THE IMPACT OF ORGANIZATION STRUCTURE ON INFORMATION MANIPULATION AND REASONING – AN FMRI STUDY

by

Joshua M. Roberts
A Dissertation
Submitted to the
Graduate Faculty
of
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in Partial Fulfillment of
The Requirements for the Degree
of
Doctor of Philosophy
Psychology

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Master of Arts
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Director: M. Layne Kalbfleisch
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DEDICATION

This is dedicated to my lovely wife, Caron, for her relentless patience as I navigated through my graduate studies and her unwavering support when I had doubts about my potential. Her expertise in APA formatting and knowledge of the DSM were quite helpful as well. I would also like to acknowledge my parents for being the best couple a kid could ask for and continuing to support my pursuits to this day.

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ABSTRACT

THE IMPACT OF ORGANIZATION STRUCTURE ON INFORMATION MANIPULATION AND REASONING – AN FMRI STUDY

Joshua M. Roberts, Ph.D.

George Mason University, 2014

Dissertation Director: Dr. M. Layne Kalbfleisch

This experiment employed the ELICIT (Experimental Laboratory for Investigating Collaboration, Information-sharing, and Trust) program within the functional magnetic resonance imaging (fMRI) environment, to examine neural systems supporting individual information management associated during choice-making and social exchange. Previous literature notes the challenge of providing an ecologically valid and complex experience associated with turn-taking (Kalbfleisch & Nissen, 2010) and reasoning (Kalbfleisch, Van Meter & Zeffior, 2006;). Specifically, we sought to extend results for the behavioral and neural correlates affiliated with two opposing organization structures; Edge and Hierarchy (Kalbfleisch et al., in review) by examining the shape and timing characteristics of the blood-oxygen level dependent (BOLD) signal that affiliates successful performance in Edge with faster response time and support from the anterior prefrontal cortex (aPFC) during game-play. This region-of-interest analysis indicates that

the advantage in response time afforded by the Edge condition is the result of individual in-game actions supporting a more compartmentalized approach to the integrative deductive reasoning process governing the posterior parietal cortex via the aPFC.

INTRODUCTION

Cognitive neuroscience has historically employed the use of simplified constrained tasks that serve as a proxy for physiological or psychological aspects of cognitive and affective processing. While critical, these types of studies often fail to account for the contextual, social, and environmental influences that may alter the reasoning process and influence the subsequent response. Evidence for this variable influence on reasoning is not scarce and spans numerous domains to include; social pressures (Insel & Fernald, 2004; Kameda, Ohtsubo, & Takezawa, 1997; Slavin, 1992), state-dependence (Kalbfleisch, Van Meter & Zeffiro, 2006, 2007; Roberts et al., 2009; Roberts, 2011), contextual priming (Burnham, McCabe, & Smith, 2000; Kalbfleisch et al., 2013), environmental interaction (Clark, Allard, Jenkins, & Merzenich, 1998; Pascual-Leone et al., 1993; Sterr et al., 1998; Tang, Wang, Feng, Kyin, & Tsien, 2001), and personal motivation (Kunda, 1990).

Before delving into specifics, it is important to note that the influences on reasoning are largely dependent on the neural systems responsible for information processing which are defined and regulated via bi-directional internal (e.g., neuronal action potentials) and external (e.g., environment) factors (Bjorklund, 2005). This relationship between brain, environment, and behavior is exercised during self-directed orientation and sensory integration, thereby strengthening goal-relevant neural connections, and ultimately improving our knowledge of the world because we detect and differentiate more aspects and features of the environment (Pick, 1992). This environmental influence on neural mechanisms and structures demonstrate the link between external influence and internal representation; however, they do not yet clearly address how external influences alter processing systems.

To address this relationship at the physiological systems level, it is important to note the role that working memory (WM) plays between external influences (e.g., interaction with the physical and social environment) and cognitive processes. Roediger's (1996) contention that memories are drawn from current mood, past interactions, current environment, the source of the information, and events that occur after the original experience, suggests this environmental and social modulation on memory systems. Since working memory systems are integral to the maintenance of information and active processing, it will be helpful to examine these influences to determine their subsequent effects on reasoning and comprehension.

By understanding the relationship between these biological, environmental, and behavioral factors, we can now examine these intertwined influences in the context of other domains. Activity of the emotional, social, and sensory integration regions of the brain results in, and is dependent upon, processing of environmental and social stimuli (Huettal, 2009). These biological restraints may result in several physical limitations, such as blindspots (Carlson, 1999), or contribute to our limited attentional capacity (Mangun, Buonocore, Girelli & Jha, 1998; Yantis, 2008; Pugh, et al., 1996). Social and environmental context may impact our drive to maintain social normality, as in the case of conformity (Asch, 1956; Berns et al., 2005; Cialdini & Trost, 1998) or psychological influences, such as motivated reasoning (Balcetis & Dunning, 2006; Dawson, Gilovich, & Regan, 2002; Jain & Maheswaran, 2000; Kunda, 1990; Nickerson, 1998; Westen, Blagov, Harenski, Kilts & Hamann, 2006), emotional priming (Goel & Dolan, 2003) and social deficits (Anderson, Demasio, H., Tranel & Demasio, A. R., 2000).

It is becoming clear that the neural processing of sensory information and the subsequent reasoning processes that follow are not immune to contextual influence. Therefore, if the cognitive process and the social factors that influence that process are mutually antagonistic, they must be considered in tandem (Pessoa, 2008). This interconnectedness of situational cognition has not gone unnoticed in the neuroscientific community, as evidenced by research on the influence of contextual priming effects on reasoning.

Examination of this priming effect through the use of ambiguous figures, a task in which two distinct, mutually-exclusive interpretations can be derived from the same image, researchers have found that if these images are primed with a stimulus associated with only one of those interpretations, they can reliably induce one decision over another. For example, Balcetis and Dale (2007) found that an ambiguous figure consisting of “a man playing saxophone” or “a woman’s face” were attenuated based on the priming concepts of “music” or “flirtation,” respectively. A similar priming effect was found for ambiguous motion quartets, whereby a subject’s decision about global movement was dependent on previous trials (Maloney, Dal Martello, Sahm, & Spillmann, 2005). The authors suggest that this is due to an unconscious analysis of recent perception to predict future perception. The findings suggest that people perceive images and motion that are dependent, not only on the stimuli in front of them (i.e., the physical environment), but also on their personal expectations (i.e., social context).

This priming effect not only has the potential to alter passive viewing, but also active reasoning, as demonstrated by an fMRI-based relational complexity task employing the use of emotionally valenced images as contextual primes (Roberts et al., 2009). Evidence indicated that not only did emotional priming have a significant behavioral effect on reasoning, but that those differences manifested via differential state-dependent neural systems. Padmala and Pessoa (2008) garnered similar results, noting superior performance following affective stimulation dependent on increased activation of early visual cortex. Research conducted by Moll et al. (2002) on neural correlates of moral judgment, and Goel and Dolan (2003) on “belief- versus fact-based” reasoning further support the contention that context-dependent decision-making relies on variably executed neural systems. Overall findings for both studies suggest differential networks of neural recruitment are dependent on emotional or social contextual influences. Specifically, Moll et al. (2002) noted discrete regions (orbitofrontal cortex) responsible for the integration of cues about the intentional and emotional states of others. These cues were derived from surface features of stimuli such as facial expression, body posture, and voice inflexions, which participants considered during the decision-making process. Goel and Dolan (2003) found that their belief-based “hot” reasoning trials evoked emotional processing regions of the ventromedial prefrontal cortex (VLPFC), whereas their fact-based “cold” reasoning implicated the left dorsolateral prefrontal cortex (L/DLPFC).

Taken together, this variable influence on reasoning that is induced by role-taking and saliency of content suggests that critical influences on social and emotional-based reasoning and behavior can have a direct impact on the outcomes of goal-directed behavior supported by dynamically configured neural systems. Since social and emotional influences render modulating effects on reasoning processes, especially within the context of fluid environments, the need to design more robust and fitted models relevant to these prevailing confounds becomes apparent. Experimentally examining this integrative process will rely on the introduction of environmental variances, social influences, and interactions amidst dependent measurement of higher-order cognition.

If our cognitive processes and subsequent actions are subject to modulation by extraneous and internal factors, it is important to understand the potential system-level processes of reasoning. Identification of these variables and how the brain interprets and responds information under these circumstances will give us a broader understanding on human cognition given non-static environments, mental states, and social context.

Information Manipulation

A critical component to cognition entails the efficient management of information. Given our limited attentional capacity (Mangun, Buonocore, Girelli & Jha, 1998; Yantis, 2008; Pugh, et al., 1996), as stimuli is presented, individuals must determine how allocate their resources. If, as discussed above, actions of selective attention requires an attentional system associated with control of decision and action (i.e., frontal cortex) along with a second system associated with the control of perception (i.e., posterior cortex; Pugh, et al., 1996), this suggests the potential for top-down drives guiding goal-directed behaviors (Kalbfleisch, et al., 2013).

Contextual influences result in this transfer of knowledge or data to not be viewed as merely a vacant route for passing information to the next user, but as an integrative sensory and social process. Discrete data introduced from external sources is not considered information until the uncertainty in that data has been removed (Goldberg, 2009). When that information is transferred to the cognitive domain it becomes awareness, which is further filtered through personal biases, prior knowledge, experience, and mental models. It is here that the concept of implicit or tacit knowledge becomes relevant. The user's implicit knowledge interacts with their explicit knowledge (e.g., the data/information) to exhibit situational awareness and informed, fluid decision-making (Goldberg, 2009). This explicit knowledge can be stored and transferred across time and space without the need for an intelligent conductor, whereas tacit knowledge garnered through practical experience via personal and contextual interaction requires unarticulated intuition, close interaction of participants, and shared trust and understanding (Lam, 2000). This is what is known as "domain-specific" and "domain-general" knowledge which, when integrated, allows for coherent information to be garnered (Moss, et al., 2011).

This information integration is best exemplified when we look at groups that have worked together on similar operations in the past (i.e., through formal training and military exercises), whereby they tend to form organizational artifacts, such as specialized language and unspoken work processes. These artifacts, consisting of collective explicit knowledge, exist between the users of an organization, not within, evoking the reliance of social context and organization. The use of this collective tacit knowledge can ultimately lead to more efficient operational objective fulfillment based on trust, common language, and compatible processes (Alberts & Hayes, 2006). The collective, tacit knowledge, based on shared beliefs and effective organizational communication, exploits the social and environmental interactions of the learning process, allowing for support of complex patterns without the need for explicit instruction and making it flexible and dynamic (i.e., agile). Thus, within the social domain, crucial information about the network users, the quality of their data, and the overall ability to disseminate, collect, and synthesize collaborative information is revealed (Alberts & Hayes, 2006).

Organizational Social Influences on Reasoning

One prominent example of this ability is reflected within the organization of the United States military, whereby various information management systems must be considered to address the need for allocation of resources and personnel, known as command and control. Since some approaches will be better suited for certain types of problems, this selection has traditionally been based on the tangible qualities of a situation (e.g., stability of warfare environment, level of user communication, strength of information; Alberts & Hayes, 2006). However, significantly less consideration has been given to which approach best supports the reasoning process at the neuro-physiological level. To illustrate this point, we can examine two opposing command and control approaches which have been employed in military operations, to examine how optimal ‘fit’ of an approach is dependent not only on the physical details of organizational social structure, but also on how the brain reasons within those details.

One tool for executing such an approach is the Experimental Laboratory for Investigating Collaboration, Information-sharing, and Trust (ELICIT), a game program that challenges the player to determine a plot for a terrorist attack and that engages players within two different organization structure that, in turn, dictates the flow and access of information.. Since social and emotional factors influence reasoning, especially within the context of fluid real-time environments, the need to design more robust and fitted models relevant to these prevailing confounds becomes apparent. This is the motivation for the multiplayer, online counterterrorism intelligence game of ELICIT, where success depends on the player’s efficiency and accuracy of identification (Kalbfleisch & Nissen, 2010; Lewelling & Nissen, 2007). Specifically, as reported by Leweling and Nissen (2007), those participants within the Edge condition outperform those in the Hierarchical organization, albeit with more volatility or inconsistency. Thus, ELICIT has the capacity to control for and identify social, contextual, and environmental influences that mediate overall performance in its model-testing experiments for two organization structures, Edge and Hierarchy (Lewelling & Nissen, 2007).

Environmental influence on cognition

This introduction of the ELICIT program allows for control of variables not possible in field experimentation which allows for empirically testing various organizational approaches, controlling for gender and rank, information data sets, patterns of communication, and environments. It is this control of environment that poses a challenge, especially relative to fMRI research, as there is a requirement address not only the environment that an individual is physically residing in, but also the induced state of their environment. While the physical domain is fairly static, the state of their physical domain can be manipulated via the artificial induction of presence.

Presence is often referred to as a sense of "being there." As outlined above, this relies on brain processes utilized to make sense of the incoming stimuli through various sensory systems, processing visual, tactile, kinesthetic, olfactory, auditory, and proprioceptive information (Barfield, 1995). People distinguish sources as being either external sources (i.e., in the physical world), or as internal sources (i.e., imagined), and do so based on contextual and perceptual cues. The more salient the cues, the greater the likelihood that the memory is accurate and not illusory. Johnson and Raye (1998) further elaborate this point by citing "time, location, spatial arrangement, emotion, or sensory perceptual details such as color and shape" (p. 137) as being closely correlated with experienced events. This source monitoring was, in fact, noted by Baumgartner et al. (2008) through the study of virtual environments. They found that a sense a presence, which is dependent on the recognition of external source stimuli, can be modulated through internal self-reflection. In other words, the subjects were able to control and regulate their depth of presence through critical evaluation of the artificial environment.

Knowing that the integrative sensory inputs within an environment induce an individual's presence and that this process is dependent on the function of perceptual and contextual reasoning processes, the goal of researchers should be to inject these aspects into the experimental paradigm in an effort to maintain ecological validity. Therefore, as proposed by Hudson and Nissen (2011), the move of ELICIT into a more naturalistic 2nd Life environment may serve to produce a greater immersive experience. Hudson reported an inability to mimic real-world results within the ELICIT interface due to a lack of immersion resultant from the limited viewpoint of the game interface. While our capabilities to host ELICIT outside of the original desktop interface, into a more heads-up display (HUD) manner as suggested by Hudson, was not possible at this point, we sought mitigate this issue by priming our participants with 2nd Life experiences prior to their trials, in an effort to induce identification with their avatars, and subsequently facilitate presence.

Information management and reasoning

With these factors in mind, our recent study (Kalbfleisch, et al., in review) sought to identify behavioral and neural responses affiliated with information management processes associated with reasoning under two conditions with contrasting organization and social context. To accomplish this we administered ELICIT using Second Life, a virtual world environment, during fMRI to distinguish the behavioral and functional discrepancies unique to the information-management approaches associated with Edge and Hierarchy.

Preliminary behavioral results partially confirmed our original hypotheses and remained consistent with previous ELICIT studies (Leweling & Nissen, 2007; Nissen & Leweling, 2010; Gatuea, 2007), favoring the Edge organizational model, as revealed by participants' faster reaction times over the more traditional Hierarchical model. Consideration of our most robust preliminary fMRI findings, reaching significance while correcting for multiple comparisons, were found within the Edge model amidst participant Integrative phases. Brain regions of significant interest noted in our task that parallel previous literature on reasoning processes fall within the anterior pre-frontal cortex (APFC) consisting of Brodmann's Areas 10 and 32. Functional neuroimaging findings relating to premise integration processes (Fangmeir, Knauff, Ruff, & Sloutsky, 2006; Kroger et al., 2000; Qui et al., 2006), and relational integration (Christoff et al., 2001; Prabhakaran, Rypma, & Gabrieli, 2001; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Waltz et al., 1999) amidst reasoning support our premises and results. We propose that inclusion of the left medial frontal and bilateral anterior cingulate indicates support for processes of inferential reasoning for unifying multiple premises into appropriate conclusions.

Further implication of BA 10 within our task is supported by its role in task-relevant working memory demands (Pochon, et al., 2002), continuous updating (Wager, Jonides, & Reading, 2004), attentional switching (Pollman, 2004), and subgoal processing (Braver & Bongiolatti, 2001). Tahken together, the regions of the APFC not only facilitate deductive reasoning processes, but potentially maintain consistent and appropriate attention and workload capacities.

Involvement of the PFC in our task was shown to extend beyond the APFC and include regions of the medial frontal cortex bilaterally, encompassing BA's 6 & 9. Again we have strong reason to believe that these regions contributed to the reasoning process as evidenced by previous related studies. Specifically relevant was the study by Goel, Grafman, Sadato, and Hallet (1995), indicating very similar coordinates (Our study: -6, 46, 28 vs. Goel study: -7, 44, 22) based on the ability of subjects to draw inferences dependent on the intentions of others. This is particularly relevant to the task herein, as it required the participant to consider the relevancy of information being fed to them by other agents and ultimately determining plot points of a terrorist scheme that had been formulated by another individual. The activation noted in medial frontal cortex could therefore represent the inferential reasoning process underway amidst our subject's attempts to solve the various details of the plot based on how an individual may have reasonably formulated the plan. For instance, if a disseminated factoid stated, "There is a large security detail protecting the ambassador in Theta", a mental model construction might consider that a terrorist would want to focus on an easier less protected target. Therefore, by assuming the beliefs and intentions of another (i.e., fictional terrorist planning the attack), the participants have demonstrated evidence of theory of mind.

These preliminary findings suggest that those participants within the Hierarchical condition would likely be making inferential connections amidst Pushing behavior more so than would be seen in the Edge condition. This is due to the difference in programmed agent behavior whereby within Hierarchy, agents are not able to post directly to specific domains, requiring the participant to spend considerable time making categorization actions. Within the Edge condition, in which agents are permitted access to all domains, there is less need for the categorization process. The result of this critical difference in information exchange and flow is that Edge participants are able to focus more fully on the integrative process (Pulling), but as a trade-off, are left to interpret novel, unfamiliar, possibly irrelevant factoids. Hierarchy participants, on the other hand, spend more time in the categorization phase (Pushing), but are able to dictate which factoids they deem worthy of posting to the specific domains and therefore during the integrative process, they are considering recognizable, relevant factoids. In order to confirm this hypothesis we conducted a more in-depth analysis of the data by examining the specific timecourses of each organizational approach as it relates to behavioral performance and neural activation.

Condensing the result of our pilot study indicates: 1) participants in the Edge condition were more likely to engage in pulling behavior, 2) participants in the Hierarchy condition were more likely to engage in pushing behavior, and 3) Edge participants reached an accurate solution more quickly. Our main physiological findings revealed: 1) pushing behavior was affiliated with insular activation, associated with the player's sense of agency (Farrer & Frith, 2002); 2) pulling behavior was affiliated with the activation of lingual gyrus, associated with retrieval processing, and reasoning (Goel & Dolan, 2004); and 3) pulling behavior in the Edge condition affiliated with the activation of the anterior prefrontal cortex (APFC) a region which supports premise integration, relational integration, inferential processing, and continuous updating of conclusions amidst reasoning (Fangmeir, Knauff, Ruff, & Sloutsky, 2006; Kroger et al., 2000; Qui et al., 2006).

Pairing these findings with behavioral performance suggests that the Edge network configuration renders a significant advantage over the traditional hierarchical command and control model. In Edge, faster response time is supported by neural systems that involved the anterior prefrontal cortex, which supports premise integration and analysis, and the insula which monitors performance and supports self-agency during game-play. We concluded that differences between Edge and Hierarchy suggest that organization configuration guides behavior, specifically in terms of how and when our participants engage in inferential reasoning processes. In order to substantiate and refine these results, we performed a region-of-interest (ROI) analysis to examine timing differences in the BOLD signal affiliated with each configuration.

As it pertains to our current study our aims were more focused on why our individuals engaged and performed as they did and how those actions were facilitated via cognitive processes. First, we hypothesized that since both intelligence and personality have a documented correlation with job performance (Rothman & Coetzer, 2003), academic performance (Poropat, 2009), and organizational behavior (Forgas, 2001), it reasoned that these factors may also be relevant to our task and that their behavioral performance and in-game actions, would correlate with certain aspects of participants' psychometric profile. Specifically, this allowed us to determine if 1) in-game actions related to behavioral performance, 2) whether performance was consistent across runs, 3) whether psychometric measures of intelligence, immersion tendency, and personality relate to game-play tactics and performance, and 4) whether in-game actions and immersion tendency predict task accuracy (ACC) and reaction time (RT). Second, we hypothesized that any activation shared between the groups represents regions supporting general reasoning processes, specifically identifying shared neural systems that support during decision making across conditions (Edge and Hierarchy). Third, we hypothesized that the time-course of the BOLD signal would vary as a function of organization assignment.

METHODS

Subjects

Twenty healthy volunteers (free from developmental or psychological disability) between the ages of 18 to 40 years of age (mean age = 22.5) were recruited to participate in the study. Inclusion criteria required current experience with the Second Life virtual world (>20 hours) and all participants were deemed right-handed based (>80%) on the Edinburgh Handedness Inventory (Oldfield, 1971). All participants were required to give written informed consent prior to participating in the experiment as approved by the Human Subject Research Board of the George Mason University. Participants were compensated with $80.00 USD for their participation. Both the behavioral session and the scanning session ran approximately 3.5 hours total, including pre-scan preparations.

Psychometric testing

Several instruments were employed prior to the scan in order to develop a more complete profile that would account for any potential idiosyncratic findings in the results, as well as permit covariance of the data based on demographics, intelligence and/or presence. Participants were administered the Two-Subtest form of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) to determine full-scale IQ based on s vocabulary and matrix reasoning. Additionally, participants were administered the Ten-Item Personality Inventory (TIPI; Gosling, Rentfrow, and Swann, 2003; Muck, Hell, & Gosling, 2007) designed to measure qualities related to the five-factor model of personality: extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience. At the conclusion of the scanning session participants were debriefed using the completion of the Immersive Tendency Questionnaire (ITQ; Witmer & Singer, 1998) designed to account for a person's potential for presence in game experiences, whereby presence relates to an individual's sense of being immersed in their current environment.

Prior to game-play, participants were familiarized to the fMRI scanning environment using a mock scanner. The aim of using the mock scanner was to reduce anxiety associated with the scanner, as well as eliminate any learning or motor confounds associated with the task by allowing participants to practice within the task interface and adjust to the physical/ergonomic constraints of using a trackball response box. Additional pre-scan training on a baseline motor task and a practice version of the ELICIT paradigm was conducted on a laptop computer. At this time, participants were randomly assigned to one of the two organization structures (Edge or Hierarchy) for the duration of the experiment.

Motor task

Participants were presented with a motor task requiring the user to move the cursor to one of four screen positions (North, South, East, and West) and with their thumb, click the left button of the trackball to respond to the placement of the cursor designated in one of the four regions on the projected screen. The movements associated with this task were complementary to those required in the ELICIT task and served as a mask condition during functional imaging analysis.

ELICIT task

Just prior to running the ELICIT paradigm, each participant logged in to the Second Life Viewer platform using his or her personal avatar. Researchers then “walked” the participant’s avatar through the designated closed-environment provided by the Virtual World Design Centre (Loyalist College, Ontario CA) into the virtual testing room outfitted with computer monitors, chairs, and a desk. The use of a participant’s personal, non-generic, avatar was required in an attempt to induce a sense of personal presence in the gaming environment. The avatar was seated in one of four chairs and then logged into the ELICIT program via the virtual desktop computer. Actual ELICIT game-play was hosted via a “real” internet browser (Firefox), not in the Second Life environment in order to maintain appropriate resolution and text size on the scanner monitor. Scanning began when the participant indicated that he or she had read the online instructions for the task and designated that they were ready to begin by clicking “Ready” in the game screen (see Figure 1).

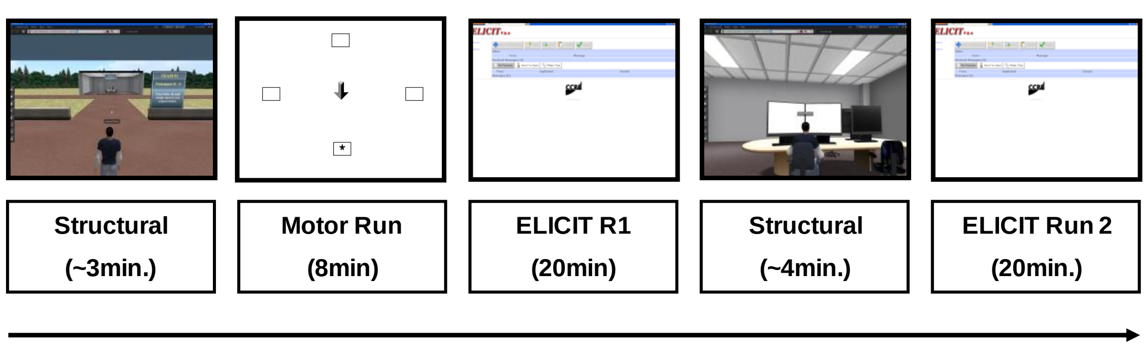

Figure 1: Estimated timeline and order of events for the scanning session.

Participants played within one of two C2 organization structures, Edge or Hierarchy. Although the method of information dissemination/access and individual structure-based roles were different between conditions, each participant received the same bits of information and was asked with determining the details of a fictional terrorist plot. In order to test the influence of the organization structure, the paradigm used the same factoid set for both conditions. Our participants played the game collaboratively with 16 other "participants" made up of automated agents. Based on disseminated factoids, participants made decisions about how to categorize or share their information in order to determine the details of the plot. The participant always began the experiment with a few factoids and as the game progressed, factoids continued to be disseminated to their inbox at designated intervals along with any additional factoids that may have been passed on to them from other members of the team. All participants, regardless of organizational structure, had the in-game ability to ADD, POST, SHARE, PULL or IDENTIFY. ADD allowed the participant to move the factoid into a personal "MyFactoids" list. POST allowed the participant to move the factoid to a domain specific (i.e., who, what, when, where) message board. SHARE allowed a direct communication of a factoid with another member of the team. PULL was used to access specific domain-relevant information within the game. IDENTIFY required determination of the "who" (e.g., Blue group), "what" (e.g., bank), "when (month)" (e.g., November), "when (date)" (e.g., 5^{th}), "when (numerical time of day)" (e.g., 8), "when (time period)" (e.g., AM), and "where" (e.g., Chiland) of the plan. Participants were able to identify any or all of the domains at any time during the game and were able to change their answers as many times as they wanted during the allotted 20-minute time period.

Hierarchical C2 organization

Within the context of the ELICIT program the Hierarchy program has similar features and a few significant differences from the Edge model. Adding a factoid to a personal inbox and the process of identification is identical in both conditions. Within the hierarchical model the participants were assigned the role of Cross-Team Coordinator (CTC). As CTC, participants acted as the head of the hierarchy with information fed to them by the “Team Leaders (TL)”, and “Team Members (TM)”. Within this role, the participant had access to all 4 domains, and all aspects of sharing, but the designed behavior of the “agents” was consistent with past human participant action. Specifically this resulted in the agents being limited in their ability to post to all domains (e.g., an agent that is a member of the “Who” team, would only be able to post their factoid to the “Who” board) (See Figure 2).

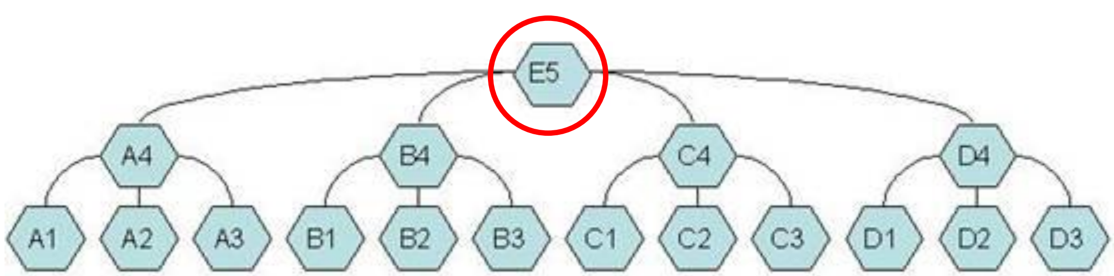

Figure 2: Graphical representation of the Hierarchical C2 model indicating the structure of command and information flow. Red circle represents player position.

Edge organization

Within the context of the ELICIT program the Edge program has more flexibility than the Hierarchical model. Adding a factoid to a personal inbox and the process of identification is identical in both conditions. Edge model agents were not specifically assigned to any one domain and have free reign to contact or post any other “player” within the game. In other words, within the Edge model, agents were permitted to post factoids to any of the domain-specific message boards, as well as, had the ability to share a factoid with anyone on the team regardless of role. Within the Edge model the participants were assigned the role of “Team Member”, as this is the only role present in Edge (See Figure 3). The resultant behavior of this model resulted in reduced peer-to-peer sharing and increased posting to appropriate domains, when compared to the Hierarchical model.

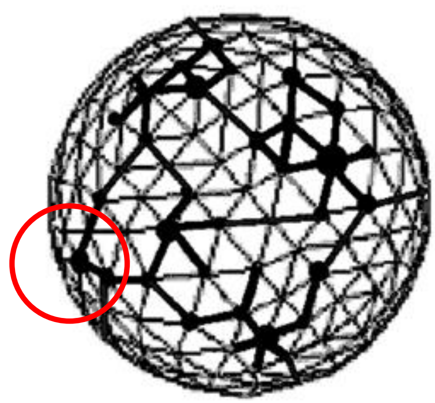

Figure 3: Graphical representation of the Edge model indicating the structure of command and information flow. Red circle represents potential player position.

The decision to relegate participants to differing roles (CTC in Hierarchy and TM in Edge) within each condition was based on the importance of providing the exact same information to each participant. If the role of TL or TM were assigned within the Hierarchy, thereby giving access to only a single domain, this would result in the participant being able to access only 25% of the information revealed to the Edge participant. Ultimately our goal was to examine the behavioral and neural correlates between two opposing organizational models (H vs. E) and not the discrepancy between individual roles (CTC vs. TL vs. TM) within the organization.

The major discernible difference in terms of participant involvement between these two conditions is how the organizational structure encourages the player to play the game. Specifically, those in Hierarchy will be implicitly encouraged to independently categorize the factoids prior to engaging in the integrative process. Edge, on the other hand, are implicitly prone to trust the domain-specific categorizations provided by their fellow agents allowing for quicker integrative engagement.

Based on the design of the ELICIT game within these organizational structures, the actions taking place during Posting activity could generally be described as a *categorization* process, wherein the participants read an incoming factoid and determine its relevance to either the "who, what, when, or where" of the fictional plot. For instance, a factoid indicating, "*The attack will be at the end of the second shift*", would be appropriately assigned to the "When" domain. Posting therefore requires comprehension of the factoid being presented in order to categorize it efficiently. Pulling activity, on the other hand, most resembles an *integrative* process, wherein the participants examine the categorized domain-specific factoids in tandem in order to reach a valid conclusion about one of the seven plot points. For example, given the four following When-relevant factoids,

1) *The new control valve is being installed at the southern oil terminal on August 15,*
2) *The second shift at all of the oil terminals ends at 11:00pm,*
3) *The attack will be at the end of the 2^{nd} shift,*
4) *The attack will occur right after the new control valve is installed,*

we can accurately determine that the attack will occur on August 15^{th} at 11::00pm. To reach a valid conclusion, the above factoids need to, first, be considered as relevant and then determine how they might be integrated to identify a plot point.

Participants completed two individual runs within the same condition (i.e., 2 runs in the Edge organization or 2 runs in the C2 Hierarchy organization) using two different datasets counterbalanced across subjects and within organization assignment.

Following the scanning session, subjects were debriefed with a post-experiment debriefing video (~2 minutes), followed by a 34-item self-reported Immersive Tendencies Questionnaire (ITQ). During this time the participants had the opportunity to ask any additional questions and were provided with feedback on their in-game behavioral performance.

MRI Data Acquisition

Structural and functional MRI data was acquired using a 3.0-tesla Siemens Allegra head-only scanner (Siemens Medical Solutions, USA) located at the Krasnow Institute for Advanced Study at George Mason University. We used a CP TX/R head coil single-channel during data collection and restricted head motion using memory foam inserts in the head coil. Functional runs were acquired using a standard BOLD (bloodoxygenation-level-dependent) gradient-echo echo-planner imaging (EPI) pulse sequence (TR = 3000 ms, TE = 30 ms, flip angle = 70º, FOV = 192 × 192 mm^2, 64 × 64 voxels).

Structural images were collected as spin-echo axial-oblique T1-weighted structural scans of the whole brain (coplanar with functional images, 50 slices, repetition time (TR) = 200ms, echo time (TE) = 3.6 ms, field of view (FOV) = 192 × 192 mm^2; slice thickness = 3 mm, flip angle = 75º; matrix size = 205 × 256).

Preprocessing

Image reconstruction was performed offline. The conversion of raw data was completed using MRIconvert (University of Oregon Lewis Center for Neuroimaging). Data processing and analysis was carried out using the Statistical Parametric Mapping software package SPM5 (Wellcome Trust Centre for Neuroimaging, London, UK). Pre-processing included slice-timing, reorientation, realignment using INRIAlign (INRIAlign, 2000), normalization to SPM EPI template, and spatial smoothing with 9 mm full width at half maximum (FWHM) isotropic Gaussian kernel. Motion inclusion criteria required less than 2 mm translational and less than 2 degree rotational movement. A high-pass filter with a cut-off period of 128s was used to remove low-frequency drifts unrelated to the experimental paradigm.

Statistical Analysis

Initial analyses

Subject performance was determined based on accuracy and reaction times for correctly solved trials. Since participants were required to identify an answer in 7 different domains: 1) who, 2) what, 3) where, 4) what month, 5) what day, 6) what numerical time, and 7) whether it is A.M. or P.M., behavioral accuracy will be considered across all identification domains separately, as well as, jointly. Since it was possible for participants to submit partial identifications within a single run and then go back later to ID other components, reaction times are represented by a single value corresponding to the mean RT for all correctly identified domains per run. Behavioral task results (mean reaction times and accuracy rates and performance on the psychometric test battery (WASI, TIPI, and ITQ) were compared between the two conditions (Edge and Hierarchy) using an independent sample t-test.

Current Analysis

Additional analyses were conducted to determine the strategies individuals employed within each condition. By examining the number of decisions delineated by action (Categorization and Integration) we were able to determine which actions were most commonly utilized within each condition. Using a Pearson correlation matrix between all variables we determine the direction and strength of the linear associations between variables. We predicted that there would be a positive correlation between total number of Integrative actions and increased accuracy and faster reaction time. We also suspected that there would be a positive association between performance across FactoidSets lending reliability to our ELICIT task. We conducted a simple linear regression to determine if ELICIT actions (i.e., # of Posts, # Pulls) and/or total ITQ (Immersion Tendency) predicts ACC. Additionally, based on behavioral data, we suspected that participants with greater mean levels of immersion tendency would exhibit a greater number of total actions within their game-play runs.

FMRI Analysis

Initial Analysis

A general linear model (GLM) was applied to the time course of activations to estimate condition effects at each voxel (Friston, et al., 1994). In the first-level (single subject) analysis, the response function was modeled to the participant's processing and responses were convolved with a canonical hemodynamic response function (Friston, et al., 1994). Several first-level contrasts were modeled against the implicit baseline to include individual, single-subject maps for 1) Integration (Pulls), 2) Categorization (Pushes), and 3) Motor. For Contrast 1 (Integration), the BOLD signal was modeled as an epoch design using a variable time-course represented by the time between the termination of a previous action and the onset of the next action. This time-course was further modified to insert a variable delay and a variable premature cessation in order to reduce potential signal overlap between processes, by capturing the middle 90% of the on-time modeled signal. The use of a variable epoch design allowed for greater statistical power, lower false positive rates, and greater consistency when compared with other methods (Grinband et al., 2006). Since there is no time-on-task component to categorization actions, in Contrast 2 the response was modeled as an event-related function locked to the moment of action. Contrast 3, which was used as a motor control task, was modeled as an epoch-related design using the subject dependent reaction time as the signal duration, as was done for Contrast 1. The fMRI data from each participant was used to generate statistical contrasts for brain activation related to the specific task condition (i.e., decision-making in the context of Edge and Hierarchy). Data was evaluated at the single subject level to disqualify data that include activation outside of neural tissue, an indication of motion and/or physiological artifact.

Based on the fidelity of the single subject data, the resulting statistical parametric maps yielded a t-statistic of each voxel value for our contrasts of interest. These data were then entered into the second-level (group) analysis. The group level map for motor activity was applied to Contrast 1 and 2 as an explicit mask to account for the persistent trackball use throughout the task. A random effects model was used to account for both scan-to-scan and subject-to-subject variability. In the second level, one-sample t-tests were applied to the first-level statistical parametric maps to correlate behavioral parameters with the blood-oxygen dependent (BOLD) signal, the cardinal measure of fMRI. Resulting statistical maps were generated to identify the activation areas related to our contrast. Peak activations were corrected for multiple comparisons using false discovery rate (FDR, $p < 0.05$), unless otherwise noted.

Current Analysis

Using the functional activation data we conducted a conjunction analysis, used as an extension of the above imaging methods, allowing for the consideration of a single hypothesis (i.e., the neural correlates of decision-making in the ELICIT environment) that implicates the involvement of more than one condition simultaneously (i.e., Edge and Hierarchy; Friston, Penny, & Glaser, 2005). This allowed for the identification of any commonalities present in the neural networks that are associated with decision-making in the context of our organizational models jointly, which also provided the ability to identify potential mediating brain regions sensitive to operational structures within ELICIT.

Further exploration of the functional data was conducted using region of interest analysis on the peak clusters of activation, with specific attention to the implicated regions of the insular cortex, lingual gyrus, and frontal cortex. This was done as a means to examine the pattern of activity for each experimental condition (Edge and Hierarchy) and also enlighten any potential changes associated with time-locked actions (Categorization and Integration). The MarsBar toolbox in SPM5 (Brett et al., 2002) was used to extract contrast values for each ROI for each contrast using 10mm spheres centered on the peak voxel coordinates discussed above along with analysis of the Finite Input Response (FIR) percent signal change values. To investigate the potential for false positives following Esterman et al's (2010) approach, we conducted leave-one-subject-out (LOSO) analysis to control for the problem of non-independence bias. Specifically, we left out one participant's data to define independent ROIs and then extracted the left-out participant's BOLD signal changes in corresponding independent ROI. Using this information we were able to more closely examine the robustly significant regions of activation, examine the task and condition-specific time courses of BOLD, and subsequently compare signal discrepancies particular to each organizational structure and relevant in-game action.

RESULTS

Behavioral Results

Initial behavioral results

Results were derived from 20 individuals ranging in ages from 19-27 (*M* = 22.15, *SD* = 2.23) with 10 participants randomly assigned to each organizational condition made up of 4 females and 16 males. Overall intelligence as determined by the WASI was consistent with a normalized population (*M* = 112.00, *SD* = 12.04), as was performance on the TIPI. Overall performance on the ELICIT game represented greater than chance identification (70%) with average solution time of 12.96 minutes. Based on in-game action statistics per run the participants were most likely to engage in Categorization (*M* = 22.85) and Integration (*M* = 35.15) behavior and utilizing the other potential actions of Adding, Sharing, and Apps very infrequently (*M* = 8.30, 0.30, and 2.20, respectively).

Statistical analysis of the psychometric and in-game behavioral performance was conducted via an independent sample t-test comparing our two organization constructs; Edge and Hierarchy. Based on these results there was no discernible statistically significant differences between our groups on intelligence (WASI), personality (TIPI), or tendency for immersion (ITQ). Statistically significant findings were noted for several in-game performance variables to include: average reaction time in factoid set 3, $t(16) = -3.96$, $p < .001$, average reaction time overall, $t(18) = -3.53$, $p < .002$, number of in-game Categorizations, $t(9.3) = -3.37$, $p < .008$, and number of in-game Integrations, $t(18) =$

3.65, $p < .002$ (see Table 1). Together these results indicate that those individuals performing in the Edge structure were faster to reach an accurate solution in the 1st factoid set as, well as, overall, and were more likely to engage in Integrative behavior and less likely to engage in Categorization behavior.

Table 1: Behavioral performance summary from initial analysis

	Edge (N=10)	Hierarchy (N=10)	Significance
% ACC of Factoid Set 1	72% (28%)	64% (32%)	0.57
RT of Factoid Set 1	11.06 min (2.27)	13.65 min (4.33)	0.12
% ACC of Factoid Set 3	84% (20%)	72% (30%)	0.32
RT of Factoid Set 3	10.68 min (2.89)	16.56 min (3.39)	0.00*
% ACC Total	7 5% (24%)	64% (29%)	0.37
Total RT (avg.)	10.67 min (1.92)	15.26 min (3.64)	0.00*

* $p < .01$

Current Behavioral Results

Additional examination of the behavioral performance was conducted using the response times for accurate results. First we ensured that the organizational-dependent performance results were derived from a relatively equal sample size with comparable contributions from each of the two organizational groupings. Although the Edge condition contributed a great number of trials contributing to the response time means (due to slightly increased accuracy rates; Edge *M* = 54%, Hierarchy *M* = 46%), it did not reach a statistically significant discrepancy. In our initial analysis of overall accuracy rates between means, we did not see a significant difference between conditions. However, examining accuracy within artificial time limits does yield discrepant results favoring the Edge condition. Specifically, out of all correctly solved trials 88% were solved in 15 minutes or less in Edge, compared with only 53% in Hierarchy ($p < 0.00$). This linear parallel pattern subsists even when examining those trials solved in 10 minutes or less with 45% and 15% for Edge and Hierarchy, respectively ($p < 0.00$) (see Figures 4 and 5).

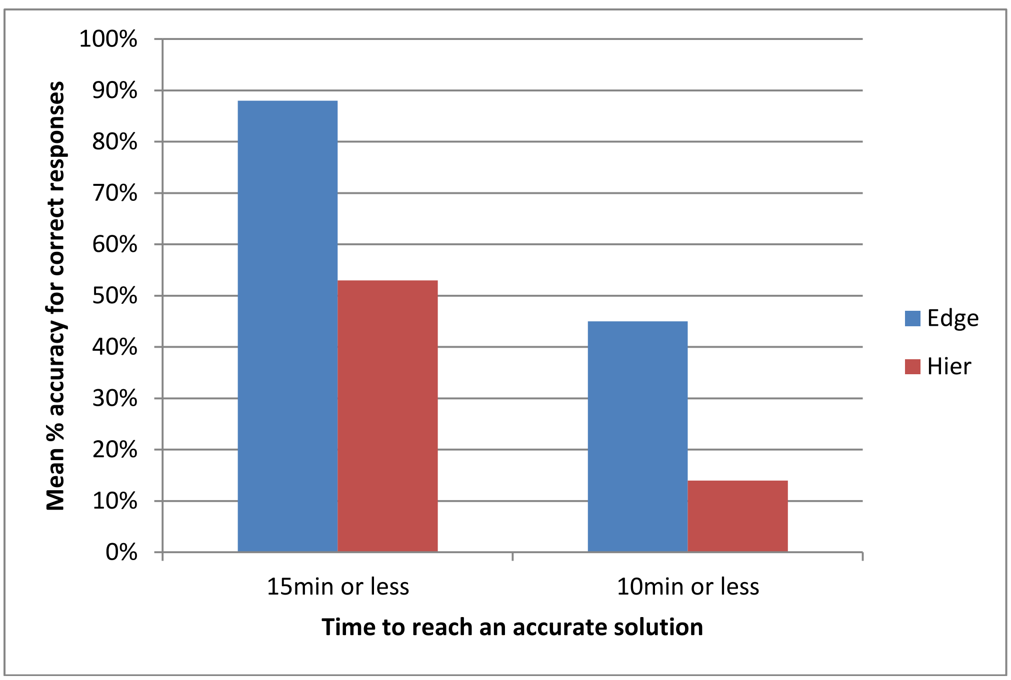

Figure 4: Mean accuracy by condition considered by time.

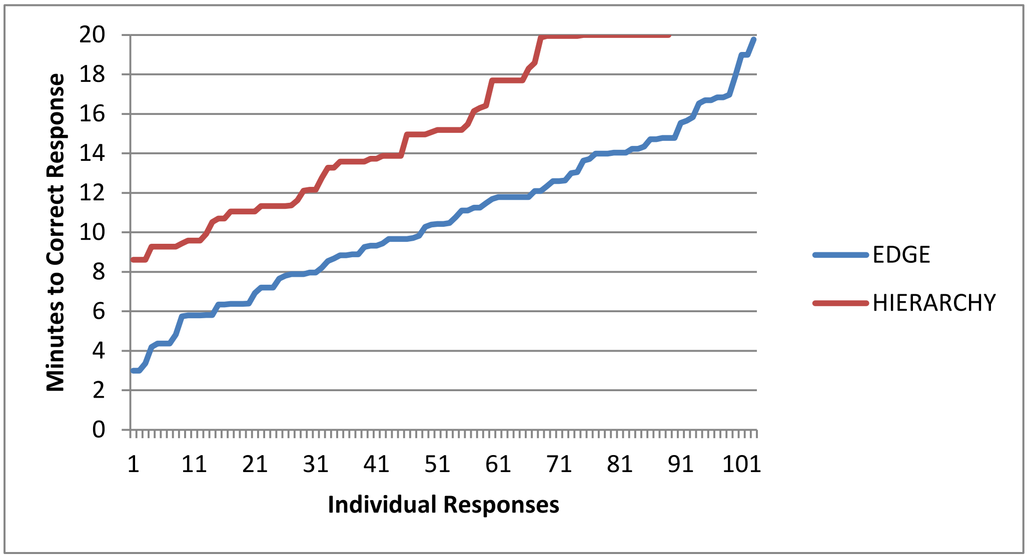

Figure 5: Organizational comparison of response accuracy by time.

A Pearson correlation was conducted on participant's in-game performance, in-game behavior, and psychometric data. Significant positive and negative correlations for relevant pairs are detailed in Table 2.

Table 2: Correlation (Pearson's R) table for relevant variables

	WASI	Categorize	Integrate	ITQ: Involvement	ITQ: Openness	TIPI: Extraver.
FS1 ACC	**0.65***	-0.42	**0.48***	**-0.51***	0.35	-0.04
FS3 ACC	0.02	-0.05	**0.47***	-0.21	-0.16	-0.21
Combined ACC	**0.46***	-0.42	**0.51***	**-0.50***	-0.28	-0.11
FS1 RT	0.25	0.05	-0.19	0.07	**-0.51***	**-0.53***
FS3 RT	0.06	**0.53***	**-0.66***	-0.21	0.01	0.04
Combined RT	0.16	0.40	-0.44	0.25	-0.28	-0.33
ITQ Involvement	-0.04	**0.52***	-0.36			

***significance *p* <.05**

A simple linear regression analysis was conducted to determine how in-game actions and immersive tendency related to task accuracy. This analysis revealed the following results: In-game performance was a good predictor of organizational assignment (R = .874, regression(F) = 5.46, p = .005) driven by frequency of categorization (t = 2.44, p = .031) and frequency of integration (t = -2.76, p = .017). ITQ and in-game performance was not a good predictor of ACC (F = 2.3, p = .094), and was additionally not a good predictor of ACC when examined by organizational assignment (i.e., not predictive within Edge participants [F = 1.62, p = .371] nor within Hierarchy participants [F = 1.096, p = .511]). ITQ and in-game performance was not a good predictor of RT overall (F = 1.016, p = .456). ITQ and in-game performance was a good predictor of RT for the Edge participants (F = 9.181, p = .048), but not for Hierarchy participants (F = 0.593, p = .732). The predictive aspect within the Edge condition relied on frequency of categorization (t = -5.409, p = .012) and frequency of integration (t = 4.125, p = .026). Immersion tendency was not an influence (t = -2.3, p = .105).

Functional MRI Results

Initial whole-brain functional MRI results

BOLD activation maps resulting from the GLM analyses were used to inform subsequent analyses specific to this examination. MNI coordinates derived from SPM5 output were translated to Talairach coordinates and identified via the Talairach Client Deamon (Lancaster, et al., 1997; Lancaster, et al., 2000), and through manual verification via the Talaraich atlas.

Maps comprised of all participants (N = 20) capturing activity induced by the motor task, indicates cluster level corrected ($p < .05$) in left postcentral gyrus (BA 3) and uncorrected ($p < .001$) activation in the left precentral gryus (BA 4), bilateral postcentral gyrus (BA 5/2), left superior parietal gyrus (BA 7), right inferior occipital lobe (BA 17), left cingulate gyrus (BA 31), right superior temporal gyrus (BA 22), and left inferior cerebellum (semi-lunar lobule).

An analysis of the groups combined to represent motor-masked Integrative behavior (N = 18, representing 31 total runs) revealed active clusters (uncorrected $p < .001$) in the right anterior cingulate gyrus (BA 24) and right lingual gyrus (BA 17). Overall participant activation, to include both organizational groups, representing motor-masked Categorization behavior (N = 17, representing 28 total runs) revealed active clusters (cluster-level correction; $p < .05$) in the left insula (BA 13) and active regions (uncorrected $p < .001$) of the left paracentral lobule (BA 31), bilateral superior temporal gyrus (BA 22/21), right middle temporal gyrus (BA 21), right lingual gyrus (BA 18), and subcortical regions of the right claustrum, bilateral insula (BA 13), right putamen, and right globus pallidus.

Examining these actions in the context of organization structure revealed Edge-relevant activation during Integration (N = 10, representing 17 runs total) in bilateral precentral gyrus (BA 4 & 6), left medial frontal gyrus (BA 9), right cingulate (BA 31), and right lingual gyrus (BA 18) at FDR correction ($p < .05$), as well as, uncorrected ($p < .001$) activation in right middle frontal gyrus (BA 10), right precentral (BA 3 6), bilateral medial frontal (BA 6 & 9), bilateral anterior cingulate (BA 32 & 24), left cingulate gyrus (BA 24, 31, & 23), left supramarginal gyrus (BA 40), bilateral precuneus (BA 7 & 31), left superior occipital gyrus (BA 19), bilateral lingual gyrus (BA 18 & 17), right middle occipital gyrus (BA 18), left fusiform gyrus (BA 19), left cuneus (BA 18), bilateral superior temporal gyrus (BA 22 & 41), right middle temporal gyrus (BA 22), bilateral cerebellar declive, and subcoritcal regions of the left insula (BA 13), left claustrum, and left thalamus.

Edge-relevant activation during Categorization (N = 9, representing 14 runs total) revealed cluster-level corrected ($p < .05$) activation in left insula (BA 13) and uncorrected ($p < .001$) activation in right inferior frontal gyrus (BA 9), right precentral gyrus (BA 6), right cingulate (BA 31), and right superior temporal gyrus (BA 22).

Hierarchy-relevant activation during Integration (N = 8, representing 14 runs total) revealed uncorrected ($p < .005$) activation in right medial frontal gyrus (BA 6), left superior frontal gyrus (BA 6) and right lingual gyrus (BA 17).

Hierarchy-relevant activation during Categorization (N = 8, representing 14 runs total) reveals uncorrected ($p < .005$) activation in right medial frontal (BA 10), left middle frontal (BA 8), bilateral anterior cingulate (BA 32), right precuneus (BA 31), right inferior parietal lobule (BA 40), right lingual gyrus (BA 18), bilateral superior temporal gyrus (BA 41 & 22), right supramarginal gyrus (BA 40), and subcortical regions in bilateral insula (BA 13), bilateral putamen, bilateral body of the caudate, bilateral globus pallidus, and right claustrum.

Current functional MRI results

We used conjunction analysis to simultaneously examine the common and distinct neural systems affiliated across and within each organization structure. The conjunction of Integrative behavior within Edge with that of Integrative behavior within Hierarchy revealed significant activation in bilateral postcentral gyrus (BA 5) and left middle occipital gyrus (BA 18). The conjunction of Categorization behavior within Edge with that of Categorization behavior within Hierarchy revealed activation in the right precentral gyrus (BA 13), bilateral superior temporal gyrus (BA 22), and right-lateralized cerebellum, claustrum, and putamen (see Table 3 and Figure 6).

Table 3: Global Null Conjunction Analysis of Edge and Hierarchy

Regions of activations		BA	Cluster voxel size (uncorrected value)	TAL coordinates			Z-score
Anatomical label				x	y	z	
Pulls							
	Frontal						
L	Postcentral Gyrus	5	25	-2	-44	62	3.92
	Occipital						
L	Middle Occipital Gyrus	18	21	24	-84	2	4.54
Pushes							
	Frontal						
R	Precentral Gyrus	13	23	49	-11	9	4.47
	Temporal						
L	Superior Temporal Gyrus	22	94	-57	-3	-6	4.12
R	Superior Temporal Gyrus	22	33	49	-48	11	3.99
	Cerebellum						
R	Tonsil		26	19	-37	-39	4.24
	Subcortical						
R	Claustrum		36	35	-2	5	4.96
R	Putamen		30	21	7	-3	4.21

All regions consist of at least 10 voxels with an uncorrected $p < 0.001$.

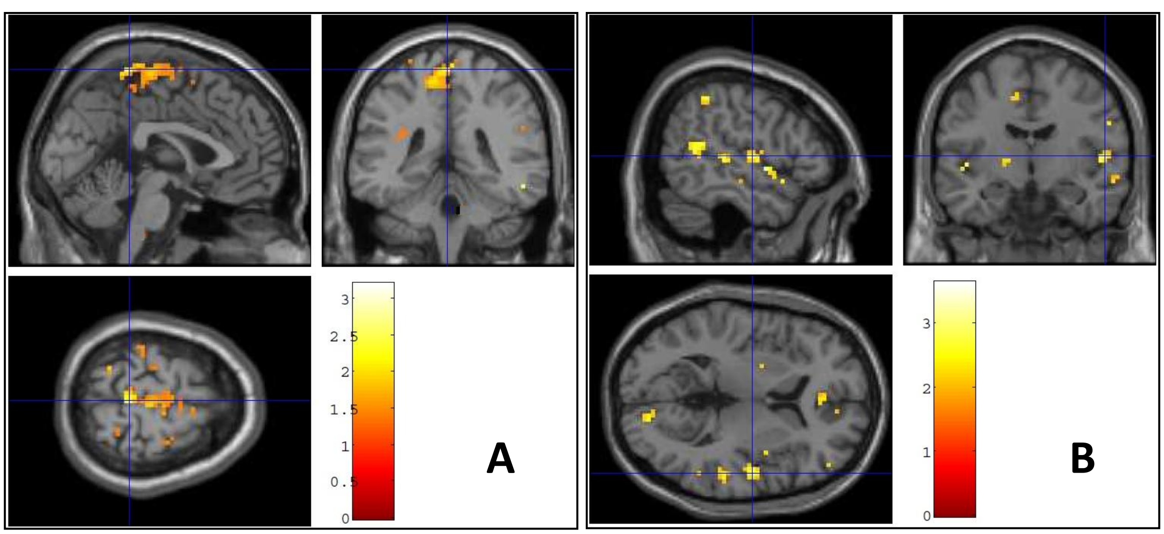

Figure 6: Conjunction analysis of Edge and Hierarchy in (A) Integration and (B) Categorization

Direct contrasts of the organizational structures representing Edge-specific activation (Edge > Hierarchy) amidst Integrative behavior (N = 18, 31 runs total) reveals relevant regions to include left medial frontal gyrus (BA 4/10/9), left precentral gyrus (BA 4), right superior frontal gyrus (BA 10), right cingulate gyrus (BA 31), left supramarginal gyrus (BA 40), bilateral precuneus (BA 7), right lingual gyrus (BA 18), left middle temporal gyrus (BA 37), and left anterior cerebellum (culmen) (uncorrecred, $p < .001$). Hierarchy-specific activation (Hierarchy > Edge) amidst Integrative behavior (N = 18, 31 runs total) includes left superior frontal gyrus (BA 6) (uncorrected, $p < .01$).

Direct contrasts of the organizational structures representing Edge-specific activation (Edge > Hierarchy) amidst Categorization behavior (N = 17, 28 runs total) reveals relevant regions of the left insula (uncorrected, $p < .001$), and right inferior frontal gyrus (BA 9), right precentral gyrus (BA 6), bilateral cingulate (BA 31 & 24), right superior parietal lobule (BA 7), and bilateral superior tempotal gyrus (BA 41 & 22) (uncorrected, $p < .01$). Hierarchy-specific activation (Hierarchy > Edge) amidst Categorization behavior (N = 17, 28 runs total) reveals relevant regions of the left caudate body, right anterior cerebellum (culmen) (uncorrected, $p < .001$), and left middle frontal gyrus (BA 46 & 10), bilateral superior frontal gyrus (BA 10 & 6), bilateral parahippocampal gyrus (BA 34), right uncus (BA 20), right inferior parietal lobule (BA 40), left supramarginal gyrus (BA 40), bilateral fusiform gyrus (BA 19, 37, & 20), bilateral anterior cerebellum (culmen), and left posterior cerebellum (declive) (uncorrected, $p < .01$).

A Region of interest (ROI) analysis provided more exact statistical information regarding each independent contrast in regions of interests that were significant in our whole-brain analysis. Significant Edge-specific activity was found in medial frontal (BA 9 & 10), precentral (BA 4), cingulate (BA 31), insula (BA 13), fusiform gyrus (BA 20), lingual gyrus (BA 17 & 18), and superior temporal gyrus (BA 22), and significant Hierarchy-specific activity in medial frontal (BA 6), insula (BA 13), putamen, and superior temporal gyrus (BA 22 & 41) (see Table 4).

Table 4: Contrast Values for designated ROIs by Condition and action

Region	BA	Coordinates (TAL)			Contrast Values	
		x	y	z	Edge	Hierarchy
Integration						
Precentral Gyrus	6	54	-3	18	0.15*	-0.03
Medial Frontal Gyrus	6	4	-14	71	0.06	0.14ǂ
Superior Frontal Gyrus	6	-2	7	62	0.02	0.08
Medial Frontal Gyrus	9	-7	44	22	0.20*	-0.08
Medial Frontal Gyrus	10	-9	52	1	0.18*	-0.04
Lingual Gyrus	17	21	-83	2	0.10*	0.06
Lingual Gyrus	18	13	-85	-6	0.18*	-0.05
Fusiform Gyrus	20	-51	-9	-24	0.13*	0.00
Cingulate Gyrus	31	1	-33	36	0.16*	-0.06
Categorization						
Medial Frontal Gyrus	10	21	48	9	0.17	0.36
Insula	13	35	-29	18	0.31	0.53ǂ
Insula	13	-43	5	-4	1.60*	0.52ǂ
Lingual Gyrus	18	13	-80	-6	0.33	0.62
Superior Temporal Gyrus	22	49	-2	5	1.13*	0.42ǂ
Precuneus	31	21	-48	41	0.00	0.32
Cingulate Gyrus	31	7	-28	42	1.11*	0.23
Anterior Cingulate	32	-7	37	10	0.34	0.45
Superior Temporal Gyrus	38	52	12	-21	0.97	0.17
Superior Temporal Gyrus	41	46	-39	7	0.22	0.50*
Putamen	Sub	-26	4	7	0.20	0.60*

$p < .01$ corrected = *, $p < .05$ corrected = ǂ

Finite Input Response (FIR) values were obtained for each designated ROI delineated by organization structure and in-game behavior. Independent sample t-tests and Pearson correlations were conducted to determine any potential percent-signal-change discrepancies between Edge and Hierarchy participants within the designated ROIs. While no statistically significant mean differences were revealed, patterns of activity as noted in our figures indicate varied time course responses (see Figures 3-6). Specifically we noted negative (or near nil) correlations between our conditions within the frontal cortex (BA 6: $r = -0.34$, $p = 0.39$; BA9: $r = 0.02$, $p = 0.96$; BA 10: $r = -0.55$, $p = 0.16$). Alternatively, the time-courses correlations within the visual processing region of the occipital cortex were more closely related (BA18: $r = 0.91$, $p = 0.00$; BA17: $r = 0.38$, $p = 0.35$). Examination of our FIR time-courses by condition additionally revealed a greater number of significant positive correlations between the various ROIs within Edge participants more so than was revealed within Hierarchical participants.

Additional examination of the FIR time-course between conditions was also conducted between game-play phases (Categorization and Integration). Using the combined mean signal change for neighboring ROIs within each phase we developed a composite FIR graph highlighting how our test groups differed amidst our two primary in-game actions. Correlational results signify a great deal of internal consistency within condition for our designated ROIs amidst Categorization behavior, indicating paralleled activation time-courses between regions of the PFC, posterior cingulate, and occipital cortex (Figure 7), especially amongst our Hierarchy participants. Amidst Integration behavior this internal consistency is less pronounced and represents a more serial processing system (Figure 8).

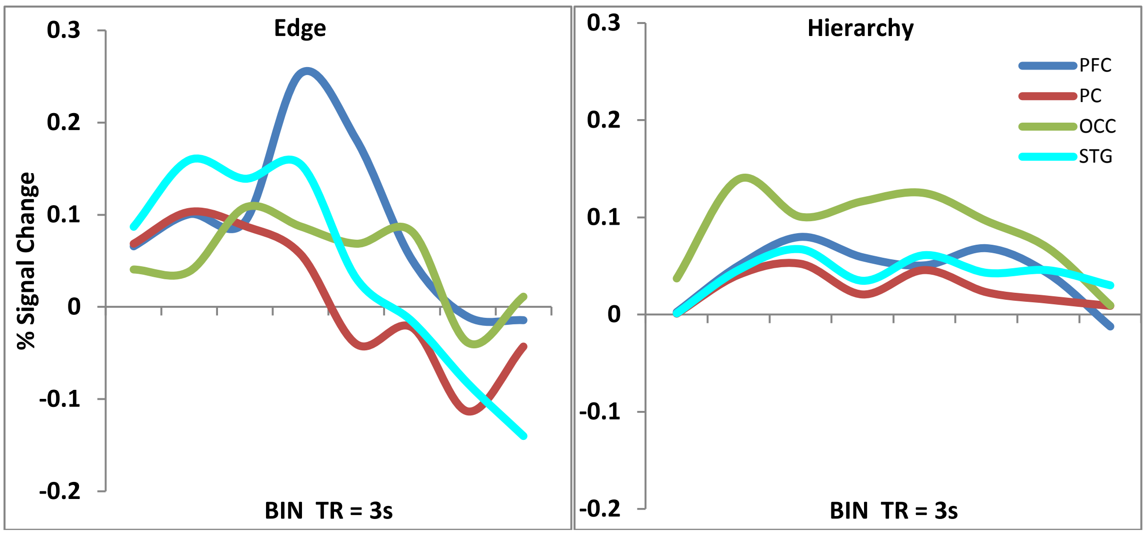

Figure 7: FIR timecourse for relevant brain regions amidst categorization

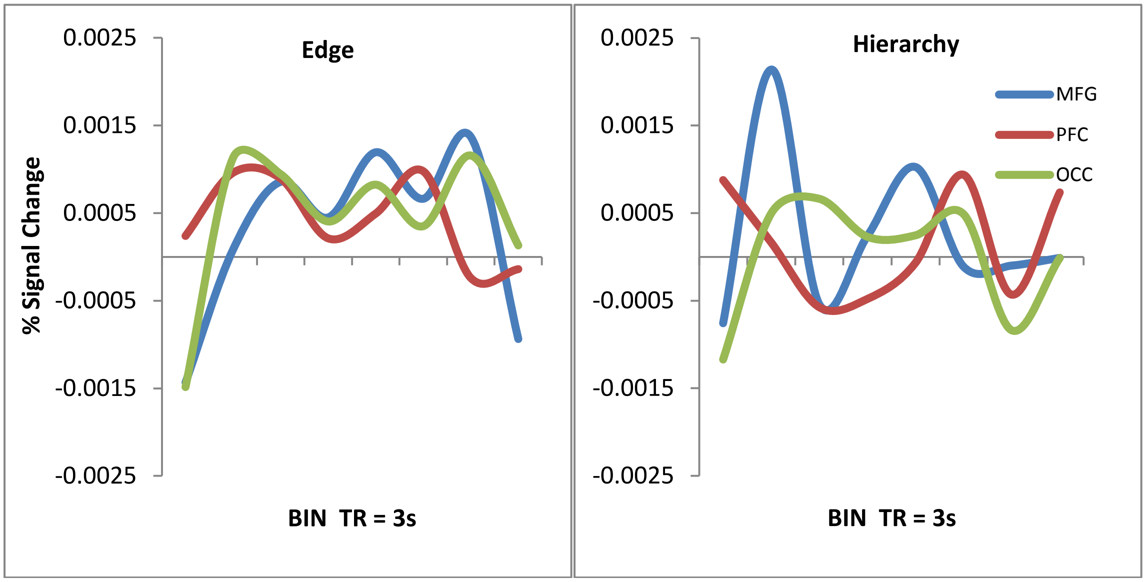

Figure 8: FIR timecourse for relevant brain regions amidst acquisition

Confirmatory results for FIR time-courses derived from the "Leave One Subject Out" technique revealed similar results implicating the anterior cingulate and lingual gyrus amidst the Integrative phase and the insular cortex and dorsal posterior cingulate amidst the Categorization phase. Examining these BOLD signals by organizational condition reveals correlated time-courses during Integration within the anterior cingulate cortex (BA 24) nearing significance ($r = 0.69$, $p = 0.06$). Alternatively, within Categorization, an independent samples t-test revealed significantly different mean signal changes, whereby the Edge condition elicited greater recruitment of dorsal posterior cingulate cortex ($p = 0.02$).

DISCUSSION

Our initial purpose of examination relied on implementation of the ELICIT program amidst functional MRI scanning along with personality and intelligence batteries to reach several general conclusions concerning the effects of organizational structure on information manipulation and integrative reasoning processes. The aim of this paper was to provide a more focused examination of those concepts using the more specific ROI statistical analyses informed by the relevant findings from the GLM analysis (Kalbfleisch et al., in review). This study reaffirms the critical role of the prefrontal cortex for integrative reasoning processes as noted in previous literature (Fangmeir, Knauff, Ruff, & Sloutsky, 2006; Kalbfleisch, Van Meter, and Zeffiro, 2007; Kroger et al., 2000; Qui et al., 2006), and our own preliminary study (Kalbfleisch et al., in review). Herein, we have gone beyond those findings to suggest that contextual influences, by way of environmental pressures and organizational constraints, alter the integrative reasoning process at physiologic and behavioral levels.

Of particular significance, concerning the social and behavioral influences on our reasoning task, preliminary findings indicated that those individuals within the Edge condition were more likely to engage in Integrative behavior and more quickly were able to reach an accurate conclusion than their Hierarchy-bound counterparts. Hierarchy participants, on the other hand, were more likely to engage in Categorization behavior and were slower to reach an accurate conclusion. Given Leweling and Nissen's (2007) contention that those individuals manipulating the filtered, synthesized and summarized information (as encountered in Edge) would outperform those individuals using information that has not been organized into a "coherent whole" (as encountered in Hierarchy), these results are unsurprising. Leweling and Nissen (2007) additionally noted that the most important aspect of the solutions in this task were accuracy and not time. Therefore if we consider accuracy based solely on the entire 20-minute scope of the trial, the advantage of Edge over Hierarchy is less impressive as no significant accuracy discrepancy between organizations was noted in our preliminary analysis. However, when we analyze behavioral performance at shorter time intervals (10 minutes or less, and 15 minutes or less), as was conducted in the current study, we see a clearly significant advantage of the Edge participants over Hierarchy. Specifically, even though each organization supported linear rates of solution as revealed in Figure 5, and ultimately reached an equal number of accurate solutions, those in the Hierarchy condition required that last 5 minute interval (between the 15 minute mark and the end of the trial), in order to "catch-up" to the accuracy rates reached in Edge in a much shorter amount of time.

Based on the correlation data in the current study, we see that greater accuracy is associated with higher intelligence, and that faster reaction times (i.e., accurate solutions) are associated with extraversion, openness, and an increased amount of in-game Integrative action. Additionally, we noted reduced accuracy in those individuals that reported a tendency to become highly involved in activities, which is, in turn, associated with an increased amount of Categorization behavior in-game. In the context of our particular task, this suggests that their success, at least in terms of speed, may be mediated by the ability to avoid getting lost in the details (excessive categorization) and focusing instead on related concepts (integration), as well as, not being apprehensive about providing an answer or filing an incorrect answer (extraversion: Identification). This assumption is further supported when examining the correlations by organizational condition independently, where we see a high 'tendency towards involvement' associated with reduced accuracy in one of the Hierarchy participant trials. Taken together, this can provide a profile as to the type of individual most likely to be successful in our task.

Given that the Edge organization supported a significant advantage over Hierarchy, we can also make some assumptions about what makes one approach more successful than another. Accounting for the evidence that Integrative behavior is correlated with increased accuracy and Categorization is related to slower reaction times, we can derive that an organizational model which not only benefits from, but requires, the promotion of Integration over Categorization would prove more successful. Indeed, our current analyses determined that the Categorization and Integration frequencies were predictive of organizational construct and further indicated that these frequencies were predictive of reaction times within the Edge model. Keeping in mind that our experimental conditions did not differ by age, personality, immersion tendency, or intelligence, this evidence suggests that the Edge model provides a unique environment that favors the integrative processes over the categorization processes. This advantage within Edge is so critical that when individuals exhibit in-game behavior favoring a more equaled Integration/Categorization ratio it results in slower reaction times. The fact that Hierarchy participant's performance was not affected by in-game actions is further supported through examination of our correlation matrix defined by organizational condition. Specifically evidenced by noted significant positive correlations between Integrative frequency and overall accuracy (p = .02, r = .75) and significant negative correlations between Categorization frequency and total reaction times (p = .03, r = -.68) seen only for our Edge participants, along with a complete absence of significant correlations between in-game actions and performance within our Hierarchy participants. This, therefore, suggests that an individual's performance while operating within the confines of the Edge condition is dependent on their game play behavior; susceptibility not present within the Hierarchical condition.

Preliminary implications of our previous study associated with Categorization and Integrative actions were further interrogated to determine how these regions may support observed in-game behaviors. General game-play activity, to include aspects of Integration and Categorization across both organizational conditions, revealed consistent activation within the superior temporal gyrus (BA 22 & 41). With the ELICIT program being heavily comprised of text-based sentences that need to be read as part of the task, it is not surprising that this region is common to game-play activity in general (Fiez & Petersen, 1998). Given this region's ubiquity in our task and its historical involvement in speech processing, semantic sensitivity (Mummery, et al., 1999), and multi-sentence processing (Fletcher, et al., 1995), this may also represent an internal dialogue as a means to "talkthrough" the premises and subsequent reasoning process using silent articulation (McGuire et al., 1996).

Identified activity within the occipital cortex, to include the lingual gyrus and postcentral gyrus amidst our Integrative phase might typically be attributed to the pervasive visual aspect of the task being presented. However, since we employed the use of a motor mask, which utilized a similar manual and eye-movement scheme to that of the ELICIT task, we have reason to suspect the potential for a more cognitive role beyond visual processing, as evidenced by the lingual gyri's role bilaterally in text-based deductive reasoning tasks (Goel & Dolan, 2004). Given that lingual gyrus activity was present across both conditions and represented by similar time-course, the association between task accuracy and Integration frequency further supports this implication. Furthermore, the significant activation noted in this region was specifically attributed to the Edge participants moreso than the Hierarchy participants suggesting that the lingual gyrus may have afforded additional supports for deductive reasoning allowing for increased performance.

Previously identified activity of the insular cortex was supported within a more narrow scope and specifically attributed to supporting Categorization behavior. An understanding into the nature of our task amidst this action clearly favors the interpretation that the insula is responsible for establishing a personal sense of agency (Farrer & Frith, 2002). Behavioral support for this interpretation is established with the significant correlation noted between Categorization behavior and tendency to become involved. Since the self-report for involvement served to inform the immersion tendency questionnaire and specifically addresses an individual's inability to disconnect from potentially immersive environments, it stands to reason that those engaging in high amounts of Categorization behavior are acutely aware of their self-centered actions eliciting the noted insular activity. The ROIs defined from our previous whole-brain analysis were graphed to yield time-locked data points representing the mean percent signal change over a 24-second period for our in-game activities (Integration and Categorization) and further delineated by condition (Edge and Hierarchy). Examination of this Finite Input Response (FIR) time-course within the insular cortex further supports the role this region plays in Categorization behavior. We know that those within the Hierarchical condition engage in large amounts of Categorization behavior and indeed this is consistent with a noted persistent insular activation maintaining a positive BOLD signal for an extended period for the Hierarchical participants; a trait not noted within the Edge participants.

Characterization of percent signal change time-course via FIR curves yielded additional results worth noting. Although a t-test did not reveal significant differences between our signals within each behavioral contrast, the shapes and time-course comparing the Integrative phase FIR to the Categorization phase FIR reveals a discrepant response curve worth noting. Comparing the mean signal change for defined ROIs amidst Integration revealed very similar time course responses in line with the expected hemodynamic response function. As expected visualization of the mean signal change curve amidst Categorization for Edge participants reveals a similar curve. Observing the curve amidst Categorization for Hierarchy participants however reveals a signal that persists above baseline well past that seen in Edge. A potential explanation for this finding relates to how the game is presented in each condition and how the participants behave within that construct. Behavioral evidence has indicated that a participant's actions (game-play) within Hierarchy has no effect on the eventual response times needed to reach a valid solution, whereas it is critical in Edge. This suggests that the Hierarchy structure provides some resistance to potential idiosyncratic behavioral actions. Considering these details in tandem with our observation of a unique signal change persistence within a Categorization phase, we suspect that those individuals operating within a Hierarchical model are employing a discrepant game-play technique. Specifically, our assumption that the deductive reasoning process would occur almost exclusively in the Integration phase, while true for our Edge participants, does not hold true for our Hierarchy participants and are in fact engaging integrative processes (notably in BA 10 and 32) during the previously-defined Categorization phase. This effect is two-fold, it reduces the amount of processing amidst Integration phases and increases processing amidst Categorization phases. This explains why their response times are resistant to in-game behaviors because their periods of integration are not linearly defined as they are within Edge, as integrative processing is ongoing during the categorization phases as they sort information. Whereas the Edge use the categorization phase as *a* means to an end, those the Hierarchy use Categorization as *the* means to an end.

Given the confirmatory results derived from our LOSO analysis we can determine that regions of the frontal cortex were critical across conditions to support the Integrative phase of the game. The true discrepancy in regional activation however was revealed within the Categorization phase, whereby those in the Edge condition were afforded significantly greater support from the dorsal posterior cingulate cortex.

Knowing that the Edge model is superior in terms of faster reaction times, we wanted to know, “what makes this networked, fluid system a better fit to human cognition than a divisional, static hierarchical model?” Given our physiological results implicating the insular cortex amidst Categorization behavior and evidence of discrepant time-courses of designated ROIs, along with our behavioral results implicating divergent use of the categorization and integration methods, we suggest that the success and failure of each approach can generally be understood by way of two opposing learning approaches first identified in the academic field (Slavin, 1995). Examination of the building-block model and the gestalt model as a parallel to the Hierarchical and Edge models, respectively, may provide insight into how these models facilitate or hinder performance in a broad sense. The building-block approach provides users only with the subcomponents of a strategy for assessment of a problem and, therefore, would be akin to the highly compartmentalized, hierarchical model. Within a learning environment, this approach has been found to be less effective than the gestalt model due to the limited information provided to users, as well as their narrow understanding of the overall objectives (Slavin, 1995). These limitations prevent users from seeing any potential long-range connections that may be present outside of this limited scope, which may result in the inability to grasp the overall concepts and themes of the task or mission. In context of our task, it becomes clear how highly compartmentalized models, such as the Hierarchical and building-block models, can be a detriment to the user and overall mission. For example, within the Hierarchy model of ELICIT, the organization is structured such that one unit is assigned to determine the "where" in a terrorist plot, another unit the "when," another unit the "what," and another unit the "how." This type of organization is similar to the modular operation representative of the building-block approach, and can result in limited communication between teammates and, subsequently, incomplete information.

This variant approach to problem solving induced by our discrepant conditions serves to inform the specific psychological underpinnings of contextually-influenced cognition, but identifying a generalized neurophysiological theory will require closer examination of the implicated brain regions within each reasoning phase as defined by organizational structure.

As we have identified in our preliminary analysis, and confirmed via our current study, the role of anterior prefrontal cortex (aPFC) served a role in higher-order cognition within our task. Its exact role, however, was not clearly defined beyond its implication in the internal generation of ideas and plans requiring inference processes which integrate externally presented information with general world knowledge (Ferstl, 2001). This idea harkens back to our discussion on tacit knowledge and the use of the ELICIT program to develop socially-contextualized information within organizational frameworks. Essentially, we required our participants to draw inferences from the text to represent coherent knowledge by elaborating on the presented propositions (factoids) via domain-general and domain-specific knowledge. Noting research from Moss and colleagues (2011), which similarly speculated that regions of the aPFC were responsible for the integration of novel text-based knowledge with inherent prior knowledge, we hoped to draw additional corollaries with our own results.

One such theory that may serve to explain this interplay of influences on reasoning and their implicated neural systems in the aPFC is known as the Gateway Hypothesis as proposed by Burgess and colleagues (2005). This theory suggests that goal-directed coordination of stimulus-independent-thought (SIT) and stimulus-oriented-thought (SOT) is gated by the anterior PFC (BA 10) favoring one over the other given the circumstances. Generally, SOT refers to externally produced stimuli, and SIT refers to internally manifested thought. In the context of our current task, SOT would be akin to the factoids/premises of the terrorist plot, whereas SIT might be associated with the creative insight into how these premises fit in a more domain-general perspective. SIT is also subject to the internal factors that guide behavior as measured by our intelligence, immersion, and personality measures. Although the delineations are not completely discrete, Burgess and fellow researchers (2005) have identified a delineation of the aPFC into medial and lateral regions which support these concepts of SOT and SIT, respectively.

As it relates to our current results, we note robust medial aPFC activation biasing toward stimulus-oriented thought amidst Integrative processes within our Edge participants. Because we expect those in Edge to exhibit greater creative insight, we would have assumed a stimulus-independent thought bias was more likely. Although not inherently intuitive, when we consider that those in Edge were significantly influenced by their game-play actions, it is more reasonable to assume that they were attuned to the details of the premises and their interactions and less prone to the focus on stimulus-independent thought. It should be noted that while medial aPFC within Edge was the only aPFC region to survive correction for multiple comparisons, other uncorrected results were noted in our task which lend credence to this hypothesis. Notably, we see lateral aPFC activation within the Categorization phase for our Hierarchy participants, as well as, within the Integration phase for our Edge participants. These findings further support our above hypothesis concerning where each organization's deductive reasoning processes are occurring in the context of the task (i.e., Categorization phase for Hierarchy and Integration phase for Edge). Additionally, activation in medial aPFC was also found to occur when coordinated attention between external stimuli and internal thought was required, demonstrating that this Gateway Hypothesis does not represent an all-or-nothing paradigm

If, as suggested above, the PFC imposes a top-down bias to mediate regional activation based on externally driven and inherently-derived influences, and further suggested by Miller and Cohen (2001), to attenuate attention, response selection, inhibitory control, and short term-memory, then it is critical to examine those regions associated with instances when PFC activity was present in our task. Specifically, we observe a significantly greater signal within the Edge condition for both Integration and Categorization phases for the dorsal posterior cingulate (BA 31), a trait not revealed for our Hierarchy participants.

The posterior cingulate activation coordinates seen in Edge were strikingly similar to those revealed in Fertl's (2001) study implicating its role in coherence, as defined as "establishing pragmatic connections between successively presented sentences". A pattern begins to emerge whereby the implicated regions of aPFC mediate the utilization of integrative deductive reasoning processes in line with our organization-dependent game-play expectations.

With the posterior cingulate activity during deductive reasoning within Edge being suggestive of a non-verbal visuospatial representation of the premises, and the Hierarchy-specific activation of the putamen and STG (41) representing a syntactic/linguistic representation of the premises (Prado, Chadha, & Booth, 2011) and verbal/semantic processing (Kuchinke, van der Meer, & Krueger, 2009) there is continued support for a 'building block' versus 'gestalt' approach as discussed above. This presented evidence points towards a fast-switch SIT/SOT approach made possible by the unique contextual supports afforded by the Edge construct. Not only are our Edge participants engaging in a gestalt method to observe the "big picture", but that very process is made available because of the manner in which the information is being internally collated and directed by a gated PFC mediator by avoiding internally provoked goal-irrelevant processing and encouraging goal-specific processing. Our results therefore support Goel's (2007) argument that no single reasoning system exists, and evidence instead suggests a fractionalized system that is susceptible to certain tasks and environmental cues.

This suggestion, of a modulated system of cognition, underlies Gazzaniga, Doron, and Funk's (2009) push towards an updated view of the brain as a complex, interconnected system. As evidenced herein, cognition does not merely exist between input and output as an orderly hierarchy, but is a continuous process consisting of brain systems acting in parallel and further influencing subsequent stimuli and response. Indeed, Gazzaniga, Doron, and Funk's (2009) contention that the brain, as a complex system, is capable of self-organization and adaptation within a changing environment parallels the overall goal of this study to characterize cognition under disparate controlled contexts. Generally, our results support this shift away from the conventional concept of a sole central executor and instead lends credence to the interactive modularity of higher order cognition.

Our current aims to better characterize how individuals operate under these differing organizational structures and how independent personality and behavioral traits affect information processing, were well realized. We demonstrated that an individual's psychometric profile was, to a limited extent, associated with in-game performance within ELICIT. The aspects of openness and extraversion were associated with faster response times and the immersive subscale of involvement was associated with a negative effect on performance and change in game-play behavior, therefore providing a starting point for profiling successful players.

Furthermore, our more focused approach has successfully provided consistent and suggestive theories concerning how organizational and social context influences the reasoning process. Herein, we have suggested several key concepts. First, we proposed that an individual's in-game actions and subsequent performance was associated with their psychometric profile. Second, within the context of organizational models, we suggested that Edge was more successful than Hierarchy because it provided a better structure with which to organize factoids, allowing for an increased ability to see the big picture (interconnectedness of related premises) and not get lost in the details. Such an ability appears to have been supported by differential involvement of the insular cortex and discrepant activation of the anterior prefrontal cortex. We further proposed that while the Edge model may have provided a more ideal framework for inducing superior performance supported by the deductive reasoning processes of the prefrontal cortex, it is more susceptible to idiosyncratic participant behavior. For this reason, a Hierarchical organizational context may provide a more stable environment less affected by differing methods of solution, but at the cost of efficiency. Third, we concluded that the deductive reasoning process necessary for task success was maintained within organizationally-discrepant, user-defined phases of game-play. More specifically, we suggested that the integrative process within Hierarchical organizations was more temporally diffuse and less compartmentalized into the Pulling phases, than was seen within the Edge condition. This altered reasoning strategy within our Hierarchical participants was instigated by the utilization of a less effective syntactic/linguistic processing based on individual details of the task as opposed to a more broadly contextualized visuospatial process as seen in the Edge participants. Lastly, our results lend credence to the proposition posed by Burgess (2001) concerning the existence of non-mutually exclusive “streams” of internal bias and sensory bias working in concert under the Gateway Hypothesis to direct the flow of inputs and outputs to produce reasonable representations.

Ultimately, our study provides evidence that contextual influences of environmental and social constructs paired with an individual’s personal attributes can, and will, influence higher-order cognition, and subsequent behavioral performance. The necessity going forward, therefore, will require an ability to identify and address these influences to better navigate avenues of approach and personnel assignment to increase chances for success. Applications stemming from this study extend beyond its primary origin within military organizations and encompass any situation in which external and internal factors guide the subjective reasoning process. Since we cannot assume consistently static attributes, commensurate across and within individuals and environments, then knowing how social context weights on the neural response and eventual outcomes becomes paramount.

REFERENCES

REFERENCES

Alberts, D.S., & Hayes, R.E. (2006). *Understanding command and control.* Command and Control Research Project (CCRP). 1-222.

Anderson, S. W., Demasion, H., Tranel, D., & Demasio, A. R. (2001). Long-term sequelae of prefrontal cortex damage acquired in early childhood. *Developmental Neuropsychology, 18,* 281-296. doi:10.1207/S1532694202Anderson

Asch, S. E. (1956). Studies of independence and conformity: A minority of one against a unanimous majority. *Psychological Monographs, 90,* 70. doi:10.1037/h0093718

Balcetis, E. & Dale, R. (2007). Conceptual set as a top-down constraint on visual object identification. *Perception, 36,* 581-595. doi:10.1068/p5678

Barfield, W., Zeltzer, D., Sheridan, T. & Slater, M. (1995). Presence and performance within virtual environments. In Barfield, W. & Furness, T. A. (Eds.), *Virtual Environments and advanced interface design* (pp. 473-510). New York: Oxford Press.

Baumgartner, T., Speck, D., Wettstein, D., Masnari, O., Beeli, G. & Jancke, L. (2008). Feeling present in arousing virtual reality worlds: Prefrontal brain regions differentially orchestrate presence experience in adults and children. *Frontiers in Human Neuroscience, 2,* 1-12. doi:10.3389/neuro.09.008.2008

Berns, G. S., Chappelow, J., Zink, C. F., Pagnoni, G., Martin-Skurski, M. E., & Richards, J. (2005). Neurobiological correlates of social conformity and independence during mental rotation. *Biological Psychiatry, 58,* 245-253. doi:10.1016/j.biopsych.2005.04.012

Bjorklund, D. F. (2005). Children’s thinking. Belmont, CA: Wadsworth/Thomson Learning.

Braver, T. S. & Bongiolatti, S. R. (2002). The role of frontopolar cortex in subgoal processing during working memory. *Neuroimage, 15,* 523-536. doi: 10.1006/nimg.2001.1019

Brett, M., Anton, J. L., Valabregue, R., Poline, & J. B. (2002). Region of interest analysis using an SPM toolbox. Presented at the 8th International Conference on Functional Mapping of the Human Brain (Available on CD-ROM in NeuroImage, Vol. 16, No. 2).

Burgess, P. W., Sinons, J. S., Dumontheil, I., & Gilbert, S. J. (2005). The gateway hypothesis of rostral prefrontal cortex (area 10) function. In Duncan, J., Phillips, L., & McLeod, P. (eds.), *Measuring the Mind: Speed, Control, and Age* (pp. 217-248) New York, Oxford University Press.

Burnham, T., McCabe, K., & Smith, V. L. (2000). Friend-or-foe intentionally priming in an extensive form trust game. *Journal of Economic Behavior & Organization, 43,* 57-73. doi:10.1016/S0167-2681(00)00108-6

Carlson, N. R. (1999). Foundation of physiological psychology. Needham Heights, MA: Allyn and Bacon.

Christoff, K., Prabhakaran, V., Dorfman, J., Zhao, Z., Kroger, J. K., Holyoak, K. J., & Gabrieli, J. D. E. (2001). Rostrolateral prefrontal cortex involvement in relational integration during reasoning. *Neuroimage, 14,* 1136-1149. doi: 10.1006/nimg.2001.0922

Cialdini, R. B. & Trost, M. R. (1998). Social influence: Social norms, conformity and compliance. In D. T. Gilbert, S. T. Fiske, et al. (Eds.), *The handbook of social psychology, Vol. 2* (4th ed., pp. 151-192). New York: McGraw-Hill.

Clark, S. A., Allard, T., Jenkins, W. M., & Merzenich, M. M. (1988). Receptive fields in the body-surface map in adult cortex defined by temporally correlated inputs. *Nature,* 332, 444-445. doi: 10.1038/332444a0

Dawson, E., Gilovich, T., & Regan, D. T. (2002). Motivated reasoning and performance on the Wason Selection Task. *Personality and Social Psychology Bulletin, 28, 1379-1387.* doi: 10.1177/014616702236869

Esterman, M., Tamber-Rosenau, B. J., Chiu, Y-C., & Yantis, S. (2010). Avoiding non-independence in fMRI data analysis: Leave one subject out. *Neuroimage, 50,* 572-576. doi: 10.1016/j.neuroimage.2009.10.092.

Fangmeier, T., Knauff, M., Ruff, C. C., & Sloutsky, V. (2006). fMRI evidence for a three-stage model of deductive reasoning. *Journal of Cognitive Neuroscience, 18,* 320-334.

Farrer, C. & Frith, C.D. (2002). Experiences oneself vs. another person as being the cause of an action: The neural correlates of the experience of agency. *NeuroImage,* 15, 596-603. doi: 10.1006/nimg.2001.1009

Ferstl, E. C. & von Carmon, D. Y. (2001). What does the frontomedian cortex contribute to language processing: coherence or theory of mind? *Neuroimage, 17,* 1599-1612. doi: 10.1006/nimg.2002.1247

Fiez, J. A. & Petersen, S. E. (1998). Neuroimaging studies of word reading. P*roceedings for the National Academy of Sciences, 95,* 914-921.

Fletcher, P. C., Happe, F., Frith, U., Baker, S. C., Olan, R. J., Frackowiak, R. S. J., & Frith, C. D. (1995). Other minds in the brain: A functional imaging study of "theory of mind" in story comprehension. *Cognition, 57,* 109-128.

Forgas, J. P. & George, J. M. (2001). Affective influences on judgments and behaviors in organizations: An information processing perspective. *Organizational Behavior and Human Decision Processes. 86,* 3-34. doi:10.1006/obhd.2001.2971

Friston, K. J., Worsley, K. J., Frackowiak, R. S. J., Mazziotta, J. C., & Evans, A. C. (1994). Assessing the significance of focal activations using their spatial extent. *Human Brain Mapping, 1,* 210–220.

Friston, K. J., Penny, W. D., & Glaser, D. E. (2005). Conjunction revisited. *Neuroimage, 25,* 661-667. doi:10.1016/j.neuroimage.2005.01.013

Gateau, J. B., Leweling, T. A., Looney, J. P., & Nissen, M. E. (2007). Hypothesis testing of edge organizations: Modeling the C2 organization design space. *Proceedings International Command & Control Research & Technology Symposium,* Newport, RI.

Gazzaniga, M. S., Doron, K. W., & Funk, C. M. (2009). Looking toward the future: Perspectives on examining the architecture and function of the human brain as a complex system. In Gazzaniga, M. S. (Ed.) *Cognitive Neuroscience* (4th Ed., pp.1247-1254) Cambridge, Massachusetts, MIT Press.

Goel, V. (2007). Anatomy of deductive reasoning. *Trends in Cognitive Sciences, 11,* 435-441. doi: 10.1016/j.tics.2007.09.003

Goel, V., & Dolan, R.J. (2003). Reciprocal neural response within lateral and ventral medial prefrontal cortex during hot and cold reasoning. *NeuroImage, 20*(4), 2314-2321. doi: 10.1016/j.neuroimage.2003.07.027

Goel, V. & Dolan, R. J. (2004). Differential involvement of left prefrontal cortex in inductive and deductive reasoning. *Cognition, 19*, 1-13. doi: 10.1016/j.cognition.2004.03.001

Goel, V., Grafman, J., Sadato, N., & Hallet, M. (1995). Modeling other minds. *Neuroreport, 6,* 1741-1746.

Goldberg, E. (2009). *The new executive brain: Frontal lobes in a complex world.* New York, NY: Oxford University Press.

Gosling, S. D., Renfrow, P. J., & Swann Jr., W. B. (2003). A very brief measure of the Big-Five personality domains. *Journal of Research in Personality, 37,* 504-528. doi:10.1016/S0092-6566(03)00046-1

Grinband, J., Wager, T. D., Lindquist, M., Ferrera, V. P., & Hirsch, J. (2008). Detection of time-varying signals in event-related fMRI designs. *Neuroimage, 43,* 509-520. doi:10.1016/j.neuroimage.2008.07.065

Hudson, K. & Nissen, M. E. (2011). Understanding the potential of virtual environments for improving C2 performance. *16th ICCRTS Collective C2 in Multinational Civil-Military Operations.*

Huettal, S. A., Song, A. W., & McCarthy, G. (2009). *Functional Magnetic Resonance Imaging (2nd Ed.)* Sunderland, MA: Sinauer Associates, Inc.

Insel, T. R. & Fernald, R. D. (2004). How the brain processes social information: Searching for the social brain. *Annual Review of Neuroscience, 27,* 697-722. doi: 10.1146/annurev.neuro.27.070203.144148

Jain, S. P. & Maheswaran, D. (2000). Motivated reasoning: A depth-of-processing perspective. *Journal of Consumer Research, 26, 358-371.* doi:10.1086/209568

Johnson, M. K. & Raye, C. L. (1998). False memories and confabulation. *Trends in Cognitive Sciences, 2,* 137-145. doi:10.1016/S1364-6613(98)01152-8

Kalbfleisch, M. L., de Bettencourt, M. T., Kopperman, R., Banasiak, M., Roberts, J. M., & Halavi, M. (2013). Environmental influences on neural systems of relational complexity. *Frontiers in Psychology, 4,* 1-15. doi: 10.3389/fpsyg.2013.00631

Kalbfleisch, M.L., & Nissen, M. (2010). Extending Hypothesis Testing of Edge Organizations Using Functional Magnetic Resonance Imaging (fMRI) During ELICIT. *Proceedings of the 15th International Command & Control Research & Technology Symposium, Santa Monica, CA* (June 2010).

Kalbfleisch, M. L., Roberts, J. M., Gillmarten, C., Ruddy, M., Hudson, K., Nissen, M. (in review). 'ELICITing' the impact of organizational configuration on problem solving – an fMRI study of hierarchy versus edge.

Kalbfleisch, M. L., VanMeter, J. W., & Zeffiro, T. A. (2007). The influences of task difficulty and response correctness on neural systems supporting fluid reasoning. *Cognitive Neurodynamics, 1,* 71-84. doi: 10.1007/s11571-006-9007-4

Kameda, T., Ohtsubo, Y., & Takezawa, M. (1997). Centrality in sociocognitive networks and social influence: An illustration in a group decision-making context. *Journal of Personality and Social Psychology, 73,* 269-309.

Kroger, K. K., Sabb, F. W., Fales, C. L., Brookheimer, S. Y., Cohen, M. S., & Holyoak, K. J. (2002). Recruitment of anterior dorsolateral prefrontal cortex in human reasoning: A parametric study of relational complexity. *Cerebral Cortex, 12,* 477-485.

Kuchinke, L., van der Meer, E., & Krueger, F. (2009). Differences in processing of taxonomic and sequential relations in semantic memory: An fMRI investigation. *Brain and Cognition, 69,* 245-251. doi: 10.1016/j.bandc2008.07.014

Kunda, Z. (1990). The case for motivated reasoning. *Psychological Bulletin*, 108, 480-498. doi:10.1037/0033-2909.108.3.480

Lam. A. (2000). Tacit knowledge, organizational learning, and societal institutions: An integrated framework. *Organization Studies, 21,* 487-513. doi: 10.1177/0170840600213001

Lancaster, J. L., Rainey, L. H., Summerlin, J. L., Freitas, C. S., Fox, P. T., Evans, A. C., Toga, A. W., & Mazziotta, J. C. (1997). Automated labeling of the human brain: A preliminary report on the development and evaluation of a forward-transform method. *Human Brain Mapping 5,* 238-242.

Lancaster, J. L., Woldorff, M. G., Parsons, L. M., Liotti, M., Freitas, C. S., Rainey, L., Kochunov, P. V., Nickerson, D., Mikiten, S. A., & Fox, P. T., (2000). Automated talairach atlas labels for functional brain mapping. *Human Brain Mapping 10,* 120-131.

Leweling, T.A., & Nissen, M. (2007). Hypothesis testing of edge organizations: Laboratory experimentation using the ELICIT Multiplayer Intelligence Game. *Proceedings of the International Command & Control Research & Technology Symposium*, Newport, RI.

Maloney, L. T., Dal Martello, M. F., Sham, C., & Spillmann, L. (2005). Past trials influence perception of ambiguous motion quartets through pattern completion. *Proceedings of the National Acedmy of Sciences, 102,* 3164-3169. doi:10.1073/pnas.0407157102

Mangun, G. R., Buonocore, M. H., Girelli, M. & Jha, A. P. (1998). ERP and fMRI measures of visual spatial selective attention. *Human Brain Mapping, 6,* 383-389. doi:10.1002/(SICI)1097-0193(1998)6:5/6<383::AID-HBM10>3.3.CO;2-Q

McGuire, P. K., Silbersweig, D. A., Murray, R. M., David, A. S., Frackowiak, R. S. J., & Frith, C. D. (1996). Functional anatomy of inner speech and auditory verbal imagery. *Psychological Medicine, 26,* 29-38. doi: 10.1017/S0033291700033699

Miller, E. K. & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review in Neuroscience, 24,* 167-202. doi:10.1146/annurev.neuro.24.1.167

Moll, J., de Oliveira-Souza, R., Bramati, I.E., Grafman, J. (2002). Functional Networks in Emotional Moral and Nonmoral Social Judgments. *Neuroimage,* 16, 696-703. doi:10.1006/nimg.2002.1118

Moss, J., Schunn, C. D., Schneider, W., McNamara, D. S., & VanLehn, K. (2011). The neural correlates of strategic reading comprehension: Cognitive control and discourse comprehension. *Neuroimage, 58,* 675-86. doi: 0.1016/j.neuroimage.2011.06.034

Muck, P. M., Hell, B., & Gosling, S. D. (2007). Construct validation of a short five-factor model instrument: A self-peer study on the German adaptation of the Ten-Item Personality Inventory (TIPI-G). *European Journal of Psychological Assessment, 23,* 166-173. doi: 10.1027/1015-5759.23.3.166

Mummery, C. J., Shallice, T., & Price, C. J. (1999). Dual-process model in semantic priming: a functional imaging perspective. *Neuroimage*, *9*, 516-525.

Nickerson, R. S., (1998). Confirmation bias: A ubiquitous phenomenon in many guises. *Review of General Psychology,* 2, 175-220. doi:10.1037//1089-2680.2.2.175

Nissen, M. E. & Leweling, T. A. (2010). Knowledge sharing as a contingency in the design of counterterrorism organizations. *The International C2 Journal, 4,* 1-28.

Oldfield, R.C. (1971). The assessment and analysis of handedness: the Edinburgh inventory. *Neuropsychologia*, *9,* 97–113. doi: 10.1016/0028-3932(71)90067-4

Padmala. S. & Pessoa, L. (2008). Affective learning enhances visual detection and response in primary visual cortex. *The Journal of Neuroscience, 28,* 6202-6210. doi:10.1523/JNEUROSCI.1233-08.2008

Pascual-Leone, A., Cammarota, A., Wassermann, E. M., Brasil-Neto, J. P., Cohen, L. G., & Hallett, M. (1993). Modulation of motor cortical outputs to the reading hand of Braille readers. *Annals of Neurology,* 34, 33-37. doi:10.1002/ana.410340108

Pessoa, L. (2008). On the relationship between emotion and cognition. *Nature Reviews Neuroscience, 9*, 148-158. doi:10.1038/nrn2317

Pick, H. L. (1992). Eleanor J. Gibson: Learning to perceive and perceiving to learn. *Developmental Psychology, 28,* 787-794. doi:10.1037//0012-1649.28.5.787

Pochon, J. B., Levy, R., Fossati, P., Lehricy, S., Poline, J. B., Pillon, B., LeBihan, D., & Dubois, B. (2002). The neural system that bridges reward and cognition in humans: An fMRI study. *Proceedings of the National Academy of Sciences, 99,* 5669-5674. doi: 10.1073/pnas.082111099

Pollman, S. (2004). Anterior prefrontal cortex contributions to attention control. *Experimental Psychology, 51,* 270-278. doi: 10.1027/1618-3169.51.4.270

Poropat, A. E. (2009). A meta-analysis of the five-factor model of personality and academic performance. *Psychological Bulletin, 135,* 322-338. doi: 10.1037/a0014996

Prabhakaran, V. Narayanan, K., Zhao, Z., & Gabrieli, J. D. E. (2000). Integration of diverse information in working memory within the frontal lobe. *Nature Neuroscience, 3,* 85-91.

Prabhakaran, V., Rypma, B., & Gabrieli, J. D. E. (2001). Neural substrates of mathematical reasoning: A functional magnetic resonance imaging study of neocortical activation during performance of the necessary arithmetic operations test. *Neuropsychology, 15,* 115-127. doi: 10.1037//0894-4105.15.1.115

Prado, J., Chadha, A., & Booth, J. R. (2011). The brain network for deductive reasoning: A quantitative meta-analysis of 28 neuroimaging studies. *Journal of Cognitive Neuroscience, 23,* 3483-3497. doi: 10.1162/jocn_a_00063

Pugh, K. R., Shaywitz, B. A., Shaywitz, S. E., Fulbright, R. K., Byrd, D., Skudlarski, P., Shankweiler, D. P., Katz, L., Constable, T., Fletcher, J., Lacadie, C. Marchione, K., & Gore, J. C. (1996). Auditory selective attention: An fMRI investigation. *Neuroimage, 4,* 159-173. doi:10.1006/nimg.1996.0067

Qui, J., Li, H., Huang, X., Zhang, F., Chen, A., Luo, Y., Zhang, Q., & Yuan, H. (2006). The neural basis of conditional reasoning: An event-related potential study. *Neuropsychologia, 45,* 1533-1539. doi: 10.1016/j.neuropsychologia.2006.11.014

Roberts, J.M., Stoneham, E.T., Halavi, M., Serpati, L.A., deBettencourt, M.T., Donohue, M.E., Loughan, A.R., Zhang, D.X., Kalbfleisch, M.L. (2009). *Differential neural systems of state-dependent reasoning*. (Nanosymposium Presentation). Society for Neuroscience, Chicago, IL.

Roberts, J. M. (2011). *Gender-specific sensitivity to time-discrepant task conditions of reasoning during fMRI*. (Unpublished master's thesis). George Mason University, Fairfax, VA.

Roediger, H. L. (1996). Memory illusions. *Journal of Memory and Language, 35,* 76-100. doi:10.1006/jmla.1996.0005

Rothman, S. & Coetzer, E. P. (2003). The big five personality dimensions and job performance. *Journal of Industrial Psychology, 29,* 68-74.

Slavin, R. E. (1992). When and why does cooperative learning increase achievement? Theoretical and empirical perspectives. In R. Hertz-Lazarowitz, & N. Miller (Eds.), *Interaction in cooperative groups: The theoretical anatomy of group learning* (pp. 145-173). New York, NY: Cambridge University Press.

Sterr, A., Muller, M. M., Elbert, T., Rockstroh, B., Pantev, C., & Taub, E. (1998). Perceptual correlates of changes in cortical representation of fingers in blind multifinger Braille readers. *The Journal of Neuroscience,* 18, 4417-4423. Retrieved from http://www.jneurosci.org/

Tang, Y.-P., Wang, H., Feng, R., Kyin, M. & Tsien, J. Z. (2001). Differential effects of enrichment on learning and memory function in NR2B transgenic mice. *Neuropharmacology,* 41, 779-790. doi:10.1016/S0028-3908(01)00122-8

Wager, T., Jonides, J., & Reading, S. (2004). Neuroimaging studies of shifting attention: A meta-analysis. *Neuroimage, 22,* 1679-1693. doi: 10.1016/j.neuroimage.2004.03.052

Waltz, J. A., Knowlton, B. J., Holyoak, K. J., Boone, K. B., Mishkin, F. S., de Menezes Santos, M., Thomas, C. R., & Miller, B. L. (1999). A system for relational reasoning in human prefrontal cortex. *Psychological Science, 10,* 119-125. doi: 10.1111/1467-9280.00118

Wechsler, D. (1999). Wechsler Abbreviated Scale of Intelligence. The Psychological Corporation: Harcourt Brace & Company. New York, NY

Westen, D., Blagov, P. S., Harenski, K., Kilts, C., & Hamann, S. (2006). Neural Bases of Motivated Reasoning: An fMRI Study of Emotional Constraints on Partisan Political Judgment in the 2004 U.S. Presidential Election. *Journal of Cognitive Neuroscience, 18, 1947-1958.* doi:10.1162/jocn.2006.18.11.1947

Witmer, B. G. & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence, 7,* 225-240. doi:10.1162/105474699566477

Yantis, S. (2008). The neural basis of selective attention: Cortical sources and targets of attentional modulation. *Psychological Science,2,* 86-90. doi:10.1111/j.1467-8721.2008.00554.x

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