UNIVERSITY OF CALIFORNIA
RIVERSIDE

Interhemispheric Interaction and Creativity

A Dissertation submitted in partial satisfaction
of the requirements for the degree of

Doctor of Philosophy

in

Psychology

by

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August 2016

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ACKNOWLEDGEMENTS

First and foremost, I want to thank my mother, Diane Felton, for all her sacrifices involved in supporting my dreams and me. And her patience. Oh the patience. I love you and I owe my success to your hard work and inspiration.

I would like to thank my committee members: Dr. Christine Chiarello, Dr. Curt Burgess, and Dr. Weiwei Zhang. Your recommendations and insights were very helpful and made this a better project.

I want to thank my family: my pops, Bruce Buck; the other Feltons: Karen, Dave, Cyrus, Paige, and Annabelle; Dennis, Carol, Brad, Sandy, and Huxley. And of course Chuck.

I started the psychology adventure in 2006. Since that time, there have been a lot of fallen soldiers. I want to thank the following for their part in my life: Betty, Janet, Becky, Ninja, and Bing.

I would like to thank Christine Chiarello for her mentorship. I appreciate the countless hours she's spent reading my work, giving me feedback, explaining how to calculate visual eccentricity, etc. Thank you for allowing me into your lab and training me as a researcher.

If anyone can commiserate with Chris, it's Thomas Holtgraves. I never understood/appreciated how exhausting it can be to teach people to do research. Thank you for your mentorship.

I would like to thank all of my research assistants on this project: Tanya Tran, Gina Waneis, John Pangilinan, Nick Notti, Merin Alvarez-Guzman, Crystal Leon, Divya

Subramanian, Yesenia Ramirez, Sonia Talukder, Ranjit Nair, and Sagar Akre. Together you've all given me thousands of hours of help. I think this acknowledgment should just about cover it.

I would like to thank my lab mates over the years: David Vazquez, Adam Daily, and Alessandra McDowell/MacBeth. I've learned a lot working with all of you and I'm sure you've all saved me somehow. Honorable mention to my ghost lab mate: Mike Hade. Thank you, Mike, for saving me multiple times with your IT/excel/VBA wizardry!

Several people have aided the research I've conducted. I would like to thank James Kaufman for answering my questions about creativity. I would like to thank Joseph Hellige, whose fantastic book helped shape the direction of my dissertation. I would like to thank Stephen Christman for giving science some weird puzzles that I've pursued. Thanks to Rakel Larson and Russell Cohen Hoffing for research feedback and miscellaneous. I would like to thank Kate Sweeny for collaborating on the conformity project. I would like to thank Dan Ozer for continuing to answer my never-ending statistical questions.

I would like to thank the following people for their friendship, support, (mis)adventure, etc: Will Townsend, Kat Duggan, Matt Della Porta, Rakel Larson, Russell Cohen Hoffing, Tanya Tran, Catalina Zavala, Mike Hade, Amanda Roos, Brian Gendron, Eric Chen, Jasa Whatever, Ana Banana Marcello, Russell Pierce, Patricia Kemerer, Michelle Stephanie Calderwood, Eva Parill, Nick Boushe, Jelly Gerstorff, and Tanya Karam-Zanders. I would like to thank the UCR boxing club and Raincross Boxing Academy: Josue Palacios, Celia Miranda, Jigesh "Jiggy" Patel, Jose Jimenez, Mario

Dorado, Josh Quintana, Diana Tran, Luke Yoo, David Narain, Mark Ross, and Erik Phung. I would also like to thank 10th Planet Jiujitsu Riverside: Randall Dolf, Gus Saldivar, Freddie Escamilla, Miguel Magallanes, and the rest of the gang.

I need to thank Faye Harmer and Renee Young. Thank you for everything you did for my research and TA-ing. You went above and beyond what was required and you benefited science, students, and myself. Thank you! Additionally, I would like to thank Ryan Lipinski and Sonja Lyubomirsky for ensuring I had a TA spot and thus thwarting my homelessness for at least that quarter.

I would like to thank my intellectual genealogy for getting me here: John Robbins, Daniel Quinn, Derrick Jensen, and Elliot Aronson.

Plot twist: I would like to thank my mom again. It can't be overstated enough: I owe my success to everything you've done for me. You are smart, beautiful, and inspiring. Hope your new adventures are wonderful.

As can be seen, a lot of people have helped me get where I am today. I owe them a lot. This acknowledgement pays back all debts and obligations owed. We're even.

ABSTRACT OF THE DISSERTATION

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by

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Doctor of Philosophy, Graduate Program in Psychology
University of California, Riverside, August 2016
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Years of research have shown that the brain uses both hemispheres to produce creative thought. Despite this, the relation between interhemispheric interaction and creativity is understudied. The present study investigated how interhemispheric summation, integration, and control related to creativity while controlling for verbal IQ and openness. The study utilized three interhemispheric interaction tasks – bilateral gain, across-field advantage, and metacontrol – to predict multiple measures of convergent and divergent creativity. Remote associates test accuracy was associated with decreased left hemispheric metacontrol. This suggests that, to the extent that the left hemisphere dominates processing, some forms of creativity are reduced. No other measure of interhemispheric interaction was associated with creativity performance. It was found that verbal IQ and openness were more consistent predictors of creativity measures than measures of interhemispheric interaction. This study suggests that the interhemispheric advantage of summation and integration plays a limited role in creative performance, but that hemispheric control is involved in verbal convergent creativity.

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Chapter 1

Creativity has gained momentum as a topic of interest in both social science and beyond. The neuroscience of creativity, however, is in its inchoate phase. To date, there are few theories that link creativity to the brain (Dietrich, 2004, 2007) and even fewer that account for hemispheric contributions to creativity (e.g., Kounios & Beeman, 2014); there is also a dearth of research investigating the relation between hemispheric coordination and integration in creativity. The purpose of the present study is to investigate to what extent interhemispheric interaction is associated with creativity.

In cognitive neuroscience, the dominant theory of creativity is the creative cognition approach (Abraham & Windmann, 2007; Fink, Benedek, Grabner, Staudt, & Neubauer, 2007; Smith, Ward, & Finke, 1995). In this approach, creativity is broken down into ordinary cognitive subprocesses common to all people. These subprocesses can range from perception to expert decision-making. At the perceptual level, an individual's focus of attention and perceptual frame can limit the extent of creative generation (Reisberg, 2005). Is a person able to come up with a novel way to use an item, or are they plagued by functional fixedness? If given an example, does a person anchor on the example and/or how far do they adjust? Research has shown that people who are able to manipulate their perceptual frame and go far beyond given examples, produce more creative works (e.g., Ward, Smith, & Finke, 1999).

Differences in semantic memory organization can lead to differences in the activation and selection of novel, verbal responses (Kounios & Beeman, 2014; Mednick, 1962). Atchley, Keeney, and Burgess (1999) found that highly creative individuals have greater (bilateral) access to subordinate meaning than less creative individuals. Expertise even comes into play at several points in the creative process. In some areas of expertise, a certain high-level of competence is required to generate creative ideas; for example, creative solutions in discrete mathematics require a solid grasp of both basic and advanced mathematics. Additionally, identifying what even constitutes a work of creativity can require expertise; perhaps two individuals can come up with the same creative products, but the highly creative individual identifies and chooses the most creative final product. Research has shown that individuals with greater expertise have greater levels of creativity (Kaufman, 2009).

The creative cognition approach is popular because it builds directly on cognitive neuroscience research. By far, the most dominant research approach in the neuroscience of creativity is to administer a creativity task, report the neurological underpinnings, and then tie the neurological correlates of the creativity task to the respective correlates of other cognitive processes (e.g., Abraham et al., 2012; Jung, Mead, Carrasco, & Flores, 2013; Kühn et al., 2013; Takeuchi et al., 2012). For example, Abraham et al. (2012) administered two creativity tasks and two control tasks and reported areas of the brain whose activity level correlated with the creativity tasks: anterior inferior frontal cortex, temporal poles, and lateral frontopolar cortex. They then linked those areas associated with creativity to areas reported in previous research not dealing with creativity: semantic selection, semantic processing, and cognitive control, respectively.

Verbal creativity is a form of creativity that underlies prose, poetry, irony, puns, humor, etc. Verbal creativity, in particular, is a phenomenon of creativity, in general;

other forms of nonverbal creativity include visual creativity (e.g., painting) and physical creativity (e.g., ballet). Like creativity in general, the processes underlying verbal and nonverbal creativity can be dissociated and interpreted by the creative cognition approach. Verbal creativity relies on semantic associations, the ability to go beyond given words and dominant associations (akin to anchoring and adjusting), inhibition, fluency and speed of processing, and experience (Kaufman, 2009; Maini, 1973). Nonverbal creativity relies on perceptual reference frame adjustment, inhibition, fluency, and experience (Ward et al., 1999).

Convergent and Divergent Creativity

There are at least two forms of creative thinking: convergent and divergent. Both verbal and nonverbal creativity can involve convergent and divergent processes. Convergent creativity requires the selection of one correct creative product while divergent creativity is the creation of multiple creative products (Cropley, 2006). These two types of creativity have been analogized evolutionarily: divergent creativity represents generation of variants while convergent creativity represents selection (Kaufman, 2009). The processes underlying divergent creativity involve fluency (Kaufman, 2009), anchoring and adjusting (Smith et al., 1995), and distant semantic activation (Burgess, 1998). Most likely, this form of creativity involves weak semantic activation (Kuonios & Beeman, 2014) and is aided by contexts that nurture weak semantic associations (e.g., positive moods – Ashby, Isen, & Turken, 1999). Processes underlying convergent creativity, conversely, involve analytic problem solving, comparisons between alternatives, conscious selection, etc. This form of creativity, therefore, probably involves a decision requiring greater activation above a threshold (Jung-Beeman, 2005).

The processes underlying these two forms of creativity differ theoretically and, when measured, convergent and divergent creativity are weakly, if at all, correlated (Brophy, 2001; Kaufman, 2009; Lee & Therriault, 2013). While there may be some overlap between the cognitive processes, they do seem to be measuring different phenomena empirically as demonstrated by weak behavioral correlations and different neural activation. Further evidence is needed to demonstrate dissociable processes between the two.

Convergent and divergent thinking are theorized to be distinct styles in both the creativity and cognitive neuroscience of creativity literatures. Abraham et al. (2012) found that fMRI activation patterns were different between the unusual uses task for divergent (hippocampal formation, amygdala, dorsal medial prefrontal cortex, ventromedial prefrontal cortex, and posterior cingulate cortex; activation was stronger in the left hemisphere, although areas were activated bilaterally), and the remote associates test for convergent (right posterior medial cortex, right dorsolateral prefrontal cortex, and right frontopolar cortex), thinking.

The ubiquitous convergent creativity task is the remote associates test (RAT). Mednick (1962), in the original paper describing the task, theorized that the RAT involves divergent processes – requiring activation of weak and distant associations. It has only been after Mednick's pioneering work that subsequent researchers have labeled the RAT a convergent task. The RAT is labeled a convergent task because it requires the solver to converge onto the one correct answer. Hence, divergent and convergent tasks have overlap of processes. In the remote associates test (RAT), participants are given three unrelated probe words and asked to generate a fourth target word that relates to all three probes. The target word can be associated with the probe words semantically (Elephant – Lapse – Vivid: Memory) or form compound words with them (Night – Wrist – Stop: Watch). Solutions to these problems can come instantaneously or through problem solving (Kounios et al., 2008).

Solutions to RAT problems can reflect different cognitive processes. Beeman and colleagues (reviewed in Kounios & Beeman, 2014) have provided evidence for hemispheric contributions to insight-style solutions – finding that moments before, and simultaneous with, the insight, the right hemisphere (in particular the anterior cingulate) showed increased brain activity – speculated to reflect conflict monitoring and cognitive control. Gupta, Jang, Mednick, and Huber (2012) have demonstrated a role of inhibition in RAT solutions; in this study, they created a model that inhibited the activation of the dominant semantic associates, allowing for more distant and weaker semantic associates to be activated. This model significantly reflected patterns in participant responses. Additionally, Lee and Therriault (2013) have recently provided evidence for a positive relation between nonverbal intelligence, measured using Raven's progressive matrices and convergent creativity, but not divergent creativity. For verbal intelligence (VIQ), they found a positive relation between VIQ and both convergent and divergent creativity. The RAT reflects convergent creativity, but there are tasks designed to measure divergent creativity. In a study of bilinguals, Hommel, Colzato, Fischer, & Christoffels (2011) found that high proficient bilinguals showed greater performance for convergent (RAT) but worse performance for divergent (unusual uses task) tasks compared to lower-proficiency bilinguals – presumably due to greater top-down processing in higher-proficiency bilinguals.

The most widely used divergent creativity task is the unusual uses task (Guilford, 1967). In the unusual uses task (UUT), participants are told to generate as many uses as possible for a certain mundane item (e.g., brick) within a particular time frame. Typically, participants start with obvious uses (e.g., "make a building") and proceed to more novel uses (e.g., "step for leg exercises") (Silvia et al., 2008). Responses on the UUT also involve multiple cognitive processes, ranging from fluency to intelligence (Lee & Therriault, 2013). The UUT can be measured in several ways: fluency, originality, top two, etc. Fluency is a score that counts the number of ideas for a use (e.g., "to sand down" and "paper weight"). Originality, or frequency, is the number of times an idea has been given by the sample divided by the total number of the samples' ideas. The top two measure requires participants to select their top two most creative responses. The two most frequently used measures for the UUT are fluency and originality (Silvia et al., 2008).

Both the UUT and RAT are the dominant measures of creativity in the cognitive neuroscience of creativity. The UUT is a verbal task, in that the input and output of the task are verbal; the UUT, however, may involve more perceptual and imagined-motoric processes than the RAT. The UUT and RAT are distinct tasks that have both been correlated with real-world creativity outcomes (Kaufman, 2009).

Neuroscience of Creativity

Creativity involves cognitive processes ranging from perception to semantic activation to expertise and decision-making. It is no wonder, then, that many brain areas are associated with creativity (e.g., Abraham et al., 2012; Dietrich, 2004; Fink et al., 2007). As previously discussed, the cognitive neuroscience of creativity typically correlates performance on various creativity tasks with some neurological technique. In reviewing the research on the cognitive neuroscience of insight, Kounios and Beeman (2014) identify the right anterior superior temporal gyrus, bilateral hippocampus, parahippocampal gyri, anterior cingulate cortex, and posterior cingulate cortex in fMRI research on insight and a burst of gamma-band activity in the right temporal lobe in EEG research; these areas implicate memory (Battaglia et al., 2011), semantic (Binder, Desai, Graves, & Conant, 2009), and conflict monitoring (Botvinick & Braver, 2015) processes. Although there isn't a direct correspondence between neural structure and function, there is an association, such that differences in structure correspond to experience and functional difference (e.g., Draganski & May, 2008). In a review of the structural neuroscience of creativity, Jung et al. (2013) reported a positive correlation between creativity scores and grey matter thickness of the right posterior cingulate cortex and a negative correlation for left frontal lobe, lingual gyrus, cuneus, angular gyrus, inferior parietal lobe, and fusiform gyrus. Jung et al. also reported a positive correlation between the creativity achievement questionnaire (an "objective" measure of creative accomplishments) and the thickness of the right angular gyrus and a negative correlation for the left lateral orbitofrontal region. Note that increased creativity and creative achievement are both associated with increased thickness in the right hemisphere but decreased thickness in the left hemisphere. This could imply greater right hemisphere processing ability and/or more efficient left hemisphere processing ability. These areas are functionally associated with cognitive control, the semantic network, and visual processing (Mechelli et al., 2000). Abraham et al. (2012) report overall stronger brain activation in the left hemisphere for creativity generally, but specific activation of the left inferior frontal gyrus, left mid-anterior inferior frontal gyrus, left temporal pole, and left lateral frontal polar cortex for conceptual expansion ("the ability to widen the conceptual structures of acquired concepts," p. 1907), areas associated with linguistic (Price, 2012) and semantic (Binder et al., 2009) processing. For divergent creativity, they found activation of the bilateral hippocampal formation and amygdala, dorsal medial prefrontal cortex, ventromedial prefrontal cortex, and posterior cingulate cortex – areas associated with memory (Battaglia, Benchenane, Sirota, Pennartz, & Wiener, 2011), emotion (Maddock, Garrett, & Buonocore, 2003), and the default mode network (Buckner, Andrews-Hanna, & Schacter, 2008). For convergent thinking, they found right hemisphere activation of the following areas: posterior medial cortex, superior parietal lobule, dorsolateral frontal, dorsolateral prefrontal, and frontopolar cortex, associated with working memory and the semantic network. Based on the neuroimaging literature, regions activated for convergent tasks are associated with cognitive control and working memory. Divergent tasks are associated with areas linked to memory and emotion. Both types of creativity appear to activate portions of the semantic network and default mode.

The neuroscience of creativity has revealed that creativity is complex and involves many cognitive processes (Fink et al., 2007). Because of this complexity, many diffuse and inconsistent neural regions have activity associated with the components of creativity (Dietrich & Kanso, 2010; Sawyer, 2011). This activity occurs in bilateral regions often associated with the semantic network (Binder et al., 2009) and cognitive control (Botvinick & Braver, 2015). The neuroscience of verbal creativity shows associations with bilateral areas involved in language, semantic memory, and cognitive control. This is, perhaps, not surprising as the verbal component of verbal creativity probably relies on linguistic processes. What may be surprising, in light of the pervasive right-hemisphere-creativity view (for a critical review, see Dietrich, 2007), is that, across many studies, both hemispheres are involved in creativity. In sum, neuroimaging has not identified distinct regions associated with creativity, broadly, or creativity tasks, in particular. This may reflect theoretical approaches, which lack fleshed-out sub-processes underlying creativity, or methodologies (i.e., tasks) which are unable to unambiguously address the sub-processes underlying creativity (Dietrich & Kanso, 2010).

The bulk of research investigating the neural correlates of creativity has involved correlating fMRI activity and structural MRI values with RAT and UUT performance. While this is crucial to understand the unique contributions of particular areas, it necessarily leaves out the concerted activity of multiple areas. The cognitive neuroscience of creativity has demonstrated there is no one neural structure that contributes to creativity. Since the 1960s, research has shown that the hemispheres can act as qualitatively independent information processors (see Hellige, 1993). It is important, then, to conduct research at the level of the cerebral hemispheres in addition to the more popular independent-structure approach.

Network analysis is a step forward from the more common independent-structure approach as it investigates the concerted activation of multiple structures. Rather than looking for unique contributions, it examines how different brain regions show a pattern of activation together. This is closer to the level of hemispheric processing because instead of looking at individual structures, researchers are investigating how patterns of activation across brain regions correlate with cognitive processes.

By far, the most popular network to investigate for creativity is the default mode network. The default mode network consists of areas that are active when a person is not actively engaged in an external task and deactivate at the onset of an external task (Buckner et al., 2008). Areas that compose the default mode network include dorsolateral prefrontal cortex, inferior temporal lobe, medial prefrontal cortex, temporal pole, posterior cingulate, and precuneus. These regions are coactivated when not actively engaged in an external task and concurrently deactivate when performing an external task. It has been associated with the semantic network (Binder et al., 2009) because of substantial overlap between the two networks.

Takeuchi et al. (2012) reported a positive correlation using resting state connectivity between the medial prefrontal cortex and posterior cingulate and creativity – with the medial prefrontal cortex and posterior cingulate being identified as core regions of the default mode network. Takeuchi et al. (2011) found that reduced precuneus task-induced deactivation during a working memory task was associated with higher creativity.

They suggested that reduced deactivation of the precuneus during cognitive tasks in highly creative people might indicate an inability to inhibit irrelevant cognitive activity – potentially associated with mind wandering (Baird et al., 2012) and disorganized thinking (Batey & Furnham, 2008).

Relating creativity to the default mode network, Kühn et al. (2013) correlated structural MRI data with three measures of the UUT: cognitive flexibility (the number of different categories a participant's responses belonged to), average uniqueness (frequency of participant's response in entire sample), and average creativity (rating of each participant's responses on a 5-point scale for creativity). Cognitive flexibility positively correlated with volume in the ventromedial prefrontal cortex, right temporal-parietal-junction, right superior frontal gyrus, right inferior temporal gyrus, and left insula. Average uniqueness positively correlated with volume in the ventromedial prefrontal cortex, precuneus, left frontal pole, left thalamus, and left insula. Average creativity positively correlated with ventromedial prefrontal cortex, right temporal parietal junction, left precuneus, and left insula. Kühn et al. reasoned that all measures of the UUT involved the ventromedial prefrontal cortex and that the ventromedial prefrontal cortex was a "core region" of the DMN.

In a study investigating resting-state functional connectivity and creativity, Lotze, Erhard, Neumann, Eickhoff, and Langer (2014) found a positive relation between increased creativity scores and increased connectivity between right hemispheric caudate and left intraparietal sulcus, the former associated with executive control functioning (Berger & Posner, 2000). For experts in creative writing, Lotze et al. found decreased resting functional connectivity between left and right inferior frontal gyri, which are associated with semantic selection (Jung-Beeman, 2005). Again, creativity was not associated with any one particular hemisphere but was associated with bilateral patterns.

Investigating functional connectivity beyond the default mode network and resting-state connectivity, Green, Cohen, Raab, Yedibalian, and Gray (2015) found increased left frontopolar activity functionally associated with anterior cingulate and right frontopolar cortex during state creativity, which is a temporary increase of creative ability manipulated by an experimenter. As before, these areas are associated with cognitive control (Botvinick & Braver, 2015) and are functionally bilateral.

Converging with the data reported for independent structures and activations, creativity has been associated with bilateral activation in functional networks. The main advantage of investigating creativity in terms of coactivity networks is that networks more accurately reflect the brain's multifaceted role in creativity, rather than identifying independently activating structures. All levels of analysis are needed to understand creativity, but previous research has generally neglected the role of interhemispheric interaction.

Interhemispheric Interaction and Creativity

Research investigating hemispheric contributions to creativity has been relatively sparse, though hemispheric theories of creativity are popular in both academic (Kounios & Beeman, 2014; Mihov, Denzler, & Forster, 2010; see Dietrich, 2007 and Lindell, 2011 for critical reviews) and lay circles (Edwards, 2012). Jung-Beeman (2005), for example, argues that the right hemisphere supports insight problem solving, in part, because the right hemisphere allows for the activation, integration, and selection of more distant meanings. Both convergent and divergent creativity benefit from such processes – activation and integration for divergent creativity and selection for convergent creativity. Additionally, with the view of the right hemisphere as the "holistic" and "artistic" hemisphere, it has been argued that the right hemisphere is responsible for seeing "the big picture" and allowing an integration of differentiated information (discussed in Hellige, 1993). Though this view has received a lot of discussion from the non-scientific community, its scientific support has been minimal. Fleshed out theories of the hemispheric asymmetry of creativity are scant.

As described in the reporting of previous MRI studies, creativity relies on processes from both hemispheres; however, the role of how the hemispheres work together is understudied. Creativity requires many subprocesses. Do these subprocesses benefit from the transferring of information between the hemispheres? Does creativity relate to cerebral dominance – that is, if both hemispheres are provided the same information, does one hemisphere dominate the processing of that information? It is also unclear if increased interhemispheric interaction (IHI) allows greater access to right hemisphere processing; if so, is a person with greater IHI more likely to be creative?

Hemispheric explanations of creativity have had little to say about the role of IHI. IHI is the exchange, coordination, or inhibition of information between the hemispheres. IHI is likely not one process, but a set of processes (Hellige, 1993) that are involved in, at least, the summation, integration, and control of lateralized information. Some research (i.e., bilateral/redundancy gain) has identified a summative aspect of IHI (e.g., Hasbrooke

& Chiarello, 1998). In this research, redundant information presented bilaterally is shown to have a processing advantage over information presented unilaterally. Some research (i.e., using the across-field advantage paradigm) has identified an integrative aspect of IHI (e.g., Banich & Belger, 1990). Interhemispheric integration requires different information presented to left and right visual fields to be compared and analyzed to make a decision. Both summation and integration are measures of interhemispheric processing, with an interhemispheric advantage indicating that outcomes benefit more from the combined efforts of the hemispheres versus the processing of one hemisphere alone. Relying on bilateral processes, creativity may benefit from an advantage of interhemispheric information transfer above unilateral processing. Other research (i.e., metacontrol studies) has identified instances when the processing style of a single hemisphere takes control of processing in a task regardless of relative hemispheric advantage (Hellige, Taylor, & Eng, 1989). If the right hemisphere has greater access to distant semantic associates (Burgess & Simpson, 1988; Jung-Beeman, 2005), then creativity should benefit from greater right hemisphere, and reduced left hemisphere, metacontrol. The current study explored the association of creative ability with each of these types of IHI.

Interhemispheric summation can be examined using the bilateral gain paradigm. In bilateral gain research, participants' performance for lateralized trials (i.e., when a stimulus is presented to a single visual field) is compared to bilateral, redundant, trials (when identical stimuli are simultaneously presented to both visual fields). Generally, it has been shown that participants are faster when information is presented bilaterally

(Hasbrooke & Chiarello, 1998; Mohr, Pulvermüller, & Zaidel, 1994). There are two potential explanations. First, and less supported, is the race-model view (Coney, 1985). In this view, bilateral presentation of stimuli allows the faster hemisphere to respond; the fastest hemisphere wins, resulting in an overall advantage for bilateral trials. Though this theory is parsimonious in that it explains bilateral gain without interhemispheric interaction, it has generally not been supported. Hasbrooke and Chiarello (1998) investigated the race model theory by having participants engage in a bilateral gain task. The researchers created a distribution of reaction times (RTs) by randomly pairing LVF and RVF trials, and then selecting the fastest unilateral (RVF/LVF) trial from each pair. That distribution of reaction times was then compared to actual performance on bilateral trials. The race model was significantly faster than actual performance on bilateral trials, demonstrating that the race model theory was insufficient for explaining actual bilateral gain performance.

A second explanation for why bilateral redundant presentation leads to faster performance than lateralized trials is that the hemispheres combine information or activation (Miller, 2004). One plausible way this could occur is through a summation of bilateral associations leading to activation above a given threshold (Jung-Beeman, 2005; Mohr, Endrass, Hauk, & Pulvermüller, 2007). Additionally, it is plausible that information above the perceptual level is shared between the hemispheres. Mohr et al. (1994) found bilateral gain in a lexical decision task for words but not for pronounceable non-words; this suggests that bilateral gain effects are not merely perceptually based, but can be sensitive to semantic content. In the current investigation, bilateral gain was used as a measure to investigate interhemispheric summation of redundant information. As creativity appears to involve bilateral processes, efficient ability to summate information across the hemispheres could aid creativity.

Integration of differing information across hemispheres can be examined by utilizing Banich's interhemispheric integration paradigm (Weissman & Banich, 2000). In the classic version of the across-field advantage visual field task, a different probe letter is displayed in both the left and right visual field and both are presented relatively toward the top of the display. A third letter, the target, is presented in either the left or the right visual field and is presented more central and toward the bottom of the display. See example Figure 1 and Figure 2 from Weissman and Banich (2000, pg. 45):

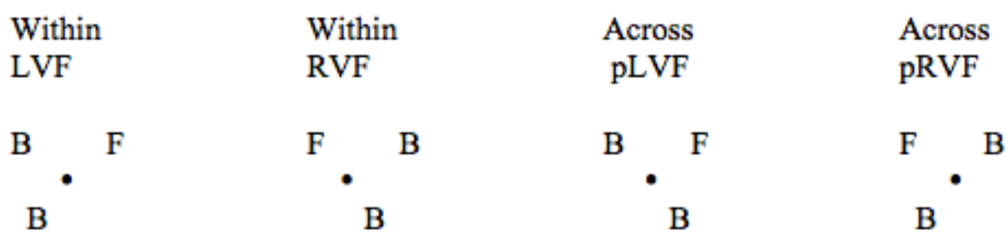

Figure 1. Letter-matching example from across-field advantage task from Weissman and Banich (2000)

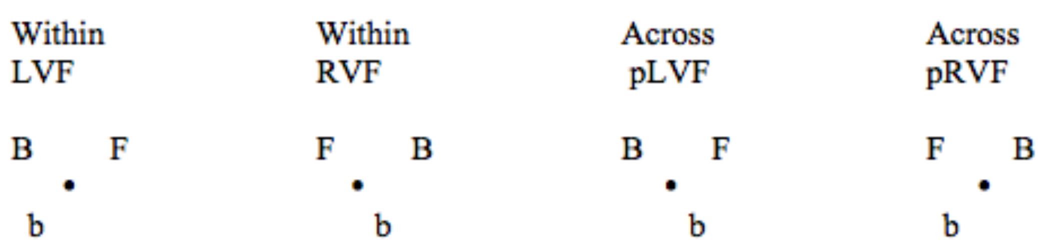

Figure 2. Name-matching example from across-field advantage task from Weissman and Banich (2000)

Participants decide whether or not the target matches one of the probes. There are two types of match trials with variations on visual field and complexity. For *visual field*, there are two levels: the target matches a probe in the same visual field (within) or opposite visual field (across). For *complexity*, there are two levels: the target is the same physical letter as the probe (physical identity; e.g., A-A) or the target is the same name as the probe (name identity; e.g., a-A). Banich and colleagues (Weissman & Banich, 2000) have found that there is a within-field advantage for simple tasks, but an across-field advantage for complex tasks. Participants are faster to respond to the simple, physical identity condition when the stimuli are both in the same visual field. Participants respond more quickly in the name identity condition when the matching stimuli are in different visual fields. There appears to be a processing cost for information transfer and integration between the hemispheres. Hence, for simple tasks, it is more efficient to process information in one hemisphere whereas it is more efficient for complex tasks to distribute the processing between hemispheres. The across-field advantage task demonstrates interhemispheric processing because information from one visual field cannot simply be summated with information from the other visual field – an integration of physically different stimuli must occur. One purpose for the current study was to investigate the relation between information integration and creativity. It was predicted that, due to the complex nature of creativity, an increased across-field advantage would relate to better creativity performance.

A third type of interhemispheric interaction concerns *metacontrol*: what happens when both hemispheres have equal access to identical stimuli? Does one hemisphere show an advantage and does the best hemisphere dominate in the processing? Studies of metacontrol have shown that there are instances when a hemisphere will dominate the processing of certain stimuli but the dominating hemisphere does not necessarily show better processing (Hellige, 1993; Lohr et al., 2006). In one study, Hellige and Michimata (1989) had participants make same or different judgments for two uppercase-letters when presented to either the left visual field (LVF), right visual field (RVF), or bilaterally (BVF). They found that reaction times to bilateral presentations matched the pattern of RVF trials more than LVF trials – despite LVF superiority for different trials. This demonstrates left hemisphere metacontrol.

In a more frequently used methodology, Hellige, Taylor, and Eng (1989) had participants say aloud and spell consonant-vowel-consonant nonsense syllables. Each CVC was presented to either the LVF, RVF, or bilaterally to each VF, or the center of the screen. The researchers recorded the type of errors that would occur: the incorrect first letter, last letter, or other error. Qualitative error scores are calculated for each visual field condition (LVF, RVF, BVF) as (last errors – first errors) / (total errors). Critically, the qualitative error scores on bilateral trials mirrored the pattern of LVF trials – despite fewer overall errors for RVF trials. Research on metacontrol, then, demonstrates that the hemisphere that dominates processing is not necessarily the best hemisphere for the task. Another purpose of the current study was to investigate the relation between metacontrol and creativity. Because of the right hemisphere's advantage in distant semantic meaning (Burgess & Simpson, 1988), it was predicted that RH metacontrol would be positively correlated with creativity.

Degree of hand preference, strength of preference independent of particular hand, has been hypothesized to reflect interhemispheric interaction (Prichard, Propper, & Christman, 2013). Hand preference questionnaires (e.g., Oldfield, 1971) ask participants to choose the hand they would prefer to use with various objects and tasks and the strength of that preference. Prichard et al. (2013) hypothesized that people who have a weak preference for either hand (i.e., mixed handedness) have greater interhemispheric interaction than people with a strong hand preference (i.e., consistent handers). Degree of handedness, then, is a possible indirect approach to studying IHI. Prichard et al. (2013) argued that mixed handers have greater access to right hemispheric processing; Sontam and Christman (2012) found that mixed handers have greater activation of subordinate meanings than consistent handers. In a direct study of handedness and creativity, Shobe, Ross, and Fleck (2009) report a mixed hander advantage for multiple measures (fluency, categorical distinctiveness, appropriateness, and originality) of the UUT over consistent handers. To date, Shobe et al. is the only published study to investigate the relation between IHI and creativity. Work from our lab, however, has failed to replicate the relation between hand preference and creativity reported by Shobe et al. (Felton & Chiarello, 2014a, 2014b). The differences in findings may be explained, at least in part, by the fact that our study had a larger sample (over 200 compared to Shobe et al.'s 60), more measures of handedness, and more measures of creativity (the RAT and UUT compared to Shobe et al.'s UUT). To date, then, there has been no direct investigation of the relation between IHI and creativity. In addition to the direct measures of IHI, we also investigated the association between handedness and creativity.

Present Study

For this study, I proposed to more directly investigate the relation between IHI and creativity. I used a bilateral gain task, the across-field advantage task, and a metacontrol task to measure different aspects of IHI. To measure creativity, I administered the RAT, UUT, and, in addition to those verbal creativity measures, two nonverbal measures: the dot insight problem and an image creation task. Because of the known relation between openness and creativity (King et al., 1996) and intelligence and creativity (Lee & Therriault, 2013), I administered measures to control for the potential influence of openness and verbal intelligence on creativity.

It is unclear to what extent interhemispheric interaction is associated with creativity. Does creativity improve to the extent that interhemispheric interaction is increased? If so, then all measures of interhemispheric interaction should positively correlate with creativity scores independent of convergent or divergent task. Because convergent creativity may rely more heavily on a decision requiring greater activation above a threshold than divergent creativity, it could be predicted that there would be a positive correlation between bilateral gain performance and RAT performance but not for UUT performance. Because creativity is complex and involves multiple processes, it was predicted that a greater across-field advantage would be associated with higher rates of both convergent and divergent creativity. Additionally, because both types of creativity may, at some point, require activation of semantic units with the more distant, weaker association strength of the right hemisphere, it was predicted that, for more creative people, bilateral trials in the metacontrol task would reflect the pattern of RH trials more than LH trials. Hence, more creative people would show a RH-mirrored patterning of errors for bilateral trials than less creative people, who would show a more LH-mirrored patterning of errors because of dominant LH linguistic processing. Secondarily, handedness groups are theorized to have differing levels of interhemispheric interaction (Prichard et al., 2013), so if it is the case that interhemispheric differences exist between handedness groups, it can be predicted that handedness group would interact with IHI, such that mixed handers would have greater interhemispheric advantage over consistent handers. Similarly, if it is the case that mixed handers have greater access to right hemispheric processing, it could be predicted that mixed handers would score higher on all measures of creativity.

Chapter 2

Method

Participants

The study recruited participants (*N* = 151; females = 103; males = 48; mean age = 19.61). Participants were native-English speakers with at least 20/30 or corrected-to-normal vision and no known neurological problems. The study enrolled participants of any handedness and gender. Participants were recruited from both the psychology department subject pool and through flyers offering monetary compensation.

Overall Procedure

The study consisted of three sessions completed on different days, each lasting 45-50 minutes. The amount of time between the sessions was not critical, but the aim was to complete all three sessions within two weeks. Before the first session was run, potential participants were screened via phone call or email. Participants were screened for language history, neurological problems, and vision. Additionally, participants were given a brief overview of the study. At Session 1, participants were provided an overview of the study. A vision test was administered to ensure 20/30 or corrected-to-normal vision. They received the language history questionnaire (Li, Zhang, Tsai, & Puls, 2014) and handedness forms. After filling out the forms (and meeting language history questionnaire criteria), the metacontrol task was administered. Session 2 consisted of the bilateral gain task followed by the verbal IQ test. Session 3 consisted of the across-field advantage task, the personality inventory, RAT, UUT, dot insight problem, and image creation task, administered in that order.

Materials and Standardized Tests

A language history questionnaire was used to ensure participants were native English speakers. This questionnaire ascertains languages known, when the languages were learned, and how the languages are used alone and interpersonally. A modified, 10-item Edinburgh handedness inventory (Oldfield, 1971) was used to measure hand preference for various tasks and establish handedness groups.

The Big Five Inventory (John, Naumann, & Soto, 2008) is a self-report measure that was administered to control for the influence of personality on creativity scores. Openness measures intellectual curiosity and artistry and consists of the following 10 items: "is original, comes up with new ideas;" "is curious about many different things;" "is ingenious, a deep thinker;" "has an active imagination;" "is inventive;" "values artistic, aesthetic experience;" "prefers work that is routine" (reverse coded); "likes to reflect, play with ideas;" "has few artistic interests" (reverse coded); "is sophisticated in art, music, or literature." Participants rated the degree to which they agreed or disagreed with each of the items by using a 5-point scale ranging from "strongly disagree" (1) to "strongly agree" (5). Given that the relation between openness and creativity is well documented (e.g., King, Walker, & Broyle, 1996), it is important to statistically control for openness to examine the unique contribution of interhemispheric interaction on creativity.

The Wechsler Abbreviated Scale of Intelligence (Wechsler, 1997) was administered to participants to control for verbal intelligence. Participants completed the vocabulary and similarities subtests which consisted of vocally defining words and providing similarities between words. There is a positive relation between verbal intelligence and creativity (Kaufman, 2009; Lee & Therriault, 2013). It is thus important to control for verbal intelligence when investigating creativity.

The remote associates test (RAT) consisted of the materials of Bowden and Jung-Beeman (2003a). There were 21 trials visually presented using Psyscope software (Cohen, MacWhinney, Flatt, & Provost, 1993) to participants. The participant's task was to vocally identify the fourth word that related to the three probe words that were unrelated to each other. The reaction time of the participant's response was recorded as voice onset time and their accuracy was recorded via experimenter. Reaction time analyses were conducted only on correct responses. RAT accuracy was calculated as percent correct.

In the unusual uses task, participants generated as many uses as they could for mundane items (Guilford, 1967). In this study, participants were given three minutes per item to write down possible uses for "brick" and "automobile tire." Based on responses, a *fluency* score (the number of ideas generated) and an *originality* score (frequency of response within entire sample) were generated. Originality was calculated as the percentage of participants in the sample who gave the response (Plucker, Qian, & Wang, 2011). The average was taken for the two items, multiplied by 1000, and subtracted from 1000 so that higher scores indicated more originality. Additionally, participants were asked to circle their two self-identified most original responses per item (Silvia et al., 2008); this *top two* response was then evaluated by four independent raters on a scale of 1-5, ranging from least creative to most creative.

The dot insight problem (Lee & Therriault, 2013) consisted of four dots on a sheet of paper that the participant was instructed to solve along with a word anagram within three minutes. Participants were told to draw two straight lines to connect the four dots without lifting their pencil. This was a measure of nonverbal creativity and it was scored for completion. Another measure of nonverbal creativity was the image creation task adapted from Finke and Slayton (1988). In this task, participants were given a sheet of paper with the task of drawing images using only the nine shapes shown on the sheet – D, C, square, 8, triangle, circle, rectangle, V, and a straight line. The shapes could be enlarged or rotated, but not fundamentally changed – hence a rectangle could not become a triangle. Participants were given three minutes to complete as many legitimate figures (i.e., abstract figures did not count) as possible directly on their paper. After the three minutes, participants labeled their figures. This task produced three measures: fluency, creativity, and components. The fluency score was how many images the participant created. The creativity score was a rating, from 1 to 5, of how creative each image was. Higher scores indicated more creativity. This creativity rating was then assessed for inter-rater reliability between two raters and an average creativity score was calculated for each participant between the trials and raters. The component score was how many, of 9, shapes the participant used in each figure averaged together. The component measure was used because elaboration, or the amount of detail, is a frequent measure of creativity (e.g., Kaufman, Plucker, & Russell, 2012).

Procedure

Bilateral gain task. This lexical decision task was patterned after Mohr et al. (1994). In this task, words and pronounceable non-words were presented to either the LVF, the RVF, or bilaterally. Participants were seated 60 cm in front of a screen and their head positions kept constant via headrest. The participant's task was to identify whether the target was a word or a non-word by pressing the respective button on the ioLab USB button response box with both hands. Participants simultaneously used their index fingers on both hands for yes and the middle fingers of both hands for no; the fastest response was recorded. Response mapping was incompletely balanced across participants, but no effect of response mapping was found.

After the initial presentation of a fixation cross, which continued throughout the duration of the trial, the target appeared on the screen for 100 ms. Ninety word and ninety non-words from Mohr et al. (1994) were used and randomly presented in lower-case Helvetica 20-point font. The horizontal visual angle for the stimuli was an average of 1.14°, 1.62°, 1.81°, and 2.00° for 3 to 6 letter strings, respectively, and the vertical visual angle was .38°. Visual eccentricity from innermost edge of stimulus to the center of the fixation cross was 1.62°. There were 20 practice trials with 10 word and 10 non-words randomly presented to visual field.

Bilateral gain interhemispheric advantage is a bilateral processing advantage gained above unilateral processing. Interhemispheric advantage for percent correct accuracy is calculated as the difference between bilateral and unilateral accuracy divided by the average. Interhemispheric advantage for reaction time is calculated as the difference between unilateral and bilateral correct RTs divided by the average.

Across-field advantage task. The stimuli for this task were modeled after the name-matching task of Banich and Belger (1990). There were seven uppercase and lowercase letters (A, B, D, F, G, H, and N) serving as probes and targets. The lowercase letters were in a larger Helvetica font size (44-pt) than the uppercase letters (38-pt) to help equate for size and accessibility. There was a within-field and across-field condition. This task used a 7 (letters) x 2 (matching) X 2 (VF) design resulting in 28 combinations. There were 15 practice trials followed by 4 blocks of 28 trials for a total of 112 experimental trials.

Participants were seated 60 cm in front of a screen and their head positions kept constant via headrest. Participants first saw a fixation cross at the center of the screen for 500 ms. The three-letter presentation then appeared for 140 ms and the participant's task was to make a decision whether the target matches the probe (yes or no). The two probe letters were presented 2.58° lateral to and 1.05° above fixation. The target digit appeared 1.33° lateral to and 1.43° below fixation. Responses were made on an ioLab USB button response box with the same fingers (index: yes and middle: no) of both hands; the fastest response was used. Response mapping was incompletely balanced across participants, but again, no effect of response mapping was found.

Across-field interhemispheric advantage is an across-field processing advantage gained above within-field processing. Across-field interhemispheric advantage for percent correct accuracy is calculated as the difference between across-field and within-field accuracy divided by the average. Across-field interhemispheric advantage for reaction time is calculated as the difference between unilateral and bilateral RTs divided by the average.

Metacontrol task. A consonant-vowel-consonant (CVC) task was used (following Hellige, Taylor, & Eng, 1989). The task used nine letters – six consonants (f, g, k, p, s, and t) and three vowels (a, e, and o)– to produce pronounceable, nonsense syllables. Stimuli were presented in 18-point Helvetica font. There were three blocks of 37 CVCs presented to the participant. The CVCs were presented vertically and presented in either the left, right, or bilateral visual fields. The CVC was initially presented at 150 ms. Presentation of the CVC was followed by a mask for 210 ms. The mask consisted of the following symbols: #&#. Stimuli were presented at an eccentricity of 1.72° and subtended a vertical angle of 1.52°. The participant's task was to pronounce the CVC and spell it out. Accuracy, reaction time, and spelling were recorded. Performance was adjusted via staircase design, increasing or decreasing 10 ms for a maximum of 150 ms to a minimum of 10 ms, to keep performance between 40-60% correct. The participant completed 36 practice trials (using 12 other CVCs) before the experimental trials.

Chapter 3

Results

Preliminary Analyses

Preliminary analyses were conducted to check that performance on the experimental tasks replicated previous studies. For both bilateral gain and across-field advantage tasks, preliminary analyses identified which measure, between accuracy and reaction time, produced the greater interhemispheric advantage. The measure with the strongest interhemispheric advantage was used in subsequent regressions. Means, standard deviations, and ranges for the interhemispheric interaction tasks are shown in Table 1.

Table 1. *Means (Standard Deviations) for each Interhemispheric Task by Visual Field Conditions*

Measure	Accuracy	RT
Bilateral Gain Task		
BVF	91.33 (6.88)	759 (143)
LVF	69.66 (13.58)	843 (165)
RVF	86.71 (10.97)	768 (159)
Unilateral	78.18 (8.91)	806 (154)
Across-Field Advantage Task		
Across	87.11 (8.43)	876 (155)
Within	86.19 (8.24)	892 (155)
Metacontrol Task (Qualitative Error Scores)		
BVF	.257 (.51)	
LVF	.497 (.31)	
RVF	.314 (.41)	

Bilateral Gain

For the bilateral gain task, it was expected that participants would be more accurate and faster for bilateral trials than either single visual field condition. A one-way repeated measures analysis of variance (ANOVA) was conducted for bilateral and unilateral, the average of left and right, visual field on accuracy and reaction time. Indeed, the bilateral condition was more accurate than the unilateral conditions, $F(1, 150) = 330.41$, $p < .001$. Likewise, the bilateral condition was faster than the unilateral conditions for correct trials, $F(1, 150) = 85.54$, $p < .001$. To ensure that there was true bilateral gain above and beyond either unilateral visual field, a second ANOVA compared the bilateral condition to the LVF and RVF conditions. There was a main effect of visual field on accuracy, $F(2, 300) = 198.22$, $p < .001$. Post hoc analyses showed that bilateral trials were more accurate than RVF, $p < .001$, and more accurate than LVF, $p < .001$, trials. There was a main effect of visual field on reaction time, $F(2, 300) = 84.10$, $p < .001$. Post hoc tests showed that bilateral trials were also faster than LVF trials, $p < .001$, but not RVF trials, $p = .287$.

As mentioned previously, one explanation (race model) for a bilateral gain effect could be simply that the fastest hemisphere is responding, as opposed to a synergistic increase from both hemispheres working together. To test that the bilateral gain was different from a race between independent processors, a race model was created to compare to bilateral performance. Following Hasbrooke and Chiarello (1998), pairs of data were randomly selected without replacement from each participant, (each pair consisting of one LVF and one RVF trial). For each pair, the fastest score was selected and the average of these scores was compared to the participant's average performance on bilateral trials. Replicating Hasbrooke and Chiarello, bilateral trials ($M = 758$, $SE = 12$) differed from the race model ($M = 690$, $SE = 10$), $F(1,150) = 221.802$, $p < .001$.

Bilateral gain, therefore, cannot be explained by a race model account. To conclude, the bilateral gain task showed a robust interhemispheric advantage for accuracy but not for reaction time. Hence, subsequent correlations and regressions used the bilateral gain accuracy measure. For the mean, standard deviation, and range of bilateral gain IHI advantage, see Table 2.

Table 2. *Means (Standard Deviations) and Ranges of IHI Measures*

	M (SD)	Range
Bilateral Gain Advantage Accuracy	.079 (.06)	-.059 to .273
Across-Field Advantage RT	.009 (.028)	-.054 to .122
Metacontrol BVF Qualitative Error	.257 (.505)	-1.00 to 1.00

Across-Field Advantage Task

For the across-field advantage task, it was expected that participants would be more accurate and faster for across-field than within-field trials - see Table 1 for means and standard deviations of the visual field conditions. A one-way repeated-measures ANOVA was conducted for across and within visual field on accuracy and reaction time. Participants were marginally more accurate for across trials than within trials, $F(1, 140) = 3.288$, $p = .072$. Participants were faster for across trials than within trials, $F(1, 140) = 11.839$, $p < .001$. To conclude, the across-field advantage task showed a more robust interhemispheric advantage for reaction time than for accuracy and hence the reaction time across-field advantage was used for subsequent correlations and regressions.

Metacontrol

Average exposure (ms) across visual fields (*M* = 31, *range*: 10 to 150) were similar to each visual field: BVF (*M* = 31, *range*: 10 to 150), RVF (*M* = 31, *range*: 10 to 150), and LVF (*M* = 32, *range*: 10 to 150), $F < 1$. It was predicted that the qualitative error score (the difference of last errors minus first errors divided by total errors) for bilateral trials would be closer to LVF trials than RVF trials, replicating Hellige et al. (1989). A one-way repeated-measures ANOVA was conducted for visual field on accuracy and reaction time. There was a main effect of visual field for qualitative error scores, $F(2, 316) = 23.038$, $p < .001$. Counter to predictions, post hoc analyses showed that the qualitative error scores of the bilateral trials were indistinguishable from RVF trials, $p = .39$. Bilateral trials qualitative error scores were significantly lower than LVF trials, $p < .05$. As can be seen in Figure 3, the bilateral trials more closely mirrored the RVF trials for first and last letter error types than the LVF; this is counter to what is generally found (e.g., Hellige et al., 1989), where the errors of bilateral trials match more closely with the errors of the LVF. These current results suggest left hemisphere metacontrol at the group level.

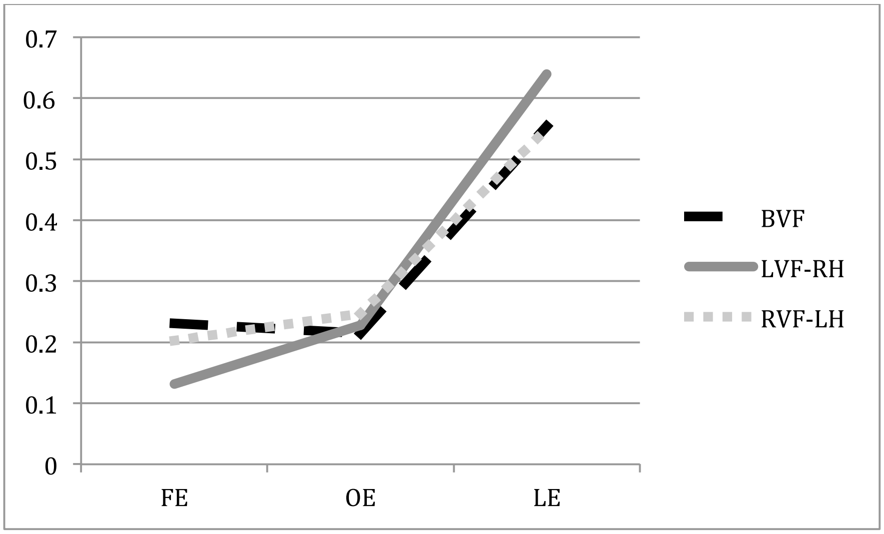

Figure 3. First error (FE), other error (OE), and last error (LE) by visual field for the metacontrol task

Correlations across Interhemispheric Measures

Pearson's correlations were conducted across measures of bilateral gain, across field advantage, and bilateral visual field qualitative error scores. As shown in Table 3, no significant correlations between interhemispheric advantage and qualitative error measures were found. This suggests that each measure reflected different facets of interhemispheric interaction.

Table 3. *Correlation Coefficients (r) between Measures of Interhemispheric Interaction*

	Bilateral Gain Advantage	Across-Field Advantage
Across-Field Advantage	0.057	1
Metacontrol BVF QE	-0.081	0.03

Creativity Measures

The dot insight measure was dropped due to low completion rates and a mid-study confound: one of the classes contributing to the subject pool was taught how to solve the problem. Reliability scores were calculated for the UUT top two and image creation task creativity ratings. There were four raters for the top two measure for both items. Cronbach's α was .81 for brick and .66 for tire. The top two ratings across raters were averaged together for both items to create a single top two score. There were two raters for the image creation task's creativity measure; Cronbach's α was .82. The scores of both raters were averaged together to create a single image creation task creativity score.

See Table 4 for descriptive statistics of the creativity measures. Pearson's correlations were conducted between all creativity measures (see Table 5). Increases in UUT fluency were associated with increases in originality and top two scores. UUT fluency and top two scores did not correlate with RAT accuracy or RAT RT, suggesting that the tasks measure different facets of creativity. However, UUT originality had a positive, weak correlation with RAT RT: faster RAT responses were associated with less original UUT responses. Of the UUT measures, only fluency correlated positively with image creation task fluency, creativity, and components – a larger number of UUT responses was associated with more images, more creative images, and the use of more components in the images; this suggests that the nonverbal image creation task shares some aspects of creativity with the UUT. RAT accuracy negatively correlated with RAT RT, but no other creativity measure, such that increases in accuracy were associated with faster correct responses. Unlike UUT frequency, increases in the number of images created were associated with lower image creativity and lower numbers of components used in the images. This indicates that there was a creativity cost associated with the production of more, simpler images. Overall, these results demonstrate that divergent measures are generally distinct from convergent measures.

Table 4. *Means (Standard Deviations) and Ranges of Creativity Measures*

	M (SD)	Range
Unusual Uses Task		
Fluency	8.01 (3.23)	3.00 to 20.50
Originality	72.83 (8.91)	41.60 to 92.70
Top Two	2.95 (.44)	1.38 to 3.88
Remote Associates Test		
Accuracy (percent correct)	56.70 (16.57)	9.52 to 90.48
RT (sec)	5.45 (1.25)	2.43 to 10.16
Image Creation Task		
Fluency	4.31 (2.12)	1.00 to 13.00
Creativity	2.13 (.87)	1.00 to 5.00
Components	3.99 (1.76)	1.00 to 9.00

Table 5. *Correlation Coefficients (r) between Creativity Measures*

	UUT Fluency	UUT Originality	UUT Top Two	RAT Accuracy	RAT RT	ICT Fluency	ICT Creativity	ICT Components
UUT Fluency	1							
UUT Originality	.547***	1						
UUT Top Two	.243***	.157	1					
RAT Accuracy	-0.002	-0.144	0.112	1				
RAT RT	-0.007	.175*	0.001	-.284***	1			
ICT Fluency	.196*	0.004	0.134	0.168	-0.075	1		
ICT Creativity	.241**	0.092	-0.011	-0.061	-0.081	-.225**	1	
ICT Components	.234**	0.159	0.021	-0.034	-0.042	-.477***	.641***	1

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

Primary Analyses

It was predicted that all measures of creativity (RAT accuracy, RAT RT, UUT fluency, UUT originality, UUT top two, image creation task (ICT) fluency, ICT creativity, and ICT components scores) would correlate with the bilateral gain and across-field advantage tasks' interhemispheric advantage. However, if convergent creativity benefits from stronger association strength, it could be predicted that the RAT measures and not the UUT measures would be associated with bilateral gain interhemispheric advantage. It was also predicted that a relation would hold even when accounting for verbal IQ and personality via simultaneous regressions. The same creativity measures were expected to positively correlate with the bilateral qualitative error scores of the metacontrol task, even when controlling for verbal IQ and personality. The primary analyses are here reported first as the correlations between the creativity and interhemispheric interaction measures followed by their respective regressions.

RAT accuracy. As shown in Table 6, RAT accuracy did not correlate with bilateral gain or the across-field advantage. RAT accuracy did, however, negatively correlate with metacontrol BVF qualitative error scores, indicating that decreases in RAT performance were associated with greater left hemisphere metacontrol or, potentially, that RAT performance increases with greater right hemisphere metacontrol (see Figure 4). This finding does not support the hypothesis that creativity would be positively correlated with BVF qualitative error rates but may suggest RH metacontrol. Additionally, increases in RAT accuracy were associated with increases in verbal IQ.

Table 6. *Correlation Coefficiencts (r) between Interhemispheric Interaction and Creativity Measures*

	RAT ACC	RAT RT	UUT Fluency	UUT Originality	UUT Top Two	ICT Fluency	ICT Creativity	ICT Components
Bilateral Gain Advantage Accuracy	-0.054	0.051	-0.018	0.056	-0.074	0.103	-0.148	-0.141
Across-field Advantage RT	-0.108	-0.011	0.007	0.071	-0.018	-0.002	-0.043	-0.124
Metacontrol BVF QE	-.235**	0.098	-0.005	0.014	-0.034	-0.102	0.151	0.154
Openness	0.044	0.001	.256**	0.153	0.145	.184*	.178*	.198*
Verbal IQ	.275**	-.300***	-0.142	-0.147	0.017	0.051	0.139	0.05

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

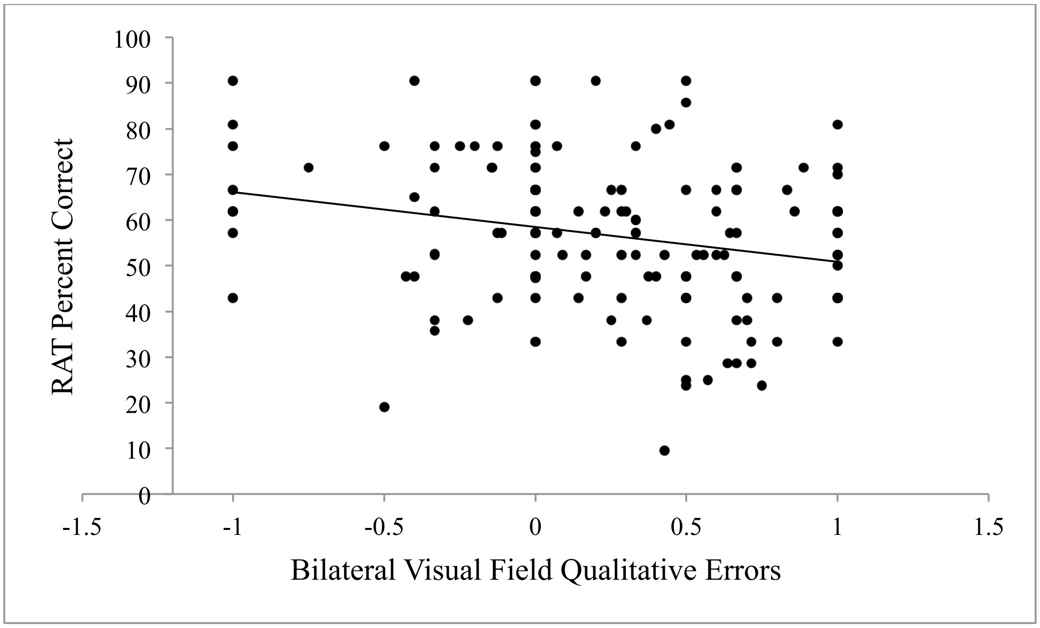

Figure 4. Relation between metacontrol bilateral visual field qualitative error scores and RAT accuracy

Three different multiple regressions, one per interhemispheric task, with verbal IQ, openness, and the interhemispheric measure, found that the only interhemispheric task predicting RAT accuracy was metacontrol's bilateral visual field qualitative error scores (see Table 7). Both qualitative error scores and verbal IQ uniquely predict RAT accuracy; higher verbal IQs were associated with higher accuracy scores on the RAT, across all regressions.

Table 7. *Multiple Regression Predictors of RAT Accuracy*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	-.034		
Across Field Advantage β		-.090	
Metacontrol β			-.285***
Verbal IQ β	.267**	.244**	.293***
Openness β	.008	.023	.004
Model R^2	.047	.072	.154
Model F	3.581*	3.438*	8.101***

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

RAT reaction time. As shown in Table 6, RAT RT did not correlate with any measure of interhemispheric interaction. However, faster RAT responses were associated with higher verbal IQ scores. Three different multiple regressions, one per interhemispheric task, with the interhemispheric measure, verbal IQ, and openness predicting RAT RT did not find any interhemispheric task predicting creativity (see Table 8). As with RAT accuracy, verbal IQ predicted RAT RT, such that higher verbal IQ was associated with faster reaction times across all regressions.

Table 8. *Multiple Regression Predictors of RAT RT*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	.033		
Across Field Advantage β		-.034	
Metacontrol β			.133
Verbal IQ β	-.302***	-.299***	-.315***
Openness β	.039	.037	.040
Model R^2	.093	.088	.109
Model *F*	4.527**	4.217**	5.425***

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

Unusual uses task - fluency. As shown in Table 6, UUT fluency scores did not correlate with any measure of interhemispheric interaction. Increases in fluency scores were associated with higher rates of openness. Three different multiple regressions, one per interhemispheric task, with the interhemispheric measure, verbal IQ, and openness did not find any interhemispheric task predicting fluency (see Table 9). Both verbal IQ and openness uniquely predicted fluency, across all regressions. Higher scores on openness were associated with greater fluency scores. As verbal IQ scores increased, however, fluency scores decreased – indicating that people with higher verbal IQ gave fewer responses.

Table 9. *Multiple Regression Predictors of UUT Fluency*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	0.011		
Across Field Advantage β		.010	
Metacontrol β			.022
Verbal IQ β	-.166*	-.187*	-.169*
Openness β	.274***	.281***	.274***
Model R^2	0.094	.103	.094
Model *F*	4.573**	5.022**	4.592**

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

Unusual uses task – originality. The UUT originality measure did not correlate with any measure of interhemispheric interaction, openness, or verbal IQ (see Table 6). Three different multiple regressions, one per interhemispheric task, with the interhemispheric measure, verbal IQ, and openness did not find any interhemispheric task predicting originality (see Table 10). Openness positively predicted originality for the regressions investigating bilateral gain and metacontrol. Verbal IQ negatively predicted originality in the metacontrol regression, such that people with higher verbal IQs gave less original responses.

Table 10. *Multiple Regression Predictors of UUT Originality*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	.069		
Across Field Advantage β		.063	
Metacontrol β			.067
Verbal IQ β	-.159	-.142	-.170*
Openness β	.174*	.167	.174*
Model R^2	.056	.049	.056
Model *F*	2.621	2.264	2.607

* $p < .05$

Unusual uses task – top two. As shown in Table 6, the UUT top two measure did not correlate with any interhemispheric interaction measure, openness, or verbal IQ. Three different multiple regressions, one per interhemispheric task, with verbal IQ, and openness did not find any interhemispheric task predicting top two scores (see Table 11). Neither openness nor verbal IQ influenced this creativity measure.

Table 11. *Multiple Regression Predictors of UUT Top Two*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	-.053		
Across Field Advantage β		-.014	
Metacontrol β			-.024
Verbal IQ β	.000	-.031	.006
Openness β	.137	.147	.138
Model R^2	.022	.021	.020
Model *F*	.971	.933	0.872

Image creation task – fluency. As shown in Table 6, image creation fluency did not correlate with any measure of interhemispheric advantage. Greater fluency scores were associated with higher levels of openness. Three different multiple regressions, one per interhemispheric task, with the interhemispheric measure, verbal IQ, and openness did not find any interhemispheric task predicting fluency (see Table 12). Originally it was found that openness correlated with fluency, but, when controlling for the effect of the other predictors, the effect was absent in the multiple regressions.

Table 12. *Multiple Regression Predictors of ICT Fluency*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	.111		
Across Field Advantage β		.013	
Metacontrol β			-.072
Verbal IQ β	.053	.45	.057
Openness β	.171*	.169	.167
Model R^2	.045	.032	.038
Model F	2.033	1.382	1.697

* $p < .05$

Image creation task – creativity. As shown in Table 6, image creation creativity did not correlate with any measure of interhemispheric advantage. The creativity measure did positively correlate with openness. Three different multiple regressions, one per interhemispheric task, with the interhemispheric measure, verbal IQ, and openness did not find any interhemispheric task predicting fluency (see Table 13). Originally it was found that openness correlated with creativity, but, when controlling for the effect of the other predictors, the effect was absent in the multiple regressions.

Table 13. *Multiple Regression Predictors of ICT Creativity*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	-.106		
Across Field Advantage β		-.025	
Metacontrol β			.151
Verbal IQ β	.130	.128	.125
Openness β	.128	.131	.135
Model R^2	.049	.037	.061
Model F	2.249	1.653	2.801*

*p < .05

Image creation task – components. As shown in Table 6, image creation components did not correlate, via Pearson correlation, with any measure of interhemispheric interaction. Greater numbers of image creation components were associated with higher scores of openness. Three different multiple regressions, one per interhemispheric task, with the interhemispheric measure, verbal IQ, and openness did not find any interhemispheric task predicting components (see Table 14). Openness uniquely, positively predicted ICT components in the across-field advantage and metacontrol regressions; higher scores on openness were associated with higher component scores.

Table 14. *Multiple Regression Predictors of ICT components*

Variable	Bilateral Gain Advantage Model	Across Field Advantage Model	Metacontrol Model
Bilateral Gain Advantage β	-.086		
Across Field Advantage β		-.111	
Metacontrol β			.122
Verbal IQ β	.029	.014	.024
Openness β	.170	.178*	.175*
Model R^2	.039	.045	.046
Model *F*	1.774	2.027	2.119

* $p < .05$

Creativity composite. A creativity composite score was formed by z-transforming each of the creativity measures and averaging the z-scores together. In a Pearson correlation, this measure did not correlate with any interhemispheric interaction task, but it did positively correlate with openness, $r = .346$, $p < .001$.

Secondary Analyses

In addition to the primary analyses conducted to test the predicted relation between the IHI measures and creativity, exploratory analyses were conducted to investigate sex and handedness. As sex has been associated with brain asymmetry and potential interhemispheric interaction (see Welcome et al., 2009), the relation between sex, interhemispheric interaction, and creativity was investigated. Sex did not correlate with any IHI or creativity measure. Simultaneous multiple regressions were conducted using sex with each IHI measure to predict each measure of creativity. Sex did not significantly predict any creativity measure or serve as a moderator of the effects of the other predictors (openness and verbal IQ).

As handedness has been associated with brain asymmetry and potential interhemispheric interact (see Welcome et al., 2009), raw handedness scores were investigated in conjunction with creativity and interhemispheric interaction. A Pearson's correlation found that greater left handedness was associated with higher ICT fluency scores, $r = -.179$, $p < .05$. Handedness scores were put into simultaneous multiple regressions with each interhemispheric task, IQ, and openness to predict each measure of creativity. For each interhemispheric task, handedness scores negatively predicted ICT fluency scores - with bilateral gain, $\beta = -.193$, $p < .05$; with across-field advantage task, $\beta = -.183$, $p < .05$; with metacontrol, $\beta = -.181$, $p < .05$; this indicates that left handedness was associated with higher fluency scores even accounting for IHI measure, verbal IQ, and openness. The relation between handedness and interhemispheric interaction was investigated. Using a Pearson correlation, handedness scores did not correlate with any measure of interhemispheric interaction.

To further investigate handedness effects, a median split was conducted on the absolute value of handedness scores to create handedness groups (see Prichard et al., 2013): mixed handers and consistent handers. Table 15 lists means and standard deviations for IHI measure by handedness group. Handedness group differences for IHI were analyzed via an independent samples t-test – see Table 15. It was found that consistent handers had higher BVF qualitative error scores. In addition, a point-biserial correlation indicated that handedness group positively correlated with metacontrol bilateral visual field qualitative error scores, $r = .192$, $p < .05$, indicating that consistent handedness was associated with relatively greater numbers of last letter errors and hence, left hemisphere metacontrol.

Table 15. *Means (Standard Deviations) by Handedness Groups for IHI Measure and t Value of Each Contrast*

	Mixed	Consistent	*t* (140)
Bilateral Gain Advantage	.08 (.05)	.08 (.06)	.379
Across Field Advantage	.01 (.03)	.01 (.03)	.825
Metacontrol BVF QE	.17 (.56)	.35 (.43)	2.307*

* $p < .05$

Independent-samples t-tests indicated that there was no association between handedness groups and creativity measures (see Table 16). Regressions using interhemispheric tasks, handedness group, IQ, and openness did not significantly predict any creativity measure.

Table 16. *Means (Standard Deviations) by Handedness Groups for Creativity and t Value of Each Contrast*

	Mixed	Consistent	*t* (140)
Remote Associates Test			
Accuracy	57.34 (2.01)	56.09 (1.90)	.45
RT	5447 (1451)	5449 (1035)	.01
Unusual Uses Task			
Fluency	7.80 (2.54)	8.22 (3.78)	.79
Originality	72.68 (8.99)	72.92 (8.96)	.16
Top Two	2.92 (.40)	2.98 (.46)	.88
Image Creation Task			
Fluency	4.36 (2.25)	4.26 (2.00)	.28
Creativity	2.04 (.69)	2.22 (1.01)	1.26
Components	3.71 (1.63)	4.25 (1.85)	1.85

In exploratory analyses, other dimensions of personality were investigated in relation to creativity (see Table 17). Higher rates of extraversion were associated with higher scores of UUT fluency and ICT fluency – indicating that more outgoing people gave more responses. The relation between personality and interhemispheric interaction was investigated. Only agreeableness was positively correlated with the across-field advantage task's accuracy scores, $r = .217$, $p = .01$.

Table 17. *Correlation Coefficients (r) between Creativity and Personality Measures*

	Extroversion	Agreeableness	Conscientiousness	Neuroticism
UUT Fluency	.380***	0.052	0.087	-0.066
UUT Originality	0.149	0.002	-0.128	-0.068
Top Two	0.111	-0.123	0.062	0.082
RAT Accuracy	-0.043	0.019	-0.127	0.015
RAT RT	0.015	0.064	0.084	-0.12
ICT Fluency	.180*	-0.085	0.021	-0.031
ICT Creativity	0.032	0.005	-0.072	0.044
ICT Components	0.042	0.057	-0.001	0.049

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

Chapter 4

Discussion

Interhemispheric Interaction and Creativity

Creativity is complex and involves attention, semantic memory, and other subprocesses. As the neuroscience of creativity has shown, creativity cannot be localized to any particular functional area or hemisphere (Dietrich, 2004, 2007; Dietrich & Kanso, 2010; Sawyer, 2011). As previous research has yet to address the relation between creativity and hemispheric coordination, summation, and integration of information, this study sought to bridge the divide. Using multiple measures of interhemispheric interaction – bilateral gain, across-field advantage, and metacontrol – and multiple measures of creativity – RAT, UUT, and ICT – this study investigated the relation between interhemispheric interaction and creativity.

As convergent and divergent thinking are both forms of creativity, it was predicted that both, as complex products of bilateral processing, would benefit from increased interhemispheric interaction. As convergent and divergent creativity have been shown to be dissociable processes, however, differential predictions could be made such that convergent creativity, as measured by the RAT, requires a decision necessitating greater activation above a threshold (Brophy, 1994; Mohr et al., 1994) and would demonstrate a stronger, positive association with the interhemispheric advantage of bilateral gain than divergent creativity measures. It was predicted that the interhemispheric advantage and qualitative error scores of the three interhemispheric measures would correlate with and predict creativity measures independently of verbal IQ and openness.

The predictions were generally not supported. However, RAT accuracy was negatively associated with metacontrol bilateral visual field qualitative error scores even when controlling for verbal IQ and personality, suggesting that increased left hemispheric, or perhaps decreased right hemispheric, metacontrol was associated with reduced RAT performance. This has important implications for hemispheric processing of semantic associates as well as creativity, discussed further below. This finding provides some limited support for the hemispheric theory of creativity (e.g., Edwards, 2012; Kounios & Beeman, 2014; Shobe et al., 2009), which states that the right hemisphere contributes to greater creativity performance. Left hemispheric metacontrol may reflect two possible mechanisms: the taking over of processing by the left hemisphere or left hemispheric-initiated reduction of right hemispheric processing. It is interesting that the RAT is a task thought to require distant semantic meaning, which is often associated with right hemispheric processing (Jung-Beeman, 2005) and its lower accuracy is associated with increased left hemispheric metacontrol. Left hemispheric metacontrol could lead to suboptimal processing as the left hemisphere has reduced access to distant semantic meaning.

Creativity is often divided into two types of thinking: convergent and divergent. As RAT and UUT measures were uncorrelated, this would suggest that convergent and divergent creativity are distinct measures of creativity (Abraham et al., 2012; Lee & Therriault, 2013). In the present study, metacontrol BVF qualitative error scores were negatively associated with RAT accuracy, a measure of convergent creativity. An explanation for this finding could be that, as convergent processing requires activation of overlapping concepts for a decision (Jung-Beeman, 2005), decreased left hemisphere or increased right hemisphere metacontrol may strengthen the association of the appropriate answer. Convergent creativity requires a decision for a correct answer. This usually involves working through possible solutions (Beaty & Silvia, 2012), comparisons (Cropley, 2006), and a decision. For the RAT, this initially requires activation of distant and weaker semantic associates (Bowden & Beeman, 2003a; Mednick, 1962). These weaker associations, then, could be diminished with left hemisphere metacontrol and, therefore, left hemispheric metacontrol reduces creative performance on a convergent creativity task. Gupta et al. (2012) found that inhibition was critical for RAT processing because higher RAT performance was linked to inhibition of dominant semantic associates, which allowed the activation of weaker semantic associates. One possible mechanism of metacontrol could be that the performing hemisphere is inhibiting the processing of the other hemisphere. Jung-Beeman (2005) states that the left hemisphere activates dominant meanings and, as has been found by Gupta et al. (2012), RAT performance increases as dominant meanings are inhibited. This suggests that as left hemispheric metacontrol increases, the dominant associates of the left hemisphere (Jung-Beeman, 2005) are not inhibited, thus decreasing RAT accuracy. That metacontrol wasn't associated with RAT RT suggests that the quality of RAT decision is more associated with metacontrol than its speed. Additionally, metacontrol qualitative errors are independent of reaction time so they may be more associated with RAT accuracy than an RT measure.

There were three interhemispheric interaction measures and eight measures of creativity. No measure of interhemispheric advantage or bilateral visual field qualitative error predicted any measure of creativity other than RAT accuracy. This generally suggests that summation and integration processes of interhemispheric information is not related to creativity. Previous research has found bilateral activation for creativity tasks (e.g., Carlsson, Wendt, & Risberg, 2000; Kuhn et al., 2013). Bilateral activation during creativity tasks could suggest that the hemispheres are transferring information. If creativity requires bilateral processing, IHI, including the transfer and transformation of information, may not be required for creative performance. One explanation for the lack of association between IHI advantage and creativity could be that the independent processing in both hemispheres may be more important than the information they are sharing. When, for example, Howard-Jones, Blakemore, Samuel, Summers, and Claxton (2005) report increased left hemisphere (middle frontal cingulate) and right hemisphere (medial frontal gyrus and middle occipital cortex) activation in a creativity task, my research suggests that activation and processing in those areas is more crucial than the information shared via IHI.

Another explanation for the absence of association between IHI advantage and creativity is the differential nature of IHI. One assumption made in this study is that interhemispheric interaction is a general process that supports all mental activities – but this assumption may not hold. Just as creativity can be moderated by expertise (Kaufman,

2009) or mental state (Green et al., 2015; Ashby et al., 1999), IHI may also show differential activity. Lotze et al. (2014) have found results that indicate that bilateral activity can be modulated by expertise. Using resting-state fMRI, they found decreased connectivity for some left and right brain regions, such as inferior frontal gyrus and intraparietal sulcus, for creative writing experts but not for non-experts. Additionally, they found a positive correlation between creativity ratings and increased resting-state connectivity amongst left intraparietal sulcus and right caudate. These results suggest that IHI can differ between people based on experience (experts versus non-experts), as well as by task – experts may show different coactivation for tasks for which they are not experts. People with high creativity task performance may be functionally equivalent to experts and Lotze et al.'s study suggests that IHI differs between experts and non-experts. Hence, resting-state IHI may differ from task-specific IHI, such as the IHI tasks used in this study, and different tasks, such as the creativity tasks used in this study, may require different IHI activation.

Interhemispheric Interaction and Individual Differences

No measure of IHI correlated with verbal IQ or sex. Handedness was investigated in the present study as an indirect measure of IHI (Prichard et al., 2013). It has been suggested that mixed handers, those with a weak preference for either hand, have greater interhemispheric interaction, larger corpus callosa (but see Welcome et al., 2009), greater right hemisphere access, and higher rates of creativity than consistent handers (Prichard et al., 2013; Shobe et al., 2009). The present results do not fully support that theoretical position.

The only interhemispheric measure that correlated with handedness group was metacontrol, indicating that consistent handedness was associated with greater left hemisphere metacontrol. This is consistent with the theoretical position of Prichard et al. (2013), who state that consistent handers have reduced access to right hemispheric processing relative to mixed handers and thus use more left hemisphere processing (Sontam & Christman, 2012). Increased left hemisphere metacontrol could suggest less access to right hemispheric processing – possibly due to reduced corpus callosum connections (Prichard et al., 2014; but see McDowell, Felton, Vazquez, & Chiarello, 2015; Welcome et al., 2009). That is one potential mechanism of metacontrol – reduced access to the processing of the non-controlling hemisphere. An alternative mechanism, however, is that rather than having less access to right hemispheric processing, consistent handers' left hemispheres take control of processing for the tasks; so rather than having less access, left hemispheric metacontrol does not use right hemispheric processing.

An alternative way to look at handedness is, not to dichotomize, but to look at the raw handedness scores. Hellige et al. (1994) did not find an interaction between handedness and metacontrol qualitative errors. Like Hellige et al. (1994), this study also did not find a relationship between handedness score and measures of IHI.

Creativity and Individual Differences

Creativity did not correlate with sex. Only two measures of creativity, RAT accuracy and RAT RT, correlated with verbal IQ. This replicates the work of Lee and Therriault (2013). The RAT is a verbal measure so the association with verbal IQ is not surprising. Unlike Lee and Therriault, however, there was no association between verbal

IQ and the UUT measures. The relation between verbal IQ and UUT is not always found, though (Nusbaum & Silvia, 2011).

Corroborating a previous study (Felton & Chiarello, 2014a, 2014b), mixed handers again did not score higher on any measure of creativity than consistent handers. This could suggest that the mixed handed advantage for distant semantic processing (Sontam & Christman, 2012) and category flexibility (Sontam, Christman, & Jasper, 2009) does not manifest in creativity tasks. Shobe et al. (2009), however, found greater UUT performance for mixed than consistent handed participants. This could be due to their smaller sample size or methodological differences. In the present study, participants were given three minutes per item for two items and instructed to identify creative uses; in Shobe et al., participants were given one minute per item for twenty items and did not receive an instruction to be creative. It is possible that consistent handers take longer to produce creative responses so providing consistent handers more time with fewer items would lead to greater creative output. Additionally, there is research suggesting that personality has a greater influence on creative output when instructions are not explicit to be creative (Silvia et al., 2008); if mixed handers have a more creative personality or a tendency to view themselves as more creative (Grimshaw, Yelle, Schoger, & Bright, 2008; Badzakova-Trajkov, Häberling, & Corballis, 2011), their creative output may be confounded with task instructions. These differences could underlie the different results between the two studies.

Investigating raw handedness scores, instead of the dichotomized handedness groups found that raw handedness scores were associated with ICT fluency scores, such that greater left-handedness was associated with higher ICT fluency scores. As handedness was only associated with more images created and not with any other measure of creativity, it is difficult to conclude that handedness is associated with creativity. Rather it may be more associated with nonverbal fluency (but see Sontam et al., 2009).

Several measures of creativity correlated with personality. In line with previous research (King et al., 1996), openness positively correlated with UUT fluency, ICT fluency, ICT creativity, and ICT components. Openness did not correlate with UUT originality, UUT top two, or either RAT measure. When entered into regressions with IHI measures and verbal IQ as predictors of creativity, openness uniquely predicted UUT fluency, UUT originality, ICT fluency, and ICT components. As the only measure of IHI that predicted a creativity measure was metacontrol BVF qualitative errors predicting RAT accuracy, openness had a more consistent relationship with creativity than measures of interhemispheric interaction. The relationship between creativity and openness has been consistent for decades (McCrae, 1987), though this may not be surprising as the items associated with the trait include "is original," "is inventive," and "values artistic, aesthetic experience" – this latter item possibly explaining why the ICT was the only task where all measures correlated with openness.

Extroversion was positively associated with both UUT fluency and ICT fluency. Extroversion is sometimes found to be associated with creativity (e.g., King et al., 1996; Wolfradt & Pretz, 2001). That extroversion was positively correlated with measures of fluency suggests that extroverts, like their proclivity to talk, are inclined to give more answers on fluency tasks. Personality traits were generally more consistently associated with creativity than IHI measures. This suggests that trait-based behavioral and psychological orientations have a greater influence on higher-level cognitive processes, such as creativity, than interhemispheric summation, integration, and control.

Implications for Creativity Research

This study included eight measures of creativity from three different tasks. Typically, the correlation between convergent (RAT) and divergent tasks (UUT) is low (Chermahini, Hickendorff, & Hommel, 2012; Lee, Huggins, & Therriault, 2014), and this was generally confirmed in the current study. It is not surprising, then, to find limited associations between the RAT measures and the UUT and ICT measures. It is interesting, however, that RAT RT correlated with UUT originality such that slower RAT RTs were associated with higher originality scores. This may suggest that people who have slower activation of distant semantic associates have more original ideas, which was originally suggested by Mednick (1962). Higher RAT accuracy was associated with faster RAT responses, though, so this would seemingly contradict Mednick's perspective. It could be argued, however, that originality better represents what is meant by "creativity" – novel and unique products (Kaufman, 2009) – than other measures. If such is the case, then more novel responses may very well take longer to activate.

Though the ICT is a nonverbal task, it measures divergent processes like the UUT (Finke & Slayton, 1998). All three ICT measures correlated positively with UUT fluency, though not UUT originality or top two. Though UUT is a verbal task, idea generation requires nonverbal processes such as mental rotation, concept expansion, and the ability to extend beyond an anchor (Abraham & Windmann, 2007; Ward, Smith, & Finke, 1999). Because of these similar processes, different divergent tasks may have similar performance, regardless of the verbal nature of the tasks.

Implications for Interhemispheric Interaction Research

The interhemispheric interaction measures did not correlate with each other, which indicates that they are unique measures of interhemispheric interaction. Bilateral gain measures the processing in summating redundant information. Across-field advantage measures the processing in integrating different information. Metacontrol measures the extent to which one hemisphere assumes control in processing redundant information. It could be expected that the measures would correlate, as they are all measures of IHI, but it is empirically interesting that they are not. Because these tasks are uniquely measuring different aspects of IHI, future research should incorporate multiple measures of IHI.

Limitations and Conclusions

One explanation for the general lack of relation between the interhemispheric measures and creativity could be that the interhemispheric measures and creativity measures were not reliable. Preliminary analyses demonstrated that the bilateral gain and across-field advantage measures replicated previous research. However, the metacontrol BVF errors more closely matched the LH-RVF than the RH-LVF, which is counter to what is reported in the literature (Hellige, 1993; Hellige et al., 1989; Lohr et al., 2006). Although the metacontrol BVF qualitative error scores did not replicate previous research, BVF errors still showed hemispheric metacontrol. Hence, the measures generally replicated previous work and indicate that the measures are reliable.

The replicated previous research, however, did not focus on associating an interhemispheric advantage with a behavioral measure. It could be the case that the relative measure of interhemispheric advantage is inappropriate for gauging individual differences in interhemispheric interaction involved in creativity. In this exploratory study, I chose the three measures of interhemispheric interaction because they were highly reliable and have been replicated many times (e.g., Hellige, 1994; Mohr et al., 1994; Weismann & Banich, 2000). The IHI tasks did not, however, investigate IHI during creativity tasks. It could be the case that if the tasks incorporated a creative element, such as a lateralized RAT (Bowden & Jung-Beeman, 2003b) including bilateral presentation, creative performance would be more associated with interhemispheric advantage. If creative stimuli were lateralized in a bilateral gain task, then perhaps bilateral presentation would show an advantage over unilateral presentation.

One possible reason for a lack of association between IHI and creativity tasks is that the creativity measures did not really reflect individual differences. Inspection of the measures of creativity did not demonstrate restricted range. Several of the measures correlated with each other, indicating convergent validity. The measures of creativity, with the exception of UUT top two, seem to be reliable and generally replicate previous relations with openness and verbal IQ (Ashby et al., 1999; Lee & Therriault, 2013).

There could be multiple reasons why a relationship was found between a measure of IHI and a measure of convergent creativity (i.e., RAT accuracy), but not divergent creativity. These reasons can be theoretical or methodological. Because divergent creativity requires generative responses and no convergent decision, each hemisphere may respond independently, akin to a race model – such that responses from each hemisphere could be produced based off of weak associations without necessitating a decision that would require activation above a higher threshold. Alternatively, each hemisphere could also have transfer that is not associated with a bilateral advantage; as both hemispheres are crucial for creative thought, the processing of each hemisphere may be more important than the integrated and summed information they are sharing. Methodologically, the divergent tasks did not have the same time pressure as the convergent tasks: had the divergent tasks required as many creative responses as possible within 15 seconds, it is plausible that IHI may have been more associated – however, it is important to note that no measure of IHI was associated with RAT RT, the only measure of RT. Additionally, the convergent task was more verbal than either divergent task, as evidenced by the moderate correlations between verbal IQ and both measures of RAT. Had both tasks been comparatively verbal, or non-verbal, then IHI may have had similar associations. This could be potentially achieved by using a divergent fluency task instructing participants to come up with unusual uses of nouns (e.g., Seger, Desmond, Glover, & Gabrieli, 2000).

This study found a relationship between metacontrol and the RAT. Further research should investigate the possible mechanisms of metacontrol and the association with RAT performance. As discussed previously, left hemispheric metacontrol can result from, at least, reduced access to right hemispheric processing, or left hemispheric appropriation of processing. Using a separate dominant/subordinate priming task (Burgess & Simpson, 1988) and the metacontrol task could demonstrate if participants have access to right hemispheric processing, such that they have access to right hemispheric distant semantic activation but still show left metacontrol and reduced RAT performance. It would also be interesting if categorical semantic priming (Chiarello, Burgess, Richards, & Pollock, 1990) across visual fields, such as priming in the LVF for a RVF target, occurred less for people with increased rather than decreased metacontrol; is increased metacontrol associated with reduced priming transfer across hemispheres?

This study used behavioral measures of interhemispheric interaction and creativity. The visual field paradigm is a useful technique to identify differences between the hemispheres, but it would be beneficial to use neuroimaging or neuro-stimulation to identify neural regions associated with both IHI and creativity. It would be interesting, for example, if particular brain regions are involved in metacontrol: does activation in the hemisphere demonstrating metacontrol suppress activity in the other hemisphere? Is this pattern of activation observed during the RAT? These questions can be addressed with functional MRI. Additionally, TMS or tDCS could be used during creativity or IHI processing. This could help identify the neural regions and their respective hemispheres associated with increased or decreased performance on both creativity and IHI tasks.

Further research investigating the association between interhemispheric interaction and creativity could examine the corpus callosum via structural MRI or DTI. Using these methodologies would allow researchers to investigate to what extent corpus callosum size and anisotropy relate to both interhemispheric interaction and creativity.

Utilizing DTI methodology would reveal the extent to which fiber integrity supports interhemispheric interaction. DTI could also suggest which tracts are most associated with high creative performance (Takeuchi et al., 2010) and whether these tracts are associated with IHI. In addition to corpus callosum measurements, it would be useful to measure activation during creativity tasks via functional connectivity. This could establish which areas of activation at rest or during a creative task are associated with creative output.

The present study was the first to test the relation between IHI and creativity. Multiple measures of IHI were unable to predict several measures of creativity. However, Metacontrol BVF qualitative error scores were associated with RAT accuracy performance, such that greater left hemispheric metacontrol was associated with lower RAT performance. As neither bilateral gain nor across-field advantage measures were associated with creativity, this study suggests that creative performance may not require interhemispheric information processing and transfer but rather metacontrol from one, possibly the right, hemisphere. Additionally, metacontrol BVF qualitative errors were the only measure of IHI associated with handedness groups, such that consistent handers had greater left hemispheric metacontrol than mixed handers. Together, these results suggest the possibility that left hemisphere metacontrol may be associated with handedness differences in verbal (such as category flexibility or RAT) performance when they are observed. In sum, this study suggests that interhemispheric advantage of summation and integration plays a limited role in creative performance, but that hemispheric control is involved in verbal convergent creativity. Future research can address the mechanisms of hemispheric control associated with convergent creativity.

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