8-2002

Individual Differences in the Neurophysiology of Creativity

Jonna Kwiatkowski

INDIVIDUAL DIFFERENCES IN THE NEUROPHYSIOLOGY OF CREATIVITY

By

Jonna Kwiatkowski

B.A. Saint Mary's College, 1994

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(in Psychology)

The Graduate School

The University of Maine

August, 2002

Advisory Committee:

Colin Martindale, Professor of Psychology, Advisor

Jonathan Borkum, Adjunct Professor of Psychology

Michele Alexander, Assistant Professor of Psychology

Marie Hayes, Associate Professor of Psychology

Alan M. Rosenwasser, Professor of Psychology

INDIVIDUAL DIFFERENCES IN THE NEUROPHYSIOLOGY OF CREATIVITY

By Jonna Kwiatkowski

Thesis Advisor: Dr. Colin Martindale

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy
(in Psychology)
August, 2002

Theories dating back to the 1800's have suggested neurophysiological specialization as a key factor in creative production. A common theme in these theories is that greater flexibility in neurophysiological response to stimuli allows more creative individuals to customize their response to the task at hand (Martindale, 1999). In particular, more creative individuals are able to enter a more relaxed, free associative cognitive state when it is necessary for them to produce a creative solution (e.g., Kris, 1952; Mednick, 1962; Mendelsohn, 1976).

There is empirical support for individual differences in neurophysiological state between more and less creative participants performing creative tasks (e.g., Martindale, 1999). This research showed that more creative participants had more variable patterns of activation in response to creative tasks, as well as greater activation in the right hemisphere during creative tasks. This previous research was used as a model for this investigation, as well as a guide in finding new methods to investigate neurophysiological differences between more and less creative individuals.

Three experiments were conducted: (a) an investigation of differences in spectral density and cross-spectral density for six frequency bands (delta, theta, low alpha, high alpha, low beta, and high beta) during the imagination and writing of a creative story; (b) an investigation of N100 and P300 responses to stimuli presented using the classic oddball paradigm; (c) an investigation of N400 responses to congruous and incongruous sentence endings. The first experiment expanded upon previous work by increasing the number of recording sites and by investigating a wider range of frequency bands than previous research. The second and third experiment introduced new methods to creativity research, with a focus on the initial response to novel or unexpected stimuli.

Results across all three experiments were that more creative participants showed greater variability in recorded response, and that more creative participants showed generally greater activation in the right hemisphere. This is consistent with many theories of creativity, as well as the hypotheses of this investigation.

ACKNOWLEDGMENTS

If I ever act as advisor on a graduate student thesis, I think that I will make her write acknowledgements as part of her thesis proposal. Realistically, the people that I need to thank played an even bigger role than my EEG machine in getting this thing finished. I think it would have been an even better tribute to their place in my life if I had been able to acknowledge them at the beginning of this process as people who I know I can always count on, and who know they can always count on me.

It seems only fitting to start with Colin Martindale, without whom my life course would be very different. Thank you for opening up a world where neither science nor art need be ignored. I will always be grateful to you for your ideas and guidance.

It seems just as fitting to start with Oshin Vartanian, my compatriot through the thick and the thin of graduate school. Thank you for your collaboration and friendship. I know I wouldn't be writing this right now if it weren't for you.

To Colin and Oshin, I look forward to many more years of collaboration. I will always remain Your Partner In Crime.

Thanks to Lisle Kingery, who so graciously took on the completion of my data collection. I will never forget your kindness, although I'm still unsure how I could possibly repay it.

For their guidance and smiles through short deadlines, thank you to my amazing committee members: Alan Rosenwasser, Marie Hayes, Michele Alexander, and Jonathan Borkum. Jonathan, I must give additional thanks to you for your statistics help, which saved me time and again, giving me the confidence and energy to keep going.

I would also like to thank Joel Gold, my unofficial but crucial sixth committee member, who supported me in so many ways through graduate school. From your legendary statistics course, to your assistance with all kinds of problems, to your kind words and understanding, you have been a strong and positive influence on my graduate school experience. I cannot thank you enough.

Thanks to all of the University of Maine undergraduates who helped with my research, providing both the needed hands and challenging ideas to keep the research moving: Rachelle Smith, Jordan Pike, Amy Faller, Matt Qualey, Casey Brown, and Jim Lolar.

I also must acknowledge Keithley Instruments, who donated the Analog to Digital Conversion equipment that I used to collect my data. In particular, Tim Kniss was crucial to this project's success. His kind patience through all of my A/D questions was at times amazing, and always appreciated.

Time and circumstance have added a wonderful group to my list of thanks: all of my friends and colleagues at the PACE Center. Thank you all for supporting and encouraging me through this long(er than promised) process. In particular, thanks to Bob Sternberg, Elena Grigorenko, and Linda Jarvin for your time, advice, and moral support; and thanks to all of the gifted team members for putting up with my sometimes less than timely feedback.

Continued love and thanks to my family, who have supported me through many a crazy scheme (including this one). Thanks to Mary Kwiatkowski, my mother, Frank Kwiatkowski, my father, Andrew Kwiatkowski, Leslie Rose, Bob Rose, and Allie Rose.

In many big, small, and small-but-big ways, these last people, have been crucial in this and so many other of my endeavors:; Tina Newman for her calm understanding; Jean Pretz for putting up with the messiest dining room table ever; Matthew Jukes for his careful support; Silvina Horovitz for helping me in her hour of stress; The Chicago Outlet (Laura Berger, John Fitzpatrick, and Alexander Childers); Julie Williamson for tactful kicks in the tail; Adam Naples for keeping it real; Virginia Cylke for her smiles and patience; and last but certainly not least, The Tea Ladies (April O'Grady, Beth Kubik, Rachel Grover, and Michelle Maudlin) who understand better than anyone else.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

In lapidary, a careful study of all the facets of a stone will lead to the moment when tapped in just the right place, the casing falls away to reveal a perfect gem. Creativity, like the lapidarian's stone, is multifaceted with the promise of a beautiful internal structure. Theoreticians of creativity know, however, that this promise is far from realized. This dissertation is meant to elucidate further the underlying mechanisms of creativity through the use of neurophysiological techniques. The introduction is organized (a) to introduce the reader to theories of creativity that include ideas about the underlying neurophysiological mechanisms, (b) to review neurophysiological techniques likely to enhance investigations of creativity, and (c) to review research that has combined theories of creativity with neurophysiological measurement techniques. The introduction is followed by an explanation of a series of new neurophysiological experiments that have been used to explore creativity.

Section one: Overview of the Theoretical Relationships Between Creativity and Neurophysiology

Degeneration Theories

The earliest modern theories postulating a biological basis for creativity date back to the Romantic theories of the late Nineteenth century. In particular, in accord with the intellectual climate of the time, those theories postulated an unseemly association between creative inspiration and insanity: "It was conceived that geniuses evolved from the same maladaptive gene pool as the lowliest elements of society—criminals and lunatics" (Prentky, 1989, p. 245). Although philosophers such as Aristotle had stressed the relationship between creativity and psychopathology since antiquity (Prentky, 1989), the modern resurgence of the idea is attributable to Morel's introduction of the degeneration hypothesis in 1857. Degeneration can be best defined as the antithesis of development, where the "Development of the organism is seen as involving elaboration and integration while degeneration is seen as leading to disintegration and simplification which in turn lead to loss of adaptive ability" (Martindale, 1971, p. 178). Morel argued that degeneration (a) entailed anatomical as well as mental abnormalities, (b) was brought about by environmental factors, and (c) was transmitted cumulatively in a Lamarckian manner across generations. These classifications became part of the framework for all degeneration theorists.

Subsequent elaborations by Moureau de Tours (1859), Lombroso (1864), Nordau (1895), and Talbot (1898) argued that insanity and genius were brought about as the result of a degenerate genetic disposition. Moreau de Tours suggested that the common link between insanity and genius was an overexcitation of the brain. Lombroso built on this idea, proposing that an abnormal oversensitivity due to degeneration was responsible for genius. In the first systematic investigation of degeneration and genius, Lombroso (1864, 1898) concluded that "Between the physiology of the man of genius, therefore, and the pathology of the insane, there are many points of coincidence; there is even actual continuity" (p. 359). Nordau (1895) hypothesized that degeneration is a consequence of the weakening of the higher brain functions, thereby allowing a relative dominance of the lower brain functions to emerge. He distinguished between two types of degeneration, referring to 'Mysticism' as the inability of higher cognitive levels to exert control, and 'Ego-mania' as an abnormal reduction of sensory thresholds. Talbot (1898) compared degeneration to what we would today call a disinhibition syndrome, where excessive cell motion (possibly due to nervous exhaustion) leads to impaired cell growth and a "removal of checks (which the race has acquired during evolution) on the explosive expressions of egotism and mentality" (Talbot, 1898, p. 316).

Lombroso and Nordau provided lists of traits that they observed in degenerates. Important to this dissertation are their descriptions of traits that foreshadow modern views of creative thought. Lombroso (1891) claimed that degeneration causes "frequent tendencies to impulsiveness or doubt, psychical inequalities owing the excess of some faculties (memory, aesthetic taste, etc.), . . . [and] excessive originality" (pp. 5-6). Nordau lists "inability to focus attention and consequent inability to differentiate relevant from irrelevant, tendency to 'inane reverie': free-associative thinking with inability to suppress 'irrelevant associates', . . . (and) rebellious inability to adapt to the environment" (pp. 15-33). These observations are arguably the most important contributions of the degeneration theorists. For even if they were misguided in their final conclusions, they provided descriptions of the characteristics of both creativity and some mental illness that would later be operationalized into fruitful research.

The degeneration theorists attributed the characteristics listed above to a genetic predisposition, assuming that the traits of both mental illness and genius could be transmitted in their entirety from generation to generation. Martindale, Vartanian, and Kwiatkowski (2000) argue that while the degeneration theorists were correct in identifying common traits between mental illness and genius, they were incorrect in assuming total genetic transmission. Genius, particularly the *creative* component of genius, is not a single entity that can be genetically transmitted. Instead the creative component of genius is emergent, meaning that it is "a property of one level in a system that arose from interactions of elements at a lower level but that cannot be identified in those elements, taken either singly or collectively" (Michel & Moore, 1995, p. 482). From this perspective all the traits of creativity must be present in a person for creativity to emerge – they are all crucial to the composition of the creative person. The degeneration theorists did not have the benefit of this twenty-first century perspective, but fortunately that does not detract from the applicability of their theories to current research.

The degeneration theories of the late 1800's might be characterized today as biologically based disinhibition theories, where 'normal' thought processing is hampered by improper impulse control. Results from a number of more recent disinhibition studies suggest that degeneration theorists were correct, at least in the spirit of their arguments. Martindale (1969), having reviewed several empirical studies of creativity, concluded that disinhibition was indeed the common thread running through creative personalities. MacKinnon (1962) in his study of architects, Van Zelst and Kerr (1954) in their study of scientists, and Helson and Crutchfield (1970) in their study of mathematicians all reached the conclusion that disinhibition, in the form of lack of impulse control, was the characteristic associated with the more creative participants (Martindale, 1971). In a review of degenerationist ideas, Eysenck put it best by stating that Lombroso " . . . was typically right in principle but excessive in his claims" (1995, p. 115).

The Creativity Research Boom

The first 50 years of the twentieth century were relatively uneventful for creativity research. Important developments in the understanding of brain physiology occurred, but those will be discussed in a later section. It was around the middle of the century that resurgence in interest in creativity and genius occurred. This interest is often attributed to J.P. Guilford's 1950 presidential address to the American Psychological Association where he challenged all psychologists to pursue research of creativity.

Kris

In 1952 Ernst Kris introduced his theory of creativity. He used a psychoanalytic model to explain the thinking process of the creative individual. The two main elements to his model were primary and secondary process thought, which represented the two ends of a continuum. Primary process thought, at its most extreme, is free-associative and dream-like in content. Secondary process thought, at its most extreme, is the logical, reality-based thought commonly associated with conscious, purposeful thought. Kris proposed that everyone is capable of traversing the primary-secondary process continuum, but that creative people are more likely to do it more often. Uncreative people (a) are more likely to have a greatly truncated range on the primary-secondary process continuum where they remain for most of their conscious lives, (b) are less able to change their mode of thought to respond to task demands, and (c) are most likely to move into primary process mode when considering personally relevant thoughts (e.g., daydreaming). In contrast, creative people (a) are more likely to have ready access to the full range of the primary-secondary thought process continuum, (b) are more able to change their focus in the face of task demands, and (c) are just as likely to move into primary process mode to solve creative problems as to consider personally relevant thoughts. For example, when given a task demanding creative thought, the more creative person would respond by shifting to a more primary process thinking state, which affords more associative abilities. This shift in focus would allow the creative person to make more unusual associations between ideas. Once the creative solution has been found, the creative person would shift back to a more secondary process state, allowing the person to formalize the idea. The less creative person, Kris theorized, would attempt to solve all problems from a more secondary process state of consciousness. This approach to problem solving would lead to a less unique solution or no solution.

Mednick

There are two other historically significant theories of creativity that are similar to Kris' (Martindale, 1999): Mednick (1962) and Mendelsohn (1976). Mednick (1962) proposed a theory of creativity based upon associative hierarchies. An associative hierarchy is a model for how individuals store associations between concepts. It is helpful to think of an associative hierarchy of words to understand this theory. In this explanation, the word 'fish' and words associated with fish will be used as the example associative hierarchy.

Mednick's theory proposes that a given person's associative hierarchy might be steep or flat. A steep associative hierarchy is one that has few and relatively rigid associations between concepts, reducing the likelihood that new or unusual associations will arise in connection with a given concept. For example, a steep hierarchy for the word 'fish' might only include very common, predictable associations like bowl, water, and gold. A flatter associative hierarchy is one that has a greater number and more flexible associations between concepts, which allows individuals to make unusual and more associations between concepts. For example, a flat hierarchy for the word 'fish' might include bowl, water, gold, flying, Sweden, caviar, and the Grateful Dead. According to Mednick's theory, for people to be creative it is necessary that they have an abundance of associate elements (i.e., knowledge), as well as a weaker (i.e., flatter) associative network. This means that the creative person may reach the same conclusion to a given problem as the less creative person (e.g., fish is related to bowl), but that alternative solutions are also available and may impinge upon the conscious thoughts of the creative thinker (e.g., but fish is *also* related to Sweden and Grateful Dead wannabe bands). The relationship between Mednick's theory and Kris' theory is in the emphasis on loose associations that allow for unusual relationships to emerge. Mednick explained these loose associations in terms of a hierarchy of thought, while Kris explained them in terms of primary process cognition.

As evidence for his theory of associative hierarchies, Mednick cites his research with scientists rated by experts for the creativity of their work. He found that the less creative scientists gave more stereotyped responses to 80% of the words in a standardized word association task (Mednick, 1958). Mednick also created the Remote Associates Test to investigate further the importance of associative ability in creativity. In this task, participants are expected to find the association between three seemingly unrelated words. For example, given the words *party, snow, round,* an appropriate associative word and answer would be *ball.* Again, a comparison to expert ratings of creative potential, this time for a group of architects, showed that the more creative participants were better able to make the unusual associations necessary to solve the word problems. In a further test using psychology graduate students, Mednick found essentially the same relationship. More creative students, as rated by their advisors, had higher Remote Associates Test scores as compared with the less creative students (Mednick, 1962).

Mendelsohn

Mendelsohn (1976) proposed a broader definition of creativity that built upon Mednick's ideas. He suggested that Mednick's use of tasks that have well-defined answers or expectations puts unrealistic constraints on the definition and operationalization of creativity. "That is, Mednick's characterization of creative thinking as the forming of new combinations from previously remote elements is certainly defensible, but to limit the elements to discrete associations is to simplify excessively" (p. 363). He based his ideas on attention theory, suggesting that more creative people will have a greater attentional capacity, thus allowing more ideas to coexist in consciousness. It is this greater capacity that will allow creative people to distribute their resources over a wider range of concepts, increasing the likelihood of making new associations. The relationship between Mendelsohn's theory and Kris' theory is similar to the relationship with Mednick's theory. Mendelsohn explains the requisite loose associations as the result of greater attentional capacity, while Kris explained them in terms of primary process cognition.

To test his ideas, Mendelsohn asked participants to solve anagrams. For example, given the word *now*, a correct rearrangement of the letters into another word would be *won*. First, participants were asked to solve a series of anagrams without any clues. Then, they were given the clue that some of the anagram answers would be a type of animal or a type of food. He found that the higher a participant's Remote Associates Test score, the more likely he was to benefit from the clues. In other words, the more creative potential the participants showed through the Remotes Associates Test, the more likely they were to use the clues to solve the anagrams. Mendelsohn's interpretation of this result was that the clues were retained more effectively in the high Remotes Associates Test scorers. Interestingly, the low Remotes Associates Test score group actually did slightly, although not statistically, better without the clue. Other research using shadowing has supported the idea that less creative people have a more narrowly focused attentional capacity (e.g., Dykes & McGhie, 1976).

Current Creativity Research

Eysenck

Two more recent theories have taken the ideas of the above theorists and applied them to a cognitive disinhibition theory of creativity: Eysenck (1995) and Martindale (1995, 1999). Eysenck (1995) explains creativity as the result of overinclusive thought, where the creative person's attentional filtering mechanisms are not as stringent as those generally found in the population. "This overinclusiveness may be due to a failure of inhibition, characteristic of psychotics, high P-scorers, creative people, and geniuses" (p. 248). Psychoticism (P) is the personality factor on Eysenck's personality questionnaire that is related to psychopathologies such as schizophrenia and manic depression. Eysenck argues that creative people and psychotics are similar in their expression of the Psychoticism personality factor, but that creative people are differentiated from psychotics by their higher intelligence and their ability to evaluate and reject inappropriate responses. Therefore according to Eysenck's theory, creative people and psychotics are similar in that they are overinclusive (disinhibited) in their general thought processes, but they differ in that creative people can reject inappropriate responses that result from their overinclusive thought processing, whereas psychotics cannot.

Martindale

Martindale (1999) agrees in principle with Eysenck's theory. He gives disinhibition a central role in explaining the creative thought process. However, Martindale argues that while creative people are able to use cognitive disinhibition to think creatively (i.e., achieve primary process thought, work with a flatter associative gradient, or have a looser attentional focus), they are not bound to that mode of thought. The creative person, unlike the psychotic, is able to shift into a cognitive disinhibition mode when a task warrants looser associations (i.e., creative thought). The creative person is not continuously in a state of cognitive disinhibition, unable to filter responses, as Eysenck suggests. Instead, the creative person has access to cognitive disinhibition as well as other cognitive states, and draws upon these various cognitive processing styles as necessary to complete tasks. According to Martindale, this variability in cognitive processing is the hallmark of the creative individual. In comparison, the cognitive processing of psychotics is generally fixed in a state of cognitive disinhibition, whereas the cognitive processing of normal, non-creative individuals is essentially fixed in a state of cognitive inhibition.

Section Two: Overview of Neurophysiological Measurement Techniques

History of Neurophysiological Measurement

The history of recording electrical activity from the scalp of an animal begins with Richard Caton (1877). He reported that it was possible to record a weak current from the scalp. However, this work was applied only to non-humans until Hans Berger (1929). Berger is credited as the father of electroencephalogram (EEG) for his detailed descriptions of the principles and qualities of EEG. He described alpha wave activity (8-

13 cycles per second) and noted that it decreased with intention (physical or mental) or external stimulation.

Berger was also the first to associate EEG with attention. He attributed the changes in alpha wave activity to excitation of a particular action center (e.g., visual cortex excitation in response to a visual stimulus), which initiated general inhibition across the rest of the cortex. He reasoned that changes in alpha wave activity reflected the changes in cortical inhibition that accompanied excitation of different action centers, and that this inhibition-excitation variation was necessary for the processing of external or internal stimuli (Ray, 1990). Subsequently, widely distributed attention was associated with alpha wave activity, whereas focused attention was associated with a reduction or disappearance in alpha wave activity. With additional research, Berger associated higher frequency waves (which he named beta waves) with focused mental activity. He speculated that the generator for patterned wave activity was probably thalamic, as this was the assumed region for general arousal.

While most of Berger's original observations still hold, it should be noted that research has failed to show that subcortical activity is the sole generator of EEG patterns. Current research favors the hypothesis that subcortical structures such as the thalamus serve as presynaptic inputs to cortical neural pathways. The presynaptic inputs coordinate the neural activity of a large group of cortical neurons, which in turn fire. Thus it is not the neural activity of the subcortical structure itself that is recorded, but the resultant activity of an organized set of cortical neurons. Modern researchers largely agree that the likely source of scalp-recorded brain wave patterns is "depolarizations of the dendritic trees of a pyramidal cell in the cerebral cortex" (Ray, 1990, p. 390).

Overview of Frequency-based Waveforms

The following is a brief overview of the divisions of frequency-based waveforms. These are the waves that are analyzed across time, most often through Fourier analysis. There are four major divisions of EEG waveforms (delta, theta, alpha, beta). **Delta** waves are associated with sleep in healthy humans, or with diseased tissue such as brain tumors. They are identified by a frequency between 0.5-4 Hz and amplitudes up to 100-200 μV. **Theta** waves are associated with a number of psychological processes including hypnagogic imagery, REM, problem solving, hypnosis, and meditation (Ray, 1990). They are identified by a frequency between 4-7.5 Hz and amplitudes less than 30 μV. **Alpha** waves, as identified by Berger (1929), are associated with relaxed consciousness in normal humans. The frequency of alpha waves ranges between 8-13 Hz with amplitudes between 30-50 μV. Alpha waves are sometimes divided into a lower (~8-10 Hz) and upper (~10-13 Hz) band for research purposes. This further segmentation of the frequency band is a response to factor analyses that suggest that the two segments may represent different types of cognitive activities, as reviewed below (Petsche, Kaplan, von Stein, & Filz, 1997). **Beta** waves are associated with alert consciousness in normal humans. They are also often divided into two bands (slow and fast), based on statistical analyses. The slow beta is defined as ranging from 13-19 Hz, whereas fast beta represents the upper end of the beta spectrum from 20-30 Hz. Both components show amplitudes less than 20 μV.

Identification and Analysis of Frequency-based Waveforms

The waveforms described above can be visually detected in an EEG record. This is especially true for alpha and beta waveforms, as these are the higher frequency, and therefore more visually dominant, waveforms. However, it is often true that while one waveform is most prominent in the EEG record, other frequencies are contributing to the complex wave. Since it is difficult to detect all of the components of any complex waveform, statistical techniques have been developed to assist with analysis. The most common analysis used on EEG records is the fast Fourier Transform (FFT). FFT is based on an algorithm developed by Cooley and Tukey (1965). This algorithm has been incorporated into many computer programs. In this project, the SAS Spectra procedure for FFT was used.

This is the method by which FFT analyzes the component frequencies within a complex waveform. The FFT analyzes equally sized and sequential epochs (pieces) of the EEG record by breaking down each epoch (i.e., the complex waveform of each epoch) into frequency band estimates. "PROC SPECTRA uses the finite Fourier transform to decompose data series into a sum of sine and cosine waves of different amplitudes and wavelengths" (SAS/STAT User's Guide, 1999, p. 751). The equation for the Fourier transform decomposition of the series x_i is $x_i = a_0 / 2 + \Sigma [a_k \cos(\omega_k t) + b_k \sin(\omega_k t)]$ where t is the time subscript, x_t are the data, n is the number of data points, m is the number of frequencies in the Fourier decomposition (m = n / 2 if n is even; m = n – 1 / 2 if n is odd), a_0 is the mean term, a_k are the cosine coefficients, b_k are the sine coefficients, and ω_k are the Fourier frequencies (SAS Program Documentation, 2000).

The Fourier coefficients for the sine and cosine components are then plotted against frequency to produce a periodogram of the amplitudes at each frequency using the equation $J_k = n / 2 (a_k^2 + b_k^2)$. However, this periodogram is "a volatile and inconsistent estimator of the spectrum" (SAS Program Documentation, 2000, p.752), and must be smoothed. To smooth the periodogram, it is subjected to a weighting function. There are many weighting functions, commonly called windows, but the Hanning window is most commonly used in EEG analysis. The Hanning window function is $w(i) = 0.5 + 0.5 \cos(2 \pi i / W)$ for $-W/2 <= i <= W/2$ else $w(i) = 0$. The smoothed periodogram is called the spectral density estimate. The spectral density plot shows the amplitude for each frequency band in the record. These amplitudes are sometimes referred to as the *power* of the band. These power estimates are used in all further analyses.

Coherence in Frequency-based Waveforms

Coherence is another tool of the EEG researcher. It provides information about the relationship between pairs of electrodes, and therefore information about "functional relations between specific brain regions and the more general state-dependent 'competition' between functional segregation and integration reflected by brain dynamics" (Nunez et al., 1999, p. 469). In other words, coherence is meant to clarify the underlying neurophysiological mechanisms that contribute to the EEG record, and therefore the spectral density estimate. By comparing the EEG record across electrode pairs, it is possible to hone predictions about underlying brain regions that contribute to the cognitive activity.

For coherence, instead of averaging the spectral density plots, the plots are compared across electrode locations to determine how similar the EEG record is at each site. In other words, spectral density plots for different electrode locations are subjected to a specialized correlation that produces an estimate of the similarity in signal activity between sites, called the cross-spectral density. Cross-spectral density is defined as $J_k^{xy} = n / 2 (a_k^x a_k^y + b_k^x b_k^y) + i\, n / 2 (a_k^x a_k^y - b_k^x b_k^y)$ where i represents the imaginary unit -1.

Coherence is calculated with a cross-spectral density function that produces a cross-spectral density plot that represents the phase consistency between two electrode locations. The input to the cross-spectral density function is the spectral plots calculated using the FFT analysis for the EEG record at each of the two electrode locations to be compared. The output is the cross-spectral density plot. High coherence is achieved when there is high phase consistency between two electrode locations. Perfect coherence means that the power for a given frequency remained constant across all of the epoch pairs for the two electrode recording sites. Therefore, it is not necessary for a given frequency or frequency band to have high power in the original complex waveform for it to have high coherence.

Overview of Event-related Potential Waveforms

As the methods of EEG became more popular in the 1960s, it was discovered that it was also possible to record reliably shaped waveforms in response to particular stimuli and to particular thought processes. Vaughn (1969) proposed to call these dependent waveforms event-related potentials (ERPs). ERP research has extended the study of brain physiology by developing methods that show a time-linked relationship between a stimulus that requires some type of cognitive processing and the associated reaction. While EEG research has been important in delineating neurophysiological states associated with different types of thought and action, ERP has provided evidence of specific neurophysiological responses to stimuli and cognitive activity. ERP measurement is a powerful tool in determining how an individual responds to a particular stimulus.

Identification of Event-related Potential Waveforms

Most ERP waveforms are identified by their amplitude direction and latency. Positive amplitude components are indicated with a 'P', whereas negative amplitude components are indicated with an 'N'. The latency designation is given in milliseconds, which represents the average amount of time from stimulus onset until the expected form appears. Thus, a waveform identified as N100 can be interpreted as a negative component that occurs an average 100 msec after stimulus onset. It should be noted that in an interpretation of a waveform, the component (e.g., N100) is represented by the highest amplitude within a predetermined range. For example, an individual N100 amplitude score will be the highest negative amplitude point between 0-200 msec after stimulus onset (Coles, Gratton, Fabiani, 1990). A latency score for the same waveform will be the actual number of milliseconds that have passed when the highest negative amplitude is recorded. There are a number of statistical considerations involved in finding the individual amplitude and latency scores. These will be discussed in detail in the analysis section of the dissertation. To continue with the discussion of event-related potentials, the following paragraphs outline some basic features of the major ERP waveforms.

N100

N100 is a negative waveform that occurs between 0-200 msec after stimulus onset. It was the first waveform identified that suggested that ERPs could be used to study attention (Coles, Gratton, & Fabiani, 1990). Specifically, N100 is associated with selective attention, a hypothetical mechanism for controlling the stream of information in cognitive processing (e.g., Broadbent's (1957) filtering model and Kahneman's (1973) resource model) (Coles, Gratton, & Fabiani, 1990). As with traditional filtering research, N100 methods employ tone discrimination tasks where the participants are asked to attend to a particular tone. In general, N100 amplitude is larger in response to an attended stimulus.

P300

P300 was first identified by Sutton, Braren, Zubin, and John (1965). It is one of the most studied waveforms for cognitive functioning. As the name implies, it is a positive waveform that occurs approximately 300 msec after stimulus onset. The maximum amplitude for P300 is generally later than 300 msec because it is such a large waveform. The distinctive upward trend of P300 starts between 250-350 msec, but the maximum amplitude used in most analyses occurs up to 750 msec after stimulus onset.

In general, the P300 is evoked during tasks that require participants to pay attention to a number of stimuli presented one at a time. P300 amplitude increases when the participant views a rarer stimulus and/or a more intense stimulus. It can be measured over a wide distribution of the scalp, but the highest amplitudes are generally found over the parietotemporal region (Andreassi, 2000).

A typical task used to elicit a P300 is the oddball paradigm. The task design includes at least two and usually three stimulus types: target, distractor, and novel. The target stimulus is one the participant knows to expect and is usually asked to monitor, typically by counting the number of times the stimulus occurs in a series. The distractor stimulus is also expected, but the participant is not given any monitoring task for it. The novel stimulus is not expected and therefore has no monitoring task assigned to it. The target and novel stimuli occur at lower frequencies than the distractor stimulus. All stimuli are presented in a random serial order. In general, P300 amplitude increases to target and novel stimuli as the frequency of their presentation decreases. P300 latency is explained by stimulus evaluation time, so that the more time it takes to evaluate a stimulus (i.e., determine whether it is a target), the longer the time until P300 maximum amplitude is reached (Cole, Gratton, & Fabiani, 1990).

N400

N400 is a negative waveform that occurs between 400-700 msec in response to a semantic discrimination task. It should be noted that like the P300, this longer latency waveform is associated with later cognitive processing. Whereas the P300 is associated with the discrimination of physical differences between stimuli, the N400 is associated with semantic differences. It is not clear whether P300 should be expected along with N400 responses since semantic differences are by default also physical differences. However, it is clear that N400 does not occur with only physical differences (Coles, Gratton, & Fabiani, 1990). The classic experimental design for N400 was created by Kutas and Hillyard (1980). They asked participants to read sentences that were missing the final word. After the sentence was removed from the screen, a final word was presented. N400 increased in direct relation to how appropriate the final word was. For example, if the sentence was "I want to go swimming in the ____________," the final word might be "pool" (appropriate), "puddle" (less appropriate), "mountain" (inappropriate). N400 amplitude increased as the final word became more inappropriate.

While there are numerous other waveforms that have been identified through ERP research, those presented above are the most commonly analyzed, and the most relevant to this dissertation. All of these waveforms occur in response to novel or unexpected stimuli. Therefore, these waveforms will be useful for understanding individual differences in response to novel/unexpected stimuli.

Section Three: Neurophysiological Measures of Creativity

Objective of Neurophysiological Measurement of Creativity

The ideas advanced by Kris, Mednick, and Mendelsohn, and then refined by Eysenck and Martindale inspired a generation of researchers to explore creativity through more empirical means. This empirical research spans (a) attempts to validate techniques for measuring creative potential (see Michael & Wright, 1989); (b) attempts to show a relationship between creative potential and other psychological attributes (e.g., personality, motivation, leadership abilities, etc.); and (c) attempts to show a neurophysiological basis for creativity. This review will focus on the neurophysiological correlates of creativity.

One of the main objectives of these neurophysiological studies has been to determine how cognitive processing relates to creativity. The theories reviewed in the first section suggest that the more creative person is able to access cognitive states that the less creative person cannot access, or at least cannot access readily. As discussed in the second section, neurophysiological measures such as EEG and ERP have been associated with various types of cognitive processing. Combining the theories from the first section with the measures discussed in the second section, it should be evident that neurophysiological research of creativity can work to understand cognitive processing differences due to creative potential and due to task demands (i.e., creative demands).

These cognitive processing differences are often referred to as differences in attention or arousal both in the creativity literature, as well as the neurophysiological measurement literature. Neurophysiological techniques, while valid, are still not fully understood. Therefore, use of terms like 'attention' or 'arousal' are used to account for sometimes unspecified sources of activity that are nevertheless reliably associated with particular psychological traits (e.g., high creative potential) or particular task demands (e.g., creativity).

History of Neurophysiological Measurement of Creativity

Martindale (1977) reviewed a number of studies from his laboratory concerning creativity and arousal levels. He reported that more creative participants tend to show slightly higher basal arousal levels, as measured by less EEG alpha activity (using various methods) and higher skin conductance. His review of arousal variability studies included one by Bowers and Keeling (1971) that found a correlation of .49 between creativity and heart rate variability during a perceptual task. From his own laboratory, he reported that more creative participants were less able to control the amount of alpha wave activity they produced through a biofeedback task as compared with less creative participants (Martindale & Hines, 1975). In this study, alpha wave activity was calculated by taking the total amount of time that alpha wave activity was present in the EEG record and dividing it by the total recording time. This produced a measure of the percent of alpha activity. The more creative participants were actually better than the less creative participants for the first few trials at the biofeedback task, but then lost their ability to control the signal. This result, while initially surprising, fits with "the spontaneous uncontrolled nature of creative inspiration" (p. 76) reported by creative people. Furthermore, it suggests that the creative person has a fundamental variability in arousal that can only be controlled for brief periods.

Further results from Martindale and Hines (1975) showed that arousal levels, as measured inversely by EEG alpha wave activity, varied based on task type for more but not less creative participants. In this study, the researchers measured alpha wave activity while participants completed a task requiring only creative thought, a task requiring creative and IQ-based thought, and an IQ task. The high creativity group showed the greatest amount of alpha wave activity for the creative-only task, significantly less alpha for the creative and IQ task, and still less for the IQ-only task. The less creative groups (medium and low creativity) showed essentially identical alpha levels across tasks, with little variation either between groups or between tasks. This study supports the attention-based theories of creativity. In particular, it matches with Kris' (1952) theory in that the more creative participants showed task-specific shifts in their arousal levels. Kris did not use neurophysiological terms to explain his theory, but instead posited shifts in thought processes between primary and secondary modes. Nevertheless, the Martindale and Hines results can be interpreted through Kris's theory as a reflection of those shifts. The more creative task was accomplished while alpha wave activity was greatest, suggesting that the more creative participants were in a more primary process state while completing the creative task. The results can also be used to support Martindale's (1995, 1999) view of the role of disinhibition in creativity. The more creative group did not exhibit a constant state of disinhibition, which would have been shown through more alpha wave activity across all tasks. Instead, the more creative participants only showed more alpha wave activity, or less arousal, in response to a creativity task.

Martindale and Hasenfus (1978) took a slightly different approach, asking participants to create a creative story. The rationale for this study was to determine whether arousal varies based on stages of creative production, not just task type. This study was meant to mimic the stages of creative production first proposed by Helmholtz (1896), and then elaborated on by Wallas (1926). Wallas, basing his explanation on the many accounts of creative thought processes, stated that a creative product needed to go through four stages of production: *preparation* for the answer through studying likely sources of information related to the product, *incubation* of the studied ideas without active attempts at solving the problem, *illumination* when the idea for the creative product is discovered unexpectedly, and *elaboration* of the idea through a return to study and itemization of the details necessary to use the solution.

Martindale and Hasenfus's study focused on the two most easily differentiated stages of Wallas's theory, at least in terms of experimental design. In real-life creative problem solving, preparation and incubation may involve long periods of study mixed with other influences (interactions with people, reading seemingly unrelated books, etc.). To mimic realistically preparation or incubation is almost impossible within a laboratory setting. However, illumination, the period of creation, and elaboration, the period of verification, are more amenable to laboratory studies. The researchers recorded alpha indices while participants thought of a story on a given topic for three minutes (illumination) and while they wrote their story for five minutes (elaboration). Alpha indices were calculated by "dividing amount of time alpha waves were present by the total time and multiplying by 100. Indices for each epoch were then averaged to yield one score for each phase of the experiment for each subject" (p. 159). The more creative participants, as rated through a separate writing assignment from a creative writing class, showed overall significantly higher alpha indices, as well as a significant decrease in alpha during elaboration. The less creative group, while showing lower alpha indices across all stages when compared with the more creative group, also did not show any significant differences in alpha between the stages of story production.

Martindale's results are promising in that they show a consistent difference in response pattern for the more versus less creative groups. In summary, less creative participants generally show lower levels of alpha activity across all task types as compared with more creative participants. Furthermore, less creative participants do not differ in amount of alpha activity based on task type, whereas the more creative participants show great variability in alpha activity with tasks that require more creative thought processes.

It should be noted that while these results are useful in directing further research, they do not form a complete map of the creative person's neurophysiological response. Martindale's studies measured EEG activity over the right posterior temporal lobe only, and only isolated activity falling into the alpha (8-13 Hz) frequency range. While both the right hemisphere (Bogen & Bogen, 1969) and alpha activity (Petsche, Kaplan, von Stein, & Filz, 1997, to be discussed below) have been identified as potentially important components of the creative thought process, they can hardly be isolated as the crucial components based on this research. It is clear that additional research is necessary to clarify the relationship between brain wave activity and creative thought. There has been some research that has helped with this task since Martindale's work in the 1970's. The following paragraphs will outline this work, starting with that focused on hemispheric differences, and then covering the work that focused on other EEG frequencies.

Hemispheric Differences in Neurophysiological Investigations of Creativity

It is possible that dynamic relationships exist between the hemispheres that were not captured by Martindale's research thus far. For example, Andreassi (2000) reports while it is possible to find hemispheric differences based on task type, it is also likely that a more detailed analysis of the time course following task completion will reveal several shifts in dominance between the hemispheres. Furthermore, Martindale's early research used a single recording site (left posterior), which precludes any measures of coherence, a method aimed at finding similar patterns of activation at different scalp locations. Coherence measures have been used as indicators of the amount of information being processed (Andreassi, 2000).

In the spirit of the work of Sperry (1968) and Gazzaniga (1975), numerous areas of psychology have attempted to extrapolate from split-brain research to their own interests. Creativity research has been no different. Reports about the skills isolated by commisurotomy bolstered research aimed at showing right hemispheric dominance in creative thought (McCallum & Glynn, 1979). An example of this research again comes from Martindale's lab (Martindale, Hines, Mitchell, & Covello, 1984). In these later experiments, participants were again asked to complete tasks that address Wallas's stages of creative production. This research determined that the highest creativity group showed the most right hemisphere alpha activity during creative task performance. As with the previous studies, amount of alpha activity was calculated by dividing the amount of time alpha waves were present by total time and then dividing by 100.

Studies of hemispheric specialization from other labs found fewer differences between the hemispheres for more creative participants (Jausovec, 1985; Atchley, Keeney, & Burgess, 1999). Jausovec (1985) grouped 16 nine year old children into a High and Low Creativity group based on their performance on the Wallach-Kogan Creativity Tests (Wallach & Kogan, 1965) and the Torrance Tests of Creativity (Torrance, 1974). While the children were completing two of the Torrance tests (a figural task called Incomplete Figures and a verbal task called Circles), EEG was recorded. These researchers found greater right hemisphere activation for their Low Creativity group during both creative tasks, and little difference between hemispheres for their High Creativity group. They explained their results as evidence of greater "interhemispheric integration" (p. 238) for the High Creativity group.

Atchley, Keeney, and Burgess (1999) grouped 72 college students into three creativity groups based on their performance on the Wallach-Kogan Similarities subtest (Wallach & Kogan, 1965). These three groups were compared in performance on a Visual Field task, where participants were presented with a priming word and then a target word they had to name. The visual field for the target word was switched at equal intervals over the course of the experiment. They found that their High and Moderate Creativity Groups performed better than their Low Creativity Group when the target word was presented to their Left Visual Field. They explained this result as evidence of Right Hemisphere dominance for more creative participants. However, they also explain that since the High Creativity Group performed better than the Moderate and Low

Creativity Groups when the target was presented to the Right Visual Field, their research also offers support to the hemispheric integration hypothesis. The authors concede that "It would be reaching beyond [their] data to make any firm speculations about the mechanistic implication of the results from the HC [High Creativity] group" (p. 494). They conclude that the High Creativity group makes uses of both hemispheres when processing the target stimuli, whereas the Moderate creativity and the Low Creativity groups do not seem to have access to such interhemispheric processing.

Frequency Differences in Neurophysiological Investigations of Creativity

In terms of frequency analyses, it is reasonable to suggest that if alpha wave activity is related to creativity, then other frequency bands might also be related to creativity. It seems especially likely that if creativity is related to a lower frequency band pattern (i.e., alpha), then creativity might also be related to even lower frequency activity such as theta (4-7 Hz) or delta (.5-3.5 Hz). Of theta and delta waves, theta is most likely to be related to creativity. Theta waves are more generally found in babies and young children. However, they have been associated with experiences of pleasure, and with poor performance on a vigilance task in adults (Andreassi, 2000). In contrast, delta waves are generally only found in sleeping adults or in conscious adults with serious brain abnormalities such as tumors. Using the theoretical positions of Kris, Mednick, and Mendelsohn as models, beta waves (14-30 Hz) should show less relation to creativity. Beta waves are associated with alert consciousness, such as one would find in a person engaged in a conversation. Alert consciousness is the state described by Kris as secondary process, described by Mednick as steep associative, and described by Mendelsohn as a tight attentional focus, and should therefore be more prevalent in less creative individuals during creative tasks. However, it is possible that the shifts between frequencies will be important in the success of the creative thinker, demonstrated through a relationship between creativity and beta waves.

There has been research that has investigated a more complete spectrum of EEG frequency ranges in relation to creativity. For example, Whitton, Maldofsky, and Lue (1978) investigated power of frequency bands for delta, theta, low alpha (7-9.99 Hz), high alpha (10-12.99 Hz), low beta (13-15.99 Hz), and high beta (16-25 Hz). Power for each frequency band was calculated using fast Fourier Transform (FFT) on an entire record of interest (i.e., the data was not divided into epochs). The resulting spectrum from each FFT for each task (described below) was then averaged. The average spectrum for each participant was used to compare percentage of power for each frequency band between groups. They used a group of schizophrenic and a group of normal participants. Both groups were asked to complete a variety of creativity tasks (e.g., list all words that rhyme with *note*, what two words comprise the new word *brereal*, etc.). EEG waveforms were analyzed for the four seconds prior to answering each question. Interestingly, there were significant increases in delta and theta activity, and a decrease in high beta activity (i.e., waveforms between 16-25 Hz) just before the creative task was completed for both the schizophrenic group and the normal group. The variability in power was greater for the schizophrenic group, but all effects were significant for both groups. There were no significant changes in power in the alpha range associated with the creative task. Unfortunately, the researchers did not report any analyses based on quality of answers. It is therefore impossible to determine whether these results could generalize to an understanding of the more versus less creative individual. Furthermore, they did not perform coherence measures.

Frequency and Coherence Differences in Neurophysiological Investigations of Creativity

Tucker, Dawson, Roth, and Penland (1985) focused on power and coherence measures for sites over the frontal, temporal, parietal, and occipital lobe for each hemisphere (i.e., eight leads) while participants completed a word fluency test. Word fluency is considered a creative ability, where more creative participants will be able to produce more words that represent some category (e.g., uses for a brick) (Wallach & Kogan, 1965). Participants were asked to think of four words that began with a given letter and ended with a different given letter. They were given 20 seconds to complete the task before they were asked to verbally report the words they thought. Their report includes a full analysis of the EEG activity for two participants, analyzed individually with no quantitative comparisons between participants. They calculated power with fast Fourier Transform (FFT) on each 2 seconds of data. They calculated coherence using the power spectra for each epoch and each recording site. Both subjects showed a general trend toward less power in the alpha, theta, and delta bands during the word fluency task, as compared to resting. However, they both also showed greater theta and delta coherence during the word fluency task suggesting that while the task requires less alpha, theta and delta activity, it benefits from coordinated effort across multiple locations. It should be noted that the coherence patterns differed between the two participants. The first participant showed theta coherence in the left frontal lobe and almost complete coherence across all sites for delta, with a slight emphasis on the left hemisphere sites. The second participant showed greatest coherence across the right and left occipital lobe with the addition of hemisphere-specific coherence between the occipital lobes and the frontal lobes. These researchers also regressed power ratings for each frequency band at each electrode site onto word production (i.e., the total number of words generated on a given trial) in an attempt to show performance effects. They found that the patterns differed between participants and were somewhat difficult to interpret. However, it is an attempt to use EEG to explain differences in response pattern. While this study can serve as a general model for further research, it is lacking in generalizability. A study using a larger sample size and analyses across participants should help to clarify these results.

Petsche, Kaplan, von Stein, and Filz (1997) came closer to reporting a complete picture of EEG during creative thought. They asked 38 artists and non-artists to complete four tasks allotted two minutes each: (a) contemplate a slide of a painting projected onto a wall; (b) silently read a text, a distraction task; (c) memorize the painting shown earlier; (d) mentally create a picture of their choice. For each task, they looked at delta, theta, alpha 1 (7.5-9 Hz), alpha 2 (9.5-12.5 Hz), beta 1, and beta 2 power and coherence. The method of power and coherence calculation is reported as the Fast Fourier Transforms of every artifact free 2 second period, which were then grand averaged for power and cross-spectra analyzed for coherence.

They report that both artists and non-artists show decreases in alpha power while mentally creating a picture (the creativity task), but that these decreases also occur while contemplating and memorizing a picture. The artists do show less of a decrease in alpha in response to all of the picture-related tasks, but that may be attributed to their greater familiarity with the tasks. In terms of coherence, there were no significant differences between artists and non-artists. However, there were "numerous long-distance connections with increased coherence both ipsi- and contralaterally . . . " (p. 83) while the participants were mentally creating a picture, but not for any of the other tasks. The authors suggest that long-distance coherence findings might be specific to creative thought. The obvious question is then how will coherence patterns differ across those with varying creative abilities?

Petsche, Kaplan, von Stein, and Filz (1997) also reported a similar experiment with seven male composers. In this experiment, participants were presented four pieces of music of various styles (Bach, Beethoven, Schönberg, and a Jazz piece). Each piece was presented for five minutes. The composers were also asked to mentally compose for five minutes, and then write his composition for another five minutes. Their spectral analysis of the EEG record showed that for all tasks "both alpha bands were considerably involved in all subjects, but they did not behave uniformly" (p. 86). Given the variability across participants, the researchers chose to focus on one task (composition) and one participant for coherence analysis. For this participant, coherence increased in the low alpha band during composing. There was also increased "intracortical communication within and between hemispheres" (p. 86). This participant was then compared to a second composer who showed greater high alpha band coherences. While helpful in providing a model for the measurement of coherence during a creative task, the lack of individual difference analyses leaves much to be understood about coherence and creativity.

Event-related Potential Differences in Neurophysiological Investigations of Creativity

There are no published studies that have used the ERP technique described above to examine creativity or creative potential. However, the author conducted a preliminary experiment using the oddball task (Kwiatkowski & Martindale, 1999). Following the design of Courchesne (1978), the target stimulus was the letter A, the distractor stimulus was the letter B, and the novel stimuli were colored random line patterns. ERP data was gathered from three midline scalp locations (Fz, Cz, Pz). Creativity was defined as the composite score on three creativity tests: The Remote Associates Test, The Alternate Uses Test, and the Creative Personality Scale. Participants were split into a high and low creativity group using a median split of the composite creativity score.

The results were promising in that the more creative participants had higher amplitude N100 and P300 waveforms across all three stimulus types. This was a statistically significant difference between the High Creativity and Low Creativity group. As explained above, N100 and P300 are well-defined waveforms that have been associated with attention. N100 amplitude, according to Coles, Gratton, and Fabiani (1990), can be interpreted as "early filtering that reduces the processing of irrelevant information" (p. 437). P300 amplitude can be interpreted as a representation of the processing resources required for a particular task. Higher P300 amplitude is indicative of more resource allocation to a particular task. Taken together, greater N100 and P300 amplitudes for the creative group suggest that more creative participants are allocating their attentional resources differently than the less creative participants. More specifically, they seem to be allocating more resources to the processing of the oddball stimuli, as evidenced by higher amplitudes on both N100 and P300 waveforms.

Additionally, the more creative participants showed highly variable P300 amplitudes across presentations of the novel stimuli, whereas the less creative participants showed little variability. Following Courchesne's design, P300 variability was measured for six averaged groupings of novel stimulus presentations for both the frontal and parietal scalp locations. Frontal (Fz) and parietal (Pz) scalp locations were analyzed because they have previously been associated with change in processing of novel stimuli (Courchesne, 1978). The frontal electrode location, as opposed to the parietal electrode location, has been associated with initial processing of a novel stimulus because higher amplitudes are recorded at frontal locations when a new, unexpected stimulus is presented. The parietal electrode location, in contrast, has been associated with continued processing of a once-novel stimulus because increasing amplitudes are recorded with continued presentation. The central electrode location was not analyzed because it has not been implicated in this particular problem. The raw ERP record matrix for each of 18 stimuli was used, and broken into 6 averaged matrices. The matrices for the first three stimuli were averaged to form the first novel presentation group, and the matrices from the second three stimuli were averaged to form the second novel presentation group. This procedure was repeated for each of the 6 novel presentation groups.

For the less creative group, the P300 amplitude between the first and second averaged group of novel stimuli showed a slight rise in amplitude in the frontal electrode location (Fz), and the parietal (Pz) location. Then, the amplitude essentially did not vary across the next four averaged groups. The frontal P300 was slightly, although not significantly, higher than the parietal P300 across each group. Both the frontal and parietal locations followed the same amplitude pattern, almost exactly mirroring each other.

The more creative group's P300 amplitudes oscillated with every group of novel stimulus presentations. The differences across novel presentation groupings was statistically significant, although it did not follow Courchesne's predicted pattern of early increases in Fz followed by decreases at Fz mirroring increases at Pz. Unlike the less creative group, frontal and parietal P300 amplitudes did not follow the same pattern across groups. The differences between frontal and parietal recordings across time were also statistically significant. Overall, the amplitudes for both the frontal and parietal sites were statistically significant, with overall higher amplitudes for the more creative group than the less creative group. The striking difference in activation patterns suggests that more creative participants differ from less creative participants in the distribution of attentional resources. It is not just that more attention is allocated to stimulus processing, but the allocation is also more variable, in accord with the theories discussed in previous sections.

Purpose

There are a number of studies from Martindale and colleagues that examined individual differences on a variety of creative tasks. However, they did not explore all of the possible frequency bands, nor did they examine coherence between electrode locations. The absence of these measures makes it difficult to draw any solid conclusions about the neurophysiology of the more versus less creative individual. Other labs have reported more complete analyses of the neurophysiological response to creative tasks, but have not related the responses to individual differences in creative potential. The lack of this information prevents any conclusions based on the neurophysiologically-based models of creativity discussed in the previous sections. To gain a better neurophysiological understanding of creativity, it is necessary to consider both individual differences and do a more complete analysis.

Common Method

Participants

Eighty-two participants completed this project, with half ($\underline{n}$ = 41) males and half ($\underline{n}$ = 41) females. The mean age of participants was 19.55 ($\underline{SD}$ = 3.04), with a range of 18-43 years. The mean years in college was 1.66 ($\underline{SD}$ = 1.04), with a range of 1-5 years. All participants were self-reported right-handed, and scored between 6-14 points ($\underline{M}$ = 11.95, $\underline{SD}$ = 1.9) on a standard handedness questionnaire, with 14 points as the maximum right-sidedness score.

Participants were recruited from the University of Maine Psychology Department Introductory Psychology Classes, and received course credit for their participation. Males and Females were recruited separately to ensure equal numbers of participants by sex. All participants completed both parts of the assessment (i.e., paper and pencil measures and neurophysiological measures) in one session. Half of the participants completed the paper and pencil measures first, and then completed the neurophysiological assessments. The other half of the participants did the opposite. All assessments were individually administered.

Paper and Pencil Measures

To capture individual differences in creative potential, five standard creativity tests were administered to all participants. The five tests were chosen because they have been successful at measuring creative potential from different perspectives. In the analysis of the results, the scores from these tests will be standardized and combined to form a creative potential score. The five creative potential tests are the Alternate Uses Test, the Remote Associates Test, the Creative Personality Scale, the Word Association Test, and rated creativity of a story written during one of the EEG tasks (see below for details). In addition to the creative potential tasks, a measure of intellectual functioning, the Shipley Institute of Living scale, was included to ensure that results were due to creative potential and not general intellectual ability.

Alternate Uses Test

The Alternate Uses Test follows the design of Wallach and Kogan (1965) (see Appendix F). It follows the ideas of Guilford (1950) who suggested that creative thought is comprised of at least eight abilities. Based on research, one of the most successful of those eight abilities is fluency, or the ability to generate a large number of possible solutions to a problem. Wallach and Kogan's fluency task involved asking participants to give as many uses for common objects as possible. They scored the test in two ways: total number of uses and uniqueness of the uses. Total number of uses was scored by adding up the number of uses given for each object. Uniqueness of uses was scored by adding up the total number of times each response for a participant was given within the entire sample. Using the Spearman-Brown split-half reliability coefficient, they found that the uniqueness score had a .87 reliability score and that the number of instances had a .93 reliability score. Additionally, the test showed high correlations with Wallach and Kogan's other measures of creativity and no correlation with a variety of intelligence measures.

For this study, participants were presented with a common object and were asked to produce as many uses for the object as possible within three minutes. This procedure was repeated for each of three nouns. The objects used for this project were Shoe, Newspaper, and Brick. For each object, an individual total of the number of uses produced was summed ($\underline{M}_{Shoe}$ = 9.34, $\underline{SD}_{Shoe}$ = 3.56; $\underline{M}_{Newspaper}$ = 12.17, $\underline{SD}_{Newspaper}$ = 3.86; $\underline{M}_{Brick}$ = 10.66, $\underline{SD}_{Brick}$ = 3.43). A high Coefficient Alpha ($\underline{\alpha}$ = 0.85) indicates that there was internal consistency in answer patterns across the three subscales, therefore it was appropriate to combine these scores into a single total score for the Alternate Uses Test ($\underline{M}$ = 34.09, $\underline{SD}$ = 10.41). The combined score Alternate Uses Test was used for all further analyses.

The Alternate Uses Test was positively correlated with the Creative Personality Scale ($\underline{r}$ = .33, $\underline{p} < .01$). This indicated that participants showing more creative potential, as measured through the Alternate Uses Test, also reported more creative personality traits. No other creative potential measures were correlated with the Alternate Uses Test.

Remote Associates Test

The Remote Associates Test was developed by Mednick (1962) in relation to his associative theory of creativity (see “History of Creativity” above) (see Appendix F for test). It builds on the principles of word association by providing three words that have some isolated association. Participants are asked to determine the appropriate association. It is a technique meant to force participants to draw upon their ability to make unusual associations between ideas. The RAT has shown promising reliability and validity in a number of studies. In two separate studies, Spearman-Brown reliability for the RAT was .92 and .91. In comparison with expert ratings of the creativity of a group of practicing architects, the RAT showed a high positive correlation ($\underline{r}$ = .70, $\underline{p} < .01$).

In this study, participants were presented with 30 of these three-word groups, so the highest possible raw score for this task was 30. The range of scores for this task was 0 correct to 18 correct (M = 9.33, SD = 4.07).

Creative Personality Scale

The Creative Personality Scale was developed by Gough (1979) (see Appendix F). It is a subset of Gough and Heilbrun's (1979) Adjective Checklist, which asks participants to check the adjectives that they believe best describe them. Gough identified the 18 adjectives that best described the creative person and the 12 adjectives that best described the uncreative person and used these 30 adjectives to create the Creative Personality Scale. The Alpha coefficient reliabilities were reported for each sex as follows: .77 for the male composite, and .81 for the female composite. In the same study, the Creative Personality Scale was compared to six other adjective checklist scales for creativity (i.e., Domino, Shaefer, Welsh A-1, Welsh A-2, Welsh A-3, and Welsh A-4). The Creative Personality Scale was positively related to all six other scales ($p < .01$). Additionally, it was compared to expert ratings of creativity for each participant in the sample and was found to be a better predictor of rated creativity than any of the other six scales.

Scores on the Creative Personality Scale range between –12 to +18. For this sample, the average score was approximately in the center of the distribution (M = 5.22, SD = 3.95).

Word Association Test

The Word Association Test was developed by Palermo and Jenkins (1964) (see Appendix F). It is based on the idea that the types of associations people make to a given word provide insight about their cognitive state. Participants are given individual words and are asked to state the first word that comes to their minds when they see each word. Palermo and Jenkins gathered norms for each word by recording responses for 4^{th}-12^{th} grade students and for a sample of college students. Five hundred males and five hundred females were used for each grade. To score the Word Association Test, each participant's response to a given word is compared with the responses given by the appropriate normative sample (i.e., a female college student's response is compared to the responses given by female college students from the normative sample). The participant's score for a given word is the number of participants from the normative sample who gave the same response. Therefore, a higher score is indicative of a more stereotypical response, although the score is typically reverse coded to make correlations with other creativity tests easier to understand. The Word Association Test has been related to creative potential in a number of studies (see Eysenck, 1995). For example, Merten and Fischer (1999) reported that a group of expert-rated creative writers and actors provided more unique word association responses than did a group of schizophrenics or a group of normal controls.

In this study, participants were asked to write down the first word that came to their mind in association with each of 100 given words. The participants' answers were then compared with Palermo and Jenkins'(1964) normative sample, where the most common responses to a given word are listed, along with the number of participants from the normative sample who gave the response. The more participants from the normative sample who gave a response, the more common that response. To score the Word Association Test, each response was compared to the normative sample list, and the number of participants from the normative sample who gave the response was recorded. The raw Word Association Test score is the total across the 100 words. A higher score indicated more common answers, while a lower score was indicative of less common responses. The range of scores for this sample was between 1168 to 10,926 (M = 4405.94, SD = 1944.67). These raw scores were converted to z-scores and then reverse coded for all further analyses, so that a lower score is indicative of a more stereotypical (less creative) response.

Story Originality Scores

In the first EEG experiment, participants were asked to take five minutes to think of a creative story without saying it out loud. Then, they were asked to write the story out for the next five minutes. The written version of the stories were subjected to expert review for originality. Reviewers were asked to rate the originality of each participant's story on a five-point Likert scale. They were instructed to use their own understanding of originality to assess the creativity of each story. This method has been shown to produce highly reliable ratings across a number of types of creative tasks (i.e., spatial and verbal tasks). Amabile (1982) reported interrater reliabilities between .72 and .90 across seven studies of creative products. Sternberg and Lubart (1996) reported an interrater reliability of .92. Sternberg and Lubart (1996) emphasize the importance of these more open-ended methods to capture the breadth and depth of the creative process.

Two raters judged the originality of the stories produced in experiment one on a scale of 1-5 (5 = high originality). They were asked to use their own definitions of originality to score the stories, but were given an example of a story theme that fit each score (1-5). Interrater reliability for originality scores was high ($\alpha = .96$). Given the high degree of reliability for the originality ratings, the mean rating between the two judges was used for all further analyses. This mean of the judge's ratings will be referred to as Originality. The mean Originality score (i.e., score after averaging the two judge's ratings) was M = 2.77 with a standard deviation of SD = 2.00.

Intellectual Functioning

In addition to the creative potential tasks, participants were also asked to complete the Shipley Institute of Living Scale (Zachary, 1996). The scale consists of two subtests, each aimed at assessing general intellectual functioning. The first subscale is a vocabulary test where participants are asked to find the synonym to a given word out of four possible choices (e.g., LARGE is a synonym to *red, big, silent, or wet* – the answer is *big*). The second subscale is an abstraction test where participants are asked to complete a series by providing the next element in the series (e.g., Complete the series A B C D __ - the answer is E). This scale is considered an adequate short version of a test of intellectual functioning. For example, across 11 studies, the median correlation between the Shipley total score (across both subscales) and the WAIS (a considerably more complex intelligence test) was .79, with a range in correlations between .73 and .90. This scale was included to control for the possibility that individual differences in neurophysiological measures were due to general intellectual functioning and not creative potential.

In accord with numerous past studies (see Eysenck, 1995), it was not expected that creativity and intellectual functioning scores would correlate significantly, nor was it expected that intellectual functioning would have a stronger relationship with the neurophysiological measures than creative potential scores.

Both subscales of the Shipley Institute of Living Scale were used in this study. On the vocabulary subscale, participants were asked to find the synonym for each of 40 given words. The raw scores on the vocabulary subscale ranged between 22 to 38 ($\underline{M}$ = 29.52, $\underline{SD}$ = 3.67). On the abstraction subscale, participants were asked to complete 20 pattern sets where either numbers, letters, or words are left out of a given pattern. For easy comparison to the vocabulary subscale where the highest possible score was 40, Shipley Institute of Living Scale suggests doubling the raw score for the abstraction subscale where the highest possible score was 20. The doubled raw scores on the abstraction subscale ranged between 18 and 40 ($\underline{M}$ = 33.49, $\underline{SD}$ = 4.62). Coefficient Alpha ($\underline{\alpha}$ = 0.46) was moderate, indicating that there was internal consistency in answer patterns across the two subscale. Therefore, it was appropriate to combine these scores into a single total score ($\underline{M}$ = 63.01, $\underline{SD}$ = 6.72). The combined score was used for all further analyses.

Apparatus

Two adjacent rooms were used for this part of the study. The experimenter's room housed a Grass Model 89 eight channel electroencephalograph (EEG), a Toshiba Equium 7000S personal computer (PC), and a computer monitor. The PC had a Keithley DAS1202 Analog-to-Digital (A/D) conversion card installed to allow digital recording and analysis of the analog EEG signal. This card allowed up to 50K samples/sec over the total number of channels. All A/D conversions occurred at 200 Hz, which is twice the highest expected frequency from eye muscle movement, also called the Nyquist frequency. Sampling at twice the expected frequency is common practice in A/D conversion because it ensures that aliasing will not occur. Aliasing is the unintended reduction of a waveform from a higher, unsampled, frequency to a lower frequency within the sampling range. The signal was output from the EEG to the A/D card through eight shielded wires, one for each channel. These were single-ended inputs, all referring to a common ground. Sensitivity and all filters were controlled through a master switch on the EEG, and were used because they are the settings most commonly used in EEG recording, as well as the default settings for the equipment. Sensitivity was set to 7μV/mm. Low bandpass filter was set to 1Hz. High bandpass filter was set to 70 Hz. The 60Hz filter was set to eliminate common electrical interference, as 60Hz is the frequency at which most building electrical currents are set.

The participant's room held a computer monitor angled at a slight downward tilt toward the participant's chair. The average visual angle between the participant and the stimuli on the computer monitor was 2.4° (i.e., tan(Visual Angle) = Height of Stimulus / Distance from Stimulus: tan(2.4) = 5 cm / 122 cm or tan(2.4) = 2 inches / 48 inches). This computer monitor was linked to the PC in the experimenter's room through a Y-cable. This allowed the participant to view the same scene as the experimenter. The chair was a comfortable reclining chair. An electrode board was attached to the top and back of the chair near the participant's head. This electrode board was connected to the EEG in the experimenter's room through a portal in the adjoining wall. Electrodes were 1cm gold disk electrodes. Electrode application included a light *NuPrep* pumice scrub, a swipe of 70% isopropyl alcohol, and finally application with Ten20 conductive paste. A resistance check was performed for all electrode leads once they were applied. Electrodes were reapplied until resistances of 5KΩ or less were obtained for each electrode.

All stimulus presentations for the neurophysiological experiments were controlled through Testpoint, a Keithley data acquisition software product. Stimulus presentations and data acquisition were coordinated through Testpoint. Data was recorded from six lateral sites: frontal (F3, F4), central (C3, C4), and parietal (P3, P4). Eye movement was recorded from the outer canthi of the left eye, with one lead above and one lead below the eye. All electrodes were referenced to linked mastoid leads.

Common Results

Participants

There were very few significant correlations between the Creative Potential or Intellectual Functioning measures and the Participant Demographic Information (i.e., Sex, Age, Years in College, and Handedness), except for the following. Sex and Word Association Test are positively correlated ($r = 0.36$, $p < .001$), indicating higher Word Association Test scores for female participants. Considering that a high Word Association Test score is associated with more typical responses, it can be concluded that for this sample, female participants were more likely to produce typical responses. Years in College and Shipley Institute of Living Scale Vocabulary Subscale scores are positively correlated ($r = 0.31$, $p < .01$), indicating higher vocabulary scores for those who have been in college longer. Handedness and Shipley Institute of Living Scale Vocabulary Subscale scores are negatively correlated ($r = -.23$, $p < .05$), indicating higher vocabulary scores for those who report less right-handedness. Handedness and Alternate Uses Test total score are negatively correlated ($r = -.40$, $p < .001$), indicating higher total Alternate Uses Test scores for those who report less right-handedness. There are no other significant correlations between Participant Demographics and either Creativity or Intellectual Functioning Scores. All correlations are reported in Appendix A.

Paper and Pencil Measures

Creativity Tests

The Alternate Uses Test was positively correlated with the Creative Personality Scale ($r = .33$, $p < .01$). This indicates that participants showing more creative potential, as measured through the Alternate Uses Test, also reported more creative personality traits. The Creative Personality Scale was also correlated with the Word Association Test ($r = .22$, $p < .05$). This indicates that participants reporting more creative personality traits also supplied more unusual associations on the Word Association Test. The correlation between the Creative Personality Scale and the Remote Associates Test was not significant ($r = .12$), however it was in the expected direction. The correlation between the Word Association Test and the Alternate Uses Test ($r = .06$) and the Remote Associates Test ($r = .20$) were both in the expected direction, indicating a positive relationship between all other measures of creative potential with the Word Association Test. The Originality scores for the creative stories produced in experiment 1 were not significantly correlated with any other measures of creative potential.

Intellectual Functioning

The Shipley Institute of Living scale (Zachary, 1996) total score was positively correlated with the Remote Associates Test ($r = .32$, $p < .004$). No other creative potential measures were significantly correlated with the Shipley Institute of Living Scale. Furthermore, they did not show a consistent pattern of relationship with the Shipley Institute of Living Scale.

All correlations between creative potential measures and the intellectual functioning measure are reported in Table 1.

Table 1. Correlations between Creativity Measures and Intellectual Functioning Measure

	Alternate	Remote	Persnality	Word	Original	Shipley
Alternate Uses Test Total		-.05	.33**	.06	.16	-.05
Remote Associates Test			.12	.20	-.09	.31**
Creative Personality Scale				.22*	.20	.00
Word Association Test					.01	.08
Story Originality Scores						.07
Shipley Institute for Living						

* $p < .05$. ** $p < .01$.

Composite Creativity Score

For the purpose of analyzing the variances in the ERP experiments, it was necessary to create a composite creativity score from the creativity measures. First, the raw scores for each creativity measure (i.e., Alternate Uses Test, Remote Associates Test, Creative Personality Scale, Word Association Test) were converted to z-score distributions. The z-score versions of the creativity measures were then summed to create the composite creativity score. This new composite creativity score had the expected mean and standard deviation for a sum of z-score distributions ($M = 0.0$, $SD = 1.98$). The median for the composite creativity score was .0542 with a minimum value of –4.96 and a maximum value of 4.68.

The composite creativity scores were not related to the measures of intellectual functioning, either individually or combined. The correlation with the Vocabulary subscale was 0.12. The correlation with the Abstraction subscale was 0.003. The correlation with the combined intellectual functioning scores was 0.07. Furthermore, the composite creativity scores were not related to sex (r = -.18).

To create a high and low creativity group for use in experimental analyses, all scores were split at the median value of .0542. Participants with composite creativity scores above .0542 were assigned to the High Creativity Group. Participants with composite creativity scores equal to or below .0542 were assigned to the Low Creativity Group. Participants were divided evenly between the High Creativity Group (n = 40) and Low Creativity Group (n = 40). Furthermore, participant sex was divided essentially evenly between the High Creativity Group (n_{male} = 19, n_{female} = 21) and the Low Creativity Group (n_{male} = 20, n_{female} = 20).

Note that the story originality ratings were not included in this composite score. They were not included because of the difference in administration between the other creativity measures and the story creation task. All creativity tasks except the story creation task were administered individually at a desk in a quiet room, whereas the story creation task was completed while the participant was completing the neurophysiological experiments (i.e., wearing electrodes, lying in a chair, receiving instructions from a computer monitor, etc.). This difference in task demand was too great to include the story originality scores in the composite measure.

Experiment One

Hypotheses

The first neurophysiological task used the methods from Martindale and Hasenfus (1978), measuring EEG during a creative task. It was hypothesized that the more creative participants would differ from the less creative participants while creating the creative story in the lower amplitude frequency bands. It was expected that this study would replicate the findings from the original study in that alpha wave activity would be more prominent for the more creative group during the creative story task. In addition, theta and delta activity was expected to increase for the more creative group only during the creative story task, indicating a reduction in conscious attention to allow for more disparate relationships to emerge. It was also expected that the right hemisphere would show greater activity in these lower frequency waveforms during the creative story task based on the findings of Martindale, Hines, Mitchell, and Covello (1984). No differences between the high and low creative group were expected for the math problems.

For the coherence measures, we know from both the Tucker, Dawson, Roth, and Penland (1985) study and the Petsche, Kaplan, von Stein, and Filz (1997) study that coherence seems to increase with creative tasks. Tucker et al. report that it increased specifically in the alpha, theta, and delta bands for a word fluency task. However, neither study separated participants based on creativity of response. Therefore, it was expected that coherence would increase for all participants while creating the creative story, but that this increase would be greater for the more creative group. This would be reflected in differences in the ANOVA that would use the condensed measure of entire coherence. Based on Petsche, Kaplan, von Stein, and Filz (1997), it was predicted that there would not be differences in coherence between the two hemispheres for either group. Petsche et al reported strong coherence between frontal and parietal locations for both hemispheres. At best, it was predicted that the more creative group might show stronger coherence in both hemispheres as compared with the less creative group. However, this would be further support for the predicted results of the first analysis. It was unclear from the past research whether any differences would exist between anterior and posterior coherence values. Strong coherences have been found between both frontal and parietal locations during creative tasks (Tucker et al, 1985; Petsche et al, 1997). Again, the only prediction was that the more creative group would show stronger coherence at both locations than the less creative group.

Unique Methods

Stimuli

After recording five minute eyes-closed and five minute eyes-open baseline EEG, participants were asked to do the following two tasks. The order of the tasks was randomized across participants. For the first task, they were instructed to think of a creative story on the topic 'between the lines.' They were instructed to make the story as creative a possible (see Appendix G for full instructions). After five minutes, the participants were asked to write the story they had created in their minds. They were given five more minutes to write the story on paper. EEG was recorded during the time when the participants were thinking of their story and when they are writing it out. For the second task, participants were asked to mentally solve moderately difficult math problems. The math problems were intended to take no more than 30 seconds each to complete. EEG was recorded for thirty seconds. After 30 seconds, a new problem was presented.

Data Cleaning

Neurophysiological records must be subjected to inspection for unwanted electrical artifacts. This data set was first visually inspected for unusual electrical activity. A participant's record was rejected from further analysis if more than 25% of the electrical activity within the record was abnormal. This might occur when a participant displayed excessive muscle activity, or when there was a machine failure. Beyond visual inspection, all data were smoothed using a Hanning window, which is necessary to produce the spectral density plot used in further analyses.

Data Analysis

Spectral Analysis

Six frequency bands were analyzed (i.e., high beta, low beta, high alpha, low alpha, theta, and delta). Power within each frequency band was identified by spectral analysis using a fast Fourier Transform (FFT). Calculation of power within each frequency band was completed in SAS Version 8.02 (2001). To calculate power within a specified frequency band: (a) the frequency band estimate was calculated for all n / 2 frequencies (n = total data points recorded); (b) the average power within the frequency range of interest was computed by calculating the mean for all of the frequency band estimates within each frequency range (i.e., delta, theta, low alpha, high alpha, low beta, high beta); and (c) the average power within each of the six frequency bands was appended to a separate data file for use in repeated measures ANOVA analysis. The description of calculations applies individually to each electrode location used in the experiment, and was completed on each participant data file for both imagining and writing the story.

Cross-spectral Analysis

Electrodes were placed over six sites (i.e., frontal, temporal, and parietal for the left and right hemisphere). These multiple recording sites allowed for coherence analyses. The similarity in frequency bands (i.e., coherence) across the six recording sites was calculated by condition and then compared. Calculation of coherence within each frequency band was completed in SAS Version 8.02 (2001). Coherence was analyzed separately from power.

The result of coherence analysis can be expressed as a cross-spectral density plot, or as a coherence matrix for each frequency band of interest. The coherence values in a coherence matrix for a given frequency band should follow the same distribution as Pearson Product Moment correlation values. Therefore, it was necessary to convert the coherence values using a Fisher's z transformation before subjecting them to further analysis. To calculate coherence within a specified frequency band: (a) coherence was calculated for all n / 2 frequencies (n = total data points recorded); (b) the coherence values were squared; (c) the coherence values were converted using a Fisher's z transformation ($1/2 \log(1 + \text{coherence}^2) / (1 - \text{coherence}^2)$); (d) average transformed coherence values within the frequency band of interest were computed; and (e) the average transformed coherence values within each of the six frequency bands was appended to a separate data file for use in repeated measures ANOVA analysis. The description of calculations applies individually to each electrode pair used in the experiment, and was completed on each participant data file for both imagining and writing the story.

Results

For this first experiment, the between subjects variable used was the ratings of story originality. Originality ratings were subjected to a median split, and the resulting two groups were used as the between subjects variable. Originality ratings were used instead of the composite creativity score because the essential component of this task was the originality of the stories written by the participants while EEG was recorded. The composite creativity score did not include originality ratings because of the difference in task demands between the paper and pencil tasks and the story writing task. Therefore, use of composite creativity in these analyses would have been suboptimal.

Additional analyses beyond those reported below were conducted to ensure that no sex differences, differences within a single creativity test, nor differences by intellectual functioning were better predictors. There were no more valuable differences discovered for any of these analyses. These analyses are included in Appendix B.

Further exploratory analyses were conducted individually for each frequency band, as well as for each electrode location. These analyses did not produce results more elucidating than the main analysis described below, therefore they have not been included in this dissertation.

Spectral Analysis

The reduced data resulting from the spectral analysis was subjected to a 2 (Activity: Write Story, Imagine Story) x 6 (Frequency Bands: Delta, Theta, Low Alpha, High Alpha, Low Beta, High Beta) x 2 (Hemisphere) x 3 (Electrode Location) repeated measures analysis with Originality Group entered as a between subjects variable. Results from the analyses are shown in Table 2. Of particular interest to this report are the results including Originality Group. The effect for Activity x Hemisphere x Originality Group was statistically significant ($\underline{F}(1,50) = 6.11$, $\underline{p} < .02$). This result was due to a difference between the High Originality Group and the Low Originality Group while writing the story versus imagining the story. The High Originality Group shows higher spectral densities while imaging the story ($\underline{M}_{left} = .028$, $\underline{M}_{right} = .031$) versus while writing the story ($\underline{M}_{left} = .017$, $\underline{M}_{right} = .018$). In contrast, the Low Originality Group shows essentially the same spectral densities while imagining the story ($\underline{M}_{left} = .038$, $\underline{M}_{right} = .038$) versus while writing the story ($\underline{M}_{left} = .033$, $\underline{M}_{right} = .036$). In both the high and low originality groups, when there is a difference across hemispheres it is accounted for by lower left hemisphere activation than right hemisphere activation. This difference accounts for the value of Hemisphere in this interaction. This relationship is shown in Figure 1.

Figure 1. Spectral density for Activity x Hemisphere x Originality Group differences.

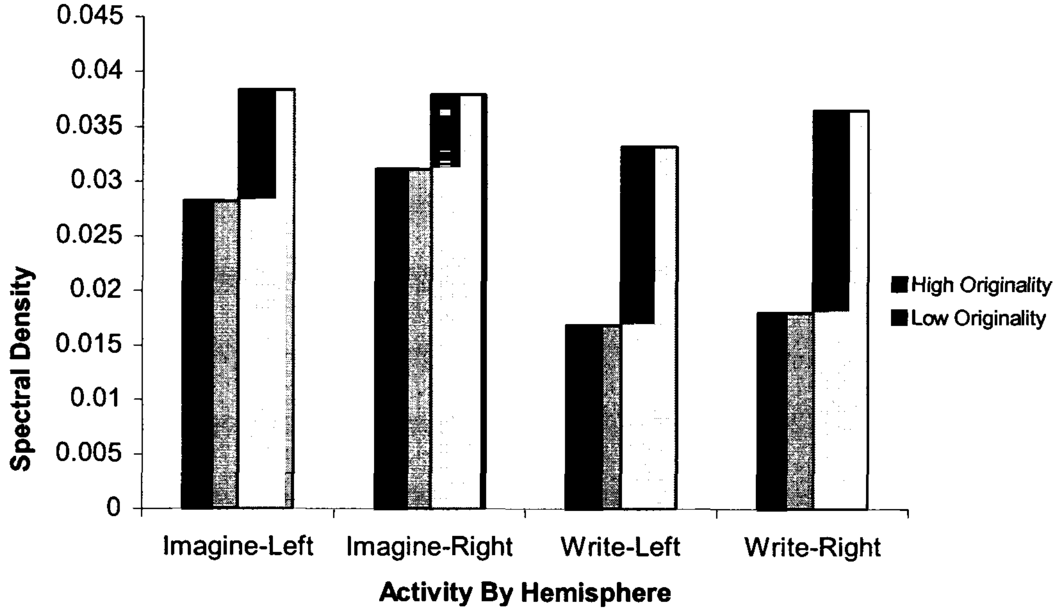


Table 2. Spectral Imagine Story and Write Story Multivariate Repeated Measures Analysis

Source	df	F
ACTIVITY	1	3.28
ACTIVITY x ORGRP	1	1.09
FREQ	5	19.78
FREQ x ORGRP	5	0.71
HEM	1	9.52**
HEM x ORGRP	1	0.25
ELEC LOC	2	38.27***
ELEC LOC x ORGRP	2	0.64
ACTIVITY x FREQ	5	12.82***
ACTIVITY x FREQ x ORGRP	5	1.37
ACTIVITY x HEM	1	0.82
ACTIVITY x HEM x ORGRP	1	6.11*
FREQ x HEM	5	2.21
FREQ x HEM x ORGRP	5	0.39
ACTIVITY x FREQ x HEM	5	0.33
ACTIVITY x FREQ x HEM x ORGRP	5	1.73
ACTIVITY x ELEC LOC	2	14.50***
ACTIVITY x ELEC LOC x ORGRP	2	0.21
FREQ x ELEC LOC	10	14.38***
FREQ x ELEC LOC x ORGRP	10	0.97

Table 2. Continued

ACTIVITY x FREQ x ELEC LOC	10	4.75***
ACTIVITY x FREQ x ELEC LOC x ORGRP	10	0.70
HEM x ELEC LOC	2	0.61
HEM x ELEC LOC x ORGRP	2	1.04
ACTIVITY x HEM x ELEC LOC	2	0.25
ACTIVITY x HEM x ELEC LOC x ORGRP	2	1.77
FREQ x HEM x ELEC LOC	10	3.21**
FREQ x HEM x ELEC LOC x ORGRP	10	0.42
ACTIVITY x FREQ x HEM x ELEC LOC	10	2.08*
ACTIVITY x FREQ x HEM x ELEC LOC x ORGRP	10	1.25

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORGRP indicates rated originality of story group (high, low).

*$p < .05$. **$p < .01$. ***$p < .001$.

To better understand the Activity x Hemisphere x Originality Group result, it was necessary to consider the spectral densities from each frequency band. This result combined all of the spectral densities from each frequency band, while it was a specific goal of this experiment to understand the contributions of each frequency band individually. None of the results for Originality Group by Frequency Band were significant, but it was nevertheless helpful to consider how each frequency band contributed to the significant Activity x Hemisphere x Originality Group result. This further breakdown of the Activity x Hemisphere x Originality Group result by frequency band is shown in Figure 2. The means for Activity x Hemisphere x Frequency Band x Originality Group are listed in Table 3. Given that the result for Activity x Hemisphere x Frequency Band x Originality Group was not statistically significant, it was not surprising that the relative contributions of the frequency bands were very similar. It was interesting to note that the Low Alpha frequency band contributed more when participants were imagining the story and less when participants were writing the story, as would be predicted. The large contribution of the Delta frequency band certainly contributed to the group differences, but was difficult to explain further. It should be noted, however, that the large contribution from the Delta band is typical for human EEG records (Horovitz, 2002)

Figure 2. Imagine Story and Write Story Spectral Density for Activity x Hemisphere x Frequency Band x Originality Group differences.

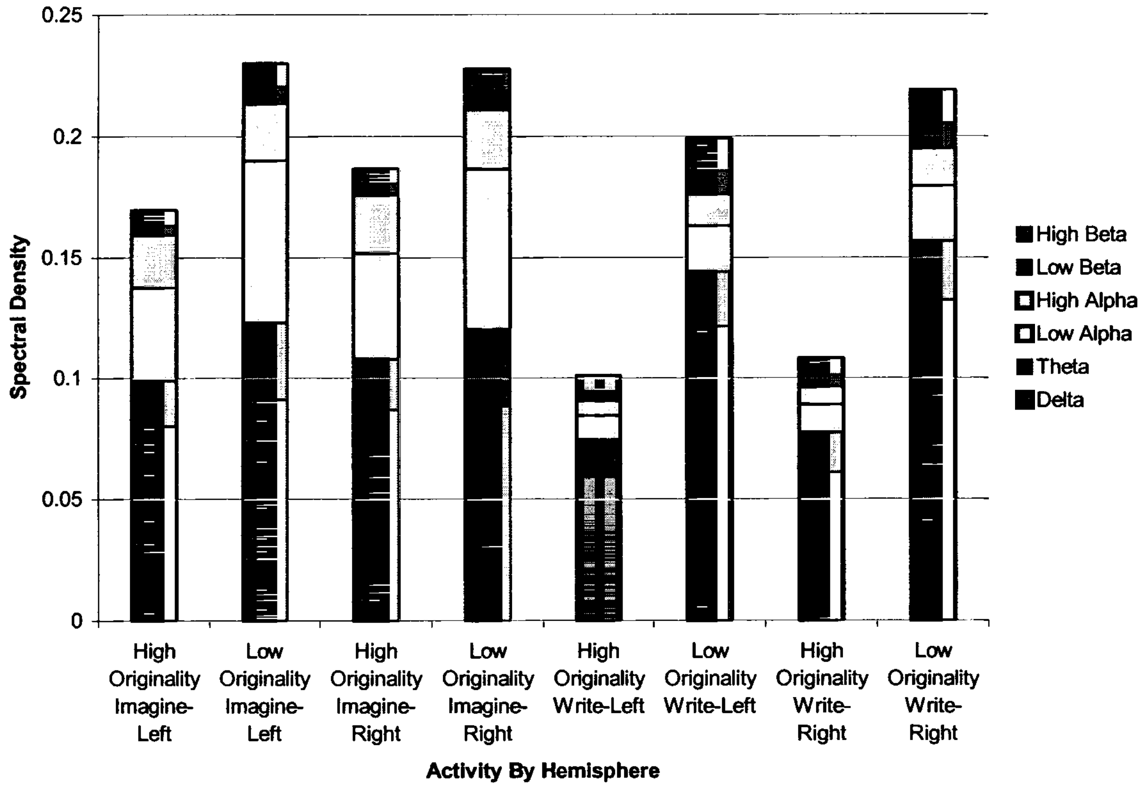


Table 3. Imagine Story and Write Story Mean Spectral Densities for Activity x Frequency x Hemisphere x Originality Group

			Originality	
Activity	Frequency	Hemisphere	High	Low
Write	Delta	Left	0.059	0.121
		Right	0.061	0.132
	Theta	Left	0.015	0.023
		Right	0.017	0.024
	Low Alpha	Left	0.010	0.019
		Right	0.012	0.023
	High Alpha	Left	0.006	0.013
		Right	0.007	0.015
	Low Beta	Left	0.004	0.010
		Right	0.005	0.011
	High Beta	Left	0.007	0.013
		Right	0.007	0.013
Imagine	Delta	Left	0.080	0.091
		Right	0.087	0.088
	Theta	Left	0.019	0.032
		Right	0.021	0.032
	Low Alpha	Left	0.038	0.067
		Right	0.044	0.066

Table 3. Continued

High Alpha	Left	0.022	0.023
	Right	0.024	0.025
Low Beta	Left	0.004	0.007
	Right	0.005	0.008
High Beta	Left	0.006	0.009
	Right	0.006	0.009

There were a number of other main effects and interactions that were significant, but did not include Originality Group. One of these results was potentially interesting in this investigation: Activity x Frequency Band ($F(5,46) = 12.82$, $p < .001$). This result was largely due to increased power in the Low Alpha and High Alpha frequency bands while participants were imagining the story, as opposed to writing the story (see means in Table 4). This relationship is shown in Figure 3. There was also overall higher power at each electrode location while participants were imagining the story, as opposed to when they were writing the story (Activity x Electrode Location $F(2,49) = 14.50$, $p < .001$) (see means in Table 5). This interaction is shown in Figure 4. The Activity x Frequency x Electrode Location and the Activity x Frequency x Hemisphere x Electrode Location interactions were also significant, but more difficult to interpret. There are some interesting features in this interaction including: (1) a relatively larger contribution from the delta frequency band as compared to the other five frequency bands, (2) greater delta and theta activity measured at frontal electrode locations as compared to central and parietal electrode locations, (3) greater low alpha and high alpha activity measured at parietal locations as compared to central and frontal locations, (4) greater overall activation in the theta, low alpha, and high alpha frequency bands while participants were imagining a story as compared to when they were writing a story, and (5) a consistent pattern across all frequencies showing greater right hemisphere activation than left hemisphere activation when activation is summed across all electrode locations. The means for these interactions are shown in Table 6, and these relationships are displayed graphically in Figure 5.

Figure 3. Write Story and Imagine Story Spectral Density for Activity x Frequency Band differences.

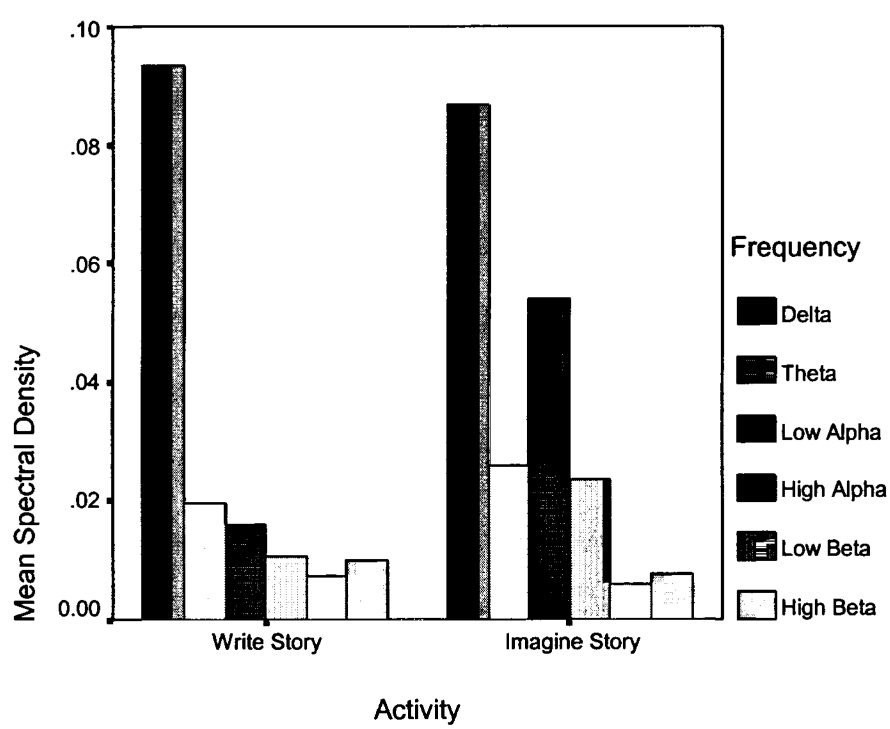


Table 4. Imagine Story and Write Story Mean Spectral Densities for Activity x Frequency

Frequency	Write	Imagine
Delta	0.094	0.087
Theta	0.020	0.026
Low Alpha	0.016	0.054
High Alpha	0.010	0.023
Low Beta	0.007	0.006
High Beta	0.010	0.008

Figure 4. Imagine Story and Write Story Spectral density for Activity x Electrode Location differences.

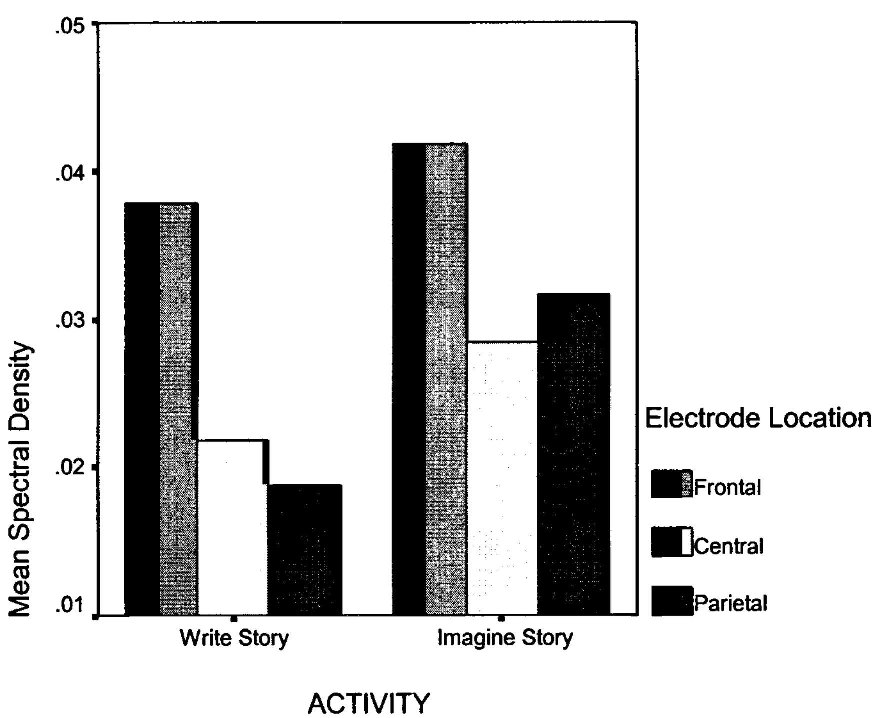


Table 5. Imagine Story and Write Story Mean Spectral Densities for Activity x Electrode Location

	Activity	
Electrode Location	Write	Imagine
Frontal	0.038	0.042
Central	0.022	0.028
Parietal	0.019	0.032

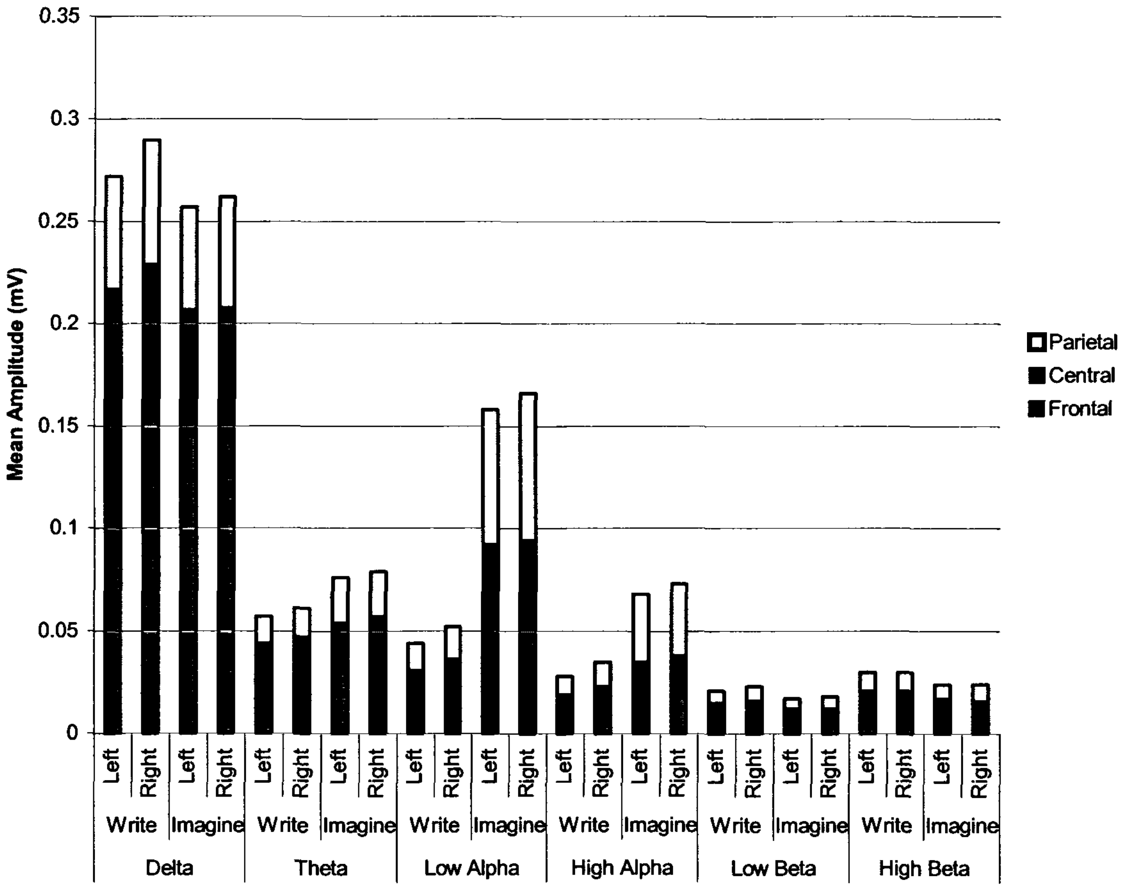
Table 6. Imagine Story and Write Story Mean Spectral Densities for Activity x Frequency x Hemisphere x Electrode Location

			Activity	
Frequency	Hemisphere	Electrode Location	Write	Imagine
Delta	Left	Frontal	0.148	0.145
		Central	0.069	0.062
		Parietal	0.055	0.050
	Right	Frontal	0.154	0.142
		Central	0.075	0.066
		Parietal	0.061	0.054
Theta	Left	Frontal	0.028	0.031
		Central	0.016	0.023
		Parietal	0.013	0.022
	Right	Frontal	0.030	0.032
		Central	0.017	0.025
		Parietal	0.014	0.022
Low Alpha	Left	Frontal	0.017	0.045
		Central	0.014	0.047
		Parietal	0.013	0.066
	Right	Frontal	0.019	0.046
		Central	0.017	0.048
		Parietal	0.016	0.072

Table 6. Continued

High Alpha	Left	Frontal	0.010	0.016
		Central	0.009	0.019
		Parietal	0.009	0.033
	Right	Frontal	0.011	0.017
		Central	0.012	0.021
		Parietal	0.012	0.035
Low Beta	Left	Frontal	0.008	0.006
		Central	0.007	0.006
		Parietal	0.006	0.005
	Right	Frontal	0.008	0.006
		Central	0.008	0.006
		Parietal	0.007	0.006
High Beta	Left	Frontal	0.011	0.008
		Central	0.010	0.009
		Parietal	0.009	0.007
	Right	Frontal	0.011	0.008
		Central	0.010	0.008
		Parietal	0.009	0.008

Figure 5. Imagine Story and Write Story Spectral density for Activity x Frequency x Hemisphere x Electrode Location differences.



In addition to imagining and writing a story, participants were also asked to solve math problems. The inclusion of this task did not provide further elucidation above and beyond that discussed above (see Table 8). The Activity x Hemisphere x Originality Group interaction remains significant in this analysis, but it is largely due to the relationship between the imagining a story activity and the writing a story activity. The pattern of activity for solving math problems was essentially the same as that for imagining a story, as shown in Table 7.

Table 7. Imagine Story, Write Story, and Math Problem Mean Spectral Densities for Activity x Hemisphere x Originality Group

		Originality	
Activity	Hemisphere	High	Low
Write	Left	0.013	0.023
	Right	0.015	0.028
Imagine	Left	0.022	0.038
	Right	0.026	0.037
Math	Left	0.018	0.035
	Right	0.021	0.034

Table 8. Spectral Imagine Story, Write Story, and Solve Math Problems Multivariate Repeated Measures Analysis

Source	df	F
ACTIVITY	2	8.87***
ACTIVITY x ORGRP	2	0.24
FREQ	5	18.40***
FREQ x ORGRP	5	1.88
HEM	1	2.73
HEM x ORGRP	1	1.01
ELEC LOC	2	14.70***
ELEC LOC x ORGRP	2	1.22
ACTIVITY x FREQ	10	6.22***
ACTIVITY x FREQ x ORGRP	10	1.11
ACTIVITY x HEM	2	2.45
ACTIVITY x HEM x ORGRP	2	5.12**
FREQ x HEM	5	2.59*
FREQ x HEM x ORGRP	5	1.18
ACTIVITY x FREQ x HEM	10	0.83
ACTIVITY x FREQ x HEM x ORGRP	10	1.14
ACTIVITY x ELEC LOC	4	8.11***
ACTIVITY x ELEC LOC x ORGRP	4	0.73
FREQ x ELEC LOC	10	7.94***

Table 8. Continued

FREQ x ELEC LOC x ORGRP	10	1.28
ACTIVITY x FREQ x ELEC LOC	20	3.91*
ACTIVITY x FREQ x ELEC LOC x ORGRP	20	1.07
HEM x ELEC LOC	2	0.08
HEM x ELEC LOC x ORGRP	2	0.76
ACTIVITY x HEM x ELEC LOC	4	0.45
ACTIVITY x HEM x ELEC LOC x ORGRP	4	0.65
FREQ x HEM x ELEC LOC	10	2.20
FREQ x HEM x ELEC LOC x ORGRP	10	0.60
ACTIVITY x FREQ x HEM x ELEC LOC	20	11.01**
ACTIVITY x FREQ x HEM x ELEC LOC x ORGRP	20	20.95***

Note. ACTIVITY indicates story activity (Imagining or Writing) and math problem solving. FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORGRP indicates rated originality of story group (high, low).

*$p < .05$. **$p < .01$. ***$p < .001$.

Cross-spectral Analysis

The resulting reduced data from the cross-spectral analysis was subjected to a 2 (Activity: Write Story, Imagine Story) x 6 (Frequency Bands: Delta, Theta, Low Alpha, High Alpha, Low Beta, High Beta) x 15 (Cross-Spectral Pairings) repeated measures analysis with Originality Group entered as a between subjects variable. Univariate analyses results with a Greenhouse-Geisser correction are shown in Table 9. Univariate analyses were used for the cross-spectral data sets because the large number of cross-spectral pairings (i.e., 15) decreased the power in the multivariate analyses to an unacceptable level. Of particular interest to this report are the results including Originality Group. However, there were no significant results that included Originality Group as a between subjects factor.

As with the spectral density estimates, there are interactions that do not include Originality Group, but are potentially interesting to understanding general differences between writing and imagining a story. The interaction for Activity x Frequency was significant ($F(1.95, 97.61) = 9.04$, $p < .001$). The most interesting aspect of this interaction was that for the Theta band and the Low Alpha band, coherency values were greater for imagining a story versus writing a story (see mean in Table 10). This relationship is shown in Figure 6. The interaction for Activity x Pair was also significant ($F(5.15, 257.45) = 18.34$, $p < .001$), but more difficult to interpret. The means for this interaction are shown in Table 11.

An additional analysis including the third activity of solving math problems was completed, but it produced the same pattern of results that is shown in Table 9. This analysis is shown in Table 12.

Table 9. Cross-spectral Imagine Story and Write Story Univariate Repeated Measures Analysis

Source	df	F
ACTIVITY	1.00	2.03
ACTIVITY x ORIGGRP	1.00	1.80
FREQ	1.73	49.64***
FREQ x ORIGGRP	1.73	0.26
PAIR	4.94	237.48***
PAIR x ORIGGRP	4.94	0.68
ACTIVITY x FREQ	1.95	9.04***
ACTIVITY x FREQ x ORIGGRP	1.95	0.91
ACTIVITY x PAIR	5.15	18.34***
ACTIVITY x PAIR x ORIGGRP	5.15	0.27
FREQ x PAIR	9.40	44.11***
FREQ x PAIR x ORIGGRP	9.40	0.49
ACTIVITY x FREQ x PAIR	7.90	12.19***
ACTIVITY x FREQ x PAIR x ORIGGRP	7.90	1.07

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). ORGRP indicates rated originality of story group (high, low).

*$p < .001$.

Table 10. Imagine Story and Write Story Mean Cross-spectral Densities for Activity x Frequency

	Activity	
Frequency	Write	Imagine
Delta	0.508	0.486
Theta	0.385	0.408
Low Alpha	0.334	0.384
High Alpha	0.316	0.272
Low Beta	0.334	0.288
High Beta	0.340	0.252

Figure 6. Imagine Story and Write Story Cross-spectral density for Activity x Frequency differences.

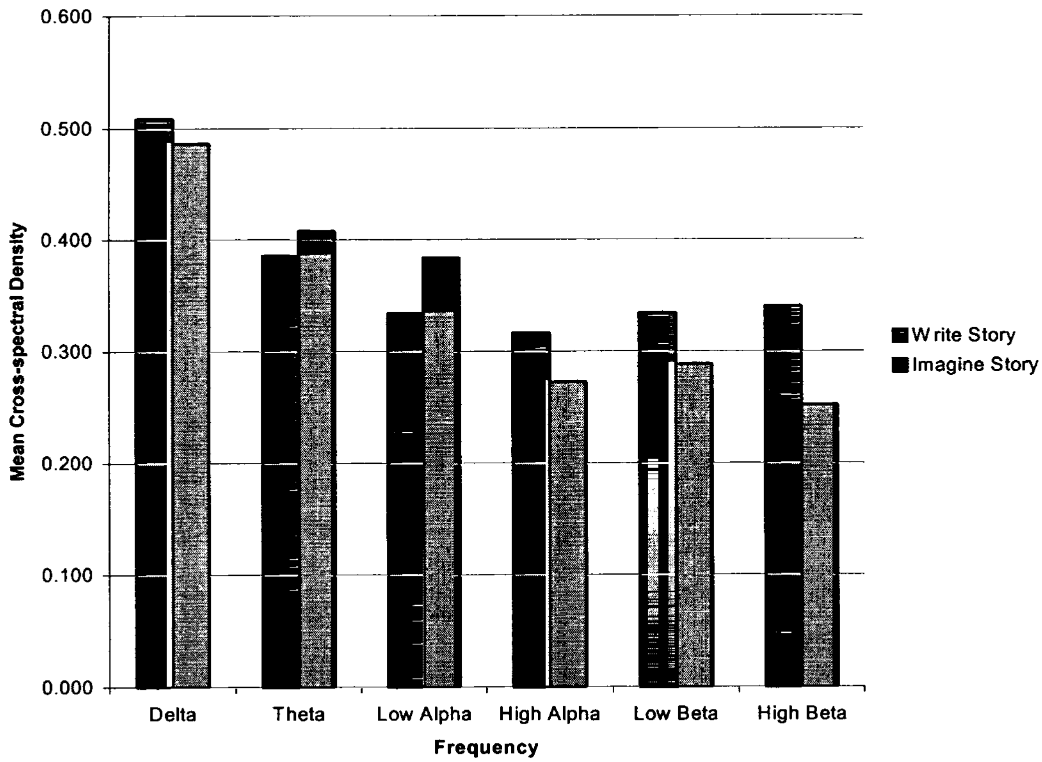


Table 11. Imagine Story and Write Story Mean Cross-spectral Densities for Activity x Pair

	Activity	
PAIR	Write	Imagine
Left Frontal-Left Central	0.626	0.618
Left Frontal-Left Parietal	0.234	0.196
Left Frontal - Right Frontal	0.491	0.575
Left Frontal - Right Central	0.292	0.301
Left Frontal - Right Parietal	0.164	0.135
Left Central - Left Parietal	0.634	0.554
Left Central - Right Frontal	0.305	0.305
Left Central - Right Central	0.342	0.326
Left Central - Right Parietal	0.245	0.206
Left Parietal - Right Frontal	0.191	0.143
Left Parietal - Right Central	0.273	0.222
Left Parietal - Right Parietal	0.348	0.312
Right Frontal - Right Central	0.595	0.613
Right Frontal - Right Parietal	0.219	0.188
Right Central - Right Parietal	0.585	0.531

Table 12. Cross-spectral Imagine Story, Write Story, and Math Problem Univariate Repeated Measures Analysis

Source	df	F
ACTIVITY	1.51	8.23***
ACTIVITY x ORIGGRP	1.51	0.00
FREQ	3.02	50.35***
FREQ x ORIGGRP	3.02	0.55
PAIR	4.33	145.57***
PAIR x ORIGGRP	4.33	1.39
ACTIVITY x FREQ	3.88	19.75***
ACTIVITY x FREQ x ORIGGRP	3.88	0.88
ACTIVITY x PAIR	6.17	9.14***
ACTIVITY x PAIR x ORIGGRP	6.17	0.45
FREQ x PAIR	8.97	25.60***
FREQ x PAIR x ORIGGRP	8.97	1.36
ACTIVITY x FREQ x PAIR	11.53	7.49***
ACTIVITY x FREQ x PAIR x ORIGGRP	11.53	0.87

Note. ACTIVITY indicates activity while EEG was recorded (Imagining a Story, Writing a Story, or Math Problems). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Discussion

Experiment one investigated differences in people's brain wave activity when they were thinking of a creative story, when they were writing the creative story, and when they were solving math problems. Brain wave activity was operationalized as the calculated spectral density and the cross-spectral density (coherence) of the digitally sampled continuous signal. Brain wave activity was recorded from three electrode sites (frontal, central, parietal) in each hemisphere (left, right). Most of the previous research of the relationship between brain wave activity during creative tasks used a mechanical filtering technique to identify the presence of alpha wave activity (e.g., Martindale & Hines, 1975; Martindale & Hasenfus, 1978). This technique is less accurate than spectral density, and limits the number of frequency bands that can be identified. By using spectral density as the technique to capture estimates of frequency band activity, this study was able to compare activity in multiple frequency bands. This previous research also used no more than two electrode recording sites, which greatly limited conclusions about hemispheric or frontal-parietal relationships, whereas this study can draw conclusions about both.

For this experiment, the addition of electrode sites did not affect results that included Originality Group as a between subjects variable. The only significant result including Originality Group was Activity (Imagine Story or Write Story) x Hemisphere x Originality Group, as shown in Figure 1. This result was somewhat difficult to interpret because it combined the spectral density estimates for all of the frequency bands (see Figure 2). However, it was clear that while the High Originality group showed variable patterns of activation between imaging the story, and writing the story, the Low Originality Group showed essentially the same pattern of activation while imagining and writing the story. This fits with theories of creativity that suggest more creative individuals will vary their cognitive state to best match a given task.

The use of spectral analysis, as opposed to a mechanical filtering technique, to isolate activity within particular frequency bands produced results different than would be predicted from earlier research. Alpha band activity did not differentiate the High Originality group from the Low Originality group, as it had differentiated more and less creative participants in past research (e.g., Martindale & Hines, 1975; Martindale & Hasenfus, 1978). However, it was true that there were differential patterns of activation by frequency band for all participants when they were imagining the story versus writing the story (see Figure 3). This fits with Wallas's (1926) stages of creative production discussed in the introduction. Martindale and Hasenfus (1978) compared the last two stages of creative production using the same story creation task as this experiment. They proposed that the illumination phase, where creation occurs, could be measured through EEG while participants imagined a story, and that the elaboration phase, where verification occurs, could be measured while participants wrote the story they had just imagined. In Martindale and Hasenfus's study, they found higher alpha indices only for highly creative participants during the illumination phase (i.e., while imagining the story). While this experiment did not replicate Martindale and Hasenfus's results for differences by creativity group, it did show that overall there was more activity in the alpha bands while participants were imagining the story as opposed to writing the story (see Figure 3).

This experiment confirmed the general relationship between creative potential, as measured by rated story originality, and cognitive state. Participants who received higher ratings for the originality of their written story did show a more flexible pattern of activation across the two tasks, imagining a story and writing a story. This experiment could be improved by challenging participants to purposefully oscillate between the two types of activities (imagining and writing) more than once. It would be interesting to investigate the consistency of these patterns across a number of activities. It would also be helpful to combine EEG measurement techniques with other brain imaging techniques such as fMRI and PET Scan. The combination of methods would clarify the relationships found here, as well as lend credence to the overall thesis that creative potential influences cognitive functioning on creative tasks.

Experiment Two

Hypotheses

This experiment used the odd-ball task, described in the introduction, to investigate individual differences in response to novel and unexpected stimuli. Given the results from preliminary research, it seemed likely that more creative participants would again show differential N100 and P300 amplitudes. It was predicted that these differences would exist across all electrode sites, with greater amplitudes measured for the more creative participants. Alexander et al. (1996) report that P300 amplitude to an auditory odd-ball task was larger over the right anterior/medial locations for a sample of 80 right-handed males. Therefore, it was expected that P300 amplitudes would in general be larger over the right frontal hemisphere for all participants. However, P300 amplitude would be greatest for the more creative participants.

Unique Methods

Stimuli

The odd-ball task, as discussed above, is a classic test known to elicit specific components of the event-related potential. There are many models for this test, however they all have in common at least two stimulus types (frequent and infrequent) and a participant task designed to ensure constant focus on the stimuli. This experiment followed the design of Courchesne (1979). The stimuli were the letter 'A' and the letter 'B,' with 'A' serving as the infrequent stimulus and 'B' serving as the frequent stimulus. Each stimulus instance was presented individually for 200 msec with a 1200 msec interval between stimulus presentations. There were three variations of stimulus presentation, which are presented in the following paragraphs.

First, participants were given a "sample" test that consisted of 24 stimuli, equally split between 'A' and 'B' types. They were told to count the total number of 'A' stimuli to themselves without vocalizing the count. They were told that at the end of the program, the experimenter would them how many 'A' stimuli they counted. This program took approximately 1.5 minutes. The purpose of this sample was to ensure that participants understood the task before starting the desired data collection.

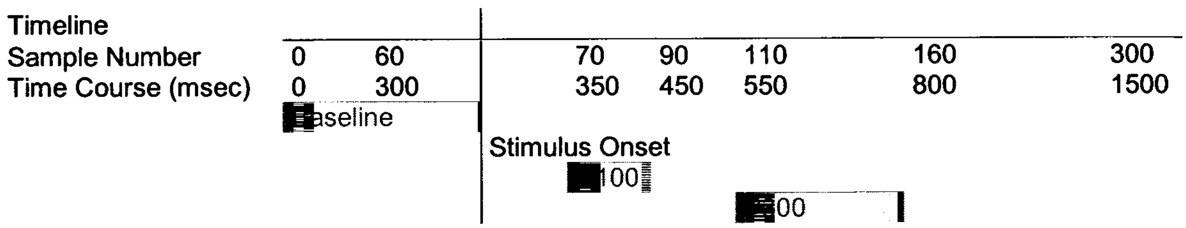
The baseline program was followed immediately by a simple odd-ball program. For the simple odd-ball program, participants were told that they should follow the same procedure as they did for the sample and count the total number of 'A' stimuli to themselves. This program was different in that it consisted of 12% 'A' stimuli and 88% 'B' stimuli (6 'A' stimuli and 44 'B' stimuli). The stimuli were presented semi-randomly. The condition for presentation of an 'A' stimulus was that at least two 'B' stimuli had been presented since the last 'A' stimulus. This program took approximately 2.5 minutes.

The simple odd-ball program was followed immediately by a novel odd-ball program. Again, participants were told to do the same task as the simple odd-ball program and the sample. They were asked to count the total number of 'A' stimuli. This was meant to establish the same expectations for stimulus types as the previous programs. However, in this program a new stimulus type was added. In addition to 12% 'A' stimuli, there were 12% novel stimuli, which were random color patterns. The last 76% of the stimuli were 'B,' making a total of 18 'A' stimuli, 18 'Novel' stimuli, and 114 'B' stimuli. As with the simple odd-ball program, the stimuli were presented semi-randomly. The condition for presentation of an 'A' stimulus or a 'Novel' stimulus was that at least two 'B' stimuli had been presented since the last 'A' stimulus or the last 'Novel' stimulus. This program took approximately 6 minutes.

Data Collection

There are many steps between the collection of brain activity responses to visual stimuli and the final analysis of those responses as ERPs. The steps followed for this analysis followed the method of Courchesne (1978). For this experiment, three types of visual stimuli were presented (i.e., frequent presentations of the letter B, infrequent presentations of the letter A, and infrequent and unexpected presentations of novel color patterns). Each time a stimulus was presented, a digital sample of the analog signal from the electrodes on the participant was collected. For each presented stimulus, an eight (electrode location) by 300 (200 Hz digital sample of the signal at each electrode location) matrix was created. The waveform for a given electrode location was represented by the 300 data points in the column associated with the electrode location. Each of the eight columns in the matrix represented a different electrode location. The 300 data points associated with a given electrode location represented the time course of digital sampling of the analog signal coming from an electrode location. A digital sample was taken from the analog signal every 5 msec, so the 300 data points represented 1.5 seconds of data recording. The time course for a given waveform is depicted in Figure 7.

Figure 7. Time course for N100 and P300 ERP experiments.



Data Cleaning

For the last Oddball Task, 150 stimuli were presented to the participant. Therefore, for every participant 150 8x300 matrices were collected. The first step in the analysis of these 150 matrices was to inspect visually each one for suspect waveforms, indicating muscle movement or eye blinks. Any matrix that shows contaminated waveforms was dropped from further analysis. Across all participants, the number of waveforms eliminated due to contamination was less than 1%.

Data Analysis

The next stop in the analysis of these 150 matrices was to create averaged matrices for each of the stimulus types (i.e., frequent B stimuli, infrequent A stimuli, and novel stimuli). Testpoint, the software used for data acquisition, allows for the creation of customized computer programs. A customized Testpoint computer program was written to calculate the averaged matrix for each of the three stimulus types (i.e., B, A, Novel). This program identified the type of stimulus associated with each 8x300 matrix and then added it to a repository matrix for that stimulus type. Once all initial (raw) matrices had been added to the appropriate repository matrix, they were divided by the total number of initial (raw) matrices to create the grand averaged matrix for each stimulus type for each participant. The result was three new matrices, one for each stimulus type.

After averaged matrices had been created for each participant, the waveform for each electrode location was inspected for peaks within specific time intervals. A customized Testpoint computer program was written to identify peaks within the time ranges of interest. For this project, N100 and P300 peaks were of interest. The Testpoint computer program worked by reading in each value between the 1st – 300th data points. The first task of the program was to calculate the average value for the first 60 data points, which represented the baseline period before the stimulus was presented. Then, it compared data points with the specified range for each peak of interest in search of the largest data point. For the N100 peak, the program searched for the largest negative data point occurring between 50 msec and 150 msec from stimulus onset. For the P300 peak, the program searched for the largest positive data point occurring between 250 and 500 msec. These are ranges that have been reported as appropriate bounds for N100 and P300 peaks (e.g., Coles, Gratton, & Fabiani, 1990). For both waveforms, the sample number associated with the maximum value was also recorded, and is referred to as the latency value. For a visual representation of the time course for N100 and P300 peaks, see Figure 7, noting that the time course for a given stimulus presentation includes 300 msec (60 samples) for baseline recording.

Results

Additional analyses beyond those reported below were conducted to ensure that no sex differences, differences within a single creativity test, nor differences by intellectual functioning were better predictors. There were no more valuable differences discovered for any of these analyses. These analyses are included in Appendix C.

N100

The N100 peak values were subjected to a 3 (Stimulus Type) x 2 (Hemisphere) x 3 (Electrode Location) repeated measures analysis with Creativity Group entered as a between subjects variable. Multivariate Analyses produced results as shown in Table 13. Of particular interest to this report are the results including Creativity Group. However, there were no significant results that included Creativity Group as a between subjects factor.

Table 13. N100 Multivariate Repeated Measures Analysis

Source	df	F
STIM TYPE	2	20.43*
STIM TYPE x CRGRP	2	2.48
HEM	1	2.26
HEM x CRGRP	2	1.55
ELEC LOC	2	45.90*
ELEC LOC x CRGRP	2	0.60
STIM TYPE x HEM	2	8.84*
STIM TYPE x HEM x CRGRP	2	1.29
STIM TYPE x ELEC LOC	4	12.40*
STIM TYPE x ELEC LOC x CRGRP	4	0.93
HEM x ELEC LOC	2	1.24
HEM x ELEC LOC x CRGRP	2	0.49
STIM TYPE x HEM x ELEC LOC	4	12.26*
STIM TYPE x HEM x ELEC LOC x CRGRP	4	1.64

Note. STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates Creativity Group (high, low).

* $p < .001$.

P300

The P300 peak values were subjected to a 3 (Stimulus Type) x 2 (Hemisphere) x 3 (Electrode Location) repeated measures analysis with Creativity Group entered as a between subjects variable. Multivariate analyses produced results as shown in Table 14. Of particular interest to this report are the results including Creativity Group. The effect for Hemisphere by Creativity Group was statistically significant ($F(1,54) = 9.05$, $p < .01$). This result was due to the interaction between hemispheric effects by creativity group. The High Creativity Group showed higher activation in the right hemisphere than in the left hemisphere ($M_{right} = .167$, $M_{left} = .154$). In contrast, the Low Creativity Group showed lower activation in the right hemisphere than in the left hemisphere ($M_{right} = .158$, $M_{left} = .162$). This relationship is shown in Figure 8.

Figure 8. P300 Hemisphere x Creativity group differences.

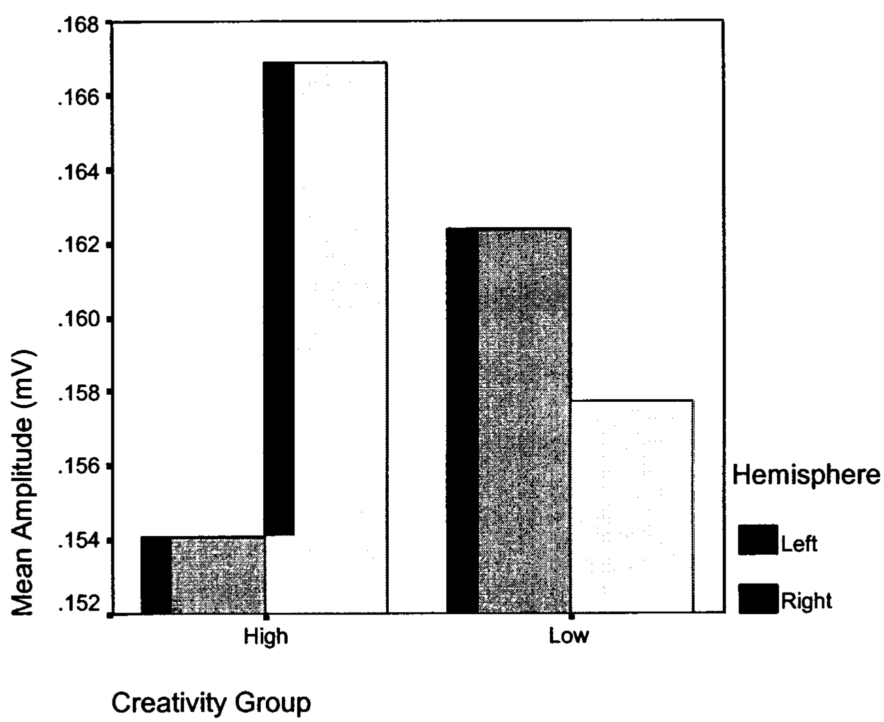


Table 14. P300 Multivariate Repeated Measures Analysis

Source	df	F
STIM TYPE	2	27.05***
STIM TYPE x CRGRP	2	2.16
HEM	1	1.98
HEM x CRGRP	1	9.05**
ELEC LOC	2	6.59**
ELEC LOC x CRGRP	2	1.69
STIM TYPE x HEM	2	11.27***
STIM TYPE x HEM x CRGRP	2	0.66
STIM TYPE x ELEC LOC	4	11.02***
STIM TYPE x ELEC LOC x CRGRP	4	0.99
HEM x ELEC LOC	2	4.45*
HEM x ELEC LOC x CRGRP	2	2.40
STIM TYPE x HEM x ELEC LOC	4	4.33**
STIM TYPE x HEM x ELEC LOC x CRGRP	4	0.23

Note. STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates Creativity Group (high, low).

*$p < .05$. **$p < .01$. ***$p < .001$.

Discussion

Experiment two investigated differences in people's initial neurophysiological response to stimuli by measuring event-related potentials in an odd-ball task. This was a new technique for exploring creativity. It was chosen because there have been waveforms in the event-related potential that have been related to responses to novel stimuli, in particular the P300 waveform. The processing of a given potentially novel stimulus was hypothesized to be related to creativity because all creative ideas are by definition novel. Preliminary investigations have shown differential patterns of response for more creative participants versus less creative participants.

Two waveforms were investigated for this experiment: N100 and P300. Creativity group was not a significant factor in any interactions for the N100 waveform. While creativity group was a significant factor in interactions with the N100 waveform in preliminary experiments, it is the less relevant waveform, when compared with the P300 waveform. The N100 waveform is seen in relation to early filtering to reduce the processing of irrelevant information (Coles, Gratton, & Fabiani, 1990), which could be argued as a benefit or a detriment to creative thinking.

The P300 waveform is related to the processing of novel stimuli, and therefore represents the amount of resources allocated to process a particular stimulus based upon its perceived novelty. This was more directly relevant to creativity, and proved to be related to creativity in the analysis of participant responses. Creativity group was a significant factor in the interaction with hemisphere for the P300 waveform. This result does not reflect a difference for just novel stimuli as defined by the experiment (i.e., not just for colored pictures), it reflects a general difference in the processing of stimuli (target A, distractor B, and novel colored pictures) by hemisphere. The High Creativity group showed much greater P300 amplitudes in the right hemisphere as opposed to the left hemisphere, whereas the Low Creativity group showed greater left hemisphere amplitudes than right hemisphere amplitudes, but with less disparity between hemispheres than the High Creativity group (see Figure 8). This result lends further support to the overlying theme of the results, showing greater variability in response for the High Creative group than for the Low Creative group. In addition, right hemisphere activation is greater for the High Creative group than the Low Creative group. This is in line with previous research that has found greater right hemisphere activation for more creative participants (e.g., McCallum & Glynn, 1979; Martindale, Hines, Mitchell, & Covello, 1984).

This experiment confirmed the general relationship between creative potential, as measured by composite score from paper and pencil creativity tasks, and cognitive state. More creative participants did show greater P300 amplitude variability in response to the novel stimuli across the hemispheres. Future directions for this type of experiment include varying the type of novel stimuli presented to participants. It would be interesting to know whether stimulus type would change the P300 response, and whether the response would also vary by creativity group. It would also be helpful to combine EEG measurement techniques with other brain imaging techniques such as fMRI and PET Scan. The combination in methods would clarify the relationships found here, as well as lend credence to the overall thesis that creative potential influences cognitive functioning on creative tasks.

Experiment Three

Hypotheses

The final ERP task focused on a different waveform: the N400. As discussed in a previous section, the N400 has been associated with semantic incongruity. Only the N400 waveform would be analyzed for this data set, as it has been shown to be the only valid measurement for semantic incongruity. Based on the theories of creativity discussed above, it was predicted that more creative participants would show greater variability in response to the presentation of incongruous words. More creative people assumably have lower thresholds for unusual word associations (see Mednick, 1962). This should influence the more creative person's expectations for the semantically incongruous words, making them more sensitive to the differences.

Unique Methods

Stimuli

Following the classic methods of Kutas and Hillyard (1980), participants were shown the first part to a sentence and told that the last word in the sentence would appear after they had read the first part (e.g., "The pizza was too hot to __________"). The last word that appeared was either semantically congruous (e.g., eat), or incongruous (e.g., cry). Fifty pairs of sentence beginnings and last words were presented. Of these, the last word was incongruous 50% of the time, and congruous 50% of the time. Participants were asked to pay attention to the sentences because questions were asked about them at the end of the experiment. This was to ensure full attention was paid to the first and second part of the sentence.

Data Collection

As with Experiment Two, there were many steps between the collection of brain activity responses to visual stimuli and the final analysis of those responses as ERPs. For this experiment, two types of stimuli were presented (i.e., sentences with Congruent endings, and sentences with Incongruent endings). As with Experiment Two, each time a stimulus was presented, a digital sample of the analog signal from the electrodes on the participant was collected. For each presented stimulus, an eight (electrode location) by 300 (200 Hz digital sample of the signal at each electrode location) matrix was created. The waveform for a given electrode location was represented by the 300 data points in the column associated with the electrode location. Each of the eight columns in the matrix represented a different electrode location. The 300 data points associated with a given electrode location represented the time course of digital sampling of the analog signal coming from an electrode location. A digital sample was taken from the analog signal every 5 msec, so the 300 data points represented 1.5 seconds of data recording. The time course for a given waveform is depicted in Figure 9.

Figure 9. Time course for N400 ERP experiments.

Timeline					
Sample Number	0	60	140	200	300
Time Course (msec)	0	300	700	1000	1500

Baseline

Stimulus Onset

N400

Data Cleaning

For the Semantic Incongruity Task, 50 stimuli were presented to the participant. Therefore, for every participant 50 8x300 matrices were collected. The first step in the analysis of these 50 matrices was to visually inspect each one for suspect waveforms, indicating muscle movement or eye blinks. Any matrix that showed contaminated waveforms was dropped from further analysis. Across all participants, the number of waveforms eliminated due to contamination was less than 1%.

Data Analysis

The next step in the analysis of these 50 matrices was to create averaged matrices for each of the stimulus types (i.e., sentences with Congruent endings, and sentences with Incongruent endings). Testpoint, the software used for data acquisition, allows for the creation of customized computer programs. A customized Testpoint computer program was written to calculate the averaged matrix for each of the two stimulus types (i.e., Congruent and Incongruent). This program identified the type of stimulus associated with each 8x300 matrix and then added it to a repository matrix for that stimulus type. Once all initial (raw) matrices had been added to the appropriate repository matrix, they were divided by the total number of initial (raw) matrices to create the grand averaged matrix for each stimulus type for each participant. The result was two new matrices, one for each stimulus type.

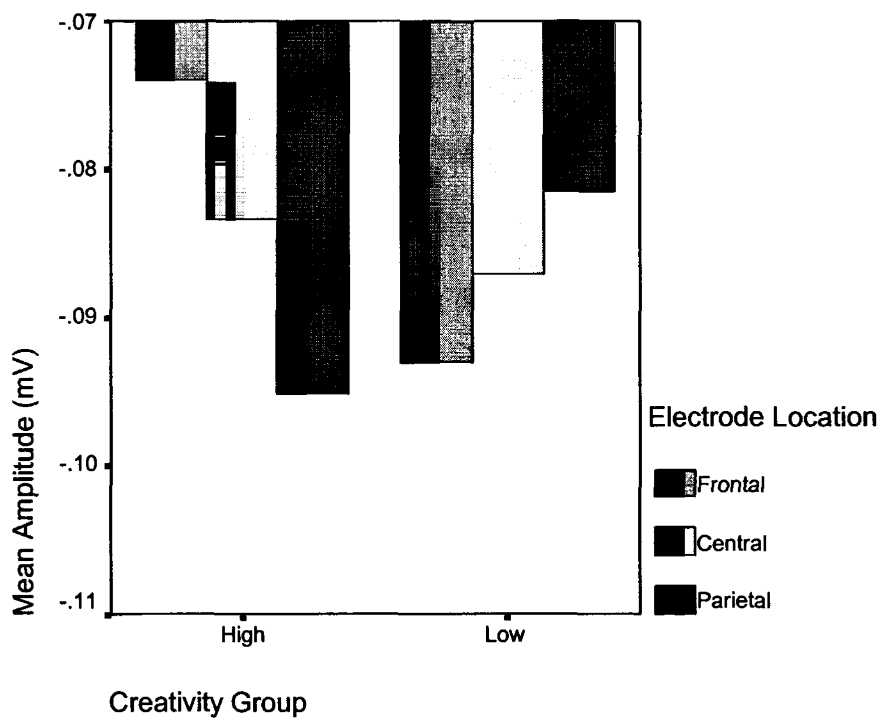
After averaged matrices had been created for each participant, the waveform for each electrode location was inspected for peaks within specific time intervals. A customized Testpoint computer program was written to identify peaks within the time ranges of interest. For this project, N400 peaks were of interest. The Testpoint computer program worked by reading in each value between the $1^{st} - 300^{th}$ data points. The first task of the program was to calculate the average value for the first 60 data points, which represented the baseline period before the stimulus was presented. Then, it compared data points with the specified range for each peak of interest in search of the largest data point. For the N400 peak, the program searched for the largest negative data point occurring between 400 msec and 700 msec from stimulus onset. These are ranges that have been reported as appropriate bounds for N400 peaks (e.g., Coles, Gratton, & Fabiani, 1990). For both waveforms, the sample number associated with the maximum value was also recorded, and will be referred to as the latency value. For a visual representation of the range for N400 peaks, see Figure 9, noting that the time course for a given stimulus presentation includes 300 msec (60 samples) for baseline recording.

Results

Additional analyses beyond those reported below were conducted to ensure that no sex differences, differences within a single creativity test, nor differences by intellectual functioning were better predictors. There were no more valuable differences discovered for any of these analyses. These analyses are included in Appendix D.

The N400 peak values were subjected to a 2 (Stimulus Type) x 2 (Hemisphere) x 3 (Electrode Location) repeated measures analysis with Creativity Group entered as a between subjects variable. Multivariate Analyses produced results as shown in Table 15. Of particular interest to this report are the results including Creativity Group. The effect for Electrode Location by Creativity Group was statistically significant ($F(2,56) = 5.59$, $p < .01$). This result was due to the interaction between electrode location effects by creativity group. The High Creativity Group showed greater dispersion between the frontal-central-parietal electrode locations than the Low Creativity Group. In addition, the High Creativity Group showed highest amplitudes at frontal locations, followed by central then parietal locations ($M_{frontal} = -.074$, $M_{central} = -.083$, $M_{parietal} = -.095$), whereas the Low Creativity Group showed the opposite pattern with highest amplitudes at parietal locations, followed by central then frontal locations ($\underline{M}_{frontal}$ = -.093, $\underline{M}_{central}$ = -.087, $\underline{M}_{parietal}$ = -.082). This relationship is shown in Figure 10.

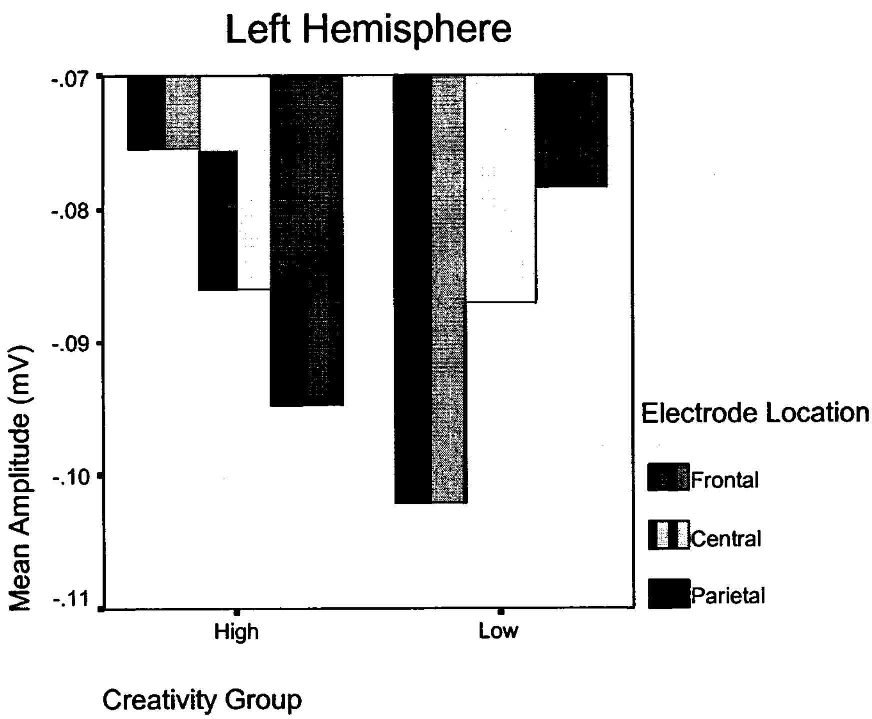
Figure 10. N400 response for Electrode Location x Creativity group differences.



The effect for Electrode Location by Hemisphere by Creativity Group was statistically significant ($\underline{F}(2,56) = 4.81$, $\underline{p} < .05$). This result was due to the interaction between electrode location effects and hemisphere effects by creativity group. The most notable difference in this interaction was dispersion of electrode location means by hemisphere for the High Creativity Group versus the Low Creativity Group. The High Creativity Group showed approximately equal patterns of dispersion between frontal, central and parietal electrodes for the left hemisphere ($\underline{M}_{frontal}$ = -.075, $\underline{M}_{central}$ = -.086,

$\underline{M}_{parietal}$ = -.095) and the right hemisphere ($\underline{M}_{frontal}$ = -.073, $\underline{M}_{central}$ = -.081, $\underline{M}_{parietal}$ = -.096). The Low Creativity Group showed wide dispersion of means in the left hemisphere ($\underline{M}_{frontal}$ = -.102, $\underline{M}_{central}$ = -.087, $\underline{M}_{parietal}$ = -.078), but almost no dispersion in the right hemisphere ($\underline{M}_{frontal}$ = -.084, $\underline{M}_{central}$ = -.087, $\underline{M}_{parietal}$ = -.085). It should also be noted that the Low Creativity Group showed opposite patterns of means when compared with the High Creativity Group, with greatest amplitudes in the Parietal electrode location instead of the Frontal electrode location. Electrode location by creativity group differences for each hemisphere are shown in Figure 11.

Figure 11. N400 response for Electrode Location x Hemisphere x Creativity group differences.



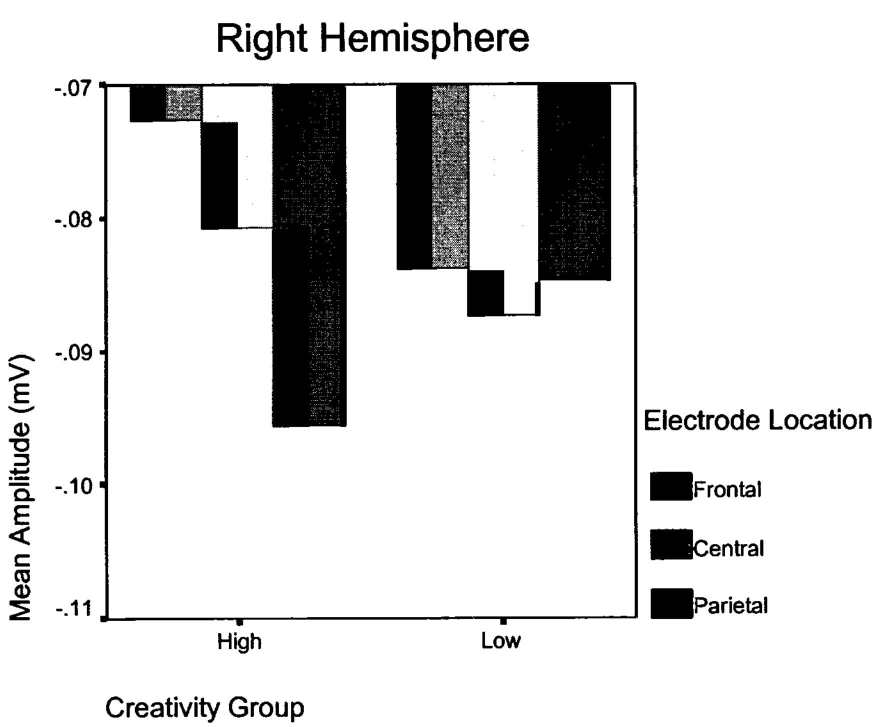


Table 15. N400 Multivariate Repeated Measures Analysis

Source	df	F
STIM TYPE	1	2.58
STIM TYPE x CRGRP	1	0.05
HEM	1	1.27
HEM x CRGRP	1	0.07
ELEC LOC	2	0.51
ELEC LOC x CRGRP	2	5.59**
STIM TYPE x HEM	1	2.33
STIM TYPE x HEM x CRGRP	1	0.57
STIM TYPE x ELEC LOC	2	7.95***
STIM TYPE x ELEC LOC x CRGRP	2	1.90
HEM x ELEC LOC	2	4.84*
HEM x ELEC LOC x CRGRP	2	4.81*
STIM TYPE x HEM x ELEC LOC	2	0.01
STIM TYPE x HEM x ELEC LOC x CRGRP	2	0.57

Note. STIM TYPE indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates Creativity Group (high, low).

* $p < .05$. ** $p < .01$. *** $p < .001$.

Discussion

Experiment three investigated people's response to incongruous grammars. Previous research has shown that the N400 waveform occurs when a participant is presented with an incongruous ending word to a sentence, and increases in amplitude as the ending word becomes more incongruous (Kutas & Hillyard, 1980). This waveform was of interest to this investigation for reasons similar to those in the previous experiment: incongruous stimuli are but another form of unexpected, novel stimuli. This more specific stimulus type allowed for added validation of the hypothesis that more creative participants would have more variable responses to stimuli.

There were two significant interactions that included creativity group. First, and more generally, Electrode Location significantly interacted with creativity group. Again, the High Creative group had more differentiation in N400 amplitude between the three electrode locations (frontal, central, and parietal) when compared with the Low Creative group. In addition, the High Creative group had their largest N400 amplitudes at the parietal location, whereas the Low Creative group had their smallest N400 amplitudes parietally. The High Creative group had their smallest N400 amplitudes frontally, whereas the Low Creative group had their largest N400 amplitudes frontally (see Figure 10). This pattern of results could be interpreted in two ways: (a) It could be seen as evidence of the importance of parietal regions to the processing of unexpected grammatical structures, or (b) it could be seen as evidence of the dominance of positive frontal activation in more creative participants regardless of task. Kutas and Hillyard (1983) reported that N400 should decrease in amplitude from frontal to parietal electrode locations, being smallest occipitally. Their result suggests that the parietal importance hypothesis is unlikely the cause of the creativity group differences. It seems more likely that the influence of positive frontal activation led to the pattern of activation in the High Creative group. This is an interesting hypothesis that should be investigated in further research. The frontal region is implicated in most information processing control research, and could therefore play a valuable role in the processing of creative ideas.

The second significant interaction that included creativity group was an extension of the interaction discussed in the previous paragraph: the interaction between hemisphere, electrode location, and creativity group was significant. This result is particularly interesting in that the N400 amplitudes in the right hemisphere are quite different for the High Creative group versus the Low Creative group. The Low Creative group has essentially no variability in N400 amplitude between electrode locations in the right hemisphere, whereas the High Creative group has wide variability (see Figure 11). This lends further support to the idea that high creative ability is related to more variability in cognitive state. Furthermore, it is additional evidence of the specialized role of the right hemisphere in information processing for more creative individuals.

This experiment confirmed the general relationship between creative potential, as measured by composite score from paper and pencil creativity tasks, and cognitive state. More creative participants did show greater N400 amplitude variability across the hemispheres in response to grammatical challenge. Future directions for this type of experiment include investigating this response with more and less emotion-laden words. This experimental design could be easily adapted for investigating the processing of more and less emotional stimuli. It would also be helpful to combine EEG measurement techniques with other brain imaging techniques such as fMRI and PET Scan. The combination in methods would clarify the relationships found here, as well as lend credence to the overall thesis that creative potential influences cognitive functioning on creative tasks.

General Discussion

The goal of these experiments was to provide further support for theories of creativity that posit flexibility in cognitive state as an essential mechanism of creative production. A number of theories of creativity hypothesize that more creative individuals show greater flexibility in their cognitive state (e.g., Kris, 1952; Mednick, 1962; Mendelsohn, 1976; Eysenck, 1995; Martindale, 1999). In addition, there is past research showing that people who do better on tests of creativity also show greater flexibility in their brain wave activity than those who do not do well on tests of creativity (e.g., Martindale, 1977; Martindale & Hines, 1975; Martindale & Hasenfus, 1978). These experiments extend this earlier research (a) by using better and more comprehensive methods (experiment one), and (b) by using new and previously unexplored neurophysiological techniques (experiments two and three).

A consistent pattern of results was found across all of the experiments in this investigation. In all of the experiments, when originality group (experiment one) or creativity group (experiments two and three) was a determinant of significant differences, the high ability group had greater variability in measured EEG activity when compared with the low ability group (see Figures 1, Figure 8, and Figure 11). Furthermore, the high ability group consistently had higher levels of activation in the right hemisphere than the low ability group. This pattern of results supports the theories of creativity that emphasize flexibility in cognitive state as essential to creativity.

REFERENCES

Alexander, J.E., Bauer, L.O., Kuperman, S., Morzorati, S., O'Connor, S.J., Rohrbaugh, J., Porjesz, B., Begleiter, H., Polich, J. (1996). Hemispheric differences for P300 amplitude from an auditory oddball task. *International Journal of Psychophysiology. 21*, 189-196.

Amabile, T. M. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology, 43*, 997-1013.

Anderson, C. C. (1968). Psychology of the scientist: XXVIII. Speculations on nonverbal creativity. *Perceptual and Motor Skills, 27,* 883-889.

Andreassi, J. L. (2000). *Psychophysiology, Fourth Edition.* Mahwah, New Jersey: Lawrence Erlbaum Associates.

Atchley, R. A., Keeney, M., Burgess, C. (1999) Cerebral hemispheric mechanisms linking ambiguous word meaning retrieval and creativity. *Brain and Cognition, 40(3)*, 479-499.

Barron, F. (1953). Complexity-simplicity as a personality dimension. *Journal of Abnormal and Social Psychology, 48*, 142-172.

Berger, H. (1929). Uber das elektrenkephalogramm des menschen. Translated and reprinted in Pierre Gloor, Hans Berger on the electroencephalogram of man. *Electroencephalography and Clinical Neurophysiology, 28(Supplement)*, 1969, Amsterdam: Elsevier.

Blum, G. S. (1961). *A model of the mind.* New York: Wiley.

Bogen, J. E., Bogen, G. M. (1969). The other side of the brain III. The corpus collosum and creativity. *Bulletin of the Los Angeles Neurological Society, 34,* 191-220.

Bowers, K. S., Keeling, K. R. (1971). Heart rate variability in creative functioning. *Psychological Reports, 29,* 160-162.

Caton, R. (1877). Interim report on investigation of the electric currents of the brain. *British Medical Journal, 1(Supplement)*, 62-65.

Cattell, R. B. (1934). Temperament tests: II. Tests. *British Journal of Psychology, 24,* 20-49.

Coles, M. G. H., Gratton, G., Fabiani, M. (1990). Event-related brain potentials. In J. T. Caccioppo & L. G. Tassinary (Eds.) *Principles of psychophysiology: Physical, social, and inferential elements* (pp. 385-412). New York: Cambridge University Press.

Cooley, J. W., Tukey, J. W. (1965). An algorithm for the machine calculation of complex Fourier series. *Mathematics of Computation, 19*, 297-301.

Courchesne, E. (1978). Changes in P3 waves with event repetition: Long-term effect on scalp distribution and amplitude. *Electroencephalography and Clinical Neurophysiology, 45*, 754-766.

Cox, C. (1926). *The early mental traits of three hundred geniuses*. Stanford: University Press.

Dykes, M., McGhie, A. (1976). A comparative study of attentional strategies of schizophrenic and highly creative normal subjects. *British Journal of Psychiatry, 128*, 50-56.

Ellis, H. (1904). *A study of British genius.* Oxford: Hurst & Blackwell.

Eysenck, H. J. (1995). *Genius: The natural history of creativity.* Cambridge: Cambridge University Press.

Galton, F. (1950). *Hereditary Genius.* London: Watts & Co.

Gazzaniga, M. S. (1975). Review of the split brain. *UCLA Educator, 17,* 9-12.

Gough, H. G. (1979). A creative personality scale for the adjective checklist. *Journal of Personality and Social Psychology, 37,* 1398-1405.

Gough, H. G., Heilbrun, A. B. (1965). *The adjective checklist manual.* Palo Alto, CA: Consulting Psychologists Press.

Guilford, J. P. (1950). Creativity. *American Psychologist, 5,* 444-454.

Hargreaves, H. L. (1927). The 'faculty' of imagination. *British Journal of Psychology.* Monograph Suppl., 10, 74.

Helmholtz, H. (1896). *Vortrage und Reden.* Braunschweig: Vieweg.

Helson, R., & Crutchfield, R. S. (1970). Mathematicians: The creative researcher and the average Ph.D. *Journal of Consulting and Clinical Psychology, 34*, 250-257.

Horovitz, S. (2002). Personal communication.

Hyden, H. (1964). Activation of nuclear RNA in neurons and glia in learning. In D. P. Kimble (Ed.) *The anatomy of memory* (pp. 178-239). Palo Alto: Science and Behavior Books.

Jausovec, N. (1985). Hemispheric asymmetries during nine-year-olds performance of divergent production tasks: A comparison of EEG and YSOLAT measures. *Creative Child and Adult Quarterly, 10*, 233-238.

Jewett, D.L., Williston, J.S. (1971). Auditory-evoked far fields averaged from the scalp of humans. *Brain, 94,* 681-696.

Johnson, R., Jr. (1989). Auditory and visual P300s in temporal lobectomy patients: Evidence for modality-dependent generators. *Psychophysiology, 26,* 633-650.

Kahneman, D. (1973). *Attention and effort.* Englewood Cliffs, NJ: Prentice Hall.

Kris, E. (1952/1964). *Psychoanalytic explorations in art.* New York: Schoken.

Kutas, M., Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207*, 203-205.

Kutas, M., Hillyard, S. A. (1983). Event-related brain potentials to grammatical errors and semantic anomalies. *Memory and Cognition, 11*, 539-550.

Kwiatkowksi, J., Martindale, C. (1999, August 21). Creativity and evoked potentials elicited by novel stimuli. American Psychological Association Annual Conference, Boston.

Kwiatkowski, J., Vartanian, O. A., & Martindale, C. (1999). Creativity and speed of information processing. *Empirical Studies of the Arts, 17,* 187-196.

Lombroso, C. (1864). *Genio e Follia.* Milano: Chinsi.

Lombroso, C. (1896). *Man of genius.* London: Walter Scott.

MacKinnon, D. W. (1962). The personality correlates of creativity: A study of American architects. In G. S. Nielson (Ed.), *Proceedings of the XIV International Congress of Applied Psychology.* Copenhagen: Munksgaard.

Martindale, C. (1999). Biological bases of creativity. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 137-152). Cambridge: Cambridge University Press.

Martindale, C. (1977-78). Creativity, consciousness, and cortical arousal. *Journal of Altered States of Consciousness, 3(1),* 69-87.

Martindale, C. (1971). Degeneration, disinhibition, and genius. *Journal of the History of the Behavioral Sciences, 7*, 177-182.

Martindale, C. (1969). Femininity, alienation, and arousal in the creative personality. Unpublished manuscript. Harvard University.

Martindale, C., Hasenfus, N. (1978). EEG differences as a function of creativity, stage of the creative process, and effort to be original. *Biological Psychology, 6,* 157-167.

Martindale, C., Hines, D. (1975). Creativity and cortical activation during creative, intellectual, and EEG feedback tasks. *Biological Psychology, 3,* 71-80.

Martindale, C., Hines, D., Mitchell, L., Covello, E. (1984). EEG alpha asymmetry and creativity. *Personality and Individual Differences, 5(1),* 77-86.

Martindale, C., Vartanian, O., Kwiatkowski, J. (2000). Disinhibition, Dopamine, and Creativity. *American Psychological Association Division Ten Bulletin, Special Edition on Creativity and Psychopathy.*

Mayer, R. E. (1999). Fifty years of creativity research. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 449-460). Cambridge: Cambridge University Press.

McCallum, A. S., Glynn, S. M. (1979). Hemispheric specialization and creative behavior. *The Journal of Creative Behavior, 13(4),* 263-273.

Mednick, S. A. (1962). The associative basis of the creative process. *Psychological Review, 69,* 220-232.

Mednick, S. A. (1958). An orientation to research in creativity (Research Memo Number Two). Berkeley, CA: University of California, Institute of Personality Assessment and Research.

Mendelsohn, G. A. (1976). Associative and attentional processes in creative performance. *Journal of Personality, 44,* 341-369.

Merten, T., Fischer, I. (1999). Creativity, personality and word association responses: Associative behaviour in forty supposedly creative persons. *Personality and Individual Differences, 27,* 933-942.

Michaels, W. B., Wright, C. R. (1989). Psychometric issues in the assessment of creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.) *Handbook of Creativity* (pp. 33-52). New York: Plenum Press.

Michel, G. F., Moore, C. L. (1995). *Developmental psychobiology.* Cambridge, MA: MIT Press.

Mora, G. (1964). One hundred years from Lombroso's first essay, 'Genius and Insanity.' *American Journal of Psychiatry, 121,* 562-571.

Moreau de Tours, P. (1859). *La Psychologie morbide dans ses rapports avec la philosophie de l'historie, ou de l'Influence des nevropathies sur le dynamisme intellectuel.* Paris.

Morel, B. A. (1857). *Traite des degenerescences physiques, intellectuelles et morales de l'espece humaine.* Paris.

Nääntenen, R. (1982). Processing negativity: An evoked potential reflection of selective attention. *Psychological Bulletin, 92,* 605-640.

Nordau, M. (1895). *Degeneration.* London: William Heinemann.

Nunez, P. L., Silberstein, R. B., Shi, Z., Carpenter, M. R., Srinivasan, R., Tucker, D. M., Doran, S. M., Cadusch, P. J., Wijesinghe, R. S. (1999). EEG coherency II: Experimental comparisons of multiple measures. *Clinical Neurophysiology, 110,* 469-486.

Palermo, D. S., Jenkins, J. J. (1964). *Word association norms: Grade school through college.* Minneapolis, MN: University of Minnesota Press.

Penfield, W., Milner, B. (1958). Memory deficit produced by bilateral lesions in the hippocampal zone. *AMA Archives of Neurology and Psychiatry, 79,* 475-497.

Petsche, H., Kaplan, S., von Stein, A., Filz, O. (1997). The possible meaning of the upper and lower alpha frequency ranges for cognitive and creative tasks. *International Journal of Psychophysiology, 26,* 77-97.

Prentky, R. (1989). Creativity and psychopathology: Gamboling at the seat of madness. In J. A. Glover, R. R. Ronning & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 243-269). New York: Plenum Press.

Ray, W. (1990). The electrocortical system. In J. T. Caccioppo & L. G. Tassinary (Eds.) *Principles of psychophysiology: Physical, social, and inferential elements* (pp. 385-412). New York: Cambridge University Press.

Renault, B. (1983). The visual emitted potentials: Clues for information processing. In A. W. K. Gaillard & W. Ritter (Eds.) *Tutorials in event-related potential research: Endogenous components (pp. 159-176).* Amsterdam: North Holland.

SAS/STAT User's Guide (Vols. 1-3). (1999). Cary, NC: SAS Institute, Inc.

Spearman, C. (1927). *The abilities of man.* London: MacMillan.

Sperry, R. W. (1968). Hemisphere disconnection and unity in conscious awareness. *American Psychologist, 23,* 733-734.

Sternberg, R. J., Lubart, T. I. (1996). Investing in creativity. *American Psychologist, 51,* 677-688.

Sutton, S., Braren, M., Zubin, J., John, E. R. (1965). Evoked potential correlates of stimulus uncertainty. *Science, 150,* 1187-1188.

Talbot, E. S. (1898/1901). *Degeneracy: Its causes, signs, and results.* New York: Charles Scribner's Sons.

Terman, L. M. (1925). *Genetic studies of genius: Vol. I. Mental and physical traits of a thousand gifted children*. Stanford: Stanford University Press.

Terman, L. M., Oden, M. H. (1959). *Genetic studies of genius: Vol. IV. The gifted child at mid-life*. Stanford: Stanford University Press.

Torrance, E. P. (1974). *Torrance Tests of Creative Thinking*. Scholastic Testing Service.

Tucker, D. M., Dawson, S. L., Roth, D. L., Penland, J. G. (1985). Regional changes in EEG power and coherence during cognition: Intensive study of two individuals. *Behavioral Neuroscience, 99*, 564-577.

Van Zelst, R. H., Kerr, W. A. (1954). Personality self-assessment of scientific and technical personnel. *Journal of Applied Psychology, 38*, 145-147.

Vaughan, H. G., Jr. (1969). The relationship of brain activity to scalp recordings of event-related potentials. In E. Donchin & D. B. Lindsley (Eds.), *Averaged evoked potentials* (pp. 45-94). Washington, DC: NASA.

Wallach, M. A., Kogan, N. (1965). *Modes of thinking in young children.* New York: Holt, Rinehart, and Winston, Inc.

Wallas, G. (1926). *The art of thought*. New York: Harcourt, Brace, and World.

Whitton, J. L., Moldofsky, H., Lue, F. (1978). EEG frequency patterns associated with hallucination in schizophrenia and "creativity" in normals. *Biological Psychiatry, 13(1),* 123-133.

Zachary, R. A. (1996). *Shipley Institute of Living scale, Revised Manual.* Los Angeles, CA: Western Psychological Services.

Appendix A – Full Correlation Matrix

Table A.1. Correlations Between All Individual Difference Measures

	SEX	AGE	YRCOL	HAND	VOCAB	ABST	AUT-B	AUT-S	AUT-N	ACL	RAT	WORD	SHIP	AUT	ORIG
SEX		-0.20	-0.27*	0.04	-0.17	-0.07	0.04	0.12	0.03	-0.11	-0.03	0.36**	-0.14	0.03	-0.01
AGE			0.57**	-0.08	0.09	-0.11	0.03	-0.02	-0.05	0.13	-0.09	-0.19	-0.03	0.08	-0.01
YRCOL				0.01	0.31**	0.09	0.15	0.00	0.04	0.19	0.13	-0.11	0.23*	0.14	0.02
HAND					-0.23	0.02	-0.30	-0.30	-0.32	-0.09	0.03	0.17	-0.11	-0.40	0.04
VOCAB						0.31**	0.13	0.09	0.07	0.02	0.21	-0.13	0.76**	0.17	0.00
ABST							-0.16	-0.30**	-0.19	-0.01	0.30**	-0.02	0.85**	-0.21	0.10
AUT-B								0.59**	0.65**	0.23*	-0.05	-0.04	-0.03	0.85**	0.22*
AUT-S									0.71**	0.19	-0.16	0.00	-0.16	0.81**	0.13
AUT-N										0.19	-0.01	-0.06	-0.09	0.83**	0.14
ACL											0.12	-0.22*	0.00	0.33**	0.20
RAT												-0.20	0.32**	-0.05	-0.09
WORD													-0.08	-0.06	0.01
SHIP														-0.05	0.07
AUT															0.16
ORIG															

Note. SEX corresponds to male (1) and female (2). AGE corresponds to reported birthdate on day of testing. YRCOL corresponds to reported whole year in college. HAND corresponds to handedness score. VOCAB corresponds to score on the vocabulary subsection of the Shipley Institute of Living Scale. ABST corresponds to score on the abstraction subscale of the Shipley Institute of Living Scale. AUT-B, AUT-S, and AUT-N correspond to number of uses written for a brick, shoe, and newspaper, respectively, on the Alternate Uses Test. ACL corresponds to score on the Adjective Checklist. RAT corresponds to score on the Remotes Associates Test. WORD corresponds to score on the Word Association Test. SHIP corresponds to total score on the Shipley Institute of Living Scale. AUT corresponds to total score on the Alternate Uses Test. ORIG corresponds to score on rated originality of written story.

* $p < .05$. ** $p < .01$.

Appendix B - Experiment One Spectral Results

Table B.1. Spectral Analysis Multivariate Repeated Measures Analysis by Adjective Checklist

Source	df	F
ACTIVITY	1	3.31
ACTIVITY x ACL	1	1.34
FREQ	5	21.07***
FREQ x ACL	5	0.65
HEM	1	10.06***
HEM x ACL	1	1.64
ELECLOC	2	37.49***
ELECLOC x ACL	2	0.14
ACTIVITY x FREQ	5	14.00***
ACTIVITY x FREQ x ACL	5	1.30
ACTIVITY x HEM	1	0.65
ACTIVITY x HEM x ACL	1	1.53
FREQ x HEM	5	2.37*
FREQ x HEM x ACL	5	0.36
ACTIVITY x FREQ x HEM	5	0.35
ACTIVITY x FREQ x HEM x ACL	5	1.22
ACTIVITY x ELECLOC	2	15.40***

Table B.1. Continued

ACTIVITY x ELECLOC x ACL	2	0.75
FREQ x ELECLOC	10	14.40***
FREQ x ELECLOC x ACL	10	0.99
ACTIVITY x FREQ x ELECLOC	10	4.82***
ACTIVITY x FREQ x ELECLOC x ACL	10	1.27
HEM x ELECLOC	2	0.70
HEM x ELECLOC x ACL	2	0.09
ACTIVITY x HEM x ELECLOC	2	0.22
ACTIVITY x HEM x ELECLOC x ACL	2	1.40
FREQ x HEM x ELECLOC	10	3.50***
FREQ x HEM x ELECLOC x ACL	10	0.48
ACTIVITY x FREQ x HEM x ELECLOC	10	2.25*
ACTIVITY x FREQ x HEM x ELECLOC x ACL	10	0.44

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ACL indicates grouped scores on the Adjective Checklist.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.2. Spectral Analysis Multivariate Repeated Measures Analysis by Remote Associates Test

Source	df	F
ACTIVITY	1	3.66
ACTIVITY x RAT	1	0.00
FREQ	5	20.53***
FREQ x RAT	5	1.77
HEM	1	10.57***
HEM x RAT	1	0.00
ELECLOC	2	38.01***
ELECLOC x RAT	2	0.56
ACTIVITY x FREQ	5	13.62***
ACTIVITY x FREQ x RAT	5	1.65
ACTIVITY x HEM	1	0.45
ACTIVITY x HEM x RAT	1	0.04
FREQ x HEM	5	2.63*
FREQ x HEM x RAT	5	0.89
ACTIVITY x FREQ x HEM	5	0.35
ACTIVITY x FREQ x HEM x RAT	5	0.44
ACTIVITY x ELECLOC	2	15.44***
ACTIVITY x ELECLOC x RAT	2	0.39
FREQ x ELECLOC	10	14.36***

Table B.2. Continued

FREQ x ELECLOC x RAT	10	1.73
ACTIVITY x FREQ x ELECLOC	10	4.86***
ACTIVITY x FREQ x ELECLOC x RAT	10	1.81
HEM x ELECLOC	2	0.71
HEM x ELECLOC x RAT	2	0.26
ACTIVITY x HEM x ELECLOC	2	0.29
ACTIVITY x HEM x ELECLOC x RAT	2	0.16
FREQ x HEM x ELECLOC	10	3.53***
FREQ x HEM x ELECLOC x RAT	10	0.69
ACTIVITY x FREQ x HEM x ELECLOC	10	2.16*
ACTIVITY x FREQ x HEM x ELECLOC x RAT	10	1.12

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). RAT indicates grouped scores on the Remote Associates Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.3. Spectral Analysis Multivariate Repeated Measures Analysis by Word Association Test

Source	df	F
ACTIVITY	1	4.02*
ACTIVITY x WORD	1	0.43
FREQ	5	18.99***
FREQ x WORD	5	0.98
HEM	1	12.52***
HEM x WORD	1	2.31
ELECLOC	2	36.51***
ELECLOC x WORD	2	0.50
ACTIVITY x FREQ	5	12.86***
ACTIVITY x FREQ x WORD	5	1.06
ACTIVITY x HEM	1	0.61
ACTIVITY x HEM x WORD	1	0.37
FREQ x HEM	5	2.38*
FREQ x HEM x WORD	5	2.37*
ACTIVITY x FREQ x HEM	5	0.31
ACTIVITY x FREQ x HEM x WORD	5	0.34
ACTIVITY x ELECLOC	2	14.10***
ACTIVITY x ELECLOC x WORD	2	0.79
FREQ x ELECLOC	10	13.78***

Table B.3. Continued

FREQ x ELECLOC x WORD	10	0.95
ACTIVITY x FREQ x ELECLOC	10	4.59***
ACTIVITY x FREQ x ELECLOC x WORD	10	1.12
HEM x ELECLOC	2	0.75
HEM x ELECLOC x WORD	2	0.03
ACTIVITY x HEM x ELECLOC	2	0.29
ACTIVITY x HEM x ELECLOC x WORD	2	0.15
FREQ x HEM x ELECLOC	10	3.20***
FREQ x HEM x ELECLOC x WORD	10	0.65
ACTIVITY x FREQ x HEM x ELECLOC	10	2.24*
ACTIVITY x FREQ x HEM x ELECLOC x WORD	10	0.50

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). WORD indicates grouped scores on the Word Association Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.4. Spectral Analysis Multivariate Repeated Measures Analysis by Alternate Uses Test

Source	df	F
ACTIVITY	1	3.71
ACTIVITY x AUT	1	0.29
FREQ	5	21.29***
FREQ x AUT	5	1.20
HEM	1	10.58***
HEM x AUT	1	0.03
ELECLOC	2	39.07***
ELECLOC x AUT	2	1.46
ACTIVITY x FREQ	5	13.81***
ACTIVITY x FREQ x AUT	5	0.74
ACTIVITY x HEM	1	0.50
ACTIVITY x HEM x AUT	1	1.02
FREQ x HEM	5	2.43*
FREQ x HEM x AUT	5	1.28
ACTIVITY x FREQ x HEM	5	0.36
ACTIVITY x FREQ x HEM x AUT	5	1.36
ACTIVITY x ELECLOC	2	15.78***
ACTIVITY x ELECLOC x AUT	2	2.20
FREQ x ELECLOC	10	17.38***

Table B.4. Continued

FREQ x ELECLOC x AUT	10	2.25*
ACTIVITY x FREQ x ELECLOC	10	4.92***
ACTIVITY x FREQ x ELECLOC x AUT	10	1.00
HEM x ELECLOC	2	0.73
HEM x ELECLOC x AUT	2	2.58
ACTIVITY x HEM x ELECLOC	2	0.31
ACTIVITY x HEM x ELECLOC x AUT	2	0.59
FREQ x HEM x ELECLOC	10	3.54***
FREQ x HEM x ELECLOC x AUT	10	1.34
ACTIVITY x FREQ x HEM x ELECLOC	10	2.18*
ACTIVITY x FREQ x HEM x ELECLOC x AUT	10	1.09

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). AUT indicates grouped scores on the Alternate Uses Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.5. Spectral Analysis Multivariate Repeated Measures Analysis by Shipley Institute of Living Scale

Source	df	F
ACTIVITY	1	3.63
ACTIVITY x SHIP	1	0.00
FREQ	5	20.06***
FREQ x SHIP	5	3.61**
HEM	1	10.98***
HEM x SHIP	1	0.61
ELECLOC	2	37.96***
ELECLOC x SHIP	2	1.09
ACTIVITY x FREQ	5	13.59***
ACTIVITY x FREQ x SHIP	5	1.87
ACTIVITY x HEM	1	0.43
ACTIVITY x HEM x SHIP	1	0.19
FREQ x HEM	5	2.49*
FREQ x HEM x SHIP	5	0.63
ACTIVITY x FREQ x HEM	5	0.33
ACTIVITY x FREQ x HEM x SHIP	5	0.43
ACTIVITY x ELECLOC	2	14.89***
ACTIVITY x ELECLOC x SHIP	2	3.00
FREQ x ELECLOC	10	14.30***

Table B.5. Continued

FREQ x ELECLOC x SHIP	10	1.75
ACTIVITY x FREQ x ELECLOC	10	4.82***
ACTIVITY x FREQ x ELECLOC x SHIP	10	1.87
HEM x ELECLOC	2	0.82
HEM x ELECLOC x SHIP	2	1.49
ACTIVITY x HEM x ELECLOC	2	0.31
ACTIVITY x HEM x ELECLOC x SHIP	2	0.26
FREQ x HEM x ELECLOC	10	3.82***
FREQ x HEM x ELECLOC x SHIP	10	1.11
ACTIVITY x FREQ x HEM x ELECLOC	10	2.17*
ACTIVITY x FREQ x HEM x ELECLOC x SHIP	10	0.65

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). SHIP indicates grouped scores on the Shipley Institutes of Living Test (intellectual functioning measure).

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.6. Spectral Analysis Multivariate Repeated Measures Analysis by Sex

Source	df	F
ACTIVITY	1	3.80
ACTIVITY x SEX	1	0.99
FREQ	5	20.04***
FREQ x SEX	5	0.61
HEM	1	10.67***
HEM x SEX	1	0.15
ELECLOC	2	38.73***
ELECLOC x SEX	2	1.59
ACTIVITY x FREQ	5	13.54***
ACTIVITY x FREQ x SEX	5	1.98
ACTIVITY x HEM	1	0.45
ACTIVITY x HEM x SEX	1	1.03
FREQ x HEM	5	2.46*
FREQ x HEM x SEX	5	0.35
ACTIVITY x FREQ x HEM	5	0.33
ACTIVITY x FREQ x HEM x SEX	5	2.46*
ACTIVITY x ELECLOC	2	15.02***
ACTIVITY x ELECLOC x SEX	2	0.77
FREQ x ELECLOC	10	14.23***
FREQ x ELECLOC x SEX	10	2.08*

Table B.6. Continued

ACTIVITY x FREQ x ELECLOC	10	5.33***
ACTIVITY x FREQ x ELECLOC x SEX	10	1.70
HEM x ELECLOC	2	0.72
HEM x ELECLOC x SEX	2	0.25
ACTIVITY x HEM x ELECLOC	2	0.31
ACTIVITY x HEM x ELECLOC x SEX	2	2.54
FREQ x HEM x ELECLOC	10	3.43***
FREQ x HEM x ELECLOC x SEX	10	0.37
ACTIVITY x FREQ x HEM x ELECLOC	10	2.20*
ACTIVITY x FREQ x HEM x ELECLOC x SEX	10	1.01

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). SEX indicates grouped scores by Male and Female.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.7. Spectral Analysis Multivariate Repeated Measures Analysis by Composite Creativity Score

Source	df	F
ACTIVITY	1	3.50
ACTIVITY x CRGRP	1	0.99
FREQ	5	20.71***
FREQ x CRGRP	5	0.63
HEM	1	10.45***
HEM x CRGRP	1	0.17
ELECLOC	2	37.52***
ELECLOC x CRGRP	2	0.23
ACTIVITY x FREQ	5	14.02***
ACTIVITY x FREQ x CRGRP	5	1.41
ACTIVITY x HEM	1	0.39
ACTIVITY x HEM x CRGRP	1	1.42
FREQ x HEM	5	2.45*
FREQ x HEM x CRGRP	5	2.11
ACTIVITY x FREQ x HEM	5	0.33
ACTIVITY x FREQ x HEM x CRGRP	5	0.44
ACTIVITY x ELECLOC	2	15.82***
ACTIVITY x ELECLOC x CRGRP	2	0.81
FREQ x ELECLOC	10	14.51***

Table B.7. Continued

FREQ x ELECLOC x CRGRP	10	1.05
ACTIVITY x FREQ x ELECLOC	10	4.82***
ACTIVITY x FREQ x ELECLOC x CRGRP	10	0.58
HEM x ELECLOC	2	0.80
HEM x ELECLOC x CRGRP	2	0.43
ACTIVITY x HEM x ELECLOC	2	0.34
ACTIVITY x HEM x ELECLOC x CRGRP	2	0.55
FREQ x HEM x ELECLOC	10	3.77***
FREQ x HEM x ELECLOC x CRGRP	10	0.86
ACTIVITY x FREQ x HEM x ELECLOC	10	2.26*
ACTIVITY x FREQ x HEM x ELECLOC x CRGRP	10	1.20

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on the composite creativity score. *$p < .05$. **$p < .01$. ***$p < .001$.

Table B.8. Spectral Analysis Multivariate Repeated Measures Analysis by Composite Creativity Score – Male Data Only

Source	df	F
ACTIVITY	1	5.93*
ACTIVITY x CRGRP	1	0.71
FREQ	5	10.00***
FREQ x CRGRP	5	0.80
HEM	1	5.11*
HEM x CRGRP	1	0.48
ELECLOC	2	14.72***
ELECLOC x CRGRP	2	2.07
ACTIVITY x FREQ	5	8.18***
ACTIVITY x FREQ x CRGRP	5	0.60
ACTIVITY x HEM	1	0.28
ACTIVITY x HEM x CRGRP	1	1.63
FREQ x HEM	5	1.36
FREQ x HEM x CRGRP	5	0.98
ACTIVITY x FREQ x HEM	5	1.55
ACTIVITY x FREQ x HEM x CRGRP	5	0.69
ACTIVITY x ELECLOC	2	6.35*
ACTIVITY x ELECLOC x CRGRP	2	0.20
FREQ x ELECLOC	10	7.28***

Table B.8. Continued

FREQ x ELECLOC x CRGRP	10	1.02
ACTIVITY x FREQ x ELECLOC	10	1.73
ACTIVITY x FREQ x ELECLOC x CRGRP	10	0.45
HEM x ELECLOC	2	0.33
HEM x ELECLOC x CRGRP	2	0.59
ACTIVITY x HEM x ELECLOC	2	0.80
ACTIVITY x HEM x ELECLOC x CRGRP	2	0.32
FREQ x HEM x ELECLOC	10	2.16
FREQ x HEM x ELECLOC x CRGRP	10	0.53
ACTIVITY x FREQ x HEM x ELECLOC	10	2.54*
ACTIVITY x FREQ x HEM x ELECLOC x CRGRP	10	1.08

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on the composite creativity score. *$p < .05$. **$p < .01$. ***$p < .001$.

Table B.9. Spectral Analyses Multivariate Repeated Measures Analysis by Originality Rating – Male Data Only

Source	df	F
ACTIVITY	1	6.20*
ACTIVITY x ORIGGRP	1	0.00
FREQ	5	9.60***
FREQ x ORIGGRP	5	0.49
HEM	1	5.37*
HEM x ORIGGRP	1	0.35
ELECLOC	2	11.99***
ELECLOC x ORIGGRP	2	0.12
ACTIVITY x FREQ	5	7.78***
ACTIVITY x FREQ x ORIGGRP	5	2.18
ACTIVITY x HEM	1	0.00
ACTIVITY x HEM x ORIGGRP	1	2.00
FREQ x HEM	5	1.36
FREQ x HEM x ORIGGRP	5	1.06
ACTIVITY x FREQ x HEM	5	1.57
ACTIVITY x FREQ x HEM x ORIGGRP	5	0.23
ACTIVITY x ELECLOC	2	6.25**
ACTIVITY x ELECLOC x ORIGGRP	2	0.01
FREQ x ELECLOC	10	5.43***

Table B.9. Continued

FREQ x ELECLOC x ORIGGRP	10	0.35
ACTIVITY x FREQ x ELECLOC	10	1.63
ACTIVITY x FREQ x ELECLOC x ORIGGRP	10	1.60
HEM x ELECLOC	2	0.29
HEM x ELECLOC x ORIGGRP	2	0.50
ACTIVITY x HEM x ELECLOC	2	0.62
ACTIVITY x HEM x ELECLOC x ORIGGRP	2	0.36
FREQ x HEM x ELECLOC	10	2.20
FREQ x HEM x ELECLOC x ORIGGRP	10	1.02
ACTIVITY x FREQ x HEM x ELECLOC	10	2.05
ACTIVITY x FREQ x HEM x ELECLOC x ORIGGRP	10	1.75

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.10. Spectral Analysis Multivariate Repeated Measures Analysis by Composite Creativity Score – Female Data Only

Source	df	F
ACTIVITY	1	0.38
ACTIVITY x CRGRP	1	0.21
FREQ	5	11.15***
FREQ x CRGRP	5	0.60
HEM	1	4.07*
HEM x CRGRP	1	0.04
ELECLOC	2	26.84***
ELECLOC x CRGRP	2	0.49
ACTIVITY x FREQ	5	6.29***
ACTIVITY x FREQ x CRGRP	5	1.29
ACTIVITY x HEM	1	1.68
ACTIVITY x HEM x CRGRP	1	0.47
FREQ x HEM	5	1.15
FREQ x HEM x CRGRP	5	1.92
ACTIVITY x FREQ x HEM	5	1.31
ACTIVITY x FREQ x HEM x CRGRP	5	0.22
ACTIVITY x ELECLOC	2	7.49***
ACTIVITY x ELECLOC x CRGRP	2	1.58
FREQ x ELECLOC	10	6.86***

Table B.10. Continued

FREQ x ELECLOC x CRGRP	10	0.88
ACTIVITY x FREQ x ELECLOC	10	2.95*
ACTIVITY x FREQ x ELECLOC x CRGRP	10	0.97
HEM x ELECLOC	2	1.09
HEM x ELECLOC x CRGRP	2	0.14
ACTIVITY x HEM x ELECLOC	2	3.08
ACTIVITY x HEM x ELECLOC x CRGRP	2	0.38
FREQ x HEM x ELECLOC	10	1.34
FREQ x HEM x ELECLOC x CRGRP	10	1.26
ACTIVITY x FREQ x HEM x ELECLOC	10	1.54
ACTIVITY x FREQ x HEM x ELECLOC x CRGRP	10	1.49

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on the composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table B.11. Spectral Analysis Multivariate Repeated Measures Analysis by Originality Rating – Female Data Only

Source	df	F
ACTIVITY	1	0.38
ACTIVITY x ORIGGRP	1	1.26
FREQ	5	10.91***
FREQ x ORIGGRP	5	0.56
HEM	1	4.69*
HEM x ORIGGRP	1	1.68
ELECLOC	2	29.72***
ELECLOC x ORIGGRP	2	1.87
ACTIVITY x FREQ	5	6.24***
ACTIVITY x FREQ x ORIGGRP	5	0.92
ACTIVITY x HEM	1	1.52
ACTIVITY x HEM x ORIGGRP	1	3.82
FREQ x HEM	5	1.45
FREQ x HEM x ORIGGRP	5	1.31
ACTIVITY x FREQ x HEM	5	1.41
ACTIVITY x FREQ x HEM x ORIGGRP	5	2.59
ACTIVITY x ELECLOC	2	7.40***
ACTIVITY x ELECLOC x ORIGGRP	2	0.32
FREQ x ELECLOC	10	8.51***

Table B.11. Continued

FREQ x ELECLOC x ORIGGRP	10	1.31
ACTIVITY x FREQ x ELECLOC	10	3.04*
ACTIVITY x FREQ x ELECLOC x ORIGGRP	10	0.40
HEM x ELECLOC	2	1.09
HEM x ELECLOC x ORIGGRP	2	0.57
ACTIVITY x HEM x ELECLOC	2	3.18
ACTIVITY x HEM x ELECLOC x ORIGGRP	2	1.92
FREQ x HEM x ELECLOC	10	1.27
FREQ x HEM x ELECLOC x ORIGGRP	10	1.48
ACTIVITY x FREQ x HEM x ELECLOC	10	1.57
ACTIVITY x FREQ x HEM x ELECLOC x ORIGGRP	10	0.98

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates Frequency Band (delta, theta, low alpha, high alpha, low Beta, high Beta). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Appendix C - Experiment One Cross-spectral Results

Table C.1. Cross-spectral Univariate Repeated Measures Analysis by Adjective Checklist

Source	df	F
ACTIVITY	1.00	2.10
ACTIVITY x ACL	1.00	1.00
FREQ	1.75	51.63***
FREQ x ACL	1.75	0.35
PAIR	5.08	245.01***
PAIR x ACL	5.08	1.34
ACTIVITY x FREQ	1.95	9.66***
ACTIVITY x FREQ x ACL	1.95	0.68
ACTIVITY x PAIR	5.12	18.50***
ACTIVITY x PAIR x ACL	5.12	0.90
FREQ x PAIR	9.41	44.92***
FREQ x PAIR x ACL	9.41	1.48
ACTIVITY x FREQ x PAIR	7.94	12.00***
ACTIVITY x FREQ x PAIR x ACL	7.94	1.40

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). ACL indicates grouped scores on the Adjective Checklist.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.2. Cross-spectral Univariate Repeated Measures Analysis by Remote Associates Test

Source	df	F
ACTIVITY	1.00	1.77
ACTIVITY x RAT	1.00	0.09
FREQ	1.73	53.70***
FREQ x RAT	1.73	2.00
PAIR	4.95	245.94***
PAIR x RAT	4.95	0.94
ACTIVITY x FREQ	1.97	9.28***
ACTIVITY x FREQ x RAT	1.97	0.38
ACTIVITY x PAIR	5.23	19.49***
ACTIVITY x PAIR x RAT	5.23	1.83
FREQ x PAIR	9.54	45.52***
FREQ x PAIR x RAT	9.54	1.19
ACTIVITY x FREQ x PAIR	7.94	12.19***
ACTIVITY x FREQ x PAIR x RAT	7.94	1.09

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). RAT indicates grouped scores on the Remote Associates Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.3. Cross-spectral Univariate Repeated Measures Analysis by Word Association Test

Source	df	F
ACTIVITY	1.00	2.39
ACTIVITY x WORD	1.00	1.40
FREQ	1.77	48.34***
FREQ x WORD	1.77	1.64
PAIR	4.97	244.17***
PAIR x WORD	4.97	1.57
ACTIVITY x FREQ	1.97	9.47***
ACTIVITY x FREQ x WORD	1.97	0.78
ACTIVITY x PAIR	5.24	18.24***
ACTIVITY x PAIR x WORD	5.24	0.79
FREQ x PAIR	9.44	44.54***
FREQ x PAIR x WORD	9.44	0.74
ACTIVITY x FREQ x PAIR	7.91	12.15***
ACTIVITY x FREQ x PAIR x WORD	7.91	0.89

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). WORD indicates grouped scores on the Word Association Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.4. Cross-spectral Univariate Repeated Measures Analysis by Alternate Uses Test

Source	df	F
ACTIVITY	1.00	1.83
ACTIVITY x AUT	1.00	3.00
FREQ	1.73	52.12***
FREQ x AUT	1.73	1.36
PAIR	4.93	248.18***
PAIR x AUT	4.93	1.20
ACTIVITY x FREQ	1.98	9.45***
ACTIVITY x FREQ x AUT	1.98	0.38
ACTIVITY x PAIR	5.17	18.93***
ACTIVITY x PAIR x AUT	5.17	0.43
FREQ x PAIR	9.44	45.24***
FREQ x PAIR x AUT	9.44	1.02
ACTIVITY x FREQ x PAIR	8.05	12.23***
ACTIVITY x FREQ x PAIR x AUT	8.05	0.43

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). AUT indicates grouped scores on the Alternate Uses Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.5. Cross-spectral Univariate Repeated Measures Analysis by Shipley Institute of Living Scale

Source	df	F
ACTIVITY	1.00	1.86
ACTIVITY x SHIP	1.00	0.11
FREQ	1.75	50.81***
FREQ x SHIP	1.75	0.36
PAIR	5.00	245.06***
PAIR x SHIP	5.00	0.57
ACTIVITY x FREQ	1.96	9.34***
ACTIVITY x FREQ x SHIP	1.96	0.23
ACTIVITY x PAIR	5.35	20.05***
ACTIVITY x PAIR x SHIP	5.35	3.29**
FREQ x PAIR	9.36	44.78***
FREQ x PAIR x SHIP	9.36	0.62
ACTIVITY x FREQ x PAIR	8.34	12.90***
ACTIVITY x FREQ x PAIR x SHIP	8.34	2.31*

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). SHIP indicates grouped scores on the Shipley Institutes of Living Test (intellectual functioning measure).

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.6. Cross-spectral Univariate Repeated Measures Analysis by Sex

Source	df	F
ACTIVITY	1.00	1.82
ACTIVITY x SEX	1.00	0.03
FREQ	1.74	52.05***
FREQ x SEX	1.74	1.27
PAIR	5.28	262.25***
PAIR x SEX	5.28	4.10
ACTIVITY x FREQ	1.95	9.76***
ACTIVITY x FREQ x SEX	1.95	1.49
ACTIVITY x PAIR	5.16	18.87***
ACTIVITY x PAIR x SEX	5.16	0.33
FREQ x PAIR	9.50	45.46***
FREQ x PAIR x SEX	9.50	1.32
ACTIVITY x FREQ x PAIR	7.97	12.59***
ACTIVITY x FREQ x PAIR x SEX	7.97	1.70

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). SEX indicates grouped scores by Male and Female.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.7. Cross-spectral Univariate Repeated Measures Analysis Composite Creativity Score

Source	df	F
ACTIVITY	1.00	1.73
ACTIVITY x CRGRP	1.00	0.33
FREQ	1.73	52.27***
FREQ x CRGRP	1.73	0.94
PAIR	4.87	247.23***
PAIR x CRGRP	4.87	1.35
ACTIVITY x FREQ	1.97	9.54***
ACTIVITY x FREQ x CRGRP	1.97	1.19
ACTIVITY x PAIR	5.13	19.40***
ACTIVITY x PAIR x CRGRP	5.13	1.67
FREQ x PAIR	9.49	44.79***
FREQ x PAIR x CRGRP	9.49	0.73
ACTIVITY x FREQ x PAIR	7.93	12.18***
ACTIVITY x FREQ x PAIR x CRGRP	7.93	0.52

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). CRGRP indicates grouped scores on the composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.8. Cross-spectral Univariate Repeated Measures Analysis by Creativity Composite Score – Male Date Only

Source	df	F
ACTIVITY	1.00	0.94
ACTIVITY x CRGRP	1.00	0.06
FREQ	1.92	17.93***
FREQ x CRGRP	1.92	0.34
PAIR	4.53	136.86***
PAIR x CRGRP	4.53	0.66
ACTIVITY x FREQ	1.62	6.76***
ACTIVITY x FREQ x CRGRP	1.62	0.59
ACTIVITY x PAIR	4.44	7.74***
ACTIVITY x PAIR x CRGRP	4.44	1.01
FREQ x PAIR	8.30	22.86***
FREQ x PAIR x CRGRP	8.30	1.22
ACTIVITY x FREQ x PAIR	5.87	8.37***
ACTIVITY x FREQ x PAIR x CRGRP	5.87	0.50

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). CRGRP indicates grouped scores on the composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.9. Cross-spectral Univariate Repeated Measures Analysis by Originality Rating – Male Data Only

Source	df	F
ACTIVITY	1.00	1.20
ACTIVITY x ORIGGRP	1.00	0.13
FREQ	1.90	16.17***
FREQ x ORIGGRP	1.90	0.54
PAIR	4.63	132.42***
PAIR x ORIGGRP	4.63	0.50
ACTIVITY x FREQ	1.54	6.19***
ACTIVITY x FREQ x ORIGGRP	1.54	1.13
ACTIVITY x PAIR	4.56	7.87***
ACTIVITY x PAIR x ORIGGRP	4.56	0.21
FREQ x PAIR	7.73	22.59***
FREQ x PAIR x ORIGGRP	7.73	0.81
ACTIVITY x FREQ x PAIR	5.68	8.35***
ACTIVITY x FREQ x PAIR x ORIGGRP	5.68	0.53

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.10. Cross-spectral Univariate Repeated Measures Analysis by Creativity Composite Score – Female Date Only

Source	df	F
ACTIVITY	1.00	0.77
ACTIVITY x CRGRP	1.00	0.27
FREQ	1.48	34.52***
FREQ x CRGRP	1.48	0.38
PAIR	4.84	119.18***
PAIR x CRGRP	4.84	0.90
ACTIVITY x FREQ	1.83	2.58
ACTIVITY x FREQ x CRGRP	1.83	0.68
ACTIVITY x PAIR	3.98	10.35***
ACTIVITY x PAIR x CRGRP	3.98	1.56
FREQ x PAIR	7.50	23.34***
FREQ x PAIR x CRGRP	7.50	0.70
ACTIVITY x FREQ x PAIR	7.55	5.11***
ACTIVITY x FREQ x PAIR x CRGRP	7.55	0.62

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). CRGRP indicates grouped scores on the composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table C.11. Cross-spectral Univariate Repeated Measures Analysis by Originality Rating – Female Data Only

Source	df	F
ACTIVITY	1.00	0.64
ACTIVITY x ORIGGRP	1.00	2.36
FREQ	1.48	35.03***
FREQ x ORIGGRP	1.48	0.33
PAIR	4.97	118.33***
PAIR x ORIGGRP	4.97	0.71
ACTIVITY x FREQ	1.83	2.63
ACTIVITY x FREQ x ORIGGRP	1.83	0.59
ACTIVITY x PAIR	3.89	10.38***
ACTIVITY x PAIR x ORIGGRP	3.89	0.51
FREQ x PAIR	7.31	23.33***
FREQ x PAIR x ORIGGRP	7.31	0.76
ACTIVITY x FREQ x PAIR	7.65	5.27***
ACTIVITY x FREQ x PAIR x ORIGGRP	7.65	1.81

Note. ACTIVITY indicates story activity (Imagining or Writing). FREQ indicates frequency band (delta, theta, low alpha, high alpha, low Beta, high Beta). PAIR indicates electrode location pairing (Left Frontal-Left Central, Left-Frontal-Left Parietal, Left Frontal-Right Frontal, etc.). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Appendix D - Experiment Two

Table D.1. N100 and P300 Multivariate Repeated Measures Analysis by Adjective Checklist

Source	df	F
WAVE	1	430.24***
WAVE x ACL	1	3.33
STIM	2	12.26***
STIM x ACL	2	0.73
HEM	1	4.34*
HEM x ACL	1	0.00
LEAD	2	5.31**
LEAD x ACL	2	2.44
WAVE x STIM	2	39.54***
WAVE x STIM x ACL	2	0.21
WAVE x HEM	1	0.22
WAVE x HEM x ACL	1	0.34
STIM x HEM	2	6.39***
STIM x HEM x ACL	2	1.31
WAVE x STIM x HEM	2	12.76***
WAVE x STIM x HEM x ACL	2	1.06

Table D1. Continued

WAVE x LEAD	2	12.61***
WAVE x LEAD x ACL	2	2.76
STIM x LEAD	4	15.37***
STIM x LEAD x ACL	4	1.64
WAVE x STIM x LEAD	4	8.38***
WAVE x STIM x LEAD x ACL	4	0.50
HEM x LEAD	2	5.01**
HEM x LEAD x ACL	2	0.44
WAVE x HEM x LEAD	2	2.74
WAVE x HEM x LEAD x ACL	2	0.23
STIM x HEM x LEAD	4	1.64
STIM x HEM x LEAD x ACL	4	1.62
WAVE x STIM x HEM x LEAD	4	9.80***
WAVE x STIM x HEM x LEAD x ACL	4	2.15

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ACL indicates grouped scores on the Adjective Checklist.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.2. N100 and P300 Multivariate Repeated Measures Analysis by Remote Associates Test

Source	df	F
WAVE	1	396.01***
WAVE x RAT	1	0.01
STIM	2	13.18***
STIM x RAT	2	1.50
HEM	1	3.81
HEM x RAT	1	1.43
LEAD	2	5.99***
LEAD x RAT	2	2.52
WAVE x STIM	2	39.13***
WAVE x STIM x RAT	2	0.39
WAVE x HEM	1	0.11
WAVE x HEM x RAT	1	2.69
STIM x HEM	2	6.68***
STIM x HEM x RAT	2	1.66
WAVE x STIM x HEM	2	13.84***
WAVE x STIM x HEM x RAT	2	1.15
WAVE x LEAD	2	10.91***
WAVE x LEAD x RAT	2	3.22*
STIM x LEAD	4	15.90***

Table D.2. Continued

STIM x LEAD x RAT	4	0.70
WAVE x STIM x LEAD	4	8.42***
WAVE x STIM x LEAD x RAT	4	1.39
HEM x LEAD	2	4.71**
HEM x LEAD x RAT	2	2.49
WAVE x HEM x LEAD	2	2.44
WAVE x HEM x LEAD x RAT	2	3.14*
STIM x HEM x LEAD	4	1.52
STIM x HEM x LEAD x RAT	4	0.55
WAVE x STIM x HEM x LEAD	4	8.65***
WAVE x STIM x HEM x LEAD x RAT	4	0.44

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). RAT indicates grouped scores on the Remote Associates Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.3. N100 and P300 Multivariate Repeated Measures Analysis by Word Association Test

Source	df	F
WAVE	1	414.36***
WAVE x WORD	1	1.26
STIM	2	10.77***
STIM x WORD	2	0.33
HEM	1	3.99*
HEM x WORD	1	0.31
LEAD	2	5.83**
LEAD x WORD	2	0.29
WAVE x STIM	2	37.46***
WAVE x STIM x WORD	2	0.61
WAVE x HEM	1	0.14
WAVE x HEM x WORD	1	0.44
STIM x HEM	2	6.05***
STIM x HEM x WORD	2	0.30
WAVE x STIM x HEM	2	11.77***
WAVE x STIM x HEM x WORD	2	2.98
WAVE x LEAD	2	10.10***
WAVE x LEAD x WORD	2	1.32
STIM x LEAD	4	15.84***

Table D.3. Continued

STIM x LEAD x WORD	4	0.59
WAVE x STIM x LEAD	4	7.98***
WAVE x STIM x LEAD x WORD	4	1.07
HEM x LEAD	2	5.22**
HEM x LEAD x WORD	2	0.08
WAVE x HEM x LEAD	2	2.58
WAVE x HEM x LEAD x WORD	2	0.67
STIM x HEM x LEAD	4	1.36
STIM x HEM x LEAD x WORD	4	3.00*
WAVE x STIM x HEM x LEAD	4	8.59***
WAVE x STIM x HEM x LEAD x WORD	4	0.89

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). WORD indicates grouped scores on the Word Association Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.4. N100 and P300 Multivariate Repeated Measures Analysis by Alternate Uses Test

Source	df	F
WAVE	1	403.59***
WAVE x AUT	1	0.17
STIM	2	12.04***
STIM x AUT	2	0.83
HEM	1	4.39*
HEM x AUT	1	9.54***
LEAD	2	4.96**
LEAD x AUT	2	0.79
WAVE x STIM	2	39.56***
WAVE x STIM x AUT	2	1.14
WAVE x HEM	1	0.24
WAVE x HEM x AUT	1	0.36
STIM x HEM	2	5.72**
STIM x HEM x AUT	2	0.14
WAVE x STIM x HEM	2	12.59***
WAVE x STIM x HEM x AUT	2	0.25
WAVE x LEAD	2	11.27***
WAVE x LEAD x AUT	2	0.80
STIM x LEAD	4	15.61***

Table D.4. Continued

STIM x LEAD x AUT	4	1.26
WAVE x STIM x LEAD	4	8.46***
WAVE x STIM x LEAD x AUT	4	0.82
HEM x LEAD	2	5.54**
HEM x LEAD x AUT	2	1.15
WAVE x HEM x LEAD	2	2.83
WAVE x HEM x LEAD x AUT	2	3.52*
STIM x HEM x LEAD	4	1.61
STIM x HEM x LEAD x AUT	4	0.24
WAVE x STIM x HEM x LEAD	4	8.96***
WAVE x STIM x HEM x LEAD x AUT	4	0.83

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). AUT indicates grouped scores on the Alternate Uses Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.5. N100 and P300 Multivariate Repeated Measures Analysis by Shipley Institute of Living Scale

Source	df	F
WAVE	1	402.44***
WAVE x SHIP	1	0.00
STIM	2	11.94***
STIM x SHIP	2	0.62
HEM	1	4.60*
HEM x SHIP	1	1.85
LEAD	2	4.75**
LEAD x SHIP	2	0.59
WAVE x STIM	2	39.41***
WAVE x STIM x SHIP	2	0.85
WAVE x HEM	1	0.30
WAVE x HEM x SHIP	1	1.53
STIM x HEM	2	5.86***
STIM x HEM x SHIP	2	1.37
WAVE x STIM x HEM	2	12.91***
WAVE x STIM x HEM x SHIP	2	0.31
WAVE x LEAD	2	10.95***
WAVE x LEAD x SHIP	2	0.29
STIM x LEAD	4	15.29***

Table D.5. Continued

STIM x LEAD x SHIP	4	0.61
WAVE x STIM x LEAD	4	8.34***
WAVE x STIM x LEAD x SHIP	4	0.61
HEM x LEAD	2	5.23**
HEM x LEAD x SHIP	2	0.41
WAVE x HEM x LEAD	2	2.92
WAVE x HEM x LEAD x SHIP	2	0.44
STIM x HEM x LEAD	4	1.67
STIM x HEM x LEAD x SHIP	4	0.31
WAVE x STIM x HEM x LEAD	4	8.95***
WAVE x STIM x HEM x LEAD x SHIP	4	0.49

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). SHIP indicates grouped scores on the Shipley Institute of Living Test (intellectual functioning measure).

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.6. N100 and P300 Multivariate Repeated Measures Analysis by Sex

Source	df	F
WAVE	1	412.27***
WAVE x SEX	1	1.46
STIM	2	11.87***
STIM x SEX	2	1.23
HEM	1	4.35*
HEM x SEX	1	0.00
LEAD	2	4.82**
LEAD x SEX	2	1.53
WAVE x STIM	2	39.31***
WAVE x STIM x SEX	2	1.54
WAVE x HEM	1	0.27
WAVE x HEM x SEX	1	0.03
STIM x HEM	2	5.85**
STIM x HEM x SEX	2	0.49
WAVE x STIM x HEM	2	12.71***
WAVE x STIM x HEM x SEX	2	0.18
WAVE x LEAD	2	10.99***
WAVE x LEAD x SEX	2	0.44
STIM x LEAD	4	16.39***
STIM x LEAD x SEX	4	1.93

Table D.6. Continued

WAVE x STIM x LEAD	4	8.38***
WAVE x STIM x LEAD x SEX	4	0.47
HEM x LEAD	2	5.11**
HEM x LEAD x SEX	2	0.28
WAVE x HEM x LEAD	2	2.87
WAVE x HEM x LEAD x SEX	2	0.24
STIM x HEM x LEAD	4	1.72
STIM x HEM x LEAD x SEX	4	2.07
WAVE x STIM x HEM x LEAD	4	9.40***
WAVE x STIM x HEM x LEAD x SEX	4	2.27

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). SEX indicates grouped scores by Male and Female.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.7. N100 and P300 Multivariate Repeated Measures Analysis by Originality Rating

Source	df	F
WAVE	1	410.60***
WAVE x ORIGGRP	1	1.69
STIM	2	11.11***
STIM x ORIGGRP	2	0.88
HEM	1	4.22*
HEM x ORIGGRP	1	0.05
LEAD	2	4.34*
LEAD x ORIGGRP	2	0.39
WAVE x STIM	2	37.15***
WAVE x STIM x ORIGGRP	2	0.16
WAVE x HEM	1	0.30
WAVE x HEM x ORIGGRP	1	0.22
STIM x HEM	2	7.94***
STIM x HEM x ORIGGRP	2	0.73
WAVE x STIM x HEM	2	12.78***
WAVE x STIM x HEM x ORIGGRP	2	0.01
WAVE x LEAD	2	13.26***
WAVE x LEAD x ORIGGRP	2	2.77
STIM x LEAD	4	15.14***

Table D.7. Continued

STIM x LEAD x ORIGGRP	4	0.15
WAVE x STIM x LEAD	4	8.27***
WAVE x STIM x LEAD x ORIGGRP	4	0.52
HEM x LEAD	2	5.57**
HEM x LEAD x ORIGGRP	2	1.61
WAVE x HEM x LEAD	2	3.56*
WAVE x HEM x LEAD x ORIGGRP	2	0.74
STIM x HEM x LEAD	4	1.84
STIM x HEM x LEAD x ORIGGRP	4	2.18
WAVE x STIM x HEM x LEAD	4	9.51***
WAVE x STIM x HEM x LEAD x ORIGGRP	4	1.73

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*p< .05. **p< .01. ***p< .001.

Table D.8. N100 and P300 Multivariate Repeated Measures Analysis by Originality Rating – Male Data Only

Source	df	F
WAVE	1	141.32***
WAVE x ORIGGRP	1	0.14
STIM	2	12.79***
STIM x ORIGGRP	2	0.74
HEM	1	2.41
HEM x ORIGGRP	1	3.19
LEAD	2	1.02
LEAD x ORIGGRP	2	0.15
WAVE x STIM	2	45.84***
WAVE x STIM x ORIGGRP	2	0.05
WAVE x HEM	1	0.09
WAVE x HEM x ORIGGRP	1	0.16
STIM x HEM	2	6.92***
STIM x HEM x ORIGGRP	2	0.01
WAVE x STIM x HEM	2	6.56**
WAVE x STIM x HEM x ORIGGRP	2	0.11
WAVE x LEAD	2	8.21***
WAVE x LEAD x ORIGGRP	2	0.45
STIM x LEAD	4	4.77**

Table D.8. Continued

STIM x LEAD x ORIGGRP	4	1.57
WAVE x STIM x LEAD	4	3.30*
WAVE x STIM x LEAD x ORIGGRP	4	5.05***
HEM x LEAD	2	2.29
HEM x LEAD x ORIGGRP	2	1.11
WAVE x HEM x LEAD	2	2.56
WAVE x HEM x LEAD x ORIGGRP	2	0.09
STIM x HEM x LEAD	4	0.96
STIM x HEM x LEAD x ORIGGRP	4	2.16
WAVE x STIM x HEM x LEAD	4	3.96**
WAVE x STIM x HEM x LEAD x ORIGGRP	4	1.07

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.9. N100 and P300 Multivariate Repeated Measures Analysis by Composite Creativity Score – Male Data Only

Source	df	F
WAVE	1	154.67***
WAVE x CRGRP	1	0.01
STIM	2	14.08***
STIM x CRGRP	2	0.60
HEM	1	2.22
HEM x CRGRP	1	4.33*
LEAD	2	1.71
LEAD x CRGRP	2	0.29
WAVE x STIM	2	50.72***
WAVE x STIM x CRGRP	2	0.22
WAVE x HEM	1	0.06
WAVE x HEM x CRGRP	1	2.59
STIM x HEM	2	4.51*
STIM x HEM x CRGRP	2	0.90
WAVE x STIM x HEM	2	6.20**
WAVE x STIM x HEM x CRGRP	2	0.40
WAVE x LEAD	2	6.10**
WAVE x LEAD x CRGRP	2	0.22
STIM x LEAD	4	4.95**

Table D.9. Continued

STIM x LEAD x CRGRP	4	0.67
WAVE x STIM x LEAD	4	3.02*
WAVE x STIM x LEAD x CRGRP	4	0.30
HEM x LEAD	2	2.31
HEM x LEAD x CRGRP	2	1.47
WAVE x HEM x LEAD	2	1.29
WAVE x HEM x LEAD x CRGRP	2	0.44
STIM x HEM x LEAD	4	0.69
STIM x HEM x LEAD x CRGRP	4	0.13
WAVE x STIM x HEM x LEAD	4	4.24**
WAVE x STIM x HEM x LEAD x CRGRP	4	0.74

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on the composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.10. N100 and P300 Multivariate Repeated Measures Analysis by Originality Rating – Female Data Only

Source	df	F
WAVE	1	331.58***
WAVE x ORIGGRP	1	6.41*
STIM	2	4.12*
STIM x ORIGGRP	2	3.24
HEM	1	1.86
HEM x ORIGGRP	1	0.93
LEAD	2	4.37*
LEAD x ORIGGRP	2	1.12
WAVE x STIM	2	11.04***
WAVE x STIM x ORIGGRP	2	0.31
WAVE x HEM	1	0.20
WAVE x HEM x ORIGGRP	1	0.08
STIM x HEM	2	2.03
STIM x HEM x ORIGGRP	2	1.23
WAVE x STIM x HEM	2	6.17**
WAVE x STIM x HEM x ORIGGRP	2	0.14
WAVE x LEAD	2	6.15**
WAVE x LEAD x ORIGGRP	2	2.25
STIM x LEAD	4	11.25***

Table D.10. Continued

STIM x LEAD x ORIGGRP	4	0.65
WAVE x STIM x LEAD	4	4.85**
WAVE x STIM x LEAD x ORIGGRP	4	0.70
HEM x LEAD	2	4.00*
HEM x LEAD x ORIGGRP	2	4.19*
WAVE x HEM x LEAD	2	1.14
WAVE x HEM x LEAD x ORIGGRP	2	1.68
STIM x HEM x LEAD	4	4.74**
STIM x HEM x LEAD x ORIGGRP	4	0.90
WAVE x STIM x HEM x LEAD	4	7.10***
WAVE x STIM x HEM x LEAD x ORIGGRP	4	3.10*

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table D.11. N100 and P300 Multivariate Repeated Measures Analysis by Composite Creativity Score – Female Data Only

Source	df	F
WAVE	1	265.76***
WAVE x CRGRP	1	0.02
STIM	2	4.63*
STIM x CRGRP	2	4.51*
HEM	1	2.40
HEM x CRGRP	1	6.61*
LEAD	2	4.92*
LEAD x CRGRP	2	2.84
WAVE x STIM	2	12.01***
WAVE x STIM x CRGRP	2	1.72
WAVE x HEM	1	0.25
WAVE x HEM x CRGRP	1	0.80
STIM x HEM	2	2.27
STIM x HEM x CRGRP	2	2.46
WAVE x STIM x HEM	2	6.04**
WAVE x STIM x HEM x CRGRP	2	0.27
WAVE x LEAD	2	5.11**
WAVE x LEAD x CRGRP	2	2.05
STIM x LEAD	4	10.79***

Table D.11. Continued

STIM x LEAD x CRGRP	4	1.15
WAVE x STIM x LEAD	4	4.82**
WAVE x STIM x LEAD x CRGRP	4	1.37
HEM x LEAD	2	3.24
HEM x LEAD x CRGRP	2	1.10
WAVE x HEM x LEAD	2	1.18
WAVE x HEM x LEAD x CRGRP	2	1.92
STIM x HEM x LEAD	4	4.82**
STIM x HEM x LEAD x CRGRP	4	0.77
WAVE x STIM x HEM x LEAD	4	5.46
WAVE x STIM x HEM x LEAD x CRGRP	4	0.35

Note. WAVE indicates waveform (N100 or P300). STIM TYPE indicates Stimulus Type (A, B, Novel). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on the composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Appendix E - Experiment Three

Table E.1. N400 Multivariate Repeated Measures Analysis by Adjective Checklist

Source	df	F
STIM	1	3.40
STIM x ACL	1	0.46
HEM	1	0.81
HEM x ACL	1	1.41
ELECLOC	2	0.20
ELECLOC x ACL	2	0.42
STIM x HEM	1	1.38
STIM x HEM x ACL	1	0.14
STIM x ELECLOC	2	4.47*
STIM x ELECLOC x ACL	2	0.14
HEM x ELECLOC	2	4.42*
HEM x ELECLOC x ACL	2	1.64
STIM x HEM x ELECLOC	2	0.06
STIM x HEM x ELECLOC x ACL	2	0.46

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ACL indicates grouped scores on the Adjective Checklist.

*p< .05. **p< .01. ***p< .001.

Table E.2. N400 Multivariate Repeated Measures Analysis by Remote Associates Test

Source	df	F
STIM	1	3.56
STIM x RAT	1	1.04
HEM	1	1.12
HEM x RAT	1	5.96*
ELECLOC	2	0.23
ELECLOC x RAT	2	0.18
STIM x HEM	1	1.44
STIM x HEM x RAT	1	0.02
STIM x ELECLOC	2	4.39*
STIM x ELECLOC x RAT	2	0.03
HEM x ELECLOC	2	4.11*
HEM x ELECLOC x RAT	2	0.70
STIM x HEM x ELECLOC	2	0.04
STIM x HEM x ELECLOC x RAT	2	0.21

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). RAT indicates grouped scores on the Remote Associates Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.3. N400 Multivariate Repeated Measures Analysis by Word Association Test

Source	df	F
STIM	1	2.53
STIM x WORD	1	0.00
HEM	1	1.16
HEM x WORD	1	0.87
ELECLOC	2	0.59
ELECLOC x WORD	2	0.02
STIM x HEM	1	2.53
STIM x HEM x WORD	1	0.32
STIM x ELECLOC	2	7.80***
STIM x ELECLOC x WORD	2	0.27
HEM x ELECLOC	2	3.89*
HEM x ELECLOC x WORD	2	1.85
STIM x HEM x ELECLOC	2	0.02
STIM x HEM x ELECLOC x WORD	2	0.13

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). WORD indicates grouped scores on the Word Association Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.4. N400 Multivariate Repeated Measures Analysis by Alternate Uses Test

Source	df	F
STIM	1	3.06
STIM x AUT	1	0.04
HEM	1	0.68
HEM x AUT	1	0.24
ELECLOC	2	0.14
ELECLOC x AUT	2	1.84
STIM x HEM	1	1.78
STIM x HEM x AUT	1	1.24
STIM x ELECLOC	2	4.80**
STIM x ELECLOC x AUT	2	0.76
HEM x ELECLOC	2	4.71**
HEM x ELECLOC x AUT	2	2.65
STIM x HEM x ELECLOC	2	0.00
STIM x HEM x ELECLOC x AUT	2	3.62*

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). AUT indicates grouped scores on the Alternate Uses Test.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.5. N400 Multivariate Repeated Measures Analysis by Shipley Institute of Living Scale

Source	df	F
STIM	1	3.46
STIM x SHIP	1	1.10
HEM	1	0.52
HEM x SHIP	1	0.84
ELECLOC	2	0.31
ELECLOC x SHIP	2	0.67
STIM x HEM	1	1.57
STIM x HEM x SHIP	1	0.26
STIM x ELECLOC	2	4.28*
STIM x ELECLOC x SHIP	2	0.20
HEM x ELECLOC	2	3.72*
HEM x ELECLOC x SHIP	2	0.00
STIM x HEM x ELECLOC	2	0.03
STIM x HEM x ELECLOC x SHIP	2	0.27

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). SHIP indicates grouped scores on the Shipley Institute of Living Test (intellectual functioning measure).

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.6. N400 Multivariate Repeated Measures Analysis by Sex

Source	df	F
STIM	1	3.18
STIM x SEX	1	0.36
HEM	1	0.61
HEM x SEX	1	0.32
ELECLOC	2	0.27
ELECLOC x SEX	2	2.32
STIM x HEM	1	1.55
STIM x HEM x SEX	1	2.48
STIM x ELECLOC	2	4.39*
STIM x ELECLOC x SEX	2	2.02
HEM x ELECLOC	2	3.90*
HEM x ELECLOC x SEX	2	1.93
STIM x HEM x ELECLOC	2	0.03
STIM x HEM x ELECLOC x SEX	2	2.32

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). SEX indicates grouped scores by Male and Female.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.7. N400 Multivariate Repeated Measures Analysis by Originality Rating

Source	df	F
STIM	1	2.83
STIM x ORIGGRP	1	2.52
HEM	1	0.50
HEM x ORIGGRP	1	0.14
ELECLOC	2	0.44
ELECLOC x ORIGGRP	2	4.28*
STIM x HEM	1	1.83
STIM x HEM x ORIGGRP	1	1.11
STIM x ELECLOC	2	4.53*
STIM x ELECLOC x ORIGGRP	2	2.44
HEM x ELECLOC	2	3.66*
HEM x ELECLOC x ORIGGRP	2	2.52
STIM x HEM x ELECLOC	2	0.06
STIM x HEM x ELECLOC x ORIGGRP	2	4.19*

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.8. N400 Multivariate Repeated Measures Analysis by Composite Creativity Score – Male Data Only

Source	df	F
STIM	1	1.48
STIM x CRGRP	1	0.06
HEM	1	2.15
HEM x CRGRP	1	0.00
ELECLOC	2	0.66
ELECLOC x CRGRP	2	0.77
STIM x HEM	1	8.57**
STIM x HEM x CRGRP	1	0.26
STIM x ELECLOC	2	4.63*
STIM x ELECLOC x CRGRP	2	0.98
HEM x ELECLOC	2	0.75
HEM x ELECLOC x CRGRP	2	2.65
STIM x HEM x ELECLOC	2	1.90
STIM x HEM x ELECLOC x CRGRP	2	0.47

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.9. N400 Multivariate Repeated Measures Analysis by Originality Rating – Male Data Only

Source	df	F
STIM	1	1.83
STIM x ORIGGRP	1	1.17
HEM	1	0.71
HEM x ORIGGRP	1	0.08
ELECLOC	2	0.66
ELECLOC x ORIGGRP	2	1.13
STIM x HEM	1	5.26*
STIM x HEM x ORIGGRP	1	0.56
STIM x ELECLOC	2	2.71
STIM x ELECLOC x ORIGGRP	2	2.22
HEM x ELECLOC	2	0.42
HEM x ELECLOC x ORIGGRP	2	1.30
STIM x HEM x ELECLOC	2	3.51*
STIM x HEM x ELECLOC x ORIGGRP	2	5.14**

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.10. N400 Multivariate Repeated Measures Analysis by Composite Creativity Score – Female Data Only

Source	df	F
STIM	1	0.78
STIM x CRGRP	1	0.49
HEM	1	0.01
HEM x CRGRP	1	0.32
ELECLOC	2	2.27
ELECLOC x CRGRP	2	7.33***
STIM x HEM	1	0.02
STIM x HEM x CRGRP	1	1.16
STIM x ELECLOC	2	3.53*
STIM x ELECLOC x CRGRP	2	1.06
HEM x ELECLOC	2	5.68**
HEM x ELECLOC x CRGRP	2	4.28*
STIM x HEM x ELECLOC	2	0.74
STIM x HEM x ELECLOC x CRGRP	2	0.14

Note STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). CRGRP indicates grouped scores on composite creativity score.

*$p < .05$. **$p < .01$. ***$p < .001$.

Table E.11. N400 Multivariate Repeated Measures Analysis by Originality Rating – Female Data Only

Source	df	F
STIM	1	0.89
STIM x ORIGGRP	1	1.22
HEM	1	0.02
HEM x ORIGGRP	1	0.08
ELECLOC	2	1.63
ELECLOC x ORIGGRP	2	3.26*
STIM x HEM	1	0.05
STIM x HEM x ORIGGRP	1	0.76
STIM x ELECLOC	2	3.19
STIM x ELECLOC x ORIGGRP	2	0.90
HEM x ELECLOC	2	5.56**
HEM x ELECLOC x ORIGGRP	2	1.07
STIM x HEM x ELECLOC	2	0.83
STIM x HEM x ELECLOC x ORIGGRP	2	1.85

Note. STIM indicates Stimulus Type (Incongruous, Congruous). HEM indicates Hemisphere (left, right). ELEC LOC indicates Electrode Location (Frontal, Central, Parietal). ORIGGRP indicates grouped scores on the rated story originality scores.

*$p < .05$. **$p < .01$. ***$p < .001$.

Appendix F – Paper and Pencil Test Instructions

Alternate Uses Test

On each of the next three pages will appear the name of a familiar object. Write down all the different ways you can think of in which the object might be used. Do not hesitate to write down whatever ways you can think of in which the object might be used as long as they are possible uses for the object. Try to be as original and creative as you can. Write each use on a separate line.

Brick

Shoe

Newspaper

Remote Associates Test

INSTRUCTIONS: In this test you are presented with three words and asked to find a fourth work which is related to all three. Write this word in the space to the right.

For example, what word do you think is related to these three?

A.	Cookies	Sixteen	Heart	________

The answer in this case is "sweet". Cookies are sweet; sweet is part of the phrase "sweet sixteen", and part of the word "sweetheart".

Here is another example:

B:	Poke	Go	Molasses	________

You should have written "slow" in the space provided. "slow Poke", "go slow", "slow as molasses". As you can see, the fourth word may be related tot he other three for various reasons.

Try these next two:

C.	Surprise	Line	Birthday	________
D.	Base	Snow	Dance	________

The answers are at the bottom of the page.

Now turn to page two and try this group of words. Many of these are not easy and you will have to think about some for a while. If you have trouble with some groups of three, go on to the next and come back to them later. You will have 30 Minutes.

Make sure your name is on this test.

The answers are: C: Party D: Ball

Page 2.

1.	stop	petty	sneak	______	1.
2.	elephant	lapse	vivid	______	2.
3.	lick	sprinkle	mines	______	3.
4.	shopping	washer	picture	______	4.
5.	stalk	trainer	king	______	5.
6.	sea	home	stomach	______	6.
7.	walker	main	sweeper	______	7.
8.	mouse	sharp	blue	______	8.
9.	envy	golf	beans	______	9.
10.	board	magic	death	______	10.
11.	athletes	web	rabbit	______	11.
12.	pot	butterflies	pump	______	12.
13.	bald	screech	emblem	______	13.
14.	note	dive	chair	______	14.
15.	cherry	time	smell	______	15.
16.	Southern	console	station	______	16.
17.	chocolate	fortune	tin	______	17.
18.	bass	complex	sleep	______	18.
19.	wicked	bustle	slick	______	19.
20.	skunk	kings	boiled	______	20.
21.	habit	pouch	road	______	21.
22.	soap	shoe	tissue	______	22.
23.	blood	music	cheese	______	23.
24.	room	Saturday	salts	______	24.
25.	widow	bite	monkey	______	25.
26.	chamber	staff	box	______	26.
27.	inch	deal	peg	______	27.
28.	puss	spit	spoiled	______	28.
29.	jump	kill	bliss	______	29.
30.	sore	shoulder	sweat	______	30.

Creative Personality Scale

Please check <u>all</u> of the words that you would use to describe yourself. Please check <u>only</u> the words that you would use to describe yourself.

1.	Affected	_____	16.	Intelligent	_____
2.	Capable	_____	17.	Interests-narrow	_____
3.	Cautious	_____	18.	Interests-wide	_____
4.	Clever	_____	19.	Inventive	_____
5.	Commonplace	_____	20.	Mannerly	_____
6.	Confident	_____	21.	Original	_____
7.	Conservative	_____	22.	Reflective	_____
8.	Conventional	_____	23.	Resourceful	_____
9.	Dissatisfied	_____	24.	Self-confident	_____
10.	Egotistical	_____	25.	Sexy	_____
11.	Honest	_____	26.	Sincere	_____
12.	Humorous	_____	27.	Snobbish	_____
13.	Individualistic	_____	28.	Submissive	_____
14.	Informal	_____	29.	Suspicious	_____
15.	Insightful	_____	30.	Unconventional	_____

Word Association Test

Please write down the first word that comes to your mind when you see each word in the following list.

1.	dark	
3.	table	
5.	spider	
7.	sickness	
9.	red	
11.	whistle	
13.	yellow	
15.	chair	
17.	head	
19.	salt	
21.	white	
23.	earth	
25.	black	
27.	justice	
29.	man	
31.	butterfly	
33.	butter	
35.	priest	
37.	bitter	
39.	doctor	
41.	sour	
43.	thief	
45.	scissors	
47.	trouble	
49.	bible	
51.	blue	
53.	bread	
55.	long	
57.	mutton	
59.	high	
61.	comfort	
63.	hungry	
65.	hard	
67.	eagle	
69.	needle	
71.	bed	
73.	river	
75.	smooth	
77.	working	
79.	ocean	
81.	cottage	
83.	sheep	
85.	thirsty	
87.	soldier	
89.	carpet	
91.	anger	
93.	light	
95.	square	

2.	deep	
4.	cheese	
6.	soft	
8.	eating	
10.	wish	
12.	king	
14.	sweet	
16.	slow	
18.	tobacco	
20.	baby	
22.	religion	
24.	dream	
26.	swift	
28.	heavy	
30.	stem	
32.	hammer	
34.	boy	
36.	hand	
38.	memory	
40.	green	
42.	bath	
44.	stove	
46.	foot	
48.	blossom	
50.	whiskey	
52.	beautiful	
54.	short	
56.	moon	
58.	city	
60.	loud	
62.	quiet	
64.	woman	
66.	rough	
68.	mountain	
70.	child	
72.	citizen	
74.	fruit	
76.	house	
78.	lamp	
80.	sleep	
82.	stomach	
84.	music	
86.	command	
88.	lion	
90.	health	
92.	cabbage	
94.	joy	
96.	street	

97.	window	
99.	cold	

98.	girl	
100.	afraid	

Shipley Institute of Living Scale – Vocabulary

In the test below, the first word in each line is printed in capital letters. Following that word are four other words. Circle the word that has the same meaning as the first word. Circle only one word in each line. A sample is provided below.

Sample

	LARGE	red	big	silent	wet
1.	TALK	draw	eat	speak	sleep
2.	PERMIT	allow	sew	cut	drive
3.	PARDON	forgive	pound	divide	tell
4.	COUCH	pin	eraser	sofa	glass
5.	REMEMBER	swim	recall	number	defy
6.	TUMBLE	drink	dress	fall	think
7.	HIDEOUS	silvery	tilted	young	dreadful
8.	CORDIAL	swift	muddy	leafy	hearty
9.	EVIDENT	green	obvious	skeptical	afraid
10.	IMPOSTER	conductor	officer	book	pretender
11.	MERIT	deserve	distrust	fight	separate
12.	FASCINATE	welcome	fix	stir	enchant
13.	INDICATE	defy	excite	signify	bicker
14.	IGNORANT	red	sharp	uninformed	precise
15.	FORTIFY	submerge	strengthen	vent	deaden
16.	RENOWN	length	head	fame	loyalty
17.	NARRATE	yield	buy	associate	tell
18.	MASSIVE	bright	large	speedy	low
19.	HILARITY	laughter	speed	grace	malice
20.	SMIRCHED	stolen	pointed	remade	soiled
21.	SQUANDER	tease	belittle	cut	waste

22.	CAPTION	drum	ballast	heading	ape
23.	FACILITATE	help	turn	strip	bewilder
24.	JOCOSE	humorous	paltry	fervid	plain
25.	APPRAISE	reduce	strewn	inform	delight
26.	RUE	eat	lament	dominate	cure
27.	DENIZEN	senator	inhabitant	fish	atom
28.	DIVEST	dispossess	intrude	rally	pledge
29.	AMULET	charm	orphan	dingo	pond
30.	INEXORABLE	untidy	involatile	rigid	sparse
31.	SERRATED	dried	notched	armed	blunt
32.	LISSOM	moldy	loose	supple	convex
33.	MOLLIFY	mitigate	direct	pertain	abuse
34.	PLAGIARIZE	appropriate	intend	revoke	maintain
35.	ORIFICE	brush	hole	building	lute
36.	QUERULOUS	maniacal	curious	devout	complaining
37.	PARIAH	outcast	priest	lentil	locker
38.	ABET	waken	ensue	incite	placate
39.	TEMERITY	rashness	timidity	desire	kindness
40.	PRISTINE	vain	sound	first	level

Shipley Institute of Living Scale – Abstraction

Complete the following by filling in either a number or a letter for each dash (__). Do the items in order, but don't spend too much time on any one item.

Example:

A B C D E

1. 1 2 3 4 5 ___
2. white black short long down ___ ___
3. AB BC CD D ___
4. Z Y x W V U ___
5. 1 2 3 2 1 2 3 4 3 2 3 4 5 4 3 4 5 6 ___ ___
6. NE/SW SE/NW E/W N/ ___
7. escape scape cape ___ ___ ___
8. oh ho rat tar mood ___ ___ ___ ___
9. A Z B Y C x D ___
10. tot tot bard drab 537 ___ ___ ___
11. mist is wasp as pint in tone ___ ___
12. 57326 73265 32657 26573 ___ ___ ___ ___ ___
13. knit in spud up both to stay ___ ___
14. Scotland landscape scapegoat ___ ___ ___ ___ ee
15. surgeon 1234567 snore 17635 rogue ___ ___ ___ ___ ___
16. tam tan rib rid rat raw hip ___ ___ ___
17. tar pitch throw saloon bar rod fee tip end plank ___ ___ ___ ___ ___ meals
18. 3124 82 73 154 46 13___

19. lag leg pen pin big bog rob ___ ___ ___

20. two w four r one o three ___

Handedness

1. Have you ever had any tendency towards left-handedness?	Yes	No
2. Which hand would you most often use to throw a ball to hit a target?	Right	Left
3. Which hand would you most often use to draw a picture?	Right	Left
4. Which hand would you most often use to erase something off of paper?	Right	Left
5. Which hand would you most often use to deal cards in a card game?	Right	Left
6. Which foot would you most often use to kick a ball?	Right	Left
7. Which foot would you most often use to pick up things with your toes?	Right	Left
8. Which foot would you step with first when starting up a staircase?	Right	Left
9. Which eye would you use most often to look through a keyhole?	Right	Left
10. If you had to look into a dark bottle to see how full it was, which eye would you use?	Right	Left
11. Which eye would you use most often to sight down a rifle?	Right	Left
12. If you wanted to listen to a conversation going on behind a closed door, which ear would you place against the door?	Right	Left
13. If you wanted to hear somebody's heartbeat, which ear would you place against their chest?	Right	Left
14. Into which ear would you place the earpiece of a transistor radio?	Right	Left

Informed Consent Form

Overview of the Study

For this study, all participants need to be at least 18 years of age. **I am at least 18 years of age**. I understand that this experiment involves two parts and **should take no longer than four hours**. It may distort the results of the study if I were told the complete nature of the experiment in the beginning. However, a complete explanation of the procedure and purpose of the research will be given to me after the experimental trial period is complete. The next two sections explain what I will be asked to do.

Part One – Filling out Questionnaires

For this part of the study, I will be asked to complete some thinking style tasks. The total time for completing these questionnaires is **approximately 1 ½ hours**. These thinking style tasks involve:

1. Thinking of uses for common objects (e.g., all the possible uses for a book)
2. Comparing three words with the goal of identifying a fourth word that is related to the first three words (e.g., Base, Snow, Dance are related through the word Ball)
3. Choosing the adjectives from a given list that describe me
4. Writing the first word that comes to me when I see each of 100 words
5. Choosing the synonym to a given word (e.g., the synonym for BIG is LARGE)
6. Completing a series with the next item in the series (e.g., A B C D E)

Part Two – Brain Wave Recording

This part of the study uses an electroencephalography (EEG) machine. I understand that before I begin this part of the study, there will be small metal disks attached to my scalp to allow recording of my brain wave activity while I complete six tasks. To attach the disks, it is necessary for the experimenter to mark the locations for the disks with a grease pencil and then lightly scrub my scalp to prepare the surface. Then, the disks will be held in place with a water-based gel and some surgical tape. I understand that once the disks are attached, I will be asked to remain relaxed and as motionless as possible, unless I choose to discontinue my participation in this research project. It takes approximately **½ hour** to attach all of the disks.

After the disks have been attached to my scalp, I will be asked to complete five tasks. The total time for completing the five tasks is **approximately 1 ¼ hours**. The tasks are described as follows:

1. I will be asked to think of a story about a topic I will be given. I will have five minutes to think of my story. Then, I will be asked to write down my story. I will be given five more minutes to write down my story.
2. I will be asked to solve 15 addition math problems. I will be shown a problem to solve (e.g., 354 + 298) and will be asked to give an answer to the problem as quickly as possible. If I cannot solve the problem, I can tell the experimenter and the next problem will be presented.
3. I will be asked to look at letters from the alphabet presented on a computer screen. I will be asked to count the total number of times that I see a particular letter. I will be asked at the end of this task how many times I saw the letter.

4. I will be asked to listen to tones presented through headphones. I will be asked to count the total number of times that I hear a particular tone. I will be asked at the end of the task how many times I heard the tone.
5. I will be asked to read the first part of sentence on a computer screen. Then, the last word for the sentence will be presented on the computer screen. I will be asked to read the last word as well. I understand that I will be asked to remember as much about each sentence that is presented as possible because I will be asked questions about the sentences after the task is complete.

What are the risks associated with participation in this project?

This research does not involve risk greater than that normally encountered in daily life or during the performance of routine psychological testing. However, there may be slight discomfort during the electrode (disk) application.

What are the benefits of participation in this project?

Most participants think that the main benefit of participation in this project is extra credit towards their PSY100 final grade. This research is also contributing to our understanding of the relationship between brain waves and thinking styles. The results will be used to develop a model of how different thinking styles can be reflected in brain waves.

What are my rights?

I have the right to refuse to participate or withdraw my participation at any time, as well as the right to refuse to answer any particular questions asked during the research project.

These refusals will not be penalized and there will be no loss of credit for research participation time allocated for the study. Also, no information which identifies me will be released without my separate consent.

I acknowledge that I have received a copy of this consent form, and my signature below indicates agreement to participate.

Participant's signature____

Date____

If I have any questions about the study, I may write or phone the office of the Project Investigator, Jonna Kwiatkowski, as 325 Little Hall, 581-2016.

Debriefing Form

This experiment was created to examine how people's brain activity is affected by multiple presentations of a stimulus. In past experiments, it was found that as a person became more comfortable with a stimulus, the parts of their brain that were activated by the stimulus shifted. We are interested in the same phenomenon, but have added measures of thinking style. Thinking style is the different ways people focus their attention during problem solving. Some people are better at focusing on the key elements of a problem, and therefore are better at solving problems with one clear solution. Others focus their attention less tightly, and are better at solving loosely-defined problems with more than one correct answer. We would like to compare the brain activity of those who focus their attention tightly versus those that focus their attention loosely. We expect to find that the brain activity of those with less focused attention will shift more slowly than the brain activity of those with more tightly focused attention.

If you have any further questions about this study, feel free to contact Jonna Kwiatkowski at 581-2016. Thank you for your time.

Appendix G – Experimenter Scripts for Neurophysiological Test

Experiment One – Record Baseline

FILENAME

c:\Testpt\Data\D###-open.txt

c:\Testpt\Data\D###-closed.txt

INSTRUCTIONS

1. This is always the first task
2. Explain that you want him/her to lie very still for five minutes with his/her eyes closed. Let him/her know that s/he should not talk during the five minutes. Also tell him/her that you will let him/her know when five minutes have passed.
3. To open the Eyes Closed program, click on the "Start" button in the lower left side of the screen, slide up to the "TestPoint" file at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Eyes Closed" file and click on it.
4. You will get a place to fill in a file name. Fill it in as follows: c:\Testpt\Data\D###-closed.txt
5. Explain that you want him/her to lie very still for five minutes with his/her eyes open. Let him/her know that s/he should not talk during the five minutes. Also tell him/her that you will let him/her know when five minutes have passed.
6. To open the Eyes Open program, click on the "Start" button in the lower left side of the screen, slide up to the "TestPoint" file at the top of the Start menu, slide over to

the "Research" file in the Testpoint menu, and finally slide down to the "Eyes Open" file and click on it.

7. You will get a place to fill in a file name. Fill it in as follows: c:\Testpt\Data\D###-open.txt

SCRIPT FOR EYES CLOSED

Okay. This first task is very easy. I want you to lie still for five minutes without talking with your eyes closed. I will tell you when five minutes have passed. Okay? Here we go.

(At the end)

Great!

SCRIPT FOR EYES OPEN

Okay. This program is similar to the last one. I want you to lie still for five minutes without talking. The only difference is that this time you should try to keep you eyes open. I will tell you when five minutes have passed. Okay? Here we go.

(At the end)

Great!

Experiment One – Creative Story

FILENAME

c:\Testpt\Data\D###-story.txt

c:\Testpt\Data\D###-write.txt

INSTRUCTIONS

1. There is no sample for this task
2. To open the Creative Story program, click on the "Start" button in the lower left side of the computer screen, slide up to the "Testpoint" folder at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Story" file and click on it.
3. You will see a welcome screen. Click on the "Real" button/
4. You will get a window for filling in the file name. Fill it in as follows: c:\Testpt\Data\D###-story.txt
5. Next, you will get a window of instructions. Read through the instructions for the subject.
6. Once the subject is ready, the program will start. The subject is supposed to think of a creative story for five minutes. At the end of five minutes, the computer will show a screen saying "Finished."
7. After thinking up the story for five minutes, the subject should be asked to sit up and write down the story s/he has thought up.
8. You should also record while the story is being written. To open the Write program, click on the "Start" button in the lower left side of the computer screen, slide up to the "Testpoint" folder at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Write" file and click on it.
9. You will see a welcome screen. Click on the "Real" button/

10. You will get a window for filling in the file name. Fill it in as follows:

    c:\Testpt\Data\D###-write.txt

11. Next, you will get a window of instructions. Read through the instructions for the subject.

12. Once the subject is ready, the program will start. The subject is supposed to write the creative story for five minutes. At the end of five minutes, the computer will show a screen saying "Finished."

SCRIPT FOR STORY

Okay. What I want you to do now is think of a creative story in your head. I will give you the topic for the story in a few minutes. It is important that you just think of the story in your head. Do not say it out loud. After five minutes, I will ask you to write your story down on paper. Do you have any questions? Okay. Let's go through the official instructions.

(THE FOLLOWING IS DISPLAYED ON THE COMPUTER SCREEN FOR THE PARTICIPANT, AND READ BY THE EXPERIMENTER)

For the next five minutes, I would like you to create a story about a topic that I will give you. You will have five minutes to think of the story in your mind. Your story should be as creative as possible. You should not talk while you are thinking of the story. You should keep your eyes closed while you are thinking of your story. After five minutes have passed, I will ask you to write down your creative story. You will have five more minutes to write the story down.

(At the end)

Okay. Now I am going to set up for you to write the story. (SET UP)

SCRIPT FOR WRITING

Okay. Now I want you to write the story you thought up. I need you to try to move as little as possible while you are writing. You should not talk out loud at all while you are writing. You should write for five minutes. I will let you know when your time is up. Do you have any questions? Okay. Let's go through the official instructions.

(THE FOLLOWING IS DISPLAYED ON THE COMPUTER SCREEN FOR THE PARTICIPANT, AND READ BY THE EXPERIMENTER)

For the next five minutes, I would like you to write down the story you created over the last five minutes. You will have five more minutes to write your story down. Remember that your story is supposed to be creative, and that your topic is "Between the Lines."

(At the end)

Okay. Your time is up. Good job. Let's move on to the next task.

Experiment One – Math Problems

FILENAME

c:\Testpt\Data\D###-math.txt

INSTRUCTIONS

1. There is no sample for this task
2. Explain that the computer is going to show addition problems that the participant should try to solve as quickly as possible.
3. Once the subject has solved the problem or 45 seconds has passed, the computer will display a black dot that the subject should look at until the next math problem appears.
4. To open the Math program, click on the "Start" button in the lower left side of the computer screen, slide up to the "Testpoint" folder at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Math" file and click on it.
5. You will see a welcome screen. Click on the "Real" button/
6. You will get a window for filling in the file name. Fill it in as follows: c:\Testpt\Data\D###-math.txt
7. Next, you will get a window of instructions. Read through the instructions for the subject.

SCRIPT FOR MATH PROBLEMS

Okay. For this program, the computer will display an addition problem that you should try to solve. An example of an addition problem is 693+942. You will be given 45 seconds to solve the problem. As soon as you solve the problem, you should say the answer. If you have not solved the problem in 45 seconds, the computer will move on to the next problem. Do you have any questions? Okay. Let's move onto the official instructions.

(At the end)

Great job. Let's move on to the next program.

Experiment Two – N100 and P300

FILE NAMES

Sample – c:\Testpt\Data\D###-ABsamp.txt

AB – c:\Testpt\Data\D###-ab.txt

c:\Testpt\Data\D###-ABnov.txt

INSTRUCTIONS

1. Always do a sample first
2. Explain that the computer is going to show him/her pictures of the letter A and pictures of the letter B. Ask him/her to count the total number of letter As and *at the end* you will ask him how many he counted. Remind him that he should count the number of As to himself.
3. To open the Count AB program, click on the "Start" button in the lower left side of the screen, slide up to the "TestPoint" file at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Count AB" file and click on it.
4. For the sample, click on the "Sample" button on the Welcome window.

5. For the sample, you will get a place to fill in a file name. Fill it in as follows:

   c:\Testpt\Data\D###-ABsamp.txt

6. After the sample, the program will close

7. Ask how many As he counted – record that number

8. Reopen the Count AB program

9. Click on the "Real" button on the Welcome window

10. For the sample, you will get a place to fill in a file name. Fill it in as follows:

    c:\Testpt\Data\D###-ab.txt

11. Ask how many As he counted – record that number

12. Explain that the computer is going to show him pictures of the letter A and pictures of the letter B. Ask him to count the total number of letter As and *at the end* you will ask him how many he counted. Remind him that he should count the number of As to himself. DO NOT tell him that there will be pictures of colored drawings.

13. To open the Count ABNovel program, click on the "Start" button in the lower left side of the screen, slide up to the "TestPoint" file at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Count ABNovel" file and click on it.

14. You will get a place to fill in a file name. Fill it in as follows: c:\Testpt\Data\D###-ABnov.txt

15. Ask how many As he counted – record that number

SCRIPT FOR SAMPLE

Okay _________________ before we start this program for real, I'm going to have you go through a sample run. What I'd like you to do is count the total number of A's that flash on the screen. I don't want you to count out loud. Count to yourself. After the program is finished, I will ask you how many A's you counted. Okay? Here we go.

(At the end)

Okay. How many A's did you count? __________________________________

(subject answers)

Great!

SCRIPT FOR AB

Okay. Now we are ready to begin for real. I want you to do the same thing this time. Just count the total number of A's that flash on the screen to yourself. At the end I will ask you how many you counted. Do you have any questions? Okay. Here we go.

(At the end)

Okay. How many A's did you count? ____________________________________

Great!

SCRIPT FOR ABNOVEL

Okay. This program is the same as the last one. I want you to just count the total number of A's that flash on the screen to yourself. At the end I will ask you how many you counted. Okay? Here we go.

(At the end)

Okay. How many A's did you count? ________________________________

(subject answers)

Great!

Experiment Three – N400

FILENAME

c:\Testpt\Data\D###-sent.txt

INSTRUCTIONS

1. There is no sample for this task
2. Explain that the computer is going to show the first part of a sentence for two seconds.
3. Then, the computer is going to show the last word in the sentence.
4. Ask him/her to read each sentence and try to remember it. Tell him/her that at the end s/he will be asked to remember the sentences.
5. To open the Sentences program, click on the "Start" button in the lower left side of the computer screen, slide up to the "Testpoint" folder at the top of the Start menu, slide over to the "Research" file in the Testpoint menu, and finally slide down to the "Sentence" file and click on it.
6. You will see a welcome screen. Click on the "Real" button/

7. You will get a window for filling in the file name. Fill it in as follows:

   c:\Testpt\Data\D###-sent.txt

8. Next, you will get a window of instructions. Read through the instructions for the subject.

SCRIPT FOR SENTENCES

Okay. For this program, you will see the first part of a sentence on the computer screen. Then, the last word of the sentence will appear by itself. I want you to read the first part of the sentence and the last word of the sentence. At the end, I will ask you to remember as many of the sentences as you can. Do you have any questions? Okay. Here we go.

(At the end)

Okay. When we finish all of the programs, I will ask you to remember the sentences. Good job.

BIOGRAPHY OF THE AUTHOR

Jonna Kwiatkowski was born in Toledo, Ohio on November 11, 1971. She was raised in Toledo, Ohio and graduated from Central Catholic High School. She attended Saint Mary's College, Notre Dame, IN and graduated in 1994 with a Bachelor's degree in Psychology, with minors in Computer Science and Mathematics. She worked as a computer programmer in Chicago until 1996 when she returned to school for graduate work. She entered the Psychology graduate program at The University of Maine in the fall of 1996.

After receiving her degree, Jonna will be continuing postdoctoral work at Yale University where she is responsible for the research on a U.S. Department of Education grant titled "Transitions in the Development of Giftedness." Jonna is a candidate for the Doctor of Philosophy degree in Psychology from The University of Maine in August, 2002.