies have examined the neural correlates of creative thinking in psychiatrically normal subjects using various neuroimaging techniques (PET, fMRI, EEG). As discussed in Chapter II, these studies have found that creative thinking is best served by increased cellular complexity in

individual networks (Bekhtereva et al., 2000; Molle et al., 1996; Molle et al., 1999; Molle et al., 1997; Starchenko et al., 2000) involving cortical regions that are connected by long cortico-cortical fibers (Bhattacharya et al., 2002; Jausovec, 2000; Jausovec et al., 2000c; Molle et al., 1996; Molle et al., 1997; Petsche, 1996; Petsche et al., 1997; Razoumnikova, 2000) and integration between both frontal lobe hemispheres (Bekhtereva et al., 2001; Bekhtereva et al., 2000; Carlsson et al., 2000; Jung-Beeman et al., 2004; Starchenko et al., 2000), especially in very creative thinkers. To date, there are no known studies that have examined neural activity during creative thinking in psychiatric populations. Given the body of evidence suggesting that schizotypal individuals have enhanced creative thinking abilities, neuroimaging studies may elucidate the specific neural correlates that are responsible for the differences in ability. Because schizotypal personality may be a genetic marker for increased liability for schizophrenia, group differences in prefrontal cortex activity were assessed between psychometric schizotypes, schizophrenics, and normal controls. NIRS was used to investigate these differences because it has excellent temporal resolution (0.1 s.) and adequate spatial resolution (20-30 mm.) to assess hemispheric differences during cognitive paradigms. In addition, the experiment avoided common problems associated with fMRI including artifacts and more flexible paradigm construction.

Aims

The major aim of the present study was to observe functional brain activation during the divergent thinking process in schizophrenic patients, schizotypal individuals, and healthy controls. In particular, this study investigated the prefrontal substrates of divergent thinking, including group differences that may help to explain findings from Chapter III. It served as a complimentary experiment to the study of the behavioral correlates of creative thinking ability, handedness, and schizotypy that was undertaken in Chapter III. Our initial hypotheses were that (1) divergent thinking would be associated with greater activity in the prefrontal cortex bilaterally across all groups, and that (2) schizotypes would show areas of enhanced bilateral prefrontal cortex activity over and above the activation seen in schizophrenic and normal control subjects.

Method

Participants

Demographics and clinical characteristics for subjects in the normal control, schizotypal, and schizophrenic groups are presented in Table 11. Recruitment inclusion/exclusion criteria were the same as

Table 11. Demographic and clinical characteristics of the NIRS creativity study sample

Demographic Variable	Group		
	Normal Control N=10	Schizotypal N=10	Schizophrenic N=10
% female	40%	50%	30%
Age	36.4 (3.1)	23.3 (1.6)	36.7 (2.9)
Years of Education	13.2 (0.4)	13.8 (0.4)	13.4 (0.3)
Laterality Score	65.0 (22.2)	66.7 (7.4)	65.9 (8.3)
SPQ	19.3 (3.5)	41.5 (1.1)	-
BPRS	-	-	13.2 (3.0)
SANS	-	-	12.9 (3.0)
SAPS	-	-	12.4 (4.3)
WASI	98.0 (5.2)	112.3 (5.3)	99.8 (6.0)
Letter Fluency	39.9 (4.0)	45.0 (3.1)	37.6 (3.1)
Category Fluency	40.2 (2.3)	42.6 (1.9)	32.2 (1.9)
Design Fluency	6.9 (1.0)	9.7 (1.5)	9.5 (0.9)

Values are given as mean (SE).

those from previous chapters. Of the 30 subjects who participated in Chapter III, 28 participated in this experiment with the addition of two additional subjects (one male schizotype and 1 female normal control). All patients were taking atypical antipsychotic drugs (clozapine, risperidone or olanzapine) at the time of testing. The study was reviewed and approved by the Vanderbilt University Institutional Review Board, and informed consent was obtained from all participants. The testing session lasted approximately two hours, and subjects were compensated for their participation. As shown in Table 11,

there were no significant group differences in sex ($\chi^2(2, N = 30) = 0.81, ns$); years of education ($F(2,27)=0.71, ns$); handedness ($F(2,27)=0.003, ns$); letter fluency($F(2,27)=1.42, ns$); design fluency($F(2,27)=1.52, ns$); or FSIQ ($F(2,27)=1.91, ns$). However, schizotypal subjects were younger than schizophrenics or normal controls ($F(2,27)=7.54, p<.01$); and schizophrenia patients had lower category fluency scores compared to normal control and schizotypal participants ($F(2,27)=8.0, p<.01$).

Cognitive Paradigm

An alternate uses divergent thinking task was employed to manipulate different styles of thinking (Figure 8). NIRS is an ideal modality to use for measuring both quantitative and qualitative responses as

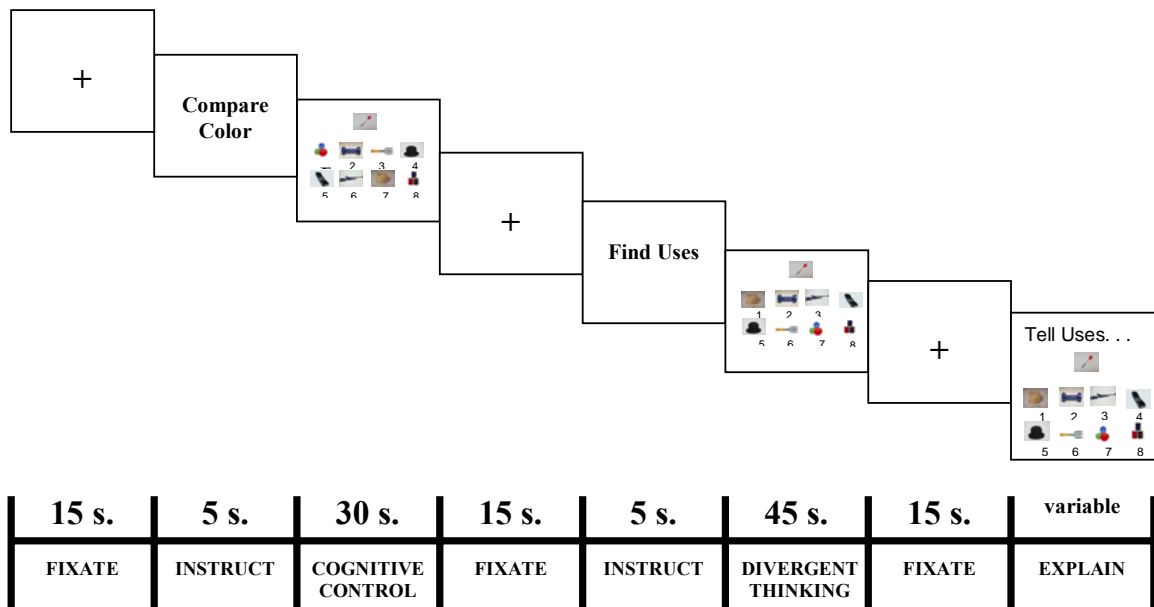


Figure 8. Cognitive paradigm used in the NIRS creativity study.

there is a great amount of flexibility during scanning. Although data from Chapter III would suggest that ambiguous objects may be the most effective probes of creativity, presenting actual objects was not appropriate for a neuroimaging study that required precise timing, and subjects' inquiries concerning the identity of ambiguous objects could not be entertained. Therefore, images of conventional household

objects were used (hat, dart, balloon, string, flower pot, telephone, clock, etc.). It should be emphasized that these images were different from the stimuli used in Chapter III.

All tasks were presented on a computer using E-Prime (*Psychology Software Tools*). Two conditions were presented for each run: (1) a cognitive control task and (2) a divergent thinking task. Six runs were presented to each subject while NIRS absorbance data was being simultaneously collected. A 15 s. baseline fixation was displayed at the beginning of each run. This was followed by a 5 s. text screen instructing the subject to make the “control” decision (compare objects for similarities in color). Then, the stimulus array was shown for 30 s. The image display for both trials consisted of a black screen with an array of 8 numbered images appearing beneath a “target” image stimulus. In the control trials, subjects were asked to select the objects similar in color to the target object. As subjects decided on matching objects, they pushed the corresponding number on the computer keyboard, registering the response and its timing. The cognitive control task was selected to control for as many cognitive and perceptual variables as possible except for the variable of interest (divergent thinking). Therefore, identical images were shown during the control and experimental trials of each run, although the order of appearance on screen was pseudo-randomized. After a 15 s. fixation, another 5 s. instruction screen instructed the subject to make the “experimental” decision (divergent thinking). The array appeared again (but this time for 45 s.), and subjects pressed corresponding keys as they determine uses for the objects. In the divergent thinking trials, subjects had to decide how the array of objects could be used with the target. After an additional 15 s. fixation, the array shown during the divergent thinking trials was displayed (indefinitely) as subjects were requested to verbally describe the uses that they generated for the given objects. These were recorded by the experimenter.

NIRS Measurement

NIRS was performed using a 22-channel 780/830 nm spectrometer (ETG-100 system; Hitachi Medical Corp.) composed of emitter-detector pairs. Each emitter was composed of two continuous laser diodes ($3\text{mW} \pm 0.15\text{mW}$) with different wavelengths (780 ± 20 and 830 ± 20 nm) which were amplitude

modulated (0.6 and 1.5 kHz). NIRS signals were mixed and transmitted through a multi-component glass bundle optical fiber cable that was placed on the scalp using a spring-loaded probe that was attached to the probe holder through an adjustable socket. Another optical fiber carried the scattered signal picked up by the optical sensor to a photodiode. An inter-fiber spacing of approximately 27 mm. produced a light penetration close to 20 mm. Signals were acquired at a sample rate of 10 Hz from 22 cortical regions on the bilateral prefrontal cortex using the 3 X 5 probe holder and corresponding optodes (Figure 9). This signal was amplified, demodulated, and then digitized. The detected signals were converted to chromophore concentrations using the modified Beer-Lambert Law.

An important attribute of the NIRS technique is its ability to separate out the oxyhemoglobin and deoxyhemoglobin contributions to the hemodynamic response. Using separate wavelengths of light penetration resulted in separate chromophore measurements for oxyhemoglobin and deoxyhemoglobin, while the summation accounted for total levels of hemoglobin in the circulating blood. Physiologic cortical activation is thought to be represented by

decrease in deoxyhemoglobin along with increases in oxyhemoglobin and total hemoglobin (Zaramella et al., 2001). For each unit decrement in deoxyhemoglobin, there is a corresponding increase in oxyhemoglobin of two to three units (Obrig & Villringer, 2003). Therefore, increases in oxyhemoglobin and total hemoglobin with accompanying decreases in deoxyhemoglobin bilaterally were expected in the prefrontal cortex when comparing the divergent thinking task to the control task. Between group contrasts should represent focal hemispheric differences similarly, and therefore oxyhemoglobin, deoxyhemoglobin, and total hemoglobin will be reported.

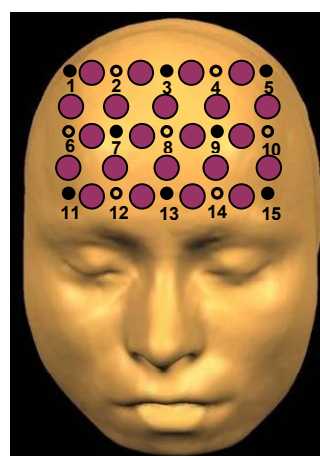


Figure 9. Placement of the NIRS optodes on the forehead. Black circles are emitters. Open circles are detectors. Channels are depicted as larger purple circles. 22 measurement channels result from the 3 X 5 probe set.

Hemispheric Localization

Probes were placed on the forehead according to the International 10-20 system of EEG electrode placement (Figure 9). The middle vertical band of optodes was placed along the z (midline) axis extending from the Fp position ventrally towards a caudal position proximal to the Fz position. This method assured a high level of standardization across subjects with the right hemisphere probes covering areas Fp2, F4 and F8 and the left hemisphere probes covering areas Fp1, F5 and F7.

Results

Behavioral Analyses

Group differences for number of uses generated in the control and divergent thinking tasks and the rate of responding to each condition were assessed. Although times for each condition were set at 30 s. (control task) and 45 s. (divergent thinking task), subjects generally did not use the entire time allotted to generate responses.

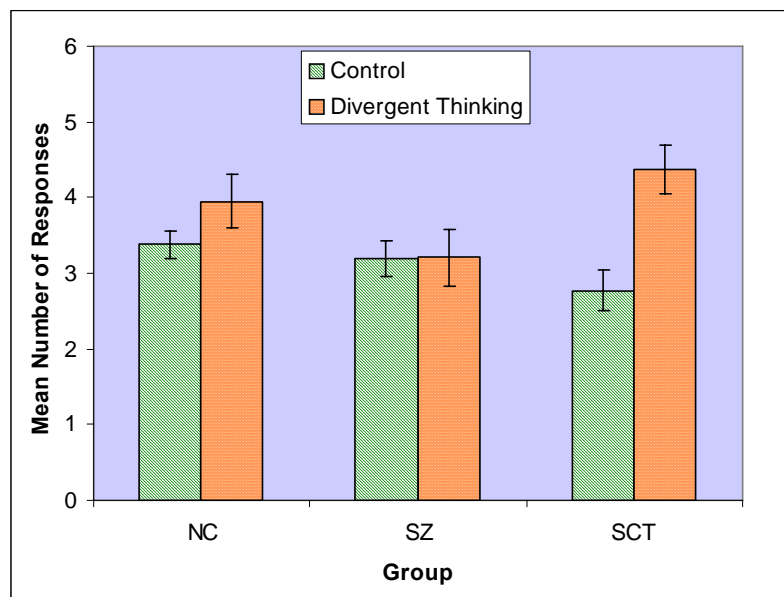


Figure 10. Number of responses given by subjects for different conditions in the NIRS study

Differences in use generation were tested using a repeated measures ANOVA for number of uses produced as the dependent variable, group as the between subjects factor, and condition type (control task, divergent thinking task) as the repeated measures factor (Figure 10). The main effect for condition type was significant, $F(1,27) = 10.68$, $p < .01$, $r_{\text{effect size}} = .70$. Overall, subjects gave more responses to the divergent thinking task ($M = 3.8$, $SE = 0.22$) compared to the color task ($M = 3.1$, $SE = 0.14$). The main effect for group was not significant, $F(2,27) = 1.19$, $p = ns$. The group X condition type interaction was significant, $F(2,27) = 4.37$, $p < .05$, $r_{\text{effect size}} = .50$. Normal controls saw more similarities on the control task ($M = 3.4$, $SE = 0.18$) than schizotypes ($M = 2.8$, $SE = 0.26$) ($p < .05$) did, and on the divergent thinking task, schizotypes generated more uses ($M = 4.4$, $SE = 0.33$) compared to schizophrenic subjects ($M = 3.2$, $SE = 0.38$) ($p < .05$).

Using a repeated measures ANOVA with rate of responding (items per second x 1000) as the dependent variable, group as the between subjects factor, and condition type (control task, divergent thinking task) as the repeated measures factor, the main effect of condition type was significant, $F(1,27) = 52.55$, $p < .001$, $r_{\text{effect size}} = .92$. Subjects responded at a higher rate to the control condition ($M = 0.24$, $SE = 0.01$) compared to the divergent thinking condition ($M = 0.15$, $SE = 0.01$). The main effect of group was not significant, $F(2,27) = 0.77$, $p = ns$. The group X condition type interaction was not significant, $F(2,27) = 0.42$, $p = ns$.

Associations with External Measures of Creativity

As with the data from the behavioral study, the relationship between measures of creative fluency and external measure of creative personality and achievement were examined. Of the 30 participants in the NIRS task, 18 of them completed the Creative Achievement Questionnaire and 24 completed the Gough Creative Personality Scale. Response fluency in the divergent thinking condition was significantly associated with creative achievement assessed by the Creative Achievement Questionnaire ($r_s = .50$, $p < .05$). However, there was not a significant association between creative personality (Gough Creative Personality Scale) and divergent thinking fluency on the NIRS task.

Near Infrared Chromophore Analyses

Data Processing. Raw NIR absorbance data was processed using Matlab (*The Math Works*). A temporal filter was first applied to remove artifacts due to respiration and cardiac variations using a bandpass filter with range 0.01– 0.5 Hz. After temporal downsampling (from 10 – 1 Hz.) using a moving average filter, normalization, and bilinear spatial smoothing, data were converted to measurements of oxyhemoglobin, deoxyhemoglobin, and total hemoglobin levels according to the modified Beer-Lambert Law and arranged into epochs. Then these data were converted into a format useable by Brain Voyager QX (*Brain Innovation*) where all subsequent analyses were performed. For the control and divergent thinking tasks, the average block was convolved with a boxcar function in order to approximately model the hemodynamic response (Boynton, Engel, Glover, & Heeger, 1996). Additional linear trend removal was performed for all optical imaging data using the Brain Voyager QX, correcting for overall linear drifts (positive and negative directions) in the data from the first to the last time points. Post hoc contrasts were protected against Type 1 inflation rates by using a false discovery rate statistic $q(\text{FDR})$. A $q(\text{FDR})$ of 0.05 sets a limit for Type 1 errors at 5% and guarantees that the contrasts produced result from 5% false positive errors, but *no more than* 5% false positive errors. All of these procedures were performed for oxyhemoglobin, deoxyhemoglobin, and total hemoglobin data.

NIRS Analyses. For each chromophore, a separate ANOVA was calculated using the epochs measured for the control and divergent thinking tasks as the two main predictors in the overall model. Separate contrasts were performed for the within subjects analyses (divergent thinking vs. cognitive control) and for the between subjects analyses (schizophrenics, schizotypes, and normal controls), where pairwise comparisons were calculated between all groups. Contrasts were set up so that each between groups comparison would result in showing increased chromophore volume for the divergent thinking task relative to the control task. Results are reported for statistical map clusters that pass a threshold criterion of at least 20 voxels. Statistical results for all chromophores are shown in Table 12.

From pilot data, the control decisions were made more quickly than the divergent thinking decisions. Fixed block durations were chosen based on the average amount of time subjects spent

determining uses for objects in the original behavioral study for the largest number (5) of conventional objects, which was the closest experimental corollary. Because subjects responded by pressing computer keys, only those time intervals that could be verified as being dedicated to the decision at hand were removed and analyzed (i.e., from stimulus onset until the time the last decision was recorded). Although these time intervals will vary between subjects, it is an attempt to boost the validity and power of the design by comparing thought processes that are actively occurring rather than being diluted with periods of cognitive “rest”, as has been the case in previous neuroimaging studies of divergent thinking.

Within groups analyses for each chromophore resulted in a pattern of increased oxyhemoglobin, deoxyhemoglobin, and total hemoglobin bilaterally. Statistical maps for the oxyhemoglobin data are shown in Figure 11 overlaid onto pictorial representations of the forehead, approximating the position for the 22 channel probe holder. Although the deoxyhemoglobin and total hemoglobin data are not represented spatially, t values from image analysis clusters are shown in Table 12. Figure 11, 1a shows the bilateral prefrontal increase in oxyhemoglobin associated with performance on the divergent thinking task compared to the cognitive control (color) task, independent of group. These data indicate that divergent thinking is associated with bilateral prefrontal activation. Total hemoglobin values also showed a significant increase bilaterally, providing confirmation for the results seen with the oxyhemoglobin chromophore. The statistically significant bilateral increase in deoxyhemoglobin was unexpected given the underlying hemodynamic effects that NIRS can be used to investigate.

Group differences (Table 12) were observed in contrasts performed on the oxyhemoglobin data which indicate a significant increase in the right prefrontal cortex for schizotypal subjects during the divergent thinking task. During the divergent thinking task, schizotypes were characterized by increased oxyhemoglobin compared to both normal controls ($p < .01$) (Figure 11, 1b) and to schizophrenic subjects ($p < .01$) (Figure 11, 1c). No significant group differences were observed in oxyhemoglobin during the divergent thinking condition between schizophrenic subjects and normal controls (Figure 11, 1d). Comparisons with the deoxyhemoglobin and total hemoglobin data showed a different pattern of group differences. All three groups showed significant increases in deoxyhemoglobin in the right prefrontal

Table 12. Hemispheric results from the NIRS analyses based on contrasts for each chromophore.

Chromophore	Contrast	Group 1	LH increase		RH increase		Group 2	LH increase		RH increase	
			Peak <i>t</i> df(46242)	<i>p</i> <	Peak <i>t</i> df(46242)	<i>p</i> <		Peak <i>t</i> df(46242)	<i>p</i> <	Peak <i>t</i> df(46242)	<i>p</i> <
Oxyhemoglobin	Within	DT-Color	13.94	.00001	10.02	.00001					
	Between	Schizotype			4.45	.00001	Normal				
		Schizophrenic					Schizotype			6.14	.00001
		Normal				Schizophrenic					
Deoxyhemoglobin	Within	DT-Color	7.24	.00001	4.31	.001					
	Between	Schizotype	3.64	.001			Normal	4.44	.00001	5.12	.00001
		Schizophrenic	4.79	.00001			Schizotype			4.94	.00001
		Normal	3.69	.001		Schizophrenic	3.72	.001	7.61	.00001	
Total Hemoglobin	Within	DT-Color	11.54	.00001	7.5	.00001					
	Between	Schizotype					Normal				
		Schizophrenic	4.41	.00001			Schizotype			5.75	.00001
		Normal	4.44	.00001	3.16	.01	Schizophrenic	3.67	.001		

DT = Divergent Thinking. All post hoc contrasts are corrected for multiple comparisons using the q(FDR) method.

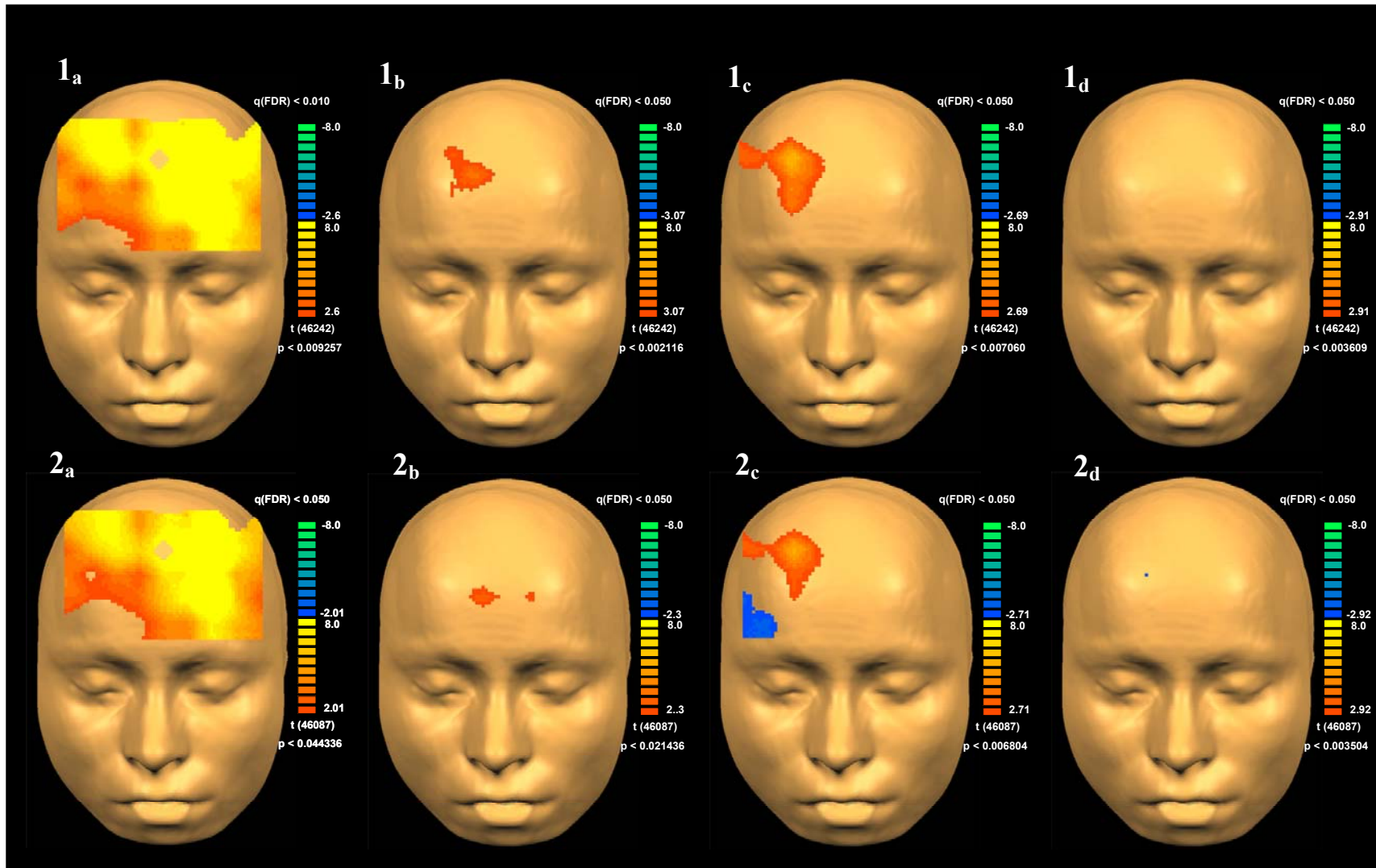


Figure 11. Oxyhemoglobin results from the NIRS creativity study. Numbers indicate analysis (1=comprehensive, 2="temporally normalized"), and letters indicate contrasts (a=within subjects (divergent thinking-control); b= schizotypes vs. normal controls (divergent thinking-control); c= schizotypes vs. schizophrenics (divergent thinking-control); d= normal controls vs. schizophrenics (divergent thinking-control)).

cortex during the divergent thinking condition, although normal controls also showed increased left prefrontal cortex deoxyhemoglobin compared to schizotypes, and schizophrenic subjects showed increased left prefrontal cortex deoxyhemoglobin compared to normal controls. Data from the total hemoglobin data indicate that schizophrenic subjects showed greater left prefrontal cortex increases in total hemoglobin compared to the other groups, while schizotypes and normal controls had greater total hemoglobin levels in the right hemisphere compared to schizophrenics.

NIRS Analyses for Temporal Normalization. Although rate of responding did not differ between groups, there was a main effect for object type. Overall, subjects responded at a higher rate (responses/second) to the control condition ($M = 0.24$, $SE = 0.01$) compared to the divergent thinking condition ($M = 0.15$, $SE = 0.01$), $F(1,27) = 52.55$, $p < .001$. Accordingly, subjects contributed more NIRS hemodynamic signal to the divergent thinking condition compared to the control condition across all runs. In order to determine the effect of this difference in response rate, the chromophore data were reanalyzed to verify that the statistical oxyhemoglobin effect that was found overall was not simply a contribution of the longer response times for the divergent thinking condition. Because the average response time across all subjects in the divergent thinking condition was approximately 28 (28.46) seconds, any time course data that exceeded 28 seconds in the divergent thinking condition was removed, and the overall ANOVA was re-computed in addition to the within and between subjects contrasts for all chromophores. Data collection methods did not allow for adjustment of the “number of uses generated” per condition dependent variable to the new timing schemes. All subjects were included in this second, temporally normalized, analysis. Overall, 88 trials needed to be corrected for temporal homogeneity, out of 180 total trials administered, involving 19 runs from schizophrenic subjects, 23 from normal controls, and 46 from schizotypal subjects.

Chromophore analysis results did not change substantially, even with the foreshortened time series. For the oxyhemoglobin chromophore, the within subjects analysis showed a bilateral activation in the divergent thinking condition compared to the control condition across all subjects (Figure 11, 2a). Comparing schizotypal subjects to normal controls (Fig. 11, 2b), schizotypes showed a smaller bilateral

effect compared to the larger right hemisphere result from the original analysis. Because the temporally normalized analysis has averaged over an earlier temporal process, this may indicate greater bilateral processing in schizotypes compared to controls during the early stages of the creative thinking process. Comparing schizotypes to schizophrenics (Fig. 11, 2c), although the dorsal right hemisphere activation for schizotypes remained, it was contrasted by a more ventral right hemisphere region that was more active in schizophrenics during the divergent thinking task. This may indicate a similarity in right hemisphere processing early in the creative thinking process between schizophrenics and schizotypes. The comparison between normal controls and schizophrenics (Fig. 11, 2d) remained essentially equivalent to the previous analysis. Thus, the temporally normalized analyses have supported the initial results with incremental evidence for processing differences that may occur during the time course of creative thinking.

Discussion

Replicating and expanding upon previous investigations, Chapter III has shown that psychometric schizotypes display enhanced divergent fluency in creative thinking tasks; however schizophrenics and normal controls are statistically matched for performance on these tasks. In addition, mechanisms involved in anomalous cerebral lateralization may be involved in this effect. The present investigation in Chapter V served to elucidate the hemispheric neural prefrontal components operating during divergent thinking tasks for schizophrenics, schizotypes, and normal controls. This investigation was undertaken in an effort to understand the neural processes that subsume these individual differences, and these data provide two important findings. First, divergent thinking involves bilateral prefrontal activity regardless of group (schizophrenic, schizotypal, or control). Second, there is preferential right prefrontal activation in psychometric schizotypes when thinking divergently.

Data from the oxyhemoglobin chromophore analysis indicate that the differences in divergent thinking between schizotypes and schizophrenics that were observed behaviorally were indicated by a greater reliance on right hemisphere prefrontal activation for schizotypal subjects. Behavioral data from

the NIRS experiment was similar to those in the individual differences study, indicating that performance for schizotypes was greater in the divergent thinking condition. Although the behavioral effect between schizotypes and controls overall was not significant, schizotypes showed a significant dissociation between associative thinking on the divergent thinking versus control tasks, while normal controls' performance did not differ significantly between task types. This indicates that the enhanced right hemisphere activation seen in schizotypes compared to both normal controls and schizophrenics is likely reflecting their behavioral performances. Our initial hypothesis was only partially supported. Our data suggest that divergent thinking recruits the prefrontal cortex bilaterally, but that the differences between the schizotypal and the schizophrenic and control groups are not a matter of degree of bilateral processing. Instead, there is a preferential recruitment of the right hemisphere in divergent thinking for schizotypes. Examining the bilateral activation seen in the within groups contrast, it is also evident that, although bilateral recruitment occurred, the left hemisphere showed a more powerful statistical difference between the divergent thinking and control tasks.

Because the prefrontal cortex is involved in the processing of novelty, it is not surprising that robust prefrontal activation was observed during divergent thinking, which involves implementing novel associations. It is also clear that prefrontal activation during divergent thinking is bilateral. However, the right hemisphere may play an especially important role in divergent thinking in schizotypes. These results support previous neuroimaging studies that showed a significant right hemisphere advantage in creative thinking. Behavioral investigations have also suggested a right hemisphere processing bias for verbal creativity in schizotypes (Gianotti et al., 2001; Weinstein et al., 2001, 2002) which may stem from a right hemisphere advantage for processing unusual associations (Faust et al., 2003; Mohr et al., 2001; Pizzagalli et al., 2001; Rodell et al., 1992). Less left hemisphere reliance for verbal creativity may allow greater access to right hemisphere processes that are particularly salient in creative thinking (Brugger & Taylor, 2003). Our data are also consistent with other studies that found support for bilateral prefrontal activation during divergent thinking, however recruitment and activation of non-frontal regions in

creative thinking paradigms has also been shown in verbal creativity tasks (Bechtereva et al., 2004).

Future studies could examine how these cortical regions are coordinated during creative thinking.

The present modified divergent thinking task employed a time limit, whereas the divergent thinking task used in Chapter III did not. Divergent thinking tasks provide maximal validity when they are not timed (Wallach, 1971), as was the procedure using the divergent thinking task where robust group differences were obtained. Although the NIRS modified divergent thinking task incorporated a time limit, schizotypes still performed significantly better than schizophrenics and showed different prefrontal cortex activation patterns compared with the other groups. Thus, despite the use of time limit in the NIRS experiment, significant group differences were still observed.

Evidence from cognitive neuropsychology is helpful in interpreting the hemispheric results. In right-handed adults, each prefrontal hemisphere tends to contribute to differential task demands, such that both the right and left prefrontal cortices are recruited in response to verbal and spatial executive tasks. However, asymmetrical contributions do appear in the temporal process (encoding, maintenance, retrieval) (Beason-Held, Golski, Kraut, Esposito, & Resnick, 2005), and according to the gross division of function (Floel et al., 2004). Thus, the dissimulation between left and right hemisphere function is not as apparent in frontal structures as it is in posterior cortices. Our finding of bilateral recruitment of prefrontal cortical function during a primarily verbal task across all subjects is not surprising. However, the preferential right hemisphere involvement in schizotypy requires further examination.

Traditional characterization of right hemisphere damage has described salient emotional changes independent of cognitive impairment. However, right, compared to left, frontal lesions have also been associated with poorer performance on cognitive flexibility tasks (Knight, Hillyard, Woods, & Neville, 1981), and there is evidence to suggest that the right prefrontal cortex contributes more overall to the development of executive function, as children with right hemisphere lesions have global executive deficits, while left prefrontal cortex lesions in childhood are associated primarily with verbal deficits (Rourke, 1987). Future investigations may want to examine the relationship between right hemisphere executive function development and developmental delays that may be related to psychosis-proneness in

reference to creative thinking ability. Superior right hemisphere performance (as opposed to left hemisphere weaknesses) have been reported in schizotypal individuals (Broks, 1984; Claridge et al., 1984). However, asymmetrical hemispheric performance could be due to three possible factors: enhanced recruitment of a hemisphere, dysfunction or weakness in the contralateral hemisphere, or changes in interhemispheric transfer through structures such as the corpus callosum. Anterior lesions of the corpus callosum have been reported to cause right-hemisphere-type dysfunction including emotional, spatial, and perceptual impairment (Buklina, 2005), which may indicate a specific process related to interhemispheric transfer in addition to hemispheric asymmetries. Some evidence of anterior corpus callosum abnormality has been reported in schizotypal personality disorder (Downhill et al., 2000).

How might the hemispheric correlates of creative thinking relate to the present results? Of particular importance to elucidating this question are results from semantic priming and attentional disinhibition experiments in relation to creativity and schizotypy. Individuals with high divergent thinking scores showed priming for unusual word associations when presented to either the left or right visual fields (Atchley et al., 1999). Groups lower in creative ability only showed unusual associative priming when the stimuli were presented to the right visual field (left hemisphere). Like creative subjects, schizotypes show a right hemisphere bias in lexical decision task performance, unlike non-schizotypes who show a left hemisphere bias (Leonhard et al., 1998), and they show increased indirect semantic priming (Gianotti et al., 2001; Mohr et al., 2001; Pizzagalli et al., 2001). Neuroimaging evidence has shown that the right frontal lobe is involved in generating unusual or distant verbal associations while the left frontal lobe is involved in generating “usual” associations.

In terms of attention, one study (Stuss & Alexander, 1999a) has shown an interesting dissociation implicating primarily right prefrontal cortex contributions in ignoring irrelevant information in a negative priming task. In this task, less complex negative priming conditions activated only the right hemisphere (including prefrontal and posterior cortices), however the left prefrontal cortex only became active under increasing task complexity, and left posterior regions were not recruited under the most complex conditions. As has been discussed previously (Carson et al., 2003; Stavridou et al., 1996), there is a

positive association between attentional disinhibition on negative priming and latent inhibition tasks and divergent thinking. In addition, schizotypes tend to show greater disinhibition on negative priming (Beech et al., 1991; Beech et al., 1989b; Gruszka, 1999; Park et al., 1996) and latent inhibition (Baruch et al., 1988b; Braunstein-Bercovitz et al., 1998; De la Casa et al., 1994; Lubow et al., 2002) tasks.

It is possible then that the right hemisphere activation seen in the NIRS task for schizotypes represents the components of attentional disinhibition and ideational connectivity that operate during divergent thinking and that these processes operate more saliently in schizotypes. It will be important for future functional neuroimaging studies of creative thinking in psychosis-prone populations to dissociate the attentional inhibition, and semantic association generation components of the divergent thinking process in reference to regional cerebral activation. This could be achieved by temporally manipulating the creative thinking process, and by comparing divergent thinking-related activity at different epochs to corresponding control tasks such as producing unusual semantic associations and probe trials with shorter response times during negative priming conditions.

There are some caveats in this study. Because the 780 nm. wavelength may have reduced sensitivity to deoxyhemoglobin compared to 690-760 nm. range (Sato, Kiguchi, Kawaguchi, & Makia, 2004), there is some reservation interpreting data obtained using this chromophore. Given maximal sensitivities to hemoglobin components in cerebral blood flow, one would expect to see increases in oxyhemoglobin and total hemoglobin paired with relative decreases in deoxyhemoglobin in our data, however this lack of agreement between oxyhemoglobin and deoxyhemoglobin data in a verbal fluency task of the prefrontal cortex using the 780 nm wavelength has been reported elsewhere (Quaresima et al., 2005), while using several more sensitive wavelengths has been shown to be more sensitive to this effect (Csibra et al., 2004; Herrmann, Ehli, & Fallgatter, 2003; Jaszewski et al., 2003). Because total hemoglobin is calculated by summing the oxyhemoglobin and deoxyhemoglobin chromophore data, the oxyhemoglobin data are being relied upon preferentially to interpret our results. In addition, although only right-handers were examined, significant differences in schizotypes and controls in the prefrontal cortical activation patterns were observed. Therefore, a future study with a full range of handedness is expected to

show even clearer effect. Both experiments in Chapters III and V showed similar creative thinking ability and prefrontal cortical function in schizophrenia and controls in contrast to most cognitive studies in schizophrenia that demonstrate deficits.

This NIRS investigation of divergent thinking in schizophrenics, schizotypes and normal controls has successfully established the utility of this technique in investigating the relationship between creativity and schizotypy. In addition, it has proven to be a useful tool in elucidating some of the hemispheric contributions to creative thinking. Future studies can take advantage of the high temporal resolution given by NIRS to dissociate different elements of the creative thinking process, and these studies could improve the discriminability between creative thinking processes that operate differently in schizotypes and controls.

CHAPTER VI

WHITE MATTER COHERENCE AND DIRECTIONALITY IN RELATION TO CREATIVE THINKING: DTI CORRELATES OF DIVERGENT THINKING IN SCHIZOPHRENICS AND NORMAL CONTROLS

Creative individuals are able to conceptualize novel products and to bring ideas together that had not been previously combined. Does this juxtaposition of mental representations have a physical substrate in the brain as well? Are basic characteristics of neural circuits that are involved in indirect associations, attentional disinhibition, mental flexibility and generativity, and novelty awareness involved in creative thinking? Horrobin (1998, 2001) has suggested that enhanced creativity may be facilitated by increased synaptic connectivity, and that this may be particularly evident in schizotypes rather than in schizophrenics. In addition, Crow (1995b) has suggested that schizophrenia and language development are linked through cerebral asymmetry: when hemispheric dominance for language occurred the increased need for bilateral communication increased plasticity and flexibility, but psychotic symptoms are precisely what happens when complete hemispheric differentiation fails. Both theories have emphasized the potential importance of structural connectivity in the production of creative ideas and in psychoses, whether at the synaptic or neural systems level.

The key to Horrobin's theory is increased connectivity at the synaptic level (microconnectivity) due to growth and proliferation of synaptic vesicles (Horrobin, 1999). Neuroimaging studies have provided indirect support for greater synaptic connectivity in creative thinking, as measures of EEG complexity (an estimate of additive individual cellular complexes that contribute to a signal) have shown increased individual neuronal elements operating in creative versus analytical thinking or convergent thinking (Molle et al., 1999; Molle et al., 1997). Haier (1993) has proposed that synaptic pruning is an essential element in enhancing human creativity in particular, and it may represent an intermediate level between normal developmental pruning and the excessive pruning seen in schizophrenia. However, to date, no studies have investigated this hypothesis directly. However, three neuropsychiatric groups may

begin to constitute models for conceptualizing how connectivity may be related to creative thinking: schizophrenics, schizotypes, and dyslexics.

Schizophrenics, schizotypes, and dyslexics show similar patterns of reduced cerebral lateralization, and data indicate that they may be more creative. Dyslexics also tend to have enhanced visuospatial abilities that allow them to process stimuli holistically (von Karolyi, Winner, Gray, & Sherman, 2003), and dyslexia is more common in highly creative artists (Gotestam, 2001; Wolff et al., 2002). Dyslexics are also more likely to report positive schizotypal traits and to have reduced cerebral lateralization (Richardson, 1994). Therefore, dyslexia may serve as a model for the relationship between interhemispheric connectivity and creative ability. Horrobin (1998, 2001) has suggested that schizophrenia and dyslexia are linked through similar mechanisms that regulate phospholipid turnover including reduced essential fatty acid incorporation into cellular membranes. As proposed by Horrobin, this common mechanism may be related to synaptic pruning and axonal proliferation through regulation of structural phospholipids that are essential to axonal and cellular integrity.

Investigations of phospholipid changes in dyslexia and in schizotypy have shown that dyslexia is associated with reduced incorporation of arachidonic acid (AA) and docosahexaenoic acid (DHA) into membrane lipid structures (Richardson, Cox, Sargentoni, & Puri, 1997) and schizotypes with dyslexia are more likely to show phospholipid abnormalities than schizotypes who do not have dyslexia (Richardson et al., 1999). This is similar to the pattern in which schizophrenics have increased phospholipase A₂ (PLA₂) activity (Gattaz & Brunner, 1996; Gattaz, Hubner, & Nevalainen, 1990), which releases fatty acids from their membrane sites, along with reduced AA and DHA levels in red blood cell membranes (Peet, Laugharne, Mellor, & Ramchand, 1996). Positive schizotypal traits are associated with increased incorporation of ω -3 and ω -6 fatty acids into red blood cell membranes (Richardson, Chylarova, & Ross, 2003), implicating abnormal polyunsaturated fatty acid incorporation or release in schizotypy.

Could microscopic changes in fatty acid levels be related to differences in creative thinking abilities? Axons, the communication fibers between neurons, are insulated with layers of myelin by oligodendrocytes. Mature myelin is composed of non-charged chemically stable galactolipids that can be

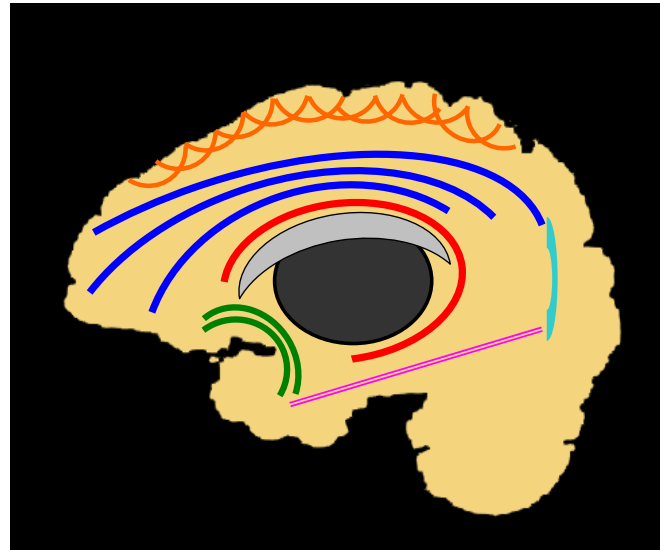
broken down into galactose sugars and fatty acids. However, developing myelin is essentially a phospholipid, which is less chemically stable and is charged. Reduced nutritional enrichment and fatty acid turnover causes reductions in myelin synthesis (DeWille & Farmer, 1992; Wiggins, 1982), which can directly affect neuronal communication and cognitive development (Nagy, Westerberg, & Klingberg, 2004). Therefore, changes in fatty acid turnover related to different spectrums of disease (e.g. schizophrenia) could mediate cognition via white matter proliferation or degeneration. Schizophrenics have increased PLA₂ (Gattaz et al., 1996; Gattaz et al., 1990) activity along with reduced AA and DHA levels in red blood cell membranes (Peet et al., 1996). The skin flushing response to topical niacin is also attenuated in schizophrenia (Messamore, 2003), signifying reduced availability of AA that cannot be converted to prostaglandin D₂. There is preliminary evidence that schizotypes (Fukuzako, Kodama, & Fukuzako, 2002) and high psychotic risk individuals (Keshavan, Stanley, Montrose, Minshew, & Pettegrew, 2003) have membrane phospholipid abnormalities. However, red blood cell ω-3 and ω-6 fatty acid concentrations increase as positive and disorganized schizotypal traits increase in normal volunteers. This relationship is especially strong between cognitive disorganization traits and the longer chain ω-6 and all of the ω-3 fatty acids measured (Richardson et al., 2003).

Candidate Neuroanatomic Regions Important for Creative Thinking

Corpus Callosum

Of particular importance to the discussion of creative thinking as a process requiring connectivity is the role of the corpus callosum (Figure 12) which is comprised of more than 200 million cortico-cortical fibers that run between the left and right hemispheres. Although uncommon in the general population, some neurosurgeons have had ample opportunity to investigate split brain patients and to make observations about changes in cognition that may occur as the result of hemispheric disconnection. It is therefore remarkable that one of the early pioneers of callosotomy should turn to creativity in theorizing the most salient effects of hemispheric division on cognition:

. . . a physiologic explanation for at least some forms of creativity seems close at hand. What is required is a partial (and transiently reversible) hemispheric independence during which lateralized cognition can occur and is responsible for the dissociation of preparation from incubation [stage of creativity]. A momentary suspension of this partial independence could account for the illumination that precedes subsequent deliberate verification. From this point of view, we can understand better the opinion of Frederic Bremer, who wrote years ago that the corpus callosum subserves "the highest and most elaborate activities of the brain"--in a word, creativity (Bogen & Bogen, 1988, p. 293).



- | | |
|------------------------------------|------------------------------------|
| ● Cingulum Bundle | ● Superior Longitudinal Fasciculus |
| ● Uncinate Fasciculus | ● Perpendicular Fasciculus |
| ● Inferior Longitudinal Fasciculus | ● Lateral Ventricles |
| ● Short Arcuate Fibers | ● Corpus Callosum |

Figure 12. Locations of major white matter pathways

While the body of the corpus callosum is comprised of fibers connecting motor and somatosensory regions, the genu of the corpus callosum connects corresponding regions in the right and left hemispheres of the frontal lobe through the forceps minor of the prefrontal cortex forming cortico-cortical connections responsible for direct interhemispheric communication between both lobes of the prefrontal cortex (Pandya & Seltzer, 1986). Severing the genu affects patients similarly to acquiring damage to the prefrontal cortex, including exhibiting disinhibition, lack of insight, impulsivity, inertia, and decreased motivation (Buklina, 2005). This indicates that *interhemispheric* communication may be as important a

contributor to higher cognitive function as *intra*hemispheric activity may be. Bilateral activation of the prefrontal cortex during creative thinking tasks has been identified in several studies (Beeman, Bowden, & Gernsbacher, 2000; Bekhtereva et al., 2000; Carlsson et al., 2000; Folley et al., 2005), although others have indicated that the right hemisphere may preferentially contribute to functional processing during creative thinking (Beeman & Bowden, 2000; Jung-Beeman et al., 2004). Studying callosal white matter with DTI would help to elucidate “hard-wired” differences in white matter organization that might be related to creative ability.

Cingulum Bundle

The cingulum bundle (Figure 12) travels along the ventral surface of the hippocampus, but anterior to the splenium of the corpus callosum, it follows the anatomy of the cingulate gyrus into the prefrontal cortex. With the fornix, the cingulum comprises one of the two major white matter pathways of the limbic system, forming the dorsal limbic pathway which links the limbic medial temporal and cingulate grey matter with the prefrontal cortex. It is involved in interpreting new information, recognition memory, attention shifting, and information transfer from short to long term memory (Stuss & Knight, 2002). Thus, it is especially important in establishing hippocampal-prefrontal connections. There is some evidence that loss of function in left medial temporal cortex is associated with increased artistic and creative skills (Miller, Boone, Cummings, Read, & Mishkin, 2000). Eysenck and Frith (1977) have suggested that the incubation stage of the creative thinking process may be critical to neuropsychological models of creativity, as the hippocampus may act to consolidate the information that was presented during the preparation stage. In this model, inhibition would increase during the preparation stage, then disinhibition would occur during and after the incubation stage to result in insight, or the ‘aha’ experience. It is reasonable to investigate this structure’s organization in relation to creativity because both prefrontal (Miller et al., 1996b) and hippocampal (Murai et al., 1998) lesions have been reported to affect creative behavior, and this structure forms the link through which they are reciprocally connected. The negative priming and latent inhibition studies produce a neural model of cognitive

inhibition that includes a hippocampal-prefrontal network that underlies cognitive inhibitory mechanisms (Gray, Feldon, Rawlins, Hemsley, & Smith, 1991). In particular, the hippocampus is perhaps the most important element in the neural circuitry that underlies latent inhibition of associative learning (Oswald et al., 2002; Weiner, 2003), and there is a positive relationship between attentional disinhibition and creativity (Baruch et al., 1988a; Carson et al., 2003; Stavridou et al., 1996).

Uncinate Fasciculus

The uncinate fasciculus (Figure 12) is one of the limbic pathways formed from fibers running from the limen insulae in the temporal lobe to the prefrontal cortex. Functionally, the uncinate fasciculus is a bundle of association fibers forming part of the ventral limbic pathway and it connects the parahippocampal region with the ventral prefrontal cortex. It is involved in higher order cognitive processing, and because the uncinate fasciculus connects the superior temporal auditory regions with orbital and medial prefrontal cortices, it may also be involved in emotional responsivity to auditory stimuli (Petrides, 1996). Of particular importance to the study of creativity are the fibers that connect the temporal lobe language areas to the prefrontal cortex through the uncinate fasciculus. Indirect semantic priming (Mohr et al., 2001; Pizzagalli et al., 2001) and semantic association to unusual or subordinate meanings (Atchley et al., 1999) have been associated with creative ability.

Diffusion Tensor Imaging

There is converging evidence to support the utility of investigating structural connectivity in reference to creative thinking ability. Of particular utility to this investigation is diffusion tensor imaging (DTI). DTI uses MR encoding gradients in several (at least six) directions to measure water movement in a three dimensional space within a voxel (Basser, Mattiello, & LeBihan, 1994) in order to probe the structure of brain white matter *in vivo*. There are two ways of quantifying the movement of water within a voxel: according to the three major orientations of movement (ϵ_1 , ϵ_2 , and ϵ_3) and their associated diffusivities (λ_1 , λ_2 , and λ_3), and according to the coherence of water movement within the encapsulated

space (anisotropy) (Le Bihan, 1995). This displacement of water can be described as being isotropic, or as being anisotropic. In an isotropic state, molecular diffusion is relatively equal in all spatial directions, as it would be in large, fluid-filled spaces or in grey matter. In anisotropy, however, diffusion of molecules is not the same in all directions, and the principal direction of this diffusion can be quantified. In white matter, axons are thin and long, and they are further compressed and insulated by the presence of myelin (Le Bihan & Breton, 1985). Thus, DTI is sensitive to myelin in white matter. Signal from diffusion weighted images is used to construct a tensor model for each voxel. The mathematical model of the tensor ($\underline{\mathbf{D}}$) is shown in Figure 13. The axes, x, y, and z are the axes upon which the gradients are encoded (the subject's left/right, anterior/posterior, and inferior/superior axes, respectively).

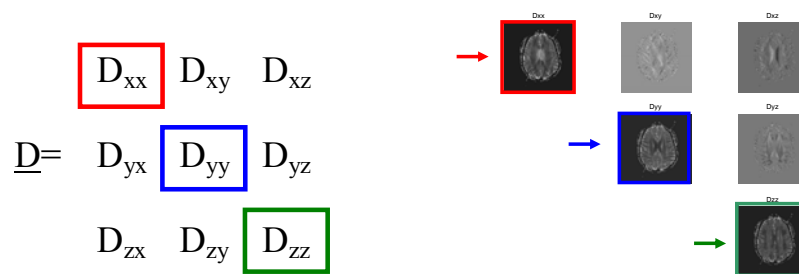


Figure 13. Structure of the diffusion tensor. On the left, the mathematical model of the diffusion matrix; on the right, corresponding images obtained from the MR images with diffusion weighting. Because the tensor is symmetrical, MR image intensity in a minimum of 6 diffusion weighting directions needs to be obtained.

The overall *magnitude* of the diffusion is expressed by the mean diffusivity. The mean diffusivity parameter identifies the average displacement of water molecules within a particular voxel (Basser & Pierpaoli, 1996), and it is calculated as the average of the eigenvalues $(\lambda_1 + \lambda_2 + \lambda_3)/3$. In addition, this average value can be decomposed into the contribution of each principal direction by quantifying λ_1 , λ_2 , and λ_3 . The predominant diffusion *orientation* corresponds to the principal eigenvector (ϵ_1), and the eigenvalue corresponding to this vector gives the magnitude of this diffusion (λ_1). It is generally assumed that the eigenvector associated with the largest eigenvalue (principal diffusivity) is oriented parallel to the

fiber track within a voxel because diffusion is restricted perpendicular to nerve fibers. Thus, using the principal eigenvalue (λ_1) as a useful index derived from DTI, it is possible to infer diffusivity along white matter fibers within voxels (Le Bihan, 2003). Measured changes in the largest principal diffusivity can reflect changes in axonal integrity, while perpendicular diffusivity (λ_2, λ_3) may be more sensitive to changes in myelin (Song et al., 2003).

The degree of *anisotropy* is expressed as fractional anisotropy (FA), the standard deviation of the eigenvalues (λ), divided by their root mean square value (Basser et al., 1996). FA is an index (0 to 1) that is independent of the orientation of diffusion, but it represents the degree of deviation from isotropic diffusion. Large values of FA represent highly anisotropic diffusion. High anisotropy represents highly regular, organized fibers within a voxel; and low anisotropy can indicate lower coherence and the presence of white matter disease. However, FA is not a direct measure of characteristics specific to white matter tissue, and in addition to fiber coherence, it can be influenced by extracellular water, cell packing density, and thickness of fibers (Shimony et al., 1999; Virta, Barnett, & Pierpaoli, 1999). Investigators must also be sensitive to the present limitations of DTI including its inability to properly resolve indices in voxels where fibers are poorly organized (Basser & Jones, 2002) or where several directional convergences occur (Le Bihan et al., 2001), therefore being insensitive to branching or crossing fibers.

Goals

Using DTI, white matter architecture can be inferred according to magnitude and direction of local water diffusion. Previous research has shown that creative thinking is characterized by bilateral prefrontal communication and by local ipsilateral communication. This would indicate the need for organized white matter fibers connecting bilateral prefrontal regions and ipsilateral prefrontal/temporal regions. Therefore, the goal of this investigation is to investigate a positive association between measures of divergent thinking and FA and λ_1 indices of white matter integrity in the following brain regions: (1) body and genu of the corpus callosum, because these are the white matter fibers that connect both hemispheres of the prefrontal cortex; (2) left and right cingulum bundle, as these fibers connect the

hippocampus (involved in cognitive inhibition) to the prefrontal cortex (involved in divergent thinking); and (3) the left and right uncinate fasciculus, as these fibers connect the prefrontal cortices with the temporal lobes (involvement in language processing and semantic networks). Given the use of language-based creativity tasks, the associations may be stronger for the left hemisphere structures than for those in the right hemisphere. In addition, the association between lateral asymmetries and measures of creative thinking will also be examined.

Method

Participants

All participants received DTI scanning in order to collect FA and diffusivity maps for comparison with creative thinking ability. Demographics and clinical characteristics for subjects in the normal control and schizophrenic groups are presented in Table 13. Recruitment inclusion/exclusion criteria were the same as those for Chapters III, IV, and V with additional MR safety requirements being met. Of the nine subjects who had DTI scanning performed, all participated in the experiment presented in Chapter I; seven participated in the experiment presented in Chapter V (3 normal controls and 4 schizophrenic individuals); and eight (2 normal control and 6 schizophrenic individuals) participated in the experiment presented in Chapter IV. All patients were taking atypical antipsychotic drugs (clozapine, risperidone or olanzapine) at the time of testing. The study was reviewed and approved by the Vanderbilt University Institutional Review Board, and informed consent was obtained from all participants. The testing session lasted approximately one hour, and subjects were compensated for their participation.

Although there were no overall differences in laterality scores ($t_7 = -1.1$, *ns*), one of the normal control subjects (male) was left-handed; however all schizophrenia patients were right-handed. As shown in Table 13, there were no significant group differences in sex ($\chi^2(1, N=9) = 0.11$, *ns*); age ($t_7 = -0.15$, *ns*); IQ ($t_7 = 0.09$, *ns*); letter ($t_7 = -0.04$, *ns*) or design ($t_7 = -2.2$, *ns*) fluencies; total divergent fluency from

Table 13. Demographic and clinical characteristics of the sample for the DTI study

Demographic Variable	Group	
	Normal Control N=3	Schizophrenic N=6
% female	33%	50%
Age	32.0 (3.8)	32.8 (3.3)
Years of Education	13.0 (0.6)	13.2 (0.5)
Laterality Score	36.7 (60.9)	82.5 (7.3)
SPQ	17.3 (5.9)	-
Illness Duration (years)		13.8 (3.0)
BPRS	-	18.5 (6.0)
SANS	-	22.3 (8.8)
SAPS	-	19.6 (7.8)
WASI FSIQ	99.3 (5.5)	98.0 (10.2)
Letter Fluency	36.7 (4.2)	37.0 (5.0)
Category Fluency	42.3 (3.2)	31.8 (1.5)
Design Fluency	8.3 (1.5)	11.5 (0.7)
Total Uses (from Experiment 1)	78.0 (11.1)	82.8 (16.1)
Gough CPS	11.0 (3.6)	9.0 (2.0)
CAQ	5.3 (2.9)	18.2 (9.1)

Values are given as mean (SE).

Chapter III ($t_7 = -0.20$, *ns*); or years of education ($t_7 = -0.21$, *ns*). In addition, subjects were relatively similar in creative personality traits ($t_7 = 0.53$, *ns*) and in creative achievement scores ($t_7 = -1.0$, *ns*). Subjects differed in their semantic (category) fluency ($t_7 = 3.5$, $p < .01$) abilities.

Apparatus and Image Acquisition Parameters

All images were collected on the General Electric 3.0 T MRI scanner at Vanderbilt University Medical Center. Diffusion images were collected using a spin echo echoplanar sequence. The following scan parameters were used: Square field of view, 260 X 260 mm.; 128 X 128 scan matrix; slice thickness = 4 mm.; interslice distance = 0 mm.; echo time = 88.5 ms. (minimum); repetition time = 9000 ms.; ramp

sampling = 1; b = 1000s/mm²; number of directions = 33. 29 axial slices were acquired covering the entire brain. Diffusion tensor imaging lasted approximately 10 minutes.

Data Analysis and Region of Interest Measurements

After reconstruction, the diffusion weighted images were transferred to a Linux workstation, where eigenvalue, eigenvector, trace, and FA maps of the diffusion tensor were calculated using Matlab. Each region of interest (ROI) was manually placed on the FA map corresponding to the appropriate slice(s) for each subject. Measurements for each structure are described below.

The Corpus Callosum. The corpus callosum was measured using a single slice (Figure 14(A)). At least three axial slices of corpus callosum crossed the midline. The middle slice was chosen, corresponding to the axial slice of corpus callosum that crossed the midline and was therefore representative of true interhemispheric fiber passage. On this slice, an ROI was placed measuring 20 pixels X 5 pixels. This ROI was placed using the crosshair tool, in an effort to place the ROI so that it was centered on the midline representing as much of the structure in the anterior direction as in the posterior one. A ruler was used to measure the parenchyma so that the midpoint of the ROI could be standardized. This procedure provided a highly reliable method of ROI placement, $r_{ICC} = .99$ (n=10, p<.001).

The Genu. The genu was identified in the midsagittal aspect of the appropriate axial plane on the colored FA map (Figure 14(B)). Most often, at least three axial slices of genu crossed the midline, so the middle slice was chosen. On this slice, an ROI was placed measuring 5pixels X 5pixels. The crosshairs were used to place the square ROI box centered on the midline of the genu, comprising as much area in the anterior direction as in the posterior one. Intrarater reliability for the genu was $r_{ICC} = .99$ (n = 10, p<.001).

The Cingulum Bundle. The cingulum bundle was identified bilaterally on the colored FA map along its most extreme dorsal convexity in the axial slice that intersected this plane (Figure 14 (C)). This required the structures to be “unbroken” in the axial plane, unlike more ventral slices of the cingulum bundle in which the left and right structures each appear separated into an anterior and a posterior bundle.

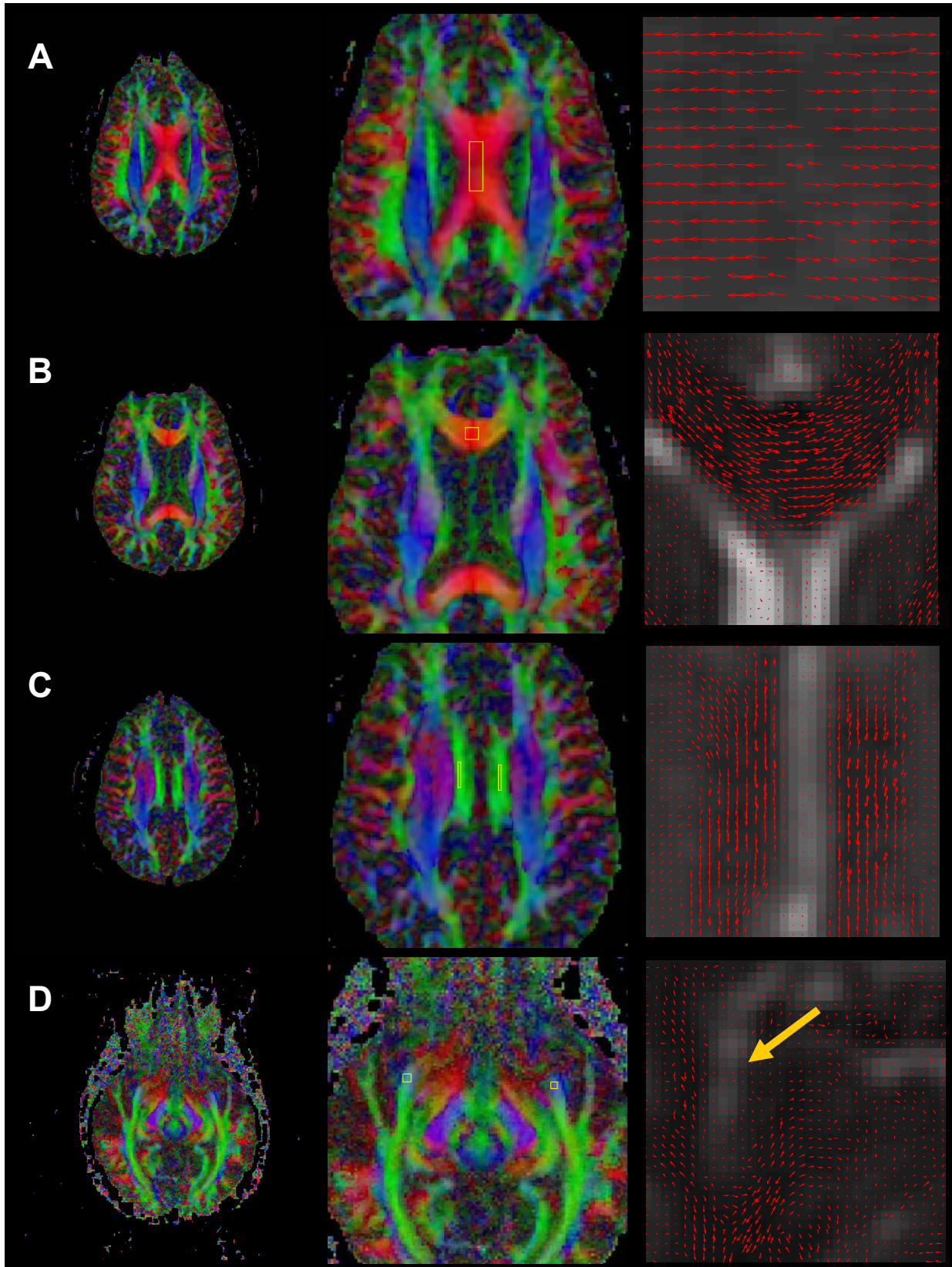


Figure 14. Placement of ROIs for DTI measurements showing the directions of principal diffusion: a) body of the corpus callosum; b) genu of the corpus callosum; c) right and left cingulum bundles; and d) right and left uncinate fasciculi.

Each side was comprised of a 10 pixel X 1 pixel ROI. ROI placement was standardized in two planes. For the axial plane, the ROI was centered proximal to the most distal line of the cingulum bundle that contained “green” pixels under the vertical crosshairs. This method allowed the most central portion of the cingulum bundle to be reliably measured. For the vertical plane, the ROI was centered at approximately half of the length of the unilateral structure. Therefore, ROIs for left and right cingulum bundles were often placed within different y-coordinates for single slice measurements. Intrarater reliability for the left cingulum bundle and for the right cingulum bundle was $r_{ICC} = .97$ ($n=10$, $p<.001$).

The Uncinate Fasciculus. The uncinate fasciculus was identified bilaterally on the colored FA map (Figure 14 (D)). The uncinate fasciculus can be difficult to identify in DTI maps, and this is complicated by its parallel trajectory with the inferior fronto-occipital fasciculus. Therefore, in order to identify fibers comprising only the uncinate fasciculus, and not the inferior fronto-occipital fasciculus, ROI delineation was restricted to the single axial slice that contains the vertex of the inverted “C”. Each side of the uncinate fasciculus was comprised of a 3 pixel X 3 pixel ROI. Most often, the uncinate fasciculus would be evident in 3 ventral slices where both the orbitofrontal cortex and the anterior temporal lobes were visible. For these subjects, the bilateral uncinate fasciculus measurements were made on the first slice where the uncinate fasciculus was visible without additional trajectory of the inferior fronto-occipital fasciculus anterior to it (the slice where the fibers went from an anterior/posterior trajectory to a caudal/ventral one, i.e. the point where the uncinate fasciculus hooks around the temporal lobe into the frontal lobe). For all other subjects’ scans, there were 2 slices with bilateral uncinate fasciculus visible. For these, the slice that was judged (by hue intensity) to be most prominent was chosen. ROIs were placed so that the center of the ROI would be approximately aligned with the center of the uncinate fasciculus as it appeared in the axial plane. Intrarater reliability coefficients for the left and right uncinate fasciculi were $r_{ICC} = .95$ ($n = 10$, $p<.001$).

Creative Thinking Measures

In order to investigate the relationship between creativity and DTI indices, divergent thinking and creative personality and achievement data were used from the experiment presented in Chapter III.

Results

Descriptive Results

Inspection of the data (Table 14) revealed that the genu was characterized by relatively high diffusivity overall (Mean Diffusivity: $M=9.62E-06$, $SD=7.15E-07$), and in the principal direction of diffusion (λ_1 : $M=1.91E-05$, $SD=1.22E-06$). The FA was also relatively higher in the genu ($M=.70$, $SD=.06$), indicating that, along with a higher directional component, the fibers were oriented relatively similarly. This could be due to relatively tight packing of the fibers that are oriented in a more uniform direction. For the body of the corpus callosum, the principal diffusivity was relatively large ($M=1.75E-05$, $SD=1.68E-06$), however the FA was lower than observed in the genu ($M=.63$, $SD=.12$). This could indicate that although fibers were tightly packed, there was less homogeneity in the directional trajectories. This could be due to placement of the ROI, which was approximately aligned with the interhemispheric fissure where the direction of diffusion in fibers tends to switch to an ipsilateral direction as fibers cross from the right to left hemispheres, reflected in a relatively lower FA value as fiber coherence switches from a left→right to a right →left direction (Figure 14A).

Indices from the uncinate fasciculi measurements indicate that there is relatively low FA (right: $M=.50$, $SD=.10$; left: $M=.46$, $SD=.07$) with relatively lower principal diffusivity (λ_1 : right $M=1.52E-05$, $SD=1.63E-06$; left $M=1.50E-05$, $SD=8.19E-07$). For the uncinate fasciculi measurements, the direction of diffusion was not “in-plane” on axial slices (see Figure 14D); rather an attempt was made to capture a sample of the structure as it entered the prefrontal cortex superiorly from the temporal lobes. Given the slice thickness (4 mm.), it could be argued that a higher degree of averaging within slices failed to capture the most uniform directional components of these structures, as both the FA and diffusion calculations

were low. This observation may be strengthened by comparing the trace and isotropic diffusivity values from the uncinate fasciculi, indicating overall diffusivity to be relatively similar to principal (directional) diffusion, and coherence (FA) to be relatively weaker. For the cingulum bundles, the data indicate a higher FA (right: $M=.65$, $SD=.14$; left: $M=.68$, $SD=.17$) than that observed in the uncinate fasciculi and in the body of the corpus callosum with relatively lower diffusivity measurements overall. This may indicate stronger fiber coherence in the anterior-posterior direction with relatively less packing, indicated by a lower λ_1 index.

Comparative Results

Table 14. FA and λ_1 of white matter tracks in relation to creativity and intelligence measures

Location	DTI Index	Value Mean (SD)	Cognitive Variable			
			Total Uses	Combinatory Uses	RAT Correct	WASI FSIQ
Right Uncinate Fasciculus	FA	.50 (0.10)	-.28	-.08	.18	-.10
	λ_1	1.52E-05 (1.63E-06)	-.10	0	.22	.07
Left Uncinate Fasciculus	FA	0.46 (0.07)	.03	.17	.49	.30
	λ_1	1.50E-05 (8.19E-07)	.18	.32	.54 (.08)	.38
Right Cingulum	FA	0.65 (0.14)	.03	-.17	-.27	-.28
	λ_1	1.64E-05 (1.76E-06)	.02	-.05	.07	-.18
Left Cingulum	FA	0.68 (0.17)	.23	0	-.45	-.07
	λ_1	1.72E-05 (2.85E-06)	-.02	-.15	-.64 (.04)	-.33
Corpus Callosum (Body)	FA	0.63 (0.12)	-.13	-.22	.10	.03
	λ_1	1.75E-05 (1.68E-06)	-.50 (.08)	-.60 (.08)	-.93 (.001)	-.70 (.02)
Genu	FA	0.70 (0.06)	.03	.42	.19	-.28
	λ_1	1.91E-05 (1.22E-06)	-.52 (.08)	.12	.16	-.23

Correlations are Spearman's rho (r_s).

Key: FA = fractional anisotropy (orientational coherence of fibers within a voxel); λ_1 = the eigenvalue of the major eigenvector which reflects the maximum diffusivity (cm^2/s).

This investigation began with a series of hypothesized relationships between white matter characteristics and creative thinking. These indicated the assumption that there would be a positive relationship between creativity variables and strength and direction of diffusion in white matter structures. The present study was able to investigate indices of FA and λ_1 in relation to divergent and convergent thinking and to psychometric intelligence. Data from these associations are reported in Table 14². The present analyses indicate that the strength of diffusion in the primary direction (λ_1) in the body of the corpus callosum (left↔right) is inversely associated with measures of convergent thinking (RAT: $r_s = -.93$, $p < .001$) and psychometric intelligence (WASI FSIQ: $r_s = -.70$, $p < .05$). Trends for significance indicate that there is also an inverse relationship between λ_1 and divergent thinking variables as well.

Associations with Creative Personality Traits and Achievement

Although creative thinking ability represents a single facet comprising creative ability overall, more seemingly complex constellations have also been measured psychometrically, including creative personality and measurable creative achievement. Using the Gough Creative Personality Scale and the Creative Achievement Questionnaire, the relationship between white matter microstructure and these more complex ‘outcome’ measures of the creativity construct were investigated ($N = 9$). Endorsed items from the Creative Personality Scale were inversely associated with corpus callosum FA measurements ($r_s = -.71$, $p < .01$), indicating an association between decreased interhemispheric fiber coherence and creative personality. This is similar to the direction of the relationship between divergent thinking variables and corpus callosum microstructure organization described previously in this chapter. Increased creative achievement measured by the Creative Achievement Questionnaire was associated with decreased white matter coherence and directional strength in the genu. Creative Achievement Questionnaire scores were inversely correlated with the genu FA ($r_s = .66$, $p < .05$).

² In spite of a large correlation matrix, corrections for multiple comparisons were not employed. Although this analysis is exploratory, several a priori hypotheses have been addressed, and the results were considered in reference to these hypotheses.

Hemispheric Differences.

The uncinate fasciculus and the cingulum are bilateral structures. In order to observe hemispheric differences in FA, a laterality index was computed for each structure. The laterality index was calculated as $(2*(L-R)/(L+R))$, thereby expressing the difference as a fraction of the mean. Because right-sided structures were subtracted from left-sided structures, positive laterality index values indicate left>right and negative values indicate right>left. Data from individual subjects are plotted in Figure 15, showing hemispheric differences in fractional anisotropy and λ_1 for the uncinate fasciculus and the cingulum bundle. Because of the relatively small sample size, a statistical comparison was not employed. However,

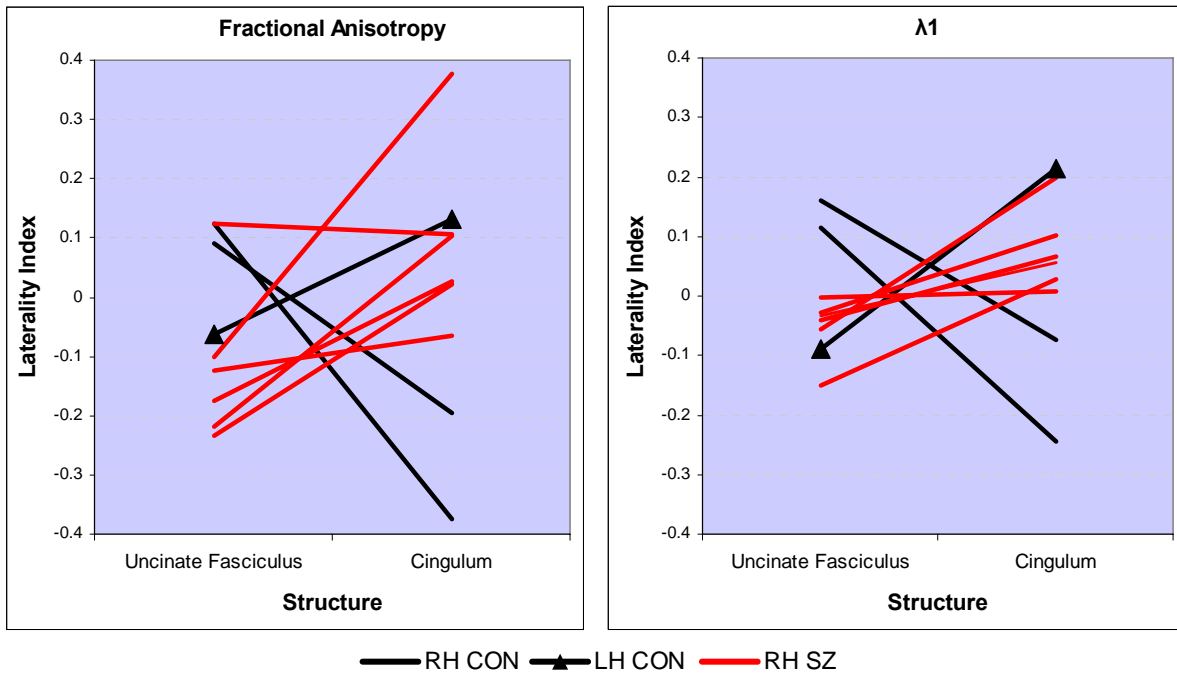


Figure 15. Laterality indices for FA and λ_1 values in the uncinate fasciculus and the cingulum bundle. RH= Right handed; LH= Left handed; CON= Normal Control; schizophrenia= Schizophrenic
A positive laterality index reflects L>R. A negative laterality index reflects R>L.

inspection of the individual data is revealing. For right-handed schizophrenics, there is generally a right>left asymmetry in FA and in λ_1 for the uncinate fasciculus, and a left>right asymmetry for the cingulum. For right-handed normal controls, the trend appears to be reversed. However, one left-handed

normal control was included in the sample, and this individual's data showed a hemispheric pattern similar to that of the right-handed schizophrenics rather than the right-handed controls. An analysis of the association between degree of asymmetry in these structures and divergent thinking scores was performed. Although relationships between a leftward asymmetry and divergent thinking ability were small and non-significant, they were in the positive direction.

Discussion

The purpose of the study presented in Chapter VI was to provide initial data regarding the relationship between DTI measures of white matter in select brain regions and demonstrated creative thinking ability. Given that this was the first known study to present data regarding this relationship, the method was exploratory in attempting to specify more precisely which brain regions may be important to investigate in creative thinking. Two groups were studied: normal controls and schizophrenics based on a convenience sample. Creative thinking and achievement data from experiments presented in Chapter III were compared from each individual to FA and λ_1 values obtained from DTI scan ROIs.

At this point, interest was given to reasonable relationships suggested by the data. It must be noted that this was an investigation based on a priori decisions regarding which brain regions to investigate. The data were not approached from a whole-brain analysis. Regions were carefully selected and reliably measured in order to obtain estimates as sensitive as possible to the goals of the investigation.

In the genu of the corpus callosum, diffusion in the primary direction (λ_1) may be inversely associated with divergent thinking, while diffusion in the primary direction in the body of the corpus callosum may be inversely related to higher intellectual thinking overall. This may be indicative of decreased fiber packing in the corpus callosum, as dense packing would increase diffusion restriction in a single direction. Water diffusion in other structures may have possible associations with convergent thinking, as assessed by the Remote Associates Test; however, the data are characterized by singular relationships that do not converge to provide incremental support for interpretation. Overall, however, there is some convergence in the two subsections of the corpus callosum that have been sampled

indicating that the structures that connect the right and left anterior hemispheres may have attributes that are associated with different thinking styles. Convergent thinking and intelligence, and to a lesser degree, creative thinking, are associated with lower diffusivity in the principal direction. From these data, further hypotheses can be generated related to the association between white matter microstructure and cognitive abilities. These data suggest that it may be the strength of diffusion along axons, rather than the directional coherence of fibers within a voxel, that may be particularly associated with creativity and intelligence in the structures measured.

The present exploratory investigation has indicated that further research is warranted to clarify the relationship between white matter properties and divergent and convergent thinking skills. This relationship may be particularly evident in the corpus callosum. If further research does substantiate an inverse relationship between principal diffusivity and cognitive ability, how would this then be understood in terms of corpus callosum function? There is evidence for both inhibitory and excitatory roles of the corpus callosum (Bloom & Hynd, 2005; Witelson, 1992). According to the excitatory model, the corpus callosum's function is to facilitate transfer of information between hemispheres by its ability to activate both hemispheres. However, according to the inhibitory callosal model, the hemispheres maintain functional separation by inhibiting the contralateral hemisphere when processing specialized information. In reality, it is most likely that the corpus callosum operates as both an inhibitory and an excitatory gateway depending on the cognitive task (Hellige, 1993). As such, the corpus callosum would allow interhemispheric communication (excitatory) when processing demands are high and when information would be processed more efficiently by utilizing both hemispheres. On the other hand, processing that is specialized within a hemisphere may invoke inhibitory mechanisms so that inefficient, non-specialized regions would not be activated.

From the experiment presented in Chapter V, in addition to previous research (cf. Carlsson et al., 2000), creative thinking involves bilateral prefrontal processing of information across all groups studied. This would imply an excitatory role of the corpus callosum in creative thinking. However, schizotypal subjects showed the same pattern of overall bilateral activation with the additional element of a strong

right hemisphere bias. This may indicate an extremely flexible role of the corpus callosum operating in schizotypal individuals (with axons being less directionally specified, as observed with lower λ_1 associations) where the excitatory mechanisms may operate to provide bilateral processing during a cognitively demanding task (creative thinking), but where inhibitory mechanisms “switch on,” allowing preferential right hemisphere processing for novel associations when this is warranted. Although this explanation is theoretical, it would certainly be an area for future research to take into account, and it would be addressed by taking the temporal course of the creative thinking process into account, thereby examining hemispheric activation during different stages of the creative thinking process.

Although associations with FA were investigated, this rotationally invariant measure of fiber coherence does not appear to be related to the styles of thinking measured in this sample. Synthesizing these data, the fastest diffusion aligned with coherent fibers is inversely associated with divergent and convergent thinking. Overall fiber coherence strength does not appear to be related to divergent or convergent thinking in this sample. Creative personality and achievement, as measured by the Gough Creative Personality Scale and Creative Achievement Questionnaire, were inversely related to FA. This may indicate that more creative individuals are characterized by less white matter fiber organization within the ROIs measured in the corpus callosum.

One important caveat in interpreting the results of the DTI investigation is that the majority (6/9) of subjects for whom diffusion tensor imaging was available were schizophrenic. Several studies have investigated characteristics of white matter microstructure in schizophrenics compared to normal controls, and significant differences have been found. Based on theories implicating abnormal connectivity in white matter circuits in the pathogenesis of schizophrenia (Phillips et al., 2003), recent studies have documented changes in white matter microstructure associated with this disorder. Using DTI, schizophrenia patients have been found to have regionally decreased fractional anisotropy in brain regions sampled in this investigation (Buchsbaum et al., 1998; Burns et al., 2003; Kubicki et al., 2002; Kubicki et al., 2003; Minami et al., 2003), and this has been explained in terms of both axonal and white matter (myelin) disruption in schizophrenia (Kubicki et al., 2005). In addition, studies that have associated

cognitive variables with white matter indices calculated from DTI have also shown that in schizophrenia there is some association between cognition and white matter disruption (Kubicki et al., 2003).

The question of plasticity still remains. Enhancement of creative solutions after sleep is thought to be subsumed by consolidation, especially after REM sleep, which may serve to strengthen conceptual associations (Stickgold & Walker, 2004). Insightful associations and problem solutions are made more quickly after the initial presentations and brief subsequent learning stages are followed by periods of sleep (Wagner, Gais, Haider, Verleger, & Born, 2004). This process of associative linking has been compared to the similar process of consolidation, which is thought to strengthen episodic memories through hippocampal activation (Ambrosini & Giuditta, 2001). The effects of neural plasticity on creative production can also be seen in relation to the development of creative ability after the onset of dementia (Fornazzari, 2005; Mendez, 2004; Miller et al., 2000; Miller et al., 1998; Miller & Hou, 2004; Miller, Ponton, Benson, Cummings, & Mena, 1996a). This may represent a form of disinhibition, or it may be related to synaptic plasticity, however, further study of this phenomenon in relation to the neurobiology of creativity is warranted.

In terms of handedness differences between the two groups that would theoretically reflect differences in hemispheric organization, one study reported a left>right asymmetry in FA in the cingulum bundle regardless of reported subject handedness (Gong et al., 2005). In terms of the representativeness of the present data, reports of DTI cingulum indices from this study are similar to those reported elsewhere (Concha, Gross, & Beaulieu, 2005). There is evidence, through post-mortem studies that the right uncinate fasciculus is larger and comprised of more fibers than the left uncinate fasciculus (Highley, Walker, Esiri, Crow, & Harrison, 2002). Hemispheric asymmetries in the uncinate fasciculus indicate that there is a ventral language pathway that runs through the uncinate fasciculus from the temporal lobe language areas to Broca's area, but that this is only characteristic of the left uncinate fasciculus, and absent in the right uncinate fasciculus (Parker et al., 2005).

Two types of fibers are present in the corpus callosum. In the anterior (genu) regions, there is a high density of thin axons that are not heavily myelinated, while fiber density is less in the body of the

corpus callosum due to relatively thick, highly myelinated (high-conducting) fibers (Aboitiz, Scheibel, Fisher, & Zaidel, 1992). According to the handedness hypothesis of ‘axon loss,’ right handedness alone may occur based on axonal death in the corpus callosum, giving left-handers an increased amount of interhemispheric communicating fibers (Witelson & Nowakowski, 1991). These data may begin to account for the enhanced creativity in schizotypy arising from increased bilateral communication. The data from the present study have shown that decreased λ_1 diffusivity, and therefore, possibly decreased fiber packing in the corpus callosum could account for some of the variance in creative thinking ability and problem-solving. If this is particularly salient in schizotypal groups, or in relatives of schizophrenics, then it may be related to a similar model of axon loss in left-handers and schizotypes.

Although DTI has demonstrated sensitivity to white matter changes and axonal disruption in the brain (Sundgren et al., 2004), specifying the exact nature of observed white matter pathophysiology is often difficult to assess using DTI alone. Some evidence suggests that axonal versus myelin-related changes can be detected by examining λ_1 (parallel: axonal) in relation to λ_2 and λ_3 (perpendicular: myelin) indices (Song et al., 2003). However, FA is not specific to these characteristics and may be affected by many contributing factors (Shimony et al., 1999; Virta et al., 1999). Therefore, it will be important for future studies to specify the relationships between axonal and myelin changes in relation to cognition, including creativity. This has important implications for investigating white matter in terms of synaptic arborization and pruning in development or in terms of myelinating factors that might be most sensitive to the connectivity-related correlates of creative thinking. Phillips and Silverstein (2003) have suggested that cognitive deficits in schizophrenia may arise from discoordination within discrete and among separate brain regions. This would suggest that changes in functional binding and structural connectivity would give rise to cognitive dysfunction and to symptoms in schizophrenia. This hypothesis has not been sufficiently investigated in terms of schizotypy, and it may be involved in the structural neurophysiology of creative thinking.

Further studies are needed to specify the relationship between structural brain connectivity and cognitive variables of creativity; however, the present investigation has established the feasibility of

conducting these types of investigations. Future studies would benefit from the use of fiber tracking in relation to creativity. In doing so, functional imaging data could be viewed in combination with structural connectivity data, allowing a more direct analysis of the data suggesting possible fiber disorganization (and discoordination) in creativity and in schizotypy.

CHAPTER VII

GENERAL CONCLUSIONS

The series of investigations undertaken in this dissertation were implemented in order to provide incremental evidence for the relationship between creativity and the schizophrenia spectrum and to elucidate some of the neurobiological and neuropsychological mechanisms of action that may contribute to this finding. Chapter III succeeded in providing evidence that schizotypy, as addressed by the Diagnostic and Statistical Manual model, is associated with enhanced divergent thinking ability and that this has shown an inverse relationship with pure right-handedness and a positive relationship with the disorganized traits of schizotypy. In addition Chapters III and V have shown, that in terms of cognitive ability, schizophrenia patients and normal controls are statistically matched for divergent thinking fluency in spite of overwhelming evidence of cognitive dysfunction in schizophrenia. After providing these initial results, Chapters IV, V, and VI addressed some of the possible neurobiological mechanisms that may contribute to enhanced creative thinking. Although the initial hypotheses in Chapter IV were not supported when investigating hemispheric contributions to verbal and non-verbal creative divergent thinking, the experiment may have helped to specify the nature of allusive thinking in comparison to divergent thinking, and it may be helpful in future investigations of social rehabilitation in schizophrenia. Chapter V was able to show, using a relatively novel neuroimaging modality, that although creative thinking requires bilateral prefrontal integration, the right hemisphere may be responsible for the enhanced creative thinking seen in schizotypes relative to schizophrenic or control subjects. Chapter VI served to identify some of the elements of structural connectivity that may be involved in creative thinking in schizophrenia patients and in normal controls. These initial results suggest that the strength of axon direction in the genu and body of the corpus callosum may contribute generally to intellectual and cognitive performance, including an association with divergent thinking.

One persisting question concerning the proposed advantage given to anomalous cerebral lateralization and creative ability is how decreased lateralization would affect the mechanism of action. Hypotheses at this point would allow for two explanations. For the first, is it possible that increased interhemispheric communication would allow greater associative networking between the left and right hemispheres, each retaining a major functional ability (left=language, right=visuospatial processing). The second possible explanation is that it may also be true that anomalous cerebral lateralization allows for a decreased degree of specialization within each hemisphere, therefore creative associations are developed more frequently because, in essence, all the parts necessary to form these associations are in close proximity to one another, within each hemisphere. So, according to the first proposed model, increased creativity through anomalous cerebral lateralization would arrive through more efficient interhemispheric communication at the level of the corpus callosum and other interhemispheric pathways. This would be analogous to a real-time model, where creative associations at each step are mediated by the efficiency of transfer through interhemispheric pathways. On the other hand, the second hypothesis allows for a more static case. If anomalous cerebral lateralization has developmentally allowed for the “crowding” of both semantic and visuospatial abilities into each hemisphere, then the proposed associative networking that gives rise to creative solutions would not need to rely on interhemispheric transfer, but on the necessary hardware had already been set up so that this processing could be accomplished intrahemispherically.

From the neuroimaging literature that has investigated creative thinking, converging results thus far have implicated bilateral processing of information for creative solutions (Bekhtereva et al., 2001; Carlsson et al., 2000; Jausovec, 2000; Jausovec et al., 2000c; Orme-Johnson et al., 1981; Razoumnikova, 2000; Starchenko et al., 2000). However, it has also been shown that increased organizational complexity *within* neuroanatomic regions has also been associated with enhanced creative performance (Molle et al., 1996; Molle et al., 1999; Molle et al., 1997). Data from the present series of experiments, in particular the NIRS investigation of creative thinking (Chapter V), have also indicated a general association with bilateral processing for creative solutions, however those with the highest creative performance have shown a right hemisphere advantage.

Bilateral results from neuroimaging paradigms that have not decoupled the neural processes from the temporal structure of the paradigm may be averaging the entire temporal structure to show a bilateral effect, but it could be that the hemispheres act differentially during different components of the task. For instance, it may be beneficial to recall that the creative process likely unfolds according to a temporal structure: preparation, incubation, illumination (or inspiration), and verification (or elaboration) stages (Wallas, 1926). Are the hemispheres operating differentially under each of the requirements associated with each stage? Future studies would benefit from being sensitive to decoupling the temporal components of the neural substrates of creative thinking.

Limitations

One of the limitations of the series of studies presented in this dissertation is the relatively small sample sizes that have been employed. Larger samples would allow future studies to disambiguate the relative contributions of different schizophrenic syndromes. In addition, larger samples of schizotypal subjects would allow concentration on the disorganized trait cluster. Data from the present series of investigations have indicated that disorganized traits may be particularly associated with creativity, and concentrating on this group may help to elucidate the specific traits involved in enhanced creativity. In addition, a larger sample size would allow different variables to be addressed within groups. For instance, controls, schizotypes, and schizophrenics could be evaluated separately in terms of the relationships between divergent thinking, handedness, and schizotypal trait measures.

Although many of the theoretical foundations expressed in this dissertation espouse the dimensional rather than categorical approach to studying psychopathology, the statistical methods that have been used largely rely on dividing individuals from these studies into discrete groups. Thus, an ANOVA model, rather than a regression model has generally been used for data analysis. Future studies may be better served by approaching the types of questions undertaken in these experiments through a continuous regression model. In part, the methodology used in this series of investigations was necessitated by the lack of ability to continuously measure groups using identical tools (i.e.

schizophrenics are not reliably measured using the SPQ). Using a larger sample would allow a better-fitting statistical model to be employed.

Using measures of divergent thinking, external creative achievement, and creative personality correlates allowed for a diffuse sampling of the creativity construct in the present series of investigations, however, these studies did not tackle the larger multi-dimensional construct of creativity and the hierarchical causal model leading from neural processes to complex behavioral products of creativity. Divergent thinking was used in order to provide a psychometrically valid way to measure the creative thinking process. Although divergent thinking has shown promise as a valid facet of the larger creativity construct, it would be naïve to suggest that divergent thinking is equated with “creativity.” In order to sufficiently address the question of the schizophrenia/creativity relationship, future studies must also incorporate creative achievement, interests, approach, and interest factors into the models being investigated.

Having incorporated biological relatives of schizophrenia patients into the present sample would have been warranted. As previously discussed, schizotypal traits identify individuals at risk for developing psychotic disorders, however not all individuals high in trait schizotypy go on to develop a psychotic disorder. Therefore, studying individuals who are more clearly at genetic risk of or relatedness to schizophrenia would help to clarify these relationships. In addition, incorporating a group of subjects with bipolar disorder would allow the comparisons made to specify a model of creativity and mental illness to be more fully expressed.

Future Directions

What insights should continued study of the relationship between creativity and schizophrenia be able to provide to psychiatry and to science? Of particular importance to this question is evaluating what has been learned since Galton (1892, pp. ix-x) when he wrote:

Still, there is a large residuum of evidence which points to a painfully close relation between the two [genius and insanity], and I must add that my own later observations have tended in the same direction, for I have been surprised at finding how often insanity

or idiocy has appeared among the near relatives of exceptionally able men. Those who are over eager and extremely active in mind must often possess brains that are more excitable and peculiar than is consistent with soundness. They are likely to become crazy at times, and perhaps to break down altogether. Their inborn excitability and peculiarity may be expected to appear in some of their relatives also, but unaccompanied with an equal dose of preservative qualities, whatever they may be. Those relatives would be “crank,” if not insane.

In contrast to his later statement,

If genius means a sense of inspiration, or of rushes of ideas from apparently supernatural sources, or of an inordinate and burning desire to accomplish any particular end, it is perilously near to the voices heard by the insane, to their delirious tendencies, or to their monomanias. It cannot in such cases be a healthy faculty, *nor can it be desirable to perpetuate it by inheritance* [italics added]. (Galton, 1892, p. x)

Clearly the scientific study of schizophrenia has traditionally focused on the deleterious effects of the disorder. This approach has elucidated many of the neurobiological components of schizophrenia that have resulted in behavioral and pharmacological treatments which have been of inestimable benefit to individuals suffering from schizophrenia. However, as Horrobin (1998, 2001) and Crow (1995a, 1995b, 1997) have suggested, studying the genetic, biological, and cognitive sequelae that are so apparent in schizophrenia may actually help us to understand evolutionary factors common to all *Homo Sapiens*, such as language, generativity, and creativity, thus suggesting the alternative appellation of *Homo Faber* (creator) that seems so saliently warranted when understanding human beings as creative environmental adaptors (Bergson, 1998).

Although the myriad studies supporting a positive relationship between schizotypal traits and creativity hint to supporting the compensatory advantage theory of schizophrenia (Polimeni & Reiss, 2003), this topic has been insufficiently addressed in the literature. Studies have approached the creativity-schizotypy association in reference to an evolutionary impetus (O'Reilly et al., 2001), however it remains to be the most interesting question associated with these studies. Approaching the evolutionary question more directly, Nettle & Clegg (2006) have shown that the unusual experiences and impulsive nonconformity components of schizotypy, unlike introverted anhedonia, are both positively related to mating success as measured by number of partners. However, the relationship between unusual

experiences and mating success is mediated by involvement in poetry and art (for both males and females). Although this model did not account for social aspects of artistic communication, it is a starting point to empirically link this relationship to evolutionary mechanisms that have been theorized for some time.

Identifying endophenotypes can clarify the neurobiological and cognitive markers peripherally related to neuropsychiatric disorders through genetic analysis. Studying endophenotypes in relation to psychiatric or personality concepts is only useful if the genetic components of the endophenotype are less measurably complicated than the overriding additive concept (Gottesman & Gould, 2003). Thus, the more complex cognitive and behavioral construct of creativity may be better studied genetically through lower-level components that must be in effect to give rise to creativity. Although attentional inhibition has already been discussed in relation to creativity, it is also an identified endophenotype associated with schizophrenia such as sensory gating, eye tracking, and working memory.

Given the associations between lower-level and multidimensional traits related to creativity and schizophrenia or schizotypy, could creativity be a *positive endophenotype* for schizophrenia? Data suggest that creative ability may be stronger in relatives of psychotic patients, yet also preserved in schizophrenia itself. Animal models are important contributors to identifying endophenotypes for psychiatric disorders because the link between genes and specific behavior can be made through a less complex pathway. Possible animal models of creativity have been identified with enhanced cognition in mice through genetic manipulation of GAP-43 phosphorylation (Routtenberg, Cantalops, Zaffuto, Serrano, & Namgung, 2000), through plasticity in bird song (Brenowitz, 2004; Marler, 1991), and through behavioral tool use in New Caledonian crows (Chappell & Kacelnik, 2002; Chappell & Kacelnik, 2004; Kenward, Rutz, Weir, Chappell, & Kacelnik, 2004). Recently, behavioral genetics has identified allelic variations that, combined with environmental interaction, result in particular intellectual or cognitive sequelae (cf. Plomin et al., 2004). Because this area will most likely uncover phenotypes associated with mental illness, it will become increasingly important to appreciate the negative *and* positive results expressed by the genes associated with particular forms of psychopathology. Thus, the

stage has been set for a more comprehensive analysis of creativity and its relation to complex neurobehavioral syndromes.

Although creativity may be considered one of the highest forms of human metacognition, while being empirically related to one of the most debilitating mental conditions, little research has focused on uncovering the elements that account for this association. The research presented in this Dissertation has made an effort to show that this line of research can be conducted empirically and that it has the potential to uncover many of the neurobiological substrates of creative thinking in general and the role that schizophrenia may have played in establishing creativity as an important element in human cognition.

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