AN EXAMINATION OF FACTORS UNDERLYING CREATIVITY

A THESIS
SUBMITTED TO THE GRADUATE SCHOOL
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE
MASTER OF ARTS CLINICAL PSYCHOLOGY

BY
BRIAN KRAUS

DR. STEPHANIE SIMON-DACK – ADVISOR

BALL STATE UNIVERSITY
MUNCIE, INDIANA
JULY, 2016
AN EXAMINATION OF FACTORS UNDERLYING CREATIVITY

A THESIS

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

MASTER OF ARTS CLINICAL PSYCHOLOGY

BY

BRIAN KRAUS

Committee Approval:

___________________________________ ___________________________
Committee Chairperson  Date

___________________________________ ___________________________
Committee Member  Date

___________________________________ ___________________________
Committee Member  Date

Departmental Approval:

___________________________________ ___________________________
Departmental Chairperson  Date

___________________________________ ___________________________
Dean of Graduate School  Date

BALL STATE UNIVERSITY
MUNCIE, INDIANA
JULY, 2016
An Examination of Factors Underlying Creativity

Creativity is the ability to conjure novel, unique solutions to a problem. In real life situations, this involves thinking of solutions that are not only practical but are also atypical compared to solutions typically generated by the general population. Despite the obvious benefits to creative thinking, the personality factors and traits associated with creativity and the underlying neural mechanisms are not well understood. Although certain personality traits have been associated with real life creativity, their exact role in facilitating creative achievement is unclear. Several of these personality traits have not only been shown to have a relationship to creativity but are also associated with symptoms of mental illnesses. Historically, there are many creative people who have suffered from mental illnesses, and this has led researchers to examine the relationship between creativity and mental illnesses (e.g. Andreasen, 2008). Studies have found that certain personality traits, such as positive schizotypal and hypomanic traits, are shared between highly creative individuals and those who suffer from psychopathology (Schuldberg, 2001; Furnham, Batey, Anand, & Manfield, 2008). This association has been theorized to be due to a shared vulnerability between those who are creative and those who suffer from psychopathology (Carson, 2011). Many studies have found that these personality traits that correlate with psychopathology also correlate with EEG activity during creative tasks (e.g. Folley & Park, 2005). Specifically, these tasks have been found to correlate with an increase in alpha (α) activity in both the frontal and parietal lobes (see Fink & Benedek, 2014). Alpha activity, representative of primarily serotonergic activity (Kaplan & Sadock, 1998), has been shown to correlate with attentional processes during task performance (Schürmann & Başar, 2001). The exact role of alpha activity during creative ideation is still uncertain, but it is currently posited that increases in alpha activity reflect higher demand of internal processing and
inward focused attention (Knyazev, 2007). Evidence from fMRI and EEG studies suggest that gamma (γ) activity may also play a role in creative cognition (Jung-Beeman et al., 2004; Nagornova, 2007). This paper examines the neural correlates of both personality traits and creative task performance. The focus will be on the influence of α and γ activity during creative task performance.

Creativity and Psychopathology

The relationship between creativity and mental illnesses has been examined in past analyses, and a correlation between mood disorders and creativity has been found (Andreasen, 2008). Other analyses have found evidence for elevated real life creativity in people with symptoms of bipolar disorders (Murray & Johnson, 2010). Bipolar disorders are defined as the presence of both a major depressive episode and a hypomanic episode for bipolar II disorder or the presence of just a manic episode for bipolar I disorder at some point during a person’s lifetime (American Psychiatric Association, 2013). A major depressive episode is defined as a period where an individual experiences symptoms such as a lack of drive, a loss of pleasure, and disturbances in their eating and sleeping habits for at least two consecutive weeks (American Psychiatric Association, 2013). A manic episode by contrast is defined as a period where an individual experiences symptoms such as an elevated mood, psychomotor agitation, and disruption in eating and sleeping habits for at least one week. A hypomanic episode is characterized by the same symptoms but they only must be present for four days instead of one week (American Psychiatric Association, 2013). The relationship between the severity of a mental disorder and increased creativity has been difficult to establish. For example, research has shown that having an elevated risk of bipolar disorder is related to increased performance on creativity tasks (Furnham et al., 2008). Bipolar disorders constitute several different diagnoses.
Bipolar I disorder is the most severe form of the disorder, bipolar II disorder is less debilitating and cyclothymic disorder is the least severe version of the disorder (American Psychiatric Association, 2013). There is evidence that those diagnosed with less severe forms of bipolar disorder, such as cyclothymic disorder and bipolar II disorder, tend to show increased creativity compared to those diagnosed with bipolar I disorder (Richards, Kinney, Benet, & Merzel, 1988). In a study correlating bipolar disorder and lifetime achievement, those diagnosed with cyclothymia and family members of those with bipolar disorder both had greater creative accomplishments than those diagnosed with bipolar I disorder, who did not score higher than controls (Richards et al., 1988). Because bipolar disorder is partially caused by genetics, this suggests that relatives of people who suffer from bipolar disorder should also possess some of the personality traits as those who are diagnosed with bipolar disorder. Because the relationship between symptom severity and creativity is unimodal and not linear in nature (Richards et al., 1988), it is plausible that it is not the mood disorders themselves but specific characteristics of them that facilitate creativity.

There is also evidence for increased creativity in individuals with schizotypal traits. These traits are encompassed by the schizophrenia spectrum disorders in the DSM 5 (American Psychiatric Association, 2013). The common traits of these disorders are positive symptoms including delusions and hallucinations, and negative symptoms such as catatonia and anhedonia (American Psychiatric Association, 2013). These symptoms are categorized as positive because they add content to sensory experience while negative symptoms reduce the content of sensory experience (American Psychiatric Association, 2013). A study by Schuldberg (2001) found a positive correlation between scores on measures of schizotypal symptoms and scores on five creative tasks. Another study found a positive correlation between scores on a measure of
schizotypal symptoms and unique responses on creativity tasks (Green & Williams, 1999). As seen in bipolar disorder, those with more severe schizotypal symptomology demonstrate less real life creative achievement than first degree relatives and offspring of those diagnosed with schizophrenia (Karlsson, 1984). This evidence suggests that like bipolar disorder, there are aspects of schizotypal ideation that contribute to creative thinking.

Because people with symptoms of both schizotypal and bipolar disorders express both positive and negative symptomatology, it is unclear from the results of these studies which specific symptoms of the disorders are associated with creativity. However, no significant correlation has been found between real life creative achievement and depressive symptoms (Silvia & Kimbrel, 2010), suggesting that only the positive symptoms of mood disorders, such as bipolar disorder, correlate with increased creativity. Supporting this idea, in a meta-analysis Baas, De Dreu, and Nijstad (2008) found no supporting evidence for negative affect positively correlating with creativity. A similar pattern was found for schizotypal and bipolar-related traits in a study by Schuldberg (2001), which found that only hypomanic symptoms, impulsivity nonconformity, and positive schizotypal ideation correlated positively with creative task performance, while depressive and anhedonic symptoms had a negative correlation with creative task performance. These studies offer evidence that it is the positive symptoms of bipolar and schizotypal disorders that correlate with increased creativity.

The shared vulnerability model (Carson, 2011) attempts to explain the relationship between creativity, intelligence, and psychopathology. The shared vulnerability model posits that creativity and psychopathology share an underlying genetic vulnerability. According to the model, the three common characteristics between creative individuals and those diagnosed with psychopathology are reduced latent inhibition, increased novelty seeking, and neural
FACTORS UNDERLYING CREATIVITY

hyperconnectivity (Carson, Peterson, & Higgins, 2003). This neural hyperconnectivity has been shown to occur between the default mode network and the precuneus as well as the medial prefrontal cortex for both schizophrenic patients and their relatives (Whitfield-Gabrieli et al., 2009). These three qualities that comprise the shared vulnerability model increase both creativity and the likelihood of being diagnosed with psychopathology. The model considers increased intelligence as a protective factor against psychopathology. Those who have an IQ higher than 120, an above average working memory capacity, and higher than average cognitive flexibility are theorized to be better protected from severe psychopathology, while still enjoying the benefits of creativity (Carson, 2011).

Creativity, Affect, and Personality Traits

A distinction is often made in creativity literature between Big-C for real life creativity and little-c for task creativity (Johnson et al., 2012). Big-C creativity is defined as real life creative achievement, such as publishing books or creating artwork, while little-c creativity is operationalized as task-related creativity in a laboratory setting. Many studies have examined the relationship between personality characteristics associated with both the positive symptoms of bipolar and schizotypal disorders and with both measures of Big-C and little-c creativity. One study found that hypomanic traits as assessed by the Hypomanic Personality Scale (HPS) (Eckblad, & Chapman, 1986) were the best predictor of both self-report of creativity and performance on a divergent thinking task (Furnham et al., 2008). Divergent creativity is defined as the ability to generate unique answers to a question that has a multitude of correct answers. The results of this study suggest that a relationship exists between elevated hypomanic symptoms and increased creativity. A moderate positive correlation has also been found between openness to experience and the likelihood of choosing a creative occupation (Feist, 1998).
Openness to experience has also been positively correlated with performance on divergent thinking tasks (McCrae & Ingraham, 1987) and with scores on self-report measures of hypomania (Kwapil et al., 2000). In addition to openness to experience, the FFM facet of neuroticism has also been shown to correlate with creativity (Burch, Pavelis, Hemsley, & Corr, 2006). Recent research has also suggested that there is an interaction between intelligence and openness to experience as it relates to creative potential. A study by Jauk, Benedek, Dunst, and Neubauer (2013) showed that for those with an IQ above 104, openness to experience was a significant indicator of creative potential. These results suggest that the personality characteristics of openness to experience and hypomania are related to a person’s level of creativity.

Intelligence is also believed to play a role in creativity (Guilford, 1967). One study found that intelligence levels predicted creative achievement in everyday life but did not predict participation in everyday creative activities, suggesting that intelligence may correlate with lifetime creative achievement but not increased creative interests (Jauk, Benedek, & Neubauer, 2013). A meta-analysis found a small positive correlation between intelligence test scores and creativity test scores (Kim, 2005). Because openness to experience has been shown to correlate with Big-C creativity (Kwapil et al., 2000), these results support the threshold hypothesis, which states that above average intelligence is a necessary but not sufficient component of Big-C creativity (Guilford, 1967). Essentially, above average intelligence is a necessary component of creative potential and creative achievement, but its presence does not ensure high creative achievement. This theory is congruent with the shared vulnerability model (Carson, 2011) and suggests that hypomania, openness to experience, and intelligence are all related to real life creative achievement.
Creativity and Qualitative Electroencephalography

Past Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) studies have examined creativity in many ways (see Arden, Chavez, Grazioplene, & Jung, 2010, and Fink, Benedek, Grabner, Staudt, & Neubauer, 2007 for a review). However, many of these studies used creative tasks that have never been replicated, and thus their efficacies as effective measures of creativity are questionable. Two of the more frequently used tasks for assessing creativity in these studies have been the Remote Associates Test (RAT) (Mednick, 1962), which measures convergent creativity and the Alternative Uses Test (AUT) (Guilford, 1967), which measures divergent creativity. Convergent creativity tasks such as the RAT (Mednick, 1962) require participants to arrive at one correct answer while divergent creativity tasks (Guilford, 1967) generally require participants to generate as many unique responses as possible.

The data from this study will be analyzed using a technique known as time-frequency analysis (TFA) (Qian & Chen, 1999). TFA is a type of spectral analysis that breaks small sections of continuous EEG data down into frequencies based on the oscillations of certain types of brain activity. These oscillations are defined in terms of Hz, which represents the amount of cycles that occur per second. These oscillations in electrical activity are picked up by the electrodes inserted into the cap worn on the scalp of the participant. The specific frequency bands of interest when analyzing EEG data are the delta, theta, alpha, beta, and gamma frequency bands (Kaplan & Sadock, 1998). The delta (δ) band is generally defined as being between 1-4 Hz and represents subcortical activity that EEG is not well suited to measure (Kaplan & Sadock, 1998). The theta (θ) band is generally defined as being between 4-8 Hz and represents clusters of cholinergic neuron activity, which are primarily excitatory (Kaplan & Sadock, 1998). The alpha (α) band is generally defined as being between 8-13 Hz and represents...
FACTORS UNDERLYING CREATIVITY

clusters of serotonergic neuron activity, which are primarily inhibitory (Kaplan & Sadock, 1998). The beta (β) band is generally defined as being between 13-28 Hz and represents clusters of GABAergic neuron activity, which are primarily inhibitory (Kaplan & Sadock, 1998). The gamma (γ) band is generally defined as being between 28-50 Hz and represents clusters of dopaminergic and glutamatergic neuron activity, which are primarily excitatory (Kaplan & Sadock, 1998). Using spectral analysis to break EEG data into its frequency bands allows for the measurement of increased (excitatory) or decreased (inhibitory) activity in cortical areas as a result of task performance (Muthuswamy & Thakor, 1998). By clustering electrodes, specific cortical areas (e.g. the right parietal lobe) can be examined for fluctuations in excitatory or inhibitory activity, which implicates their involvement during task performance (Muthuswamy & Thakor, 1998). In past studies of creativity, the α-band has been broken up into two separate bands, a high (10-12 Hz) and low band (8-10 Hz) (Fink et al., 2009). The activity of the γ and both α-bands will be focus of this study.

Past EEG research on convergent and divergent measures of creativity has found increased frontal lobe α synchronization during task performance (Fink et al., 2009). As the frontal lobe is decidedly implicated in problem solving and executive functioning (Scott & Schoenberg, 2011), increased α synchronization reflects an increased level of inhibition which could be a mechanism for the reduction of extraneous thoughts into working memory. This effect has been found for both lower and upper alpha bands (Fink et al., 2009; Benedek, Bergner, Könen, Fink, & Neubauer, 2011) and for the entire alpha band (Benedek, Schickel, Jauk, Fink, & Neubauer, 2014). When the alpha band has been separated into upper and lower bands, the upper band tends to show greater synchronization than the lower band (Fink et al., 2009; Benedek et al., 2011). However, this finding has not been consistent for convergent tasks, as other studies
have reported decreased frontal lobe $\alpha$ synchronization during convergent task performance (e.g. Benedek et al., 2014). The results of a study by Benedek et al. (2011) suggest that the degree of frontal $\alpha$ synchronization is at least partially dependent on the cognitive load of the task and not purely due to creative ideation. The study used two conditions to compare a convergent task where participants solved a word anagram. In one condition, the anagram stayed on the screen during the entire response period (the Low Internal Processing, or LIP condition) while in the other condition it was removed from the screen 500 ms after presentation (the High Internal Processing, or HIP condition). The LIP condition showed significantly less $\alpha$ synchronization than the HIP condition for the convergent task. On the divergent task in the same experiment, no significant differences in $\alpha$ synchronization were found between the two conditions. The authors posited that this was because divergent tasks require more internal processing than convergent tasks regardless of the presence of external stimuli. In another study, the authors used transcranial Alternating Current Stimulation (tACS) in order to enhance alpha band activations during performance on a creative task (Lustenberger, Boyle, Foulser, Mellin, & Fröhlich, 2015). The authors found that performance on the figural task section of the Torrance Test of Creative Thinking (TTCT; Torrance, 1966) was significantly better during tACS stimulation than during sham stimulation. Because of this conflicting evidence, it is still unclear whether increased frontal $\alpha$ synchronization is directly related to creativity or the result of other cognitive processes such as a high internal cognitive load or inward focused attention.

Past EEG research has also found an increase in bilateral parietal lobe upper-band $\alpha$ synchronization for divergent measures of creativity but not for convergent measures of creativity (Fink et al., 2009; Benedek et al., 2014). The parietal lobe is responsible for creating and forming associations between different stimuli and thus this increased $\alpha$ synchronization
could reflect the processes that underlie the formation of associations (Benedek, Könen, & Neubauer, 2012). Like the findings for the frontal lobe, this effect has been found for both upper and lower alpha bands (Fink et al., 2009; Benedek et al., 2011) as well as the whole alpha band (Benedek et al., 2014) and when the alpha band has been separated the upper alpha band has shown a greater effect than the lower alpha band (Fink et al., 2009; Benedek et al., 2011).

Convergent thinking tasks have been shown to correlate with a decrease in parietal-occipital α synchronisation during task performance (Benedek et al., 2014; Fink et al., 2009). However, there is also evidence that convergent thinking tasks in HIP conditions show greater parietal-occipital right hemisphere α synchronisation (or less α desynchronisation) when compared to LIP conditions (Benedek et al., 2014). A different pattern emerges for divergent creative thinking tasks. Many studies have found increased parietal-occipital α synchronisation during divergent creative task performance (Fink et al., 2009; Benedek et al., 2011; Benedek et al., 2014). One study also found that on a divergent creativity task, specifically an Alternative Uses Task (AUT) where participants named as many uses for an everyday object that they could think of, participants with more creative answers showed increased parietal and occipital α synchronisation in the right hemisphere versus the left hemisphere (Fink et al., 2009). This asymmetrical right hemisphere parietal-occipital α synchronisation has also been found in HIP conditions versus LIP conditions of convergent (Benedek et al., 2014) and divergent (Benedek et al., 2011) thinking tasks suggesting that it may reflect an increased amount of inward focused attention (Benedek et al., 2011) across creativity tasks. It has been suggested that this pattern of results is due to divergent creativity tasks mostly relying on internal attentional processes and convergent creativity tasks mostly relying on external attentional processes (Benedek et al., 2014), except in cases of high internal processing. Taken together, these results point to the idea
that tasks that require external cues beyond their presentation should show decreased parietal \( \alpha \) synchronization and that difficult tasks where the stimuli can be easily internalized should show increased parietal \( \alpha \) synchronization regardless of whether external cues are present. In addition, individuals with more creative answers and conditions with higher internal processing loads should also show asymmetrical parietal \( \alpha \) synchronization with the right hemisphere showing increased \( \alpha \) power. As with frontal \( \alpha \) synchronization, it is unclear whether parietal \( \alpha \) synchronization is directly related to creativity or is a result of other cognitive processes.

Past research suggests that increased frontal \( \alpha \) activity may be due to focused inward attention and that increased parietal \( \alpha \) activity may be due to both the inhibition of visual information and to the process of memory search and retrieval and is not unique to creative tasks (Fink & Benedek, 2014). It has been posited that upper \( \alpha \)-band synchronization reflects increased inward processing demands and/or increased inward focused attention (Knyazev, 2007) and thus does not have any particular relation to creative cognition specifically. However, recent evidence using tACS has suggested that this increase in power in the \( \alpha \) frequency band may be directly correlated to increased creative task creativity (Lustenberger et al., 2015). It is still uncertain whether this increase in frontal or parietal lobe \( \alpha \) synchronization during creative task performance is directly related to creative ideation.

In addition to increased \( \alpha \) synchronization, there is evidence that increased \( \gamma \) synchronization may also occur as a result of creative ideation. While there is an extensive literature for creative task performance and alpha activity (Fink & Benedek, 2014), there is much less evidence for gamma activity during creative task performance (see Arden et al., 2010). Several studies have found a diffuse increase in gamma activation during qualitative EEG for creative tasks versus control tasks (Nagornova, 2007; Shemyakina, Danko, Nagornova,
In addition, genetics research has found that genes affecting the expression of both serotonin (α) and dopamine (γ) receptors/transporters have a relationship with real life creativity (see Carson, 2011 for a brief review). These studies provide evidence that gamma activity may be involved in creative ideation.

Past fMRI research has identified cortical areas that increase and decrease in activation during working memory task performance. In a study by Fox et al. (2005) examining a neural network that mediates the activity of the default network during task performance, the intraparietal sulcus (IPS), frontal eye fields (FEF), and middle temporal cortex (MT) all showed increased activation while the medial prefrontal cortex (MPFC), posterior cingulate cortex (PCC), and lateral parietal cortex (LP) all showed decreased activation during a resting fMRI. These areas’ activations were all correlated with each other, suggesting that they are part of a network that is activated, or deactivated depending on the brain region, during complex working memory tasks. In another fMRI study, Whitfield-Gabrieli et al. (2009) measured the functional connectivity between schizophrenic patients, relatives, and controls both during rest and during working memory tasks in the regions identified by Fox et al. (2005) as having decreased activation during task performance. Whitfield-Gabrieli et al. (2009) found that schizophrenic patients and their relatives showed significantly less deactivation during working memory tasks versus rest in both the MPFC and PCC but not in the LP. In addition, their results showed that increased activation occurred in the dorsolateral prefrontal cortex (DLPFC) for patients and relatives versus controls during task performance. They also found that there was significantly increased functional connectivity between the MPFC and PCC and the default network in schizophrenic patients and their relatives versus controls. This provides evidence that those with
schizotypal traits show abnormalities in cortex function and functional connectivity and that there may be a difference in DLPFC activity for individuals with schizotypal ideation versus controls. Another study found increased $\gamma$ activity in the region of the right DLPFC during an insight task both when correct solutions were compared against incorrect solutions and when tasks were solved with the help of a hint (Sheth, Sandkühler, & Bhattacharya, 2009). This provides evidence that increased activity in the right DLPFC may correlate with increased $\gamma$ activity during creative task performance. In another study by Jung-Beeman et al. (2004), fMRI was used to identify an increase in right temporal lobe activation, specifically in the right anterior superior temporal gyrus, during problems solved with an insight solution versus problems that were not solved with insight. When this activation was subsequently investigated with EEG recording in the same paper, it was found that increased gamma activity right before the insight solution occurred in the same region as the increased activation seen with fMRI. This provides evidence that gamma activity is involved in creative cognition and that increased activity with an fMRI can correlate with increased gamma activity as recorded with an EEG during creative task performance. The results of Fox et al. (2005) also found an increase in fMRI activity in the MT cortex providing additional evidence that this area may increase in excitatory activity during task performance. In addition to the DLPFC, the Inferior Frontal Gyrus (IFG) has also been shown to increase in activation during fMRI of creative tasks (Beaty et al., 2014), more specifically in the left hemisphere (Benedek et al., 2014). Together, these results provide evidence that creative tasks may elicit increased $\gamma$ synchronization in the DLPFC, especially in the right hemisphere, and in the IFG, especially in the left hemisphere as well as in the temporal lobes.
Current Study

As discussed above, increased frontal $\alpha$ synchronization is hypothesized to be due to inward focused attention and increased parietal $\alpha$ synchronization is hypothesized to be due to increased inward focused attention and processes related to searching for and retrieving memories (Fink & Benedek, 2014). In neither of these hypotheses are creative processes believed to correlate exclusively with increased $\alpha$ synchronization. This study is designed to directly test if lower or upper $\alpha$-band synchronization is uniquely correlated with creative task performance. In order to test if these processes do correlate exclusively with creativity, cognitively analogous processes that are not creative in nature must be used to compare to convergent and divergent creativity tasks.

In this study, convergent creativity will be assessed using a modified version of the RAT (Mednick, 1962), the Compound Remote Associates test (CRA) (Bowden & Beeman, 2003). The CRA works by presenting participants with three words, (e.g. cream, cube, pick) and the participants must pick the word that fits best by forming a novel association using all three words. In the example above, the answer would be “ice” as in ice cream, ice cube, and ice pick. As a comparison, participants will be answering a series of questions about general knowledge and historical facts. These two tasks should be analogous except that the CRA is assessing for a convergent creative answer and the comparison task is assessing for a convergent non-creative answer. The CRA is a novel task for participants, while correctly recalling a historical or general fact is not. In both tasks, participant’s attention should be focused on the stimulus rather than internally, because the stimulus has important clues about the solution to the task. These two tasks should be analogous except for the CRA is assessing for a convergent creative answer and the comparison task is assessing for a convergent non-creative answer. Therefore, an increase in
the amount of frontal or parietal $\alpha$ synchronization on the CRA versus the comparison task would suggest that $\alpha$-band activity is directly related to creative cognition for convergent creativity.

Divergent creativity will be assessed using the AUT (Guilford, 1967). The AUT works by presenting participants with an object (e.g. a brick) and having participants name every use they can think of for that object (e.g. for building with, doorstop, paperweight, etc.). As a comparison, participants will be asked to name all of the members of a certain category (e.g. world countries, elements on the periodic table) that they can think of. Categories will be chosen that have enough possible answers that the list is inexhaustible in the amount of times that a participant is allowed to answer. In this way the task is exactly like the AUT, as there is no single correct answer, and there are a finite but still very large number of correct answers. In both tasks, participants’ attention should be focused inward and not on the stimulus because the stimulus has no important clues about the solution to the task. These two tasks should be analogous except for the AUT is assessing for a divergent creative answer and the comparison task is assessing for a divergent non-creative answer. Therefore, an increase in the amount of frontal or parietal $\alpha$ synchronization on the AUT versus the comparison task would suggest that $\alpha$-band activity is directly related to creative cognition for divergent creativity.

Although there is evidence that points to the idea that frontal and parietal $\alpha$ synchronization are not due to creative ideation (see Fink & Benedek, 2014), I could only find two other studies that has tested whether creative and non-creative tasks showed any task related power differences in frontal and parietal $\alpha$ synchronization. One study (Fink et al., 2009) tested the AUT task versus a task where participants had to name characteristics of objects (e.g. that a hanger is metal) and also a task where participants had to think of words for pairs of initials (e.g.
M. W. becomes Multiple Witnesses) versus a task where participants had to finish words when provided with a suffix, (e.g. –ing). They found that the AUT and object characteristic task were not significantly different in their amount of α synchronization while the suffix task showed more α synchronization than the task where participants created words from initials. Another study (Fink et al., 2007), used describing utopian situations and the same word ending task as controls.

However, there is an issue with interpreting these results as a direct contrast between creative and non-creative ideation. The issue is that in both of the tasks that require less creative ideation, it is likely that creative ideation is still necessary. For instance, when contemplating object characteristics or finishing words from suffixes, it is possible to form a novel association by realizing explicitly in the moment that an object has a certain characteristic or a word has a certain ending when this information was only previously implicitly known or not known at all. It is also possible to visualize an object or word mentally and choose characteristics that were previously not salient and thus forming an association between that characteristic and that object or word. However, in the tasks in this study, this is very unlikely to occur as it would be very difficult for someone to realize in the moment that a name is the name of a world country or to suddenly conjure the answer to a factual question. Therefore, I think that the control tasks in this study are a better comparison for creative tasks and should provide a better barometer of the role of frontal and parietal α synchronization in creative ideation.

To assess for personality correlates of real life creativity, the Hypomanic Personality Scale (HPS) will be used to assess for hypomanic traits, the Magic Ideation Scale (MIS) (Eckblad & Chapman, 1983) will be used to assess for schizotypal traits, and the Mini-Marker IPIP scales of the Five Factor Model (FFM) (Saucier, 1994) will be used to assess for openness
The scales of the Mini-Marker IPIP measure the FFM facets of extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience. To assess for Big-C creativity, the Creative Behavior Inventory (CBI) (Hocevar, 1980) will be used.

**H1:** I hypothesize that task related frontal $\alpha$ synchronization will increase for all four tasks and that task related parietal $\alpha$ synchronization will increase only for both divergent tasks. Past research has shown that increased frontal $\alpha$ synchronization occurs for both convergent and divergent tasks (Fink et al., 2009). This is believed to be due to the increased cognitive load caused by the increased difficulty of divergent creativity tasks (Benedek et al., 2014). Since these effects are not hypothesized to be the result of creative ideation, both of the comparison tasks as well as both of the creative tasks should show this effect. Since divergent and not convergent tasks show increased parietal $\alpha$ synchronization (Fink et al., 2009), only the AUT and its comparison task should show increased parietal $\alpha$ synchronization.

**H2:** I also hypothesize that the scores on all four self-report measures will all positively correlate with each other as well as with creative task performance and with the amount of frontal and parietal $\alpha$ synchronization within subjects. Because hypomanic traits (Furnham et al., 2008), schizotypal traits (Schuldberg, 2001), neuroticism (Burch et al., 2006) and openness to experience (McCrae & Ingraham, 1987) have been shown to positively correlate with task creativity, I expect that they will correlate with creative task performance as well as the measure of Big-C creativity.

**H3:** In addition, I hypothesize that participants who generate rarer answers in both the AUT and its comparison task will show a right hemisphere asymmetry in parietal $\alpha$ synchronization. As found in Fink et al. (2009), individuals who gave more creative answers during an AUT showed increased right hemisphere upper-band parietal $\alpha$ synchronization during task performance. If, as
hypothesized, increased upper-band parietal α synchronization is not relevant to creativity, then people who give more unique answers on the divergent comparison task should also show this asymmetry.

**H4:** I hypothesize that the results of the α synchronization during performance on the CRA will mirror that of the HIP condition from the Benedek et al. (2014) study. It was reported in this study that the convergent task had a high solution rate (> 85%). By comparison, the stimuli for the modified RAT have a much lower solution rate (Bowden & Jung-Beeman, 2003), especially in the 10 second interval participants will have to answer in the current study. Thus, the CRA and by extension its comparison task, should mirror the HIP condition because trials of the convergent tasks in this study should take more cognitive processing to solve than did the LIP trials in the Benedek et al. (2014) study. Therefore, the CRA and its comparison task should show bilateral frontal α synchronization, bilateral parietal α desynchronization but with increased α synchronization in the right hemisphere of the parietal lobe versus the left hemisphere.

**H5:** Lastly, I hypothesize that the two creativity tasks will show increased γ activation bilaterally in the temporal cortices, the dorsolateral prefrontal cortices and the inferior gyri. Jung-Beeman et al. (2004) found that increased fMRI activity during insight solutions observed while performing the CRA correlated with increased γ activation in the same spot on the temporal cortex. Fox et al. (2005) used fMRI and found evidence for a neural network active during tasks involving working memory which indicates that the temporal cortex increases in activation during task performance. While also investigating this same neural network with fMRI, Whitfield-Gabrieli et al. (2009) found that schizophrenic patients and their relatives showed increased activation in the right DLPFC than did controls during a 2-back working memory task. Therefore, it is plausible that during creative task performance individuals will show increased γ activity in the temporal
cortices, in the dorsolateral prefrontal cortices, and in the inferior frontal gyri. In addition, I hypothesize that the right DLPFC and temporal lobes will show increased $\gamma$ activity versus the left DLPFC and temporal lobes and that the left IFG will show increased $\gamma$ versus the right IFG.

**Method**

**Design**

This study used both within-subject and between subject designs within a correlational design examining *in vivo* creativity with an Electroencephalogram (EEG) recorded during both divergent and convergent creativity tasks and comparison tasks, as well as participants’ scores on self-report measures. The study examined neural correlates while participants performed behavioral creative and non-creative tasks.

**Participants**

This study included 65 participants, all of whom were Ball State University students. They were recruited through the Psychology 101 subject pool and received course credit for participation. Two subjects were excluded for not speaking English as their first language, another subject was excluded for stating that they were not trying. This left 62 (48 Female, Mean Age = 18.9, SD = 2.601) participants who had usable behavioral data.

Out of these participants, an additional 16 had to be excluded due to issues with their EEG recordings. Five of these participants were excluded because of technical issues with the parallel port, another 11 were excluded for not having enough usable data for all tasks. This left 46 (36 Female, Mean Age = 18.72, SD = 2.947) participants who had usable EEG data.

**Materials**

This study used a total of four self-report measures: the Hypomanic Personality Survey (HPS; See Appendix A) (Eckblad, & Chapman, 1986), the Magic Ideation Scale (MIS; See
FACTORS UNDERLYING CREATIVITY

Appendix B) (Eckblad & Chapman, 1983), the Mini-Marker IPIP scales of the FFM (Mini-IPIP scales; See Appendix C) (Saucier, 1994), and the Creative Behavior Inventory (CBI; See Appendix D) (Hocevar, 1980). These measures were keyed into E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002) and completed by participants.

The HPS is a self-report measure designed to assess hypomanic symptoms and risk for future hypomanic episodes. Eckblad and Chapman (1986) reported a coefficient $\alpha$ reliability of .87 for the HPS in an undergraduate sample of 1,519 participants. Eckblad and Chapman (1986) also reported a test-retest reliability of .81 with 89 participants after an interval of 15 weeks. The HPS has also been shown to reliably predict hypomanic episodes at a 13 year follow up (Kwapil et al., 2000).

The MIS is a self-report measure designed to quantify magical ideation, or a belief in certain forms of causation that most believe to be invalid (Eckblad & Chapman, 1983). Eckblad and Chapman (1983) reported a coefficient $\alpha$ reliability of .82 for males and .85 for females for the MIS in an undergraduate sample of 1,512 participants. They also reported good convergent validity between the MIS and the physical aberration scale and divergent validity between the MIS and the physical anhedonia scale.

The Mini-IPIP scale is a self-report measure designed to assess all 5 factors of the FFM. Saucier (1993) reported the results of a multi-sample factor analysis used to validate the items on all 5 factors as well as obtaining a coefficient $\alpha$ reliability in the mid .80’s. The items also show higher mean inter-item correlations than a longer version of the inventory providing evidence for good scale validity.

The CBI is a self-report inventory which assesses real life creative behaviors and accomplishments across many domains. The CBI has shown to have an internal consistency $\alpha$
reliability of .89 in a sample of 239 subjects (Hocevar, 1980). This measure has shown to be reliable and show good validity with other measures of creativity (for a discussion see Silvia, Wigert, Reiter-Palmon, & Kaufman, 2012).

The creativity tasks and their comparison tasks were also presented using E-Prime 2.0 (Schneider, Eschman, & Zuccolotto, 2002), which recorded the participants’ task responses to allow for distinguishing between correct and incorrect answers for all 4 tasks during data analysis. The tasks were presented on a 24 in. Dell LCD monitor and responses were entered via keyboard.

This study included two behavioral creativity tasks: the compound Remote Associates Test (RAT) (Mednick, 1962), a convergent creativity task where participants must arrive at one correct answer to form an association between three words, and the Alternative Uses Test (AUT) (Guilford, 1967), a divergent creativity task where participants must name every use of an object they can think of. For both these tasks, a non-creative comparison task was used.

The RAT is a creativity task designed to measure how well a participant can form associations between three words (Mednick, 1962). It is based on the idea that creativity is the ability to form novel associations between objects (Mednick, 1962). The RAT used in this study is a Compound Remote Associates test (CRA) (Bowden & Jung-Beeman, 2003), meaning that the answer formed a compound word with the presented three words (See Appendix E). The CRA and other insight tasks have been used in many studies of creativity and has shown modest correlations with other measures of creativity (Fink, Benedek, Grabner, Staudt, & Neubauer, 2007). There is also data available for accuracy norms on the CRA which allows researchers to compare their experimental sample’s performance to a larger sample with theoretically less random error (Bowden & Jung-Beeman, 2003). These stimuli were sampled and used for the
CRA in this study. As a convergent comparison task (See Appendix F), participants were required to answer questions about general and historical facts. Each of these questions had only one answer and required semantic recall from the participant’s long term memory. The only difference cognitively between this task and the CRA should be that the CRA requires forming new associations and recalling historical facts requires recalling already existing associations.

The AUT (See Appendix G) is a divergent creativity task where participants must conjure as many uses for a common object as they can (Guilford, 1967). In this particular task, they had twelve opportunities total to enter an answer for each object presented. The idea behind this type of task is that creativity is the ability to create novel ideas and uncommon uses for an everyday object are novel ideas (Guilford, 1967). This task, or a variation of it, has been used in a much of the research examining creativity and EEG correlates (see Arden et al., 2010). As a divergent comparison task (See Appendix H), participants were required to name as many members of a category as they could, with twelve opportunities to do so per category. Each of these categories functionally had as many possible answers as the AUT because each category had many more than twelve possible answers. The only difference cognitively between this task and the AUT should be that the AUT requires forming new associations and naming members of a category requires recalling already existing associations.

Procedure

Participants entered the lab and sat approximately 54 cm from a 24 in Dell LCD monitor. Participants received an informed consent form and agreed to participate. Participants then filled out a health survey form indicating their past and current psychiatric diagnoses, current medications, and any history of head injuries or concussions. All participants in this study reported having a history of less than 2 concussions and reported that they were not currently
taking any psychopharmalogical medications for a psychiatric diagnosis. One participant reported a past diagnosis of OCD but reported never being prescribed medication. Two participants reported that they were diagnosed with ADHD as children but since had been removed from medication. These three participants were allowed to participate because they reported that they had been managing any symptoms without the help of medication for at least over one year. Thus for purposes of this study, they were not deemed to have currently elevated levels of psychopathology that distinguished them from the general population.

An electrocap was then placed each participant’s scalp and they were connected to the EEG. Participants then completed the CRA, the AUT, and both comparison tasks in separate blocks on E-Prime 2.0 software (Schneider, Eschman, & Zuccolotto, 2002). Before each task, participants received verbal instructions and completed practice trials. These tasks were counterbalanced across participants to avoid any order effects. Responses to these tasks were entered on a Dell keyboard. The EEG recordings were stopped after each task in order to allow the participant to receive instructions for each task and complete the practice trials. Participants then completed computerized versions of the HPS, MIS, CBI, and the Mini-Marker IPIP scales of the FFM on E-Prime 2.0 software.

The comparisons of α and γ synchronization for all tasks were made using a Task-Related Power (TRP) paradigm (See Figure 1 below). In the paradigm for this study, before each trial a participant fixated on a black screen containing only a large plus sign for 6000ms. Subsequently, the critical trial was presented, and participants saw the stimulus for the trial, however they still could not answer. The stimulus remained on the screen for 6000ms for the AUT and its comparison, and for 8000ms for the CRA and its comparison. Longer intervals were given After this interval, the font turned from white to green, at which point the participant could enter an
answer. Participants’ ideation was recorded from the middle of the critical period, the period
where they could see the stimulus but not respond, or 3000ms/4000ms after stimulus onset.
These times were chosen for several reasons. Past studies (e.g. Benedek et al., 2014; Jung-
Beeman et al., 2014) have found effects for both α and γ frequencies respectively during creative
tasks while epoching from the center of a critical period in similar paradigms. The additional
time was allowed for the CRA and its comparison task because it has been shown that reading
can cause α desynchronization during problem solving (e.g. Jaušovec, 1997), and this experiment
sought to give both convergent tasks the best chance for α synchronization. After this ideation
period, participants were allowed 5000ms to type in a response after which participants could no
longer answer and whatever they had typed in was recorded as their answer. A blank screen then
appeared for 2000ms between trials before the fixation screen reappeared to start the next trial,
making the total length of each trial for the divergent tasks 18000ms or 18 seconds and 20000ms
or 20 seconds for the convergent tasks.

In a task-related power paradigm, a participant’s activity on the fixation screen is used as
a baseline for their activity on the subsequent trial. Participants had several practice trials in each
task to get used to the paradigm. The approximate length of each divergent task with instructions
was 15 minutes and by comparison each convergent task with instructions took approximately 10
minutes for participants to complete. It took participants approximately 45-50 minutes to
complete all four experimental tasks. After participants have completed all four behavioral tasks,
they completed all four self-report measures in E-Prime 2.0. These measures took approximately
15-30 minutes to complete for each participant. Afterwards, participants were debriefed and
dismissed from the study and given credit for participating.
EEG Data Recording

The EEG was recorded and analyzed for frontal and parietal α activity from four locations: the left fronto-central lobe: (Fp1, AF3, AF7, F7, F5, F3, F1, FC5, FC3, FC1), the right fronto-central lobe: (Fp2, AF4, AF8, F8, F6, F4, F2, FC6, FC4, FC2), the right parieto-occipital lobe: (TP7, CP5, CP3, CP1, P9, P7, P5, P3, P1, PO7, PO3), and the left parieto-occipital lobe: (TP8, CP6, CP4, CP2, P10, P8, P6, P4, P2, PO8, PO4) (See Figure 2).
Figure 2. Electrode clusters used for the left and right fronto-central and parieto-occipital lobes.

For additional right versus left hemisphere comparisons of α activity, the electrodes were also clustered to conform to those used in past research using this paradigm (e.g. Fink et al, 2009). The electrodes were clustered as follows in the left hemisphere; AF: (Fp1, AF7, AF3), F: (F1, F3, F5, F7), FC: (FC1, FC3, FC5, FT7), CT: (T7, C5, C3, C1), CP: (CP1, CP3, CP5, TP7), PT: (P1, P3, P5, P7, P9), and PO: (PO7, PO3, O1). The corresponding clusters in the left hemisphere were be as follows; AF: (Fp2, AF8, AF4), F: (F2, F4, F6, F8), FC: (FC2, FC4, FC6, FT8), CT: (T8, C6, C4, C2), CP: (CP2, CP4, CP6, TP8), PT: (P2, P4, P6, P8, P10), and PO: (PO8, PO4, O2) (See Figure 3).
The electrodes will also be clustered together to examine differences in $\gamma$ activity. These electrode clusters are not precise indicators of underlying brain structures, but are meant to approximate the areas of the left DLPFC: (AF3, Fp1), the right DLPFC: (Fp2, AF4), the left temporal lobe: (FT7, T7, TP7), the right temporal lobe (FT8, T8, TP8), the left IFG (AF7, F7), and the right IFG (AF8, F8) (See Figure 4).
EEG Data Analysis

EEG recordings were taken from 64 locations on the scalp arranged as a dense array 10-20 electrode system using a BioSemi ActiveTwo EEG amplifier system with two 32 electrode strands mounted in an electrocap using BioSemi recording software (BioSemi, Amsterdam, The Netherlands). Two EoG electrodes were placed adjacent to the right eye to capture vertical and horizontal eye movements. Reference electrodes were placed on each mastoid and were subsequently averaged together as an averaged mastoid reference during data processing. Data was recorded continuously throughout each task. Recordings were stopped between tasks and each task was treated as a separate data file for analysis.
The data from each task was analyzed using the EEGLAB plugin for MATLAB (Delorme & Makeig, 2004). A high pass FIR legacy filter was applied at 0.5 Hz in order to reduce spatial drift and help satisfy the assumption that the data sources are stationary for Independent Component Analysis (ICA) (Onton, Westerfield, Townsend, & Makeig, 2006). A low pass FIR legacy filter was also applied at 55 Hz. The data were visually inspected for artifacts and all muscle artifacts and external interference were visually rejected. Bad channels were then removed from the file for interpolation later. No more than 6 electrodes (<10% of the 64 scalp electrodes) were interpolated for any one subject. No more than two adjacent electrodes were removed for interpolation or that subject was excluded from further analysis. By making sure that adequate usable data channels are present in proximity to a bad channel, its activity can be adequately estimated with a high density electrode system (Greischer et al., 2004).

ICA was used to remove any remaining artifacts in the data. Decomposition of the independent components was performed in EEGLAB (version 13.2.2) using the ‘runica’ INFOMAX algorithm (Makeig, Jung, Bell, Ghahremani, & Sejnowski, 1997). Each subject in this analysis had >260 seconds of continuous data for each task from which ICA components were determined for up to 64 scalp electrodes and 2 EoG electrodes. If any scalp electrodes were deemed unsuitable for analysis, they were removed for interpolation before performing ICA. The initial learning rate for the ICA was 0.001 and the ICA converged when weight change was smaller than 1E⁻⁷. The components were visually inspected and artefactual components were rejected. Rejected components were primarily related to eye movements captured by the EoG electrodes and muscle artifacts (McMenamin et al., 2010).

The previously removed channels were then interpolated into the file using the pop_interp function for spherical interpolation in EEGLab. For each task, each participant’s data was
subsequently epoched into both baselines and critical periods for analysis. Subjects who had less than 50% usable trials (less than 18 out of 36) and baselines on the AUT and its comparison task were excluded from further analysis. Subjects who had less than 66% usable trials (less than 10 out of 15) and baselines on the CRA and its comparison were excluded from further analysis (See Table 1). The thresholds for the AUT and its comparison were set lower than those of the CRA and its comparison because the AUT and its comparison had over twice as many trials.

<table>
<thead>
<tr>
<th>Task</th>
<th>Baselines</th>
<th>Critical Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUT</td>
<td>29.57</td>
<td>31</td>
</tr>
<tr>
<td>AUT Comparison</td>
<td>30.82</td>
<td>33.07</td>
</tr>
<tr>
<td>CRA</td>
<td>12.85</td>
<td>13.78</td>
</tr>
<tr>
<td>CRA Comparison</td>
<td>12.67</td>
<td>13.28</td>
</tr>
</tbody>
</table>

Table 1. The mean number of baselines and critical periods used for data analysis for the 46 subjects whose EEG data was analyzed.

A spectral analysis was then run on both the baseline and critical period epochs using the `spectopo` function in EEGLAB (Delorme & Makeig, 2004). For maximum spectral specificity, each epoch’s spectral data was padded to the next power of 2, and a 2-second-wide Hanning tapered window with a 50% overlap was used to calculate spectral power. For each epoch, 200 linearly spaced frequencies were estimated from 1-50 Hz. Spectral power was then converted to ($\mu$V$^2$) for further analysis.

For both the baselines and divergent task critical periods, the initial and final 500ms was not analyzed. The end of each epoch was not analyzed to avoid boundary effects. This left 5000ms of the epoch for both the baselines and divergent task critical periods that was analyzed. For the convergent tasks the initial 2250ms and last 750 of each epoch were not analyzed. As
stated above, this was to give participants time to read the extra words on these trials (See Figure 5).

![Figure 5. Breaks down the sections of each epoch that were used for spectral analysis.](image)

To calculate spectral power at each electrode, the following equation was used:

\[
TRP = \log(Critical\ Period\ Power) - \log(Baseline\ Power)
\]

For examination of the α band, trials were averaged together within subjects and for each task, the average power of the critical period for all trials was subtracted from the average power of the baseline for all trials for a within subjects’ analysis. In the γ band, for all tasks, power on each individual trial was subtracted from the average power of the baseline for a between subjects’ analysis. The γ band analysis was performed this way in order to not lose inter-trial
variability by averaging together too many trials of small amplitude γ waves. Each trial was then matched up to the behavioral data to determine if it was a correct trial or not. To calculate the average power for each cluster of electrodes, the following equation was used:

\[ \text{Total TRP}_F = \frac{(E_1 \text{TRP}_F + E_2 \text{TRP}_F + \ldots + E_N \text{TRP}_F)}{N} \]

Where TRP = Task-related power, E = Electrode in a cluster, N = Number of electrodes in a cluster, and F = Frequency band of interest.

**Behavioral Data Analysis**

For each task, the number of responses for each participant was collected and each was scored for accuracy. For the CRA and its comparison task, a correct response was a response that was the correct answer to the question, an attempted response was one where an answer was attempted but was not correct, and if a response was not entered it was coded as unanswered. For the AUT and its comparison task, a correct response was a new use or member of a category that had not been previously entered, an attempted answer was an illegible response or a repeated use or member of a category, and if a response was not entered it was coded as unanswered.

For the AUT and its comparison task, participants also had their responses rated on originality (Amabile, 1983). Participants’ originality was measured by three raters who rated each response on the AUT and its comparison task from 1 – 5, with 1 being the least original and 5 being the most original (or rare). All responses were given to raters in alphabetical order, so that raters were blind to both subject and the order of the responses. If a majority of raters (2 out of 3) indicated that an item was not readable, it was assigned a 1. This did not inflate ratings for participants who gave more responses than others, as the ratings were divided by the total number of responses per subject for averaging. Then, the ratings were averaged within subjects to measure which subjects had the most creative/oddball responses to the divergent tasks and the
subjects will be separated into a high and low group for analysis of parietal interhemispheric α differences based on these ratings.

Participants were also administered computerized 4 self-report questionnaires, the CBI, HPS, MIS, and Mini-IPIP scales. These scales were scored electronically and their total scores were used for between subjects’ analyses.

**Results**

**Initial Analysis**

Past research using TRP to investigate α ERS/ERDS during creative tasks has only examined EEG correlates of correct trials (e.g. Fink et al., 2009). To test the assumption that correct trials are distinct from incorrect trials, all trials were averaged within subjects and broken down into 3 groups. Correct trials were coded as correct answers on the CRA and CRA comparison and as legible new uses/categories for the AUT and AUT comparison. Attempted trials were coded as attempted but not correct answers on the CRA and CRA comparison and on the AUT and AUT comparison as trials where either a previously entered use was re-entered or trials where the participant typed a non-legible answer. Lastly, no answer trials were coded as trials where no response was attempted for all 4 tasks.

For the lobes, two separate a Task X Response Type X Hemisphere X Lobe repeated measures ANOVAs with α band power as the DV were used to assess for interactions between different response types and the other IVs. Specifically, the ANOVAs used were 4 (AUT/AUT Comparison/ CRA /CRA Comparison) X 2 (Correct vs. Answered/No Answer) X 2 (Frontal Lobe/Parietal Lobe) X 2 (Left Hemisphere/Right Hemisphere) design. One ANOVA with all response types was not used because not all subjects had unanswered or attempted trials for all tasks so only a small subset of the data could be used in the analysis (n = 14), while substantially
more subjects could be used in both the Correct/Attempted ANOVA ($n = 24$) and the Correct/No Answer ANOVA ($n = 31$). After correcting for sphericity violations, no interactions were significant in either ANOVA. There was a significant main effect for Response Type in both the Correct/Answered $F(1,23) = 4.606, p = .043$ and Correct/No answer ANOVAs $F(1,30) = 20.264, p < .001$. In both cases, the correct trials showed the greatest $\alpha$ desynchronization from baseline. Interestingly, the means for the No Answer trial type showed the greatest $\alpha$ band power relative to baseline. This contrasts with the results from past studies in which correct trials have showed overall increased $\alpha$ synchronization from baseline for the AUT (See Table 2). However, in this study none of the response types showed any overall $\alpha$ synchronization.

<table>
<thead>
<tr>
<th>Table 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Response Type</strong></td>
</tr>
<tr>
<td>Correct</td>
</tr>
<tr>
<td>Attempted</td>
</tr>
<tr>
<td>No Answer</td>
</tr>
</tbody>
</table>

Table 2. Means for $\alpha$ band activity for Response Type and Lobe. Negative values indicate desynchronization from baseline, or that $\alpha$ power during the baseline was higher than $\alpha$ power during the critical period. Means for correct trials are from the correct/no answer ANOVA.

The same two repeated measure ANOVAs were used with the 7 Clusters of electrodes (see Figure 3) corresponding to each row of electrodes on the scalp substituted for Lobe. Specifically, the ANOVAs used were 4 (AUT/AUT Comparison/CRA /CRA Comparison) X 2 (Correct vs. Answered/No Answer) X 7 (Clusters: AF/F/FC/CT/CP/PT/PO) X 2 (Left Hemisphere/Right Hemisphere) design. Like the previous ANOVAs, after correcting for sphericity, no significant interactions involving Response Type were present. There was a significant main effect for Response Type in both the Correct/Answered $F(1,23) = 4.926, p = .037$ and Correct/No answer ANOVAs $F(1,30) = 20.742, p < .001$. Like the ANOVAs with
FACTORS UNDERLYING CREATIVITY

Lobe, the correct trials showed the greatest $\alpha$ desynchronization from baseline. Thus, for all the remaining reported analyses looking at $\alpha$ band power, all 3 Response Types are averaged together.

$H_1$: To examine $\alpha$ band ERDS/ERS over lobes, a 4 (Task) X 2 (Hemisphere) X 2 (Lobe) repeated measures ANOVA with $\alpha$ band power as the DV was used. After using a Greenhouse-Geisser correction for sphericity, a significant Task X Lobe interaction was found $F(2.5,112.499) = 3.662$, $p = .02$. Post-hoc simple effects tests indicated that while the AUT showed less $\alpha$ desynchronization than all other tasks in both the frontal and parietal lobes, the AUT comparison only showed less $\alpha$ desynchronization in the parietal lobes ($p < .05$) (see Figure 6). A significant main effect for Task $F(2.307,103.819) = 9.032$, $p < .001$ was also observed. Post hoc simple effects tests demonstrated that the AUT showed less relative $\alpha$ desynchronization compared to all other tasks and that the AUT Comparison showed less relative $\alpha$ desynchronization compared to the CRA comparison ($p < .05$). There was also a significant main effect for Lobe $F(1,44) = 21.007$, $p < .001$, indicating that across all tasks there was significantly less relative $\alpha$ desynchronization in the frontal lobe versus the parietal lobe. A Greenhouse-Geisser correction was not needed for the F-test for Lobe. No other effects were significant.
Past research however has suggested that task difficulty can increase $\alpha$ synchronization (Benedek et al., 2014). Both pairs of creative and control tasks were designed to be both equal in difficulty and cognitively analogous. To test the assumption of equal difficulty, fluency, or the amount of responses attempted, was used as a proxy for task difficulty. Fluency was used because if a task is easier, participants should attempt more responses and thus a lower fluency would indicate a harder task. Three Bonferroni corrected paired t-tests ($p < .0125$) were used to assess if any significant difficulties in task difficulty existed between the pairs of tasks. The CRA and CRA Comparison were compared on both fluency $t(45) = -1.361, p = .18$, as well as number of correct answers $t(45) = -.378, p = .707$, and neither was significantly different. The AUT and AUT Comparison were compared on fluency $t(45) = -9.345, p < .001$, and a significant difference was found indicating that fluency on the AUT was significantly lower than fluency on the AUT Comparison.
In order to test if the differences in TRP were due to differences in task difficulty, a new variable was coded for each subject by subtracting each participants AUT fluency from their AUT Comparison fluency. This variable was then inserted as a covariate into the 4 (Task) X 2 (Hemisphere) X 2 (Lobe) repeated measures ANOVA. This made the previously significant Task X Lobe interaction non-significant $F(2.498,109.929) = 1.166, p = .325$. However, there was still a significant main effect for Task $F(2.249,98.966) = 5.079, p = .002$. No other effects were significant.

However, it is still unclear whether the main effect of Task is due to differences between the AUT and AUT comparison or due to differences between the divergent and convergent tasks. In order to assess this, the same ANOVA was run but with the CRA and CRA comparison dropped from the model. A 2 (Divergent Task) X 2 (Hemisphere) X 2 (Lobe) repeated measures ANOVA was run again with fluency difference as a covariate. The main effect for Task was no longer significant $F(1,44) = 0.230, p = .634$. The results for the same ANOVAs using Clusters instead of Lobes had a similar pattern of results and thus they are not reported here. Taken together, these results provide good evidence that full $\alpha$ band synchronization during divergent creative task performance is primarily due to task difficulty. No other effects were significant.

Past studies have found different effects in both the high and low $\alpha$ bands (e.g. Fink et al., 2009). To test if these differences would emerge with the current tasks, two 4 (Task) X 2 (Hemisphere) X 2 (Lobe) repeated measures ANOVAs were ran with both the low and high $\alpha$ bands as DVs and with response fluency differences as a covariate. For the low $\alpha$ band ANOVA, a marginally significant Hemisphere X Task was found $F(3,132) = 2.431, p = .068$ even after accounting for the difference in fluency. In the high $\alpha$ band ANOVA, a marginally significant
Task X Lobe interaction was observed \( F(2.561,112.696) = 2.425, p = .079 \) after accounting for the difference in fluency. No other effects approached significance.

To test if these differences accounted for task differences between the AUT and AUT comparison, these ANOVAs were restricted to only differences between these two tasks. No significant task related effects were revealed for the low \( \alpha \) band. However, in the high \( \alpha \) band a significant main effect for Task was found \( F(1,44) = 4.174, p = .047 \), indicating that after accounting for task difficulty the AUT still showed significantly greater high \( \alpha \) band TRP than the AUT comparison. No other effects were significant. These results suggest the possibility that the activity of the high and low alpha bands may not be fully accounted for by task difficulty and that these bands may be involved in different processes of creative ideation.

**H2:** Before analysis, the internal consistency of the 4 measures used in this sample was evaluated. All of the measures used in this study showed good to excellent internal consistency for all subjects in the behavioral analysis (CBI: \( \alpha = .914 \), HPS: \( \alpha = .708 \), MIS: \( \alpha = .666 \), FFM Emot: \( \alpha = .733 \), FFM Open: \( \alpha = .69 \)) (see Table 3).
Table 3. Sample means for the behavioral measures for all subjects used in the behavioral analysis

To measure the interrelatedness of the MIS, HPS, Mini-IPIP scales, and the CBI, a correlation was run. All subjects who were excluded from the study due to unusable recordings were used in this analysis. However, the three subjects who were excluded for other reasons were not included in these analyses giving a total n for these analyses of 62. The correlation was run using the MIS total score, the HPS total score, the FFM Openness score of the Mini-IPIP scales, the FFM Emotional Stability score of the Mini-IPIP scales, and the CBI total score. A positive correlation was expected between all variables except emotional stability which is expected to show a significant negative correlation with the other predictors. Because the differences being tested were predicted a priori, the p-value was maintained at .05. A significant positive correlation was found between the HPS and the CBI r(60) = .273, p = .032, indicating that participants with more hypomanic traits had more real life creative accomplishments than participants with less hypomanic traits. There was also a marginally significant positive
correlation between scores on the MIS and HPS \( r(60) = .251, p = .049 \), indicating that scores on participants who scored high on the HPS tended to endorse more items on the MIS as well. No other effects were significant.

Table 4

<table>
<thead>
<tr>
<th>Measures</th>
<th>HPS</th>
<th>MIS</th>
<th>FFM Open</th>
<th>FFM Emot</th>
<th>CBI</th>
<th>AUT Fluency</th>
<th>AUT Comp Fluency</th>
<th>CRA Fluency</th>
<th>CRA Correct</th>
<th>CRA Comp Fluency</th>
<th>CRA Comp Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS</td>
<td>1</td>
<td>.251</td>
<td>-.181</td>
<td>.119</td>
<td>.273</td>
<td>.131</td>
<td>.033</td>
<td>.115</td>
<td>-.155</td>
<td>.120</td>
<td>-.017</td>
</tr>
<tr>
<td>MIS</td>
<td>-</td>
<td>1</td>
<td>-.014</td>
<td>-.176</td>
<td>.093</td>
<td>-.034</td>
<td>-.006</td>
<td>.037</td>
<td>.044</td>
<td>.090</td>
<td>-.009</td>
</tr>
<tr>
<td>FFM Open</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.004</td>
<td>.206</td>
<td>-.062</td>
<td>-.126</td>
<td>-.032</td>
<td>-.038</td>
<td>-.016</td>
<td>-.049</td>
</tr>
<tr>
<td>FFM Emot</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>.193</td>
<td>-.138</td>
<td>-.017</td>
<td>-.171</td>
<td>-.086</td>
<td>-.008</td>
<td>.229</td>
<td></td>
</tr>
<tr>
<td>CBI</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.160</td>
<td>.015</td>
<td>.008</td>
<td>.137</td>
<td>.093</td>
<td>-.031</td>
</tr>
<tr>
<td>AUT Fluency</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.424</td>
<td>.334</td>
<td>.012</td>
<td>.268</td>
<td>.184</td>
</tr>
<tr>
<td>AUT Comp Fluency</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.235</td>
<td>.201</td>
<td>.496</td>
<td>.464</td>
</tr>
<tr>
<td>CRA Fluency</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.360</td>
<td>.167</td>
<td>.092</td>
</tr>
<tr>
<td>CRA Correct</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.169</td>
<td>.184</td>
</tr>
<tr>
<td>CRA Comp Fluency</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>.809</td>
</tr>
<tr>
<td>CRA Comp Correct</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 4. Correlation matrix for all Subjects used in the behavioral analysis. Bolded values are significant \((p < .05)\), italicized values are marginally significant \((p < .1)\). All significant and marginally significant values are underlined.

To measure if these traits significantly predicted scores on the CBI, all 4 measures of personality traits were entered into a linear regression as interaction terms with CBI scores as the DV. These model terms were entered so that all smaller interactions and main effects were included in the model. A likelihood ratio test using a Chi-squared test of deviance was used to determine model fit, with all possible iterations of the model compared to the fit of a model.
containing just the intercept. The full model with the 4-way interaction was the only model with 3 or more interaction terms that explained significantly more deviance than the null model \( \chi^2(15) = 30.695, p = .009649 \). In addition to a likelihood ratio test, a Wald test was used to test whether the coefficients of the full model were significantly different from zero. This test was also significant, \( \chi^2(1) = 4.5909, p = .03214 \), indicating that the model’s coefficients were significantly different from zero. Compared to the models that were more parsimonious than the full model and significantly different than the null model, the full model had the lowest Akaike Information Criterion (AIC = 639.92) (Akaike, 1987) indicating that it had the best fit with the data. This model also explained a large amount of variance (\( R^2 = .3905 \)). Lastly, the sample size was small and the number of predictors was appropriate for the model without overfitting (Babyak, 2004). Due to these factors, the full model was determined to have the best fit with the data.

The interaction was interpreted using set values for each continuous IV (see Figure 7). As the graph shows, when emotional stability was low (or when neuroticism was elevated) and openness to experience was elevated, at low levels of the HPS there was a positive relationship between the HPS and MIS, but at high levels of the HPS there was a negative relationship with the MIS. However, when emotional stability was low and openness to experience was low, the pattern was reversed as there was a negative relationship between the HPS and MIS at low levels of the HPS and a positive relationship between the HPS and MIS at high levels of the HPS. As expected, these results suggest that there is a complicated relationship between personality traits and real life creative achievement.

In order to measure if these personality traits correlated with creative task results, they were inserted into a model using correct responses on all 4 tasks individually as the DV. Unexpectedly, in a model with all four terms as main effects, Emotional Stability was a
marginally significant positive predictor of correct responses on the CRA Comparison Task $\chi^2(1) = 3.206, p = .07361$. No other significant effects emerged for the influences of these surveys on creative task performance.

![Interaction predicting CBI scores](image)

Figure 7. Prevalent observed interactions of the Hypomanic Personality Scale, Magic Ideation Scale, FFM Emotional Stability, and FFM Openness to experience predicting scores on the Creative Behavior Inventory. Each line indicates a specified score on Emotional stability, Openness, and the HPS plotted against MIS scores on the X-axis. Predicted CBI scores are on the Y-axis.

**H3**: For all participants, each response to the AUT and AUT Comparison task was compiled and organized alphabetically. Repeat answers between participants were eliminated from the list to give no hint as to the number of times a particular answer was given. Three raters, two male and one female, then rated each answer for both tasks as outlined in the method section above.
Interrater reliability was poor for both tasks, $\kappa = .339$ for the AUT and $\kappa = .109$ for the AUT Comparison task. Reliability was expected to be lower for the AUT Comparison task as none of the responses were inherently creative adding a lot of ambiguity to the assessment of originality for these items. However, the reliabilities were still extremely low compared to conventional standards.

Based on participants’ mean creativity ratings, participants were divided into high and low creative groups using a median split as used in Fink et al. (2009). As was done in this study, the high $\alpha$ band was then examined for differences in TRP. Separate mixed models ANOVA were then run using both the AUT or the AUT Comparison as the DV with 7 (Clusters) X 2 (Hemisphere) as within subject IVs and Creativity Group as a between subject IV. Neither ANOVA showed any significant interactions involving Creativity group. No other results are reported here as $\alpha$ band TRP has already been reported under $H_1$.

Although not significant, the means from these tests do visually mirror those of past research (See Figure 8). Task related high $\alpha$ band power is visually higher for the high originality group versus the low originality group for both tasks, especially in the right parietal lobe. This provides evidence that the effect may be present, but no concrete conclusions can be made using the ratings in their current state.
\textbf{H4:} As can be seen in Figure 6, neither convergent task showed less $\alpha$ band desynchronization in the right parietal lobe as compared to the left parietal lobe. However, both tasks did show less $\alpha$ band desynchronization in the left parietal lobe versus the right parietal lobe in the PO cluster. To investigate this difference, a $4$ (Task) X $7$ (Clusters) X $2$ (Hemisphere) repeated measures ANOVA was run without AUT response difference as a covariate. The Task X Cluster X Hemisphere interaction was only marginally significant $F(5.205,234.207) = 2.123, p = .061$. However, post-hoc pairwise tests showed that $\alpha$ band desynchronization during the CRA in the PO cluster was significantly greater in the right hemisphere than the left hemisphere ($p = .035$). Main effects were not of interest here and thus are not reported.
To test for this difference, only CRA trials were used and a 7 (Clusters) X 2 (Hemisphere) repeated measures ANOVA was run. Again, a marginally significant interaction was found for Cluster X Hemisphere $F(2.487,111.929) = 2.325, p = .09$. Main effects were not of interest here and thus are not reported. Although the interaction was not significant, the hemispheric effects trended in the opposite direction than those found in past studies (e.g. Benedek et al., 2014). This occurred despite the convergent tasks in the current study having a much lower correct response rate than those used in past studies (43% in the current study versus (> 85%) in Benedek et al. (2014). This indicates that there may be differences in TRP between increases in task difficulty and holding items in memory while solving them.

As the AUT and its comparison task showed significant differences in activation between the low and high $\alpha$ bands that were not observed in the full $\alpha$ band, two 2 (Convergent Task) X 2 (Lobe) X 2 (Hemisphere) repeated measures ANOVAs with the low and high $\alpha$ bands as the DVs were used to assess if these differences were present for the CRA and its comparison task. For the low $\alpha$ band, a significant Task X Hemisphere interaction was observed $F(1,45) = 8.004, p = .007$. Post hoc simple effects showed that there was significantly more low $\alpha$ band synchronization in the left hemisphere of the CRA versus the right hemisphere and that this difference was not significant for the CRA comparison ($p < .05$). In addition, a marginally significant Task X Lobe X Hemisphere interaction was observed $F(1,45) = 3.233, p = .07$. This interaction appears to largely be due to greater low $\alpha$ band synchronization in the left frontal lobe of the CRA. For the high $\alpha$ band, a marginally significant Task X Lobe X Hemisphere interaction was observed $F(1,45) = 3.468, p = .069$. This interaction was largely driven by greater high $\alpha$ band synchronization in the right frontal lobe for the CRA compared to its comparison task (see Figure 9). Main effects were not of interest here and thus are not reported.
Although this interaction was not significant, it provides evidence that there may be differences in TRP between the convergent tasks across the high and low α bands.

**Figure 9.** Differences in TRP alpha power for convergent tasks across convergent tasks.

**H5:** To examine differences in γ activation, all trials for all tasks were coded for a between subjects analysis. For this hypothesis, a between subject approach was adopted because averaging trials together tends to mask the variability of power in the γ band due to the small amplitudes of the waves in this band. To test for gamma variations across tasks independent of schizotypal ideation, a 4-way between subjects ANOVA was conducted for 2 (Correct/Incorrect Answer) X 4 (Task) X 2 (Hemisphere) X 3 (Cluster: DLPFC, IFG, Temporal Lobe) with TRP in the γ band as the DV. Three significant 2-way interactions emerged. Significant main effects were observed but were not reported due to their involvement in interactions.
One of the significant interactions observed was a Correct X Task interaction $F(3,58640) = 22.462, p < .001$ (See Figure 10). Post-hoc simple effects tests showed that on the AUT, TRP in the $\gamma$ band was significantly lower when the answer was correct, while on the CRA, TRP in the $\gamma$ band was significantly higher when the answer was correct ($p < .001$). There was no significant difference however for TRP in the $\gamma$ band during either the AUT Comparison or CRA Comparison when a trial was correct or incorrect. These results are consistent with the hypothesis that creative tasks should require $\gamma$ activity in order to form novel associations while non-creative tasks should not.

![Gamma Response for Task Answers](image)

**Figure 10.** TRP in the $\gamma$ band for correct and incorrect responses for all 4 tasks.

In addition, a Correct X Cluster interaction $F(2,58640) = 7.214, p = .001$ was also observed (See Figure 11). Post hoc simple effects tests found a significant increase for $\gamma$ band power in the temporal lobe when a when an answer was correct vs. incorrect ($p < .001$). No other clusters had significant differences in $\gamma$ band TRP. These results are consistent with past research which has found increases in $\gamma$ band power during creative tasks (Jung-Beeman et al., 2004).
A Task X Hemisphere interaction also occurred $F(3,58640) = 8.876, p < .001$ (See Figure 12). Post hoc simple effects tests were used to examine the interaction. For the CRA, a significant difference was found indicating that $\gamma$ band TRP increased significantly in the right hemisphere compared to the left hemisphere ($p < .025$). The AUT also showed a significant difference with $\gamma$ band TRP increasing significantly in the left hemisphere versus the right hemisphere ($p < .001$). No other significant hemispheric differences between tasks were observed. As with the prior interaction involving Task, only both creativity tasks showed differences $\gamma$ band TRP as a function of a moderator variable. This provides evidence that $\gamma$ band TRP may be a more appropriate measure of creative task ideation than $\alpha$ band TRP.

Additional hemispheric effects for $\gamma$ band TRP were hypothesized. However, no 3-way interactions were significant due to a lack of power, and thus these hypotheses could not be evaluated.
Discussion

The objective of this study was to explore different factors that underlie creative ideation and creative behaviors. This was investigated by examining task related power in both the α and γ bands during creative and non-creative task and by assessing personality traits that were hypothesized correlates both of task related creativity and real life creativity.

TRP in the α band

TRP in the α band was assessed during all four tasks during a period where participants were actively thinking about a solution to the current problem. Although the pattern of the TRP α band power of the types of tasks used in this study mirrored those of past research (e.g. Fink et al., 2007), none of the tasks in this study actually achieved TRP α synchronization as was reported in many past studies (e.g. Benedek et al., 2014; Fink et al. 2007). Moreover, these past studies have only reported the results of trials where participants produced a valid or correct answer. However, in the present study the results showed that in fact on the trials where

Figure 12. Changes in predicted γ band power by hemisphere.
participants did not produce an answer, they showed significantly greater $\alpha$ band TRP compared to baseline. This result leads to two competing hypotheses, one being that in this study when participants did not produce an answer it was because they were thinking about something unrelated to the current task which was more complex than the current task and thus produced greater $\alpha$ band TRP. The other possibility is that when participants did not produce an answer, it was because they were thinking about the task throughout the entire ideating period thus producing greater $\alpha$ band TRP compared to correct trials. This would be because on trials where participants did produce an answer, they may have decided on their answer during the ideating period and thus may have stopped effortful cognition part way through the ideation period.

One way to examine this issue is to examine trials where participants attempted an answer, but did not produce a legible answer. Although it is likely that many factors could lead to this type of response such as typing speed, it is likely than on a majority of these trials the participant did not decide on a response until either very late in the critical period or after the critical period was over and thus they were not able to produce a legible result within the time limit. If the hypothesis about participants ideating throughout the critical period on unanswered trials is correct, we would expect trials where participants attempted a response to show increased $\alpha$ band synchronization compared to correct trials, but less $\alpha$ band synchronization compared to trials where participants did not produce an answer. If the hypothesis that participants were not attending to the task during trials where no answer was produced is correct, then we would expect attempted trials to show less $\alpha$ band synchronization than correct trials because on in this scenario on attempted trials participants should have been attending to the task the most. As shown in Table 1, the results support the hypothesis that participants likely stopped attending to the trial after they produced a correct answer, thus resulting in correct trials showing
the lowest amount of TRP in the $\alpha$ band. This result lends credence to the idea that TRP in the $\alpha$ band is primarily an index of effortful cognition and internally reflected attention.

This study also attempted to parse out whether the amount of TRP in the $\alpha$ band was related to task difficulty or specifically related to creative tasks. Past research has suggested that $\alpha$ band TRP is an index of task difficulty and is not a specific facet of creative ideation (Benedek et al., 2014). The current study was designed to use two commonly used research tasks in this literature, the CRA and AUT, and to create comparison tasks that were both cognitively analogous and to these tasks and equal difficulty. While the comparison task for the CRA appears to have been an excellent foil for the CRA, the AUT Comparison task does not appear to have been quite as difficult as the AUT. While the TRP in the $\alpha$ band of the AUT Comparison appears to mirror the pattern of the AUT, the behavioral data showed that there was likely a difference in difficulty between tasks. Both of these tasks required participants to enter as many answers as they could for each prompt over 36 trials and participants produced significantly more answers for the AUT Comparison versus the AUT. Thus it is likely that the AUT Comparison task was easier for participants to complete than the AUT, and this difference in difficulty could thus be the reason for the difference in results. To try and test if this was true a covariate was entered into the ANOVA, the difference in task fluency within each subject, to attempt to account for the variance that may have been due to task difficulty. This resulted in the differences of TRP in the $\alpha$ band between the AUT and AUT Comparison tasks becoming nonsignificant, providing good evidence that the differences between tasks in TRP in the full $\alpha$ band are due to task difficulty.

However, this distinction may not be as clear as cut as this evidence appears. Past studies have found differences in $\alpha$ band TRP between the low and high $\alpha$ bands, and it is possible that
these two $\alpha$ bands are performing simultaneous yet distinct tasks during creative ideation. This study provided evidence for this by finding that there were different marginally significant interactions in both the low and high $\alpha$ bands even after accounting for task difficulty. In addition, there were still significant differences in TRP between the AUT and AUT Comparison in the high $\alpha$ band after accounting for task difficulty. Taken together, these results suggest that the activity of the high $\alpha$ band may not be dependent solely on task difficulty but rather have at least a partial correlation to higher cognitive processes.

However, some insight into this issue may be given by the results of investigating whether originality affects TRP in the high $\alpha$ band. With the caveat that the interrater reliability for originality ratings on both tasks was poor, the results for the AUT did appear to visually mimic the results of past research. In Fink et al. (2009), the authors found that on the AUT task, high and low creativity individuals showed an asymmetry between their left and right parietal lobes with the right parietal lobe of higher creativity individuals showing increased high $\alpha$ band synchronization. Although not significant, the results of this study showed similar patterns for high $\alpha$ band TRP for both the AUT and the AUT Comparison tasks (See Figure 8). If future research is able to validate this result, it would provide evidence that this difference in high $\alpha$ band activity is not a function of better creative ability but rather better cognitive task performance. In order to draw further conclusions from this study, the creativity ratings will have to be reevaluated with stricter rating criteria.

The TRP in the $\alpha$ band of the convergent tasks was also of interest in this study. Past research has suggested that by increasing task difficulty, $\alpha$ band synchronization will increase in the right hemisphere parietal lobe as compared to the left hemisphere parietal lobe (Benedek et al., 2014). This has specifically been shown to occur when the stimulus is briefly presented
during a convergent task and then removed from view and a participant must remember the stimulus while concurrently solving the problem. However, in that study the accuracy rate of participants was high (> 85%) suggesting that the task overall was not actually difficult despite the manipulation.

In the current study, the accuracy rate was much lower (44%) and as such if the results of past research were indexing task difficulty, similar differences should have emerged. However, no evidence emerged for greater right hemisphere activation in the parietal lobe for either the CRA or its comparison in both the low and high α bands. The only hemispheric difference that was seen was greater high α synchronization for the CRA in the right hemisphere of the frontal lobe as compared to the left frontal hemisphere of the CRA and the frontal activation of the CRA comparison in the and high α band with a reversed pattern for the low α band. However, as these differences were not significant it is difficult to argue that this is any more than cursory evidence that there may be differences between TRP in the low and high α bands during creative vs. non-creative convergent tasks. These results however did provide evidence that it is likely that greater right hemisphere activation during past instances of convergent tasks was due to the cognitive task of holding a stimulus in working memory rather than an increase in task difficulty.

Overall, this study provided evidence that while full α band power appears to be significantly correlated with task difficulty, the low and high α bands may in fact be indexing different aspects of cognition related to cognitive task performance. In the past, there has been a debate as to whether alpha band power is a correlate of cortical idling or advanced cognitive processes related to the inward focus of attention (Knyazev, 2007). This study could be considered as evidence that the lower and higher α bands may in fact be accomplishing both of these tasks separately and that part of the reason for this debate is the lack of examination of the
lower and upper $\alpha$ bands in past studies. Because both bands show slightly different patterns of activation in both convergent and divergent tasks, it is possible that either the upper or lower $\alpha$ band may be primarily associated with cortical idling while the other upper or lower $\alpha$ band may be associated with increased inward focused attention. This would explain the debate in the literature about why $\alpha$ band activity has been correlated with both of these processes.

**Personality Traits and Creativity**

Another goal of this study was to look for personality correlates of both real life creative behaviors and creative task performance. This was accomplished by measuring real life creative behaviors with the CBI and creative task behavioral data and seeing how these measures were predicted using the HPS, MIS, and FFM Mini-IPIP scales. As has been found in past research, hypomanic traits were found to be the best predictor of self-reported creativity (e.g. Furnham et al., 2008). However, this study found that the relationship between creativity and personality was best accounted for by a 4-way interaction of openness to experience, emotional stability, hypomanic personality traits, and schizotypal ideation. While the relationship between these personality traits and creativity has been noticed by past researchers (e.g. Andreasen, 2008), it has long been understood that there is not a linear relationship between these traits and increased creativity (e.g. Richards et al., 1988).

As past evidence suggests, this study found a complex interaction between these traits and real life creativity providing further evidence that personality traits in one individual that contribute to increased creativity may be detrimental to another individual’s creativity. In addition, this study provides a set of predictors that can be used to evaluate if any other personality traits contribute significant variance to creativity above and beyond those measured here. While it is very unlikely that this study is a completely accurate representation of the exact
relationship between these personality traits and creativity, it provides a good framework for future research to attempt to tease apart the complex interaction of the impact of these traits on creativity.

**TRP in the γ band**

Like α band power, task related γ band power was measured during task performance from electrodes that were meant to approximate the locations of the DLPFC, IFG, and temporal lobes (see Figure 3). However, unlike α power, task related γ power showed clear differences between creative and non-creative tasks. Because the comparison tasks in this experiment were theoretically designed to mimic creative tasks in every way except that they lacked the forming of new associations during task performance, it was hypothesized that task related γ power should increase in these areas during creative task performance but not during control task performance.

This hypothesis was mostly supported as only the creative tasks showed significant differences for correct vs. incorrect answers during task performance (see Figure 8). However, while the CRA showed the predicted pattern of increased γ power for correct answers, the AUT showed the opposite effect with increased γ power reflecting incorrect answers. Past research has reported that task difficulty can increase γ power during task performance (Simos, Papanikolaou, Sakkalis, & Micheloyannis, 2002). It could be that like α band power, task related γ band power is partially an index of task difficulty. However, if this were the case it would be likely that there would be some difference for either comparison task, especially the CRA comparison which was very similar to the CRA both behaviorally and in terms of task related α band power. Because both comparison tasks do not show any significant differences in task related γ power for correct or incorrect trials, it is possible that this activation is somehow related to the forming of novel
associations. This explanation would be consistent with other lines of research which implicate dopaminergic activity in synaptic plasticity (e.g. Calabresi, Picconi, Tozzi, & Di Filippo, 2007).

In addition, the results showed that temporal lobe activation was significantly greater across tasks for correct trials versus incorrect trials. This result is congruent with prior research which has shown increased right temporal activity in the γ band in response to answering a CRA trial correctly with insight (Jung-Beeman et al., 2004). This suggests that the right temporal lobe may be involved with cognitive task performance, which indeed is also in line with prior research (e.g. Simos et al., 2002). The current results forward this idea by suggesting that during a cognitive task, fluctuations in temporal γ band power can directly affect performance on a trial by trial basis. This effect also does not appear to be restricted to creative trials, as this interaction is seen across all tasks. This suggests that it may be differences in frontal task related γ band power that differentiate creative from non-creative tasks.

Specific hemispheric differences were also hypothesized for task related γ power between the clusters. However, the only hemispheric differences found were in an interaction with task. Additional work will be needed to measure if there are asymmetries in task related γ power during creative task performance.

**Limitations**

Despite the many strengths of this study, there are several methodological limitations. One limitation of this study is despite the theoretical reasoning behind the use of the comparison tasks, neither has ever been normed before in a large sample. Therefore, it is possible that they are not as equivalent to the control tasks as they are theoretically believed to be. However, in both behavioral measures and α band power, these tasks do appear to be similar.
In addition, self-report data was used to assess creative behaviors as well as different personality traits. It is possible that the scores on these measures do not entirely reflect the underlying constructs that are believed to be assessed by these measures. Thus, the interaction that was found with these measures may not be wholly representative of the personality variables that underlie creativity.

Another issue is the use of subjective ratings to assess the creativity of responses. As interrater reliability was poor, these ratings very likely do not reflect the true creativity of these responses. A better system to achieve more consistent ratings will have to be implemented to improve the reliability of the creativity ratings.

Conclusions

The current study sought to advance the current understanding of the EEG correlates of creative ideation. The results indicate that while task related $\alpha$ power is a likely correlate of creative ideation, task related $\gamma$ power may be a better mechanism to distinguish creative tasks from non-creative tasks. In addition, the results support the use of the FFM facets of emotional stability and openness to experience, as well as schizotypal traits hypomanic personality traits as predictors of real life creative behaviors. Additional research will be needed to parse out the exact relationship of neurological correlates for real life creativity.
References


during creative problem solving by means of EEG and fMRI. *Human Brain Mapping, 30*, 734-748.


FACTORS UNDERLYING CREATIVITY


Appendix A

Hypomaniac Personality Scale

Please answer each item true or false. Please do not skip any items. It is important that you answer every item, even if you are not quite certain which is the best answer. An occasional item may refer to experiences that you have had only when taking drugs. Unless you have had the experience at other times (when not under the influence of drugs), mark it as if you have not had that experience.

Some items may sound like others, but all of them are slightly different. Answer each item individually, and don't worry about how you answered a somewhat similar previous item.

Circle either:

True   False

1. The beauty of sunsets is greatly overrated.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I consider myself to be pretty much an average kind of person.</td>
<td>T</td>
</tr>
<tr>
<td>2.</td>
<td>It would make me nervous to play the clown in front of other people.</td>
<td>T</td>
</tr>
<tr>
<td>3.</td>
<td>I am frequently so “hyper” that my friends kiddingly ask me what drug I’m taking.</td>
<td>T</td>
</tr>
<tr>
<td>4.</td>
<td>I think I would make a good nightclub comedian.</td>
<td>T</td>
</tr>
<tr>
<td>5.</td>
<td>Sometimes ideas and insights come to me so fast that I cannot express them all.</td>
<td>T</td>
</tr>
<tr>
<td>6.</td>
<td>When with groups of people, I usually prefer to let someone else be the center of attention.</td>
<td>T</td>
</tr>
<tr>
<td>7.</td>
<td>In unfamiliar surroundings, I am often so assertive and sociable that I surprise myself.</td>
<td>T</td>
</tr>
<tr>
<td>8.</td>
<td>There are often times when I am so restless that it is impossible for me to sit still.</td>
<td>T</td>
</tr>
<tr>
<td>9.</td>
<td>Many people consider me to be amusing but kind of eccentric.</td>
<td>T</td>
</tr>
<tr>
<td>10.</td>
<td>When I feel an emotion, I usually feel it with extreme intensity.</td>
<td>T</td>
</tr>
<tr>
<td>11.</td>
<td>I am frequently in such high spirits that I can’t concentrate on any one thing for too long.</td>
<td>T</td>
</tr>
<tr>
<td>12.</td>
<td>I sometimes have felt that nothing can happen to me until I do what I am</td>
<td>T</td>
</tr>
</tbody>
</table>
meant to do in life.

13. People often come to me when they need a clever idea. T F
14. I am no more self-aware than the majority of people. T F
15. I often feel excited and happy for no apparent reason. T F
16. I can’t imagine that anyone would ever write a book about my life. T F
17. I am usually in an average sort of mood, not too high and not too low. T F
18. I often have moods where I feel so energetic and optimistic that I feel I could outperform almost anyone at anything. T F
19. I have such a wide range of interests that I often don’t know what to do next. T F
20. There have often been times when I had such an excess of energy that I felt little need to sleep at night. T F
21. My moods do not seem to fluctuate any more than most people’s do. T F
22. I very frequently get into moods where I wish I could be everywhere and do everything at once. T F
23. I expect that someday I will succeed in several different professions. T F
24. When I feel very excited and happy, I almost always know the reason why. T F
25. When I go to a gathering where I don’t know anyone, it usually takes me a while to feel comfortable. T F
26. I think I would make a good actor, because I can play many roles convincingly. T F
27. I like to have others think of me as a normal kind of person. T F
28. I frequently write down the thoughts and insights that come to me when I am thinking especially creatively. T F
29. I have often persuaded groups of friends to do something really adventurous or crazy. T F
30. I would really enjoy being a politician and hitting the campaign trail. T F
31. I can usually slow myself down when I want to. T F
32. I am considered to be kind of a “hyper” person. T F
33. I often get so happy and energetic that I am almost giddy. T F
34. There are so many fields I could succeed in that it seems a shame to have to pick one. T  F
35. I often get into moods where I feel like many of the rules of life don’t apply to me. T  F
36. I find it easy to get others to become sexually interested in me. T  F
37. I seem to be a person whose mood goes up and down easily. T  F
38. I frequently find that my thoughts are racing. T  F
39. I am so good at controlling others that it sometimes scares me. T  F
40. At social gatherings, I am usually the “life of the party”. T  F
41. I do most of my best work during brief periods of intense inspiration. T  F
42. I seem to have an uncommon ability to persuade and inspire others. T  F
43. I have often been so excited about an involving project that I didn’t care about eating or sleeping. T  F
44. I frequently get into moods where I feel very speeded-up and irritable. T  F
45. I have often felt happy and irritable at the same time. T  F
46. I often get into excited moods where it’s almost impossible for me to stop talking. T  F
47. I would rather be an ordinary success in life than a spectacular failure. T  F
48. A hundred years after I’m dead, my achievements will probably have been forgotten. T  F
Appendix B

The Magical Ideation Scale

Please answer each item true or false. Please do not skip any items. It is important that you answer every item, even if you are not quite certain which is the best answer. An occasional item may refer to experiences that you have had only when taking drugs. Unless you have had the experience at other times (when not under the influence of drugs), mark it as if you have not had that experience.

Some items may sound like others, but all of them are slightly different. Answer each item individually, and don't worry about how you answered a somewhat similar previous item.

Circle either:

True    False

1. The beauty of sunsets is greatly overrated.

1. I have occasionally had the silly feeling that a TV or radio broadcaster knew I was listening to him. T F
2. I have felt that there were messages for me in the way things were arranged, like in a store window. T F
3. Things sometimes seem to be in different places when I get home, even though no one has been there. T F
4. I have never doubted that my dreams are the products of my own mind. T F
5. I have noticed sounds on my records that are not there at other times. T F
6. I have had the momentary feeling that someone's place has been taken by a look-alike. T F
7. I have never had the feeling that certain thoughts of mine really belonged to someone else. T F
8. I have wondered whether the spirits of the dead can influence the living. T F
9. At times I perform certain little rituals to ward off negative influences. T F
10. I have felt that I might cause something to happen just by thinking too much about it. T F
11. At times, I have felt that a professor's lecture was meant especially for me. T F
12. I have sometimes felt that strangers were reading my mind. T F
13. If reincarnation were true, it would explain some unusual experiences I have had. T F
14. I sometimes have a feeling of gaining or losing energy when certain people look at me or touch me. T F
15. It is not possible to harm others merely by thinking bad thoughts about them. T F
16. I have sometimes sensed an evil presence around me, although I could not see it.  T    F
17. People often behave so strangely that one wonders if they are part of an experiment.  T    F
18. The government refuses to tell us the truth about flying saucers.  T    F
19. I almost never dream about things before they happen.  T    F
20. I have sometimes had the passing thought that strangers are in love with me.  T    F
21. The hand motions that strangers make seem to influence me at times.  T    F
22. Good luck charms don't work.  T    F
23. I have sometimes been fearful of stepping on sidewalk cracks.  T    F
24. Numbers like 13 and 7 have no special powers.  T    F
25. I have had the momentary feeling that I might not be human.  T    F
26. I think I could learn to read others' minds if I wanted to.  T    F
27. Horoscopes are right too often for it to be a coincidence.  T    F
28. Some people can make me aware of them just by thinking about me.  T    F
29. I have worried that people on other planets may be influencing what happens on Earth.  T    F
30. When introduced to strangers, I rarely wonder whether I have known them before.  T    F
Appendix C

Mini-IPIP Scales

Please use this list of common traits to describe yourself as accurately as possible. Describe yourself as you see yourself at the present time, not as you wish to be in the future. Describe yourself as you are generally or typically, as compared with other persons you know of the same sex and of roughly the same age.

Before each trait, please write a number indicating how accurately that trait describes you, using the following rating scale:

<table>
<thead>
<tr>
<th>Inaccurate</th>
<th>?</th>
<th>Accurate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slightly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slightly</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderately</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extremely</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>8</td>
<td>9</td>
</tr>
</tbody>
</table>

1. Bashful
2. Bold
3. Careless
4. Cold
5. Complex
6. Cooperative
7. Creative
8. Deep
9. Disorganized
10. Efficient
11. Energetic
12. Envious
13. Extraverted
14. Fretful
15. Harsh
16. Imaginative
17. Inefficient
18. Intellectual
19. Jealous
20. Kind
21. Moody
22. Organized
23. Philosophical
24. Practical
25. Quiet
26. Relaxed
27. Rude
28. Shy
29. Sloppy
30. Sympathetic
31. Systematic
32. Talkative
33. Temperamental
34. Touchy
35. Uncreative
36. Unenvious
37. Unintellectual
38. Unsympathetic
39. Warm
40. Withdrawn
Appendix D

Creative Behavior Inventory

This is an inventory, not a test. The inventory is simply a list of activities and accomplishments that are commonly considered to be creative. For each item, circle the answer that best describes the frequency of the behavior in your adolescent and adult life. Be sure to answer every question, and don’t worry about duplicate or similar items.

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Received an award for acting.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>2.</td>
<td>Worked as an editor for a school or university literary publication.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>3.</td>
<td>Worked as an editor for a newspaper or similar organization.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>4.</td>
<td>Constructed something that required scientific knowledge such as a radio, telescope, scientific apparatus, etc. (excluding school or university course work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>5.</td>
<td>Painted an original picture.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>6.</td>
<td>Designed and made your own greeting card.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>7.</td>
<td>Gave a recital.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>8.</td>
<td>Presented an original mathematics paper to a professional or special interest group.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>9.</td>
<td>Founded a literary magazine or similar publication.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>10.</td>
<td>Made a craft out of metal (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>11.</td>
<td>Made candles.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>12.</td>
<td>Knitted or crocheted something (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>13.</td>
<td>Put on a puppet show.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>14.</td>
<td>Made your own holiday decorations.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>15.</td>
<td>Built a hanging mobile (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>16.</td>
<td>Received an award for performance in modern dance or ballet.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>17.</td>
<td>Received an award for performance in popular dance.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>18.</td>
<td>Had a mathematics paper published.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>19.</td>
<td>Made a sculpture (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>20.</td>
<td>Had an original music published or publicly performed.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>21.</td>
<td>Had a piece of literature (poem/short stories, etc.) published in a school or university publication.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>22.</td>
<td>Developed an experimental design (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>23.</td>
<td>Wrote poems (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
<tr>
<td>24.</td>
<td>Entered a project into a science contest.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
</tr>
</tbody>
</table>
### FACTORS UNDERLYING CREATIVITY

<p>| | | | | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25.</td>
<td>Received an award for an artistic accomplishment.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26.</td>
<td>Received an award for making a craft.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27.</td>
<td>Made a craft out of plastic, Plexiglas, stained glass or a similar material.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.</td>
<td>Made cartoons.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29.</td>
<td>Made a leather craft.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30.</td>
<td>Made a ceramic craft.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31.</td>
<td>Wrote music for one instrument.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32.</td>
<td>Wrote music for several instruments.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33.</td>
<td>Designed and made a piece of clothing</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34.</td>
<td>Cooked an original dish.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.</td>
<td>Prepared an original floral arrangement.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>36.</td>
<td>Applied math in an original way to solve a practical problem (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.</td>
<td>Wrote an original computer program (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38.</td>
<td>Drew a picture for aesthetic reasons.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>39.</td>
<td>Wrote the lyrics to a song.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.</td>
<td>Choreographed a dance.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>41.</td>
<td>Wrote a short story (excluding school or university work).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42.</td>
<td>Wrote something humorous such as jokes, limericks, satire, etc.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>43.</td>
<td>Made jewelry.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>44.</td>
<td>Recorded a music record or CD.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>45.</td>
<td>Put on a radio show.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46.</td>
<td>Had a piece of literature (poem, short story, etc.) published (not in a school or university-related publication).</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>47.</td>
<td>Took and developed your own photographs.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>48.</td>
<td>Performed ballet or modern dance in a show or contest.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>49.</td>
<td>Had art work or craft work publicly exhibited.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50.</td>
<td>Won an award for musical accomplishments.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>51.</td>
<td>Wrote clever or humorous letters.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52.</td>
<td>Won an award for a scientific project or paper.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53.</td>
<td>Assisted in the design of a set for a musical or dramatic production.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54.</td>
<td>Had art work published in a school or university publication.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>55.</td>
<td>Had a role in a dramatic production.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>56.</td>
<td>Had art work published.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>57.</td>
<td>Started but did not finish a novel.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>58.</td>
<td>Wrote and completed a novel.</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3-4</td>
<td>5-6</td>
<td>7+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Factor</td>
<td>Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>-----------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Made or helped make a film or video tape.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Won an award for some achievement in literature.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entered a mathematical paper or project into a contest.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Had a scientific paper published.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planned and kept a garden.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kept a sketch book.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Was a participating member of a symphony orchestra.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entered a contest as a singer.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Entered a contest as a musician.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Directed or managed a dramatic production.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Designed and made a costume.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Played an instrument (percussion, including piano) with a reasonable degree of proficiency.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Played an instrument (string) with a reasonable degree of proficiency.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Played an instrument (brass) with a reasonable degree of proficiency.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Played an instrument (wind) with a reasonable degree of proficiency.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participated in a drama workshop, club, or similar organization.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participated in a craft workshop, club, or similar organization.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participated in a writers’ workshop, club, or similar organization.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Participated in a dance workshop, club, or similar organization.</td>
<td>0 1 2 3-4 5-6 7+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix E

RAT Task Stimuli

Instructions: Welcome to this portion of the experiment. During this task, you will be asked to come up with one word that belongs with a group of three other words. There will only be one correct answer for each group of words. For instance, if the group of words given was: Cottage Swiss Cake, The answer would be Cheese. This is because the word Cheese can be used to make the words Cottage Cheese, Swiss Cheese, and Cheese Cake. The answer may be placed before or after a word to form a common phrase or object. Your task will be to name one word in each trial that can be used to form a word or phrase with the words presented. Before the experiment starts, you will be presented with some practice trials. The first screen of these trials will contain a large + sign. This sign will remain on the screen for a few seconds, please focus on the + sign while it is on the screen. After that, another screen will appear with the three words that you will be thinking of an answer for. Please focus on the three words while they are on the screen. When the words turn green, you will have a few seconds to enter an answer. There will then be a break for a few seconds and the correct answer will be briefly displayed before the + sign reappears to start the next trial.

(Note: The correct answer is only displayed for practice trials to help participants get acclimated to the task. There is no feedback given on any of the tasks’ experimental trials.)

Practice Stimuli

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cream Skate Water</td>
<td>Ice</td>
</tr>
<tr>
<td>Loser Throat Spot</td>
<td>Sore</td>
</tr>
<tr>
<td>Fish Mine Rush</td>
<td>Gold</td>
</tr>
</tbody>
</table>

Experimental Stimuli

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Show Life Row</td>
<td>Boat</td>
</tr>
<tr>
<td>Safety Cushion Point</td>
<td>Pin</td>
</tr>
<tr>
<td>Pie Luck Belly</td>
<td>Pot</td>
</tr>
<tr>
<td>Measure Worm Video</td>
<td>Tape</td>
</tr>
<tr>
<td>--------------------</td>
<td>------</td>
</tr>
<tr>
<td>Night Wrist Stop</td>
<td>Watch</td>
</tr>
<tr>
<td>Worm Shelf End</td>
<td>Book</td>
</tr>
<tr>
<td>Date Alley Fold</td>
<td>Blind</td>
</tr>
<tr>
<td>Sandwich House Golf</td>
<td>Club</td>
</tr>
<tr>
<td>Aid Rubber Wagon</td>
<td>Band</td>
</tr>
<tr>
<td>Dress Dial Mail</td>
<td>Sun</td>
</tr>
<tr>
<td>Dream Break Light</td>
<td>Day</td>
</tr>
<tr>
<td>Pine Crab Sauce</td>
<td>Apple</td>
</tr>
<tr>
<td>Dew Comb Bee</td>
<td>Honey</td>
</tr>
<tr>
<td>French Car Shoe</td>
<td>Horn</td>
</tr>
<tr>
<td>Cane Daddy Plum</td>
<td>Sugar</td>
</tr>
</tbody>
</table>
Appendix F

RAT Comparison Task Stimuli

Instructions: Welcome to this portion of the experiment. During this task, you will be asked to come up with an answer to a question about general knowledge or a historical fact. There will only be one correct answer for each question. For instance, if the question given was: Who invented alternating current as an alternative to direct current? The answer would be Nikolas Tesla. Your task will be to determine the answer to each question presented. Before the experiment starts, you will be presented with some practice trials. The first screen of these trials will contain a large + sign. This sign will remain on the screen for a few seconds, please focus on the + sign while it is on the screen. After that, another screen will appear with the question that you will be thinking of an answer for. Please focus on the question while it is on the screen. When the question turns green, you will have a few seconds to enter an answer. There will then be a break for a few seconds and the correct answer will be briefly displayed before the + sign reappears to start the next trial.

Practice Stimuli

Q: Now known as the date that lives in infamy, what date did the attack on Pearl Harbor take place? A: December 7th, 1941
Q: Who is credited with inventing the Cotton Gin? A: Eli Whitney
Q: What turn of the 20th century Detroit industrialist once said, "You can have the model T in any color, as long as it's black?" A: Henry Ford

Experimental Stimuli

Q: What day is the United States’ independence day? A: July 4th, 1776
Q: Which cabinet position did Condoleezza Rice hold during the second term of the Bush White House? A: Secretary of State
Q: In what country is Big Ben located? A: The United Kingdom
Q: Which country currently has the highest Gross Domestic Product in the world? A: United States
Q: In which state is Mount Rushmore located? A: South Dakota

Q: Which city is the iconic Wall Street stock exchange located in? A: New York City

Q: Who was president of the Union during the American Civil War? A: Abraham Lincoln

Q: In what city did the Soviet Union build a wall in during the cold war that became an iconic symbol of the divide between the East and the West? A: Berlin

Q: Who was the leader of the Soviet Union during World War II? A: Josef Stalin

Q: What is the northern most US state? A: Alaska

Q: Which Roman aristocrat was famously quoted as saying "Veni, Vidi, Vici" in reference to his conquest of the Gallic tribes? A: Gaius Julius Caesar

Q: What famous Civil War battle took place in Pennsylvania during 1863 and lasted three days? A: The Battle of Gettysburg

Q: What form of government was originally conceived of by Karl Marx in his Manifesto? A: Communism

Q: During what war did the United States drop two atom bombs on Japan? A: WWII

Q: Name one of the first two states to hold presidential primaries every four years. A: Iowa or New Hampshire
Appendix G

AUT Task Stimuli

Instructions: Welcome to this portion of the experiment. During this task, you will be asked to come up with alternative uses for different objects. These objects will be common everyday objects with a known use, but you will be thinking of many different ways to use these objects. For instance, if you were given a chair as an item, a chair is normally used to sit in. However, a chair could also be used as a ladder, as a doorstop, to support plywood while cutting it, and as a coat rack among many other possible uses.

Before the experiment starts, you will be presented with some practice trials. The first screen of these trials will contain a large + sign. This sign will remain on the screen for a few seconds, please focus on the + sign while it is on the screen. After that, another screen will appear with the object that you will be thinking of an alternative use for. Please focus on the word while it is on the screen. When the word turns green, you will have a few seconds to enter an alternative use for the object. There will then be a break for a few seconds before the + sign reappears to start the next trial.

Practice Stimuli

Umbrella x3 repetitions

Coffee Mug x3 repetitions

Experimental Stimuli

Brick x12 Repetitions

Mop x12 Repetitions

Paper Clip x12 Repetitions
Appendix H

AUT Comparison Task Stimuli

Instructions: Welcome to this portion of the experiment. During this task, you will be asked to come up with answers that fit a certain category. These categories will have many different possible answers, and any answer that you come up with is okay. For instance, if the category given was trees, I could name pine trees, oak trees, gingko trees, and birch trees among many other possibilities. Your task will be to name one item in each category per trial.

Before the experiment starts, you will be presented with some practice trials. The first screen of these trials will contain a large + sign. This sign will remain on the screen for a few seconds, please focus on the + sign while it is on the screen. After that, another screen will appear with the category that you will be thinking of answers for. Please focus on the category while it is on the screen. When the category turns green, you will have a few seconds to enter an answer. There will then be a break for a few seconds before the + sign reappears to start the next trial.

Practice Stimuli

US States x3 repetitions

Soda Brands x3 repetitions

Experimental Stimuli

Periodic Table Elements x12 Repetitions

World Countries x12 Repetitions

Chain Restaurants x12 Repetitions