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Exploring the Limits of Strategic Thought: Evaluating how Different Communication Modalities Affect the Nature of Strategic Decision-Making using Cognitive Hierarchy

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THESIS

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Abstract

This research examines and quantifies the degree to which both information communication modality and the situational complexity affect individuals' ability to process the provided information and determine an effective strategy. Human subject testing herein consists of benign benevolent intervention involving the presentation of a series of strategic situations. For each situation, a participant attempts to identify their best response for a two-player, normal-form game with complete information. In each such game, players seek to maximize their own utility while considering their own actions, their opponent's actions, and each player's respective preferences over outcomes resulting from the possible combinations of actions. Dual channel theory directly informs our experiment's design; it specifies both the manner in which humans process information and the existence of capacity limits to such cognitive mechanisms. Through a computerized test instrument, participants attempt to determine the best response to normal form games of size 2×2, 3×3, 4×4, and 5×5, each presented via three different communication modalities: audio-only, visual-only, and audio-and-visual. To determine whether the difference in communication modalities affected the strategic nature of decisions, participant responses were evaluated with and without non-equilibrium models. Categorical data analysis techniques such as the Generalized Cochran-Mantel-Haenszel test and multiple-correspondence analysis are first utilized on raw response information to determine the association between actions and communication modalities. Utilization of the Cognitive Hierarchy model characterizes the changes in the population's average level of strategic thought based upon varying communication modalities and situational complexities. Analysis shows that inclusion of visual communication resulted in statistically significantly different

participant responses and an increased level of strategic thought relative to audio-only communication.

Within the same communication modality, the increased difficulty showed a gradual increase in strategic thought for the audio-only presentation. However, this increase was assessed to be upper bounded by a low-to-moderate level of strategic thought. Visual-only and audio-and-visual modalities showed an increase in strategic thought from 2×2 to 3×3 games, conjectured to the larger 3×3 games requiring more concentrated thought, whereas the smaller 2×2 games being too simple to trigger enough response. This followed by a steady decrease as the difficulty in scenarios increased to the maximum 5×5 scenario. Across all scenario sizes, a statistically significant increase existed in the population's average level of strategic thinking for the visual-only modality compared to the audio-only.

Dedicated to wife, whose love and support is more infinite than the real numbers. To my daughter and son, may your quest for knowledge have no limit.

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I. Introduction

Strategic planning is foundational to achieving desired organizational outcomes. Within the military, such planning considers goals, capabilities, and resources – and the same information about an adversary – to develop a competitive strategy that is feasible, acceptable, suitable, and complete. The volume of information to process, most of it written, can overwhelm even the best decision-makers, given they have a limited time to understand, evaluate, and compare the strategic options. Within the military context, a sub-optimal decision is inhumane, yielding undesired friendly casualties, unnecessary adversary casualties, and greater risks to non-combatants; the importance of making sound strategic decisions cannot be overstated. As a first step to enable better strategic decision-making, this research seeks to understand the manners in which humans are limited in their ability to process information within the context of strategic decision-making.

1.1 Motivation and Background

Having priorities aligned with the National Security Strategy (Trump 2017) and National Military Strategy (Mattis 2018), the National Command Authority (i.e., the President of the United States and the Secretary of Defense) provides direction to-and-through commandant commanders (CCDRs) for the development of plans to implement and achieve strategic *ends* (i.e., desired outcomes). The commanders are

responsible for planning the *ways* (i.e., implementation plans) to achieve the ends, whereas the Joint Chiefs of Staff provide the *means* (i.e., personnel, equipment, and material) to support the CCDRs. At the national level, the development and communication of guidance to the CCDRs occur via a process known as Adaptive Planning and Execution (APEX). APEX has four major functions: (1) strategic guidance and planning, (2) concept development planning, (3) plan development planning, and (4) plan assessment planning. The final process leverages the RATE (Refine, Adapt, Terminate, Execute) methodology (Joint Chiefs of Staff 2017), impelling commanders to review and evaluate the plan continuously, and accordingly refine, adapt, terminate, or execute it as strategic conditions change.

At the level of combatant commands, sub-unified joint commands, and joint task forces (JTFs), strategic military planning is informed by doctrine, principles, and concepts. Within the US Military, Joint Publication 5-0 *Joint Planning* (Joint Chiefs of Staff 2017) (JP 5-0) sets forth the doctrinal guidance of the Joint Planning Process (JPP) for campaigns and operations. JP 5-0 also establishes the principles of joint planning and the concept of operational design, the latter of which "provides the conceptual basis for structuring campaigns and operations" (Joint Chiefs of Staff 2017). The principles of joint operations aid in the development of courses of action (COAs) within the JPP. The concept of operational design seeks to address complex situations via analysis to inform COA development amendable to varying levels of risk, with flexibility. The JPP is a non-descriptive tool used by military planners to "frame a problem; examine a mission; develop, analyze, and compare alternative COAs; select the best COA; and produce a plan or order. The application of operational design provides the conceptual basis for structuring campaigns and operations" (Joint Chiefs of Staff 2017).

The JPP has seven sequential steps: (1) planning initiation, (2) mission analysis,

(3) course of action (COA) development, (4) COA analysis and wargaming, (5) COA comparison, (6) COA approval, and (7) plan or order development. Step 1 begins with the appropriate authority recognizing the need to employ military capabilities to support national objectives or respond to a crisis. In Step 2, the CCDR and their staff derive the mission statement by analyzing the problem and determining mission accomplishment necessities. This effort provides information to subordinate and supporting commanders, allowing them to begin their estimates and planning efforts in parallel. Step 3 involves the creation of COAs to address the problem statement. In Step 4, the wargaming of each COA provides information to inform the analysis and comparison of their relative advantages and disadvantages to performance criteria developed in Step 5. In Step 6, the commander receives the results of the previous staff work and decides which COA to implement, after which the staff disseminates the plan to subordinate and supporting organizations and components during Step 7. Commanders exercise latitude and discretion regarding the degree of their involvement in the planning process. At a minimum, commanders receive a mission analysis briefing after Step 2, at which point they issue guidance to the staff regarding COA development, and a COA decision briefing after Step 6.

Somewhat complicating matters, the seven JPP steps roughly correspond to the APEX functions. The APEX strategic guidance planning function aligns with JPP Steps 1 and 2, and the APEX concept development planning function parallels JPP Steps 3-6. Although the APEX plan development function is emulated by JPP Step 7, the plan assessment function within APEX does not have a formal counterpart within the JPP (Joint Chiefs of Staff 2017).

One aim of the JPP's formalized structure is to ensure that planning is deliberate and thorough, such that decision-makers receive and consider requisite information needed to formulate an effective strategic plan. The prescribed step-wise structure

also makes the planning process somewhat standardized across different joint staffs, ensuring new personnel can readily contribute. A second-order effect of this deliberate standardization is that the JPP is process-driven: it requires considerable time, effort, and personnel. Although some steps can be truncated, greater risk is incurred when commanders and staffs do not take the time, or have the patience to, take part in the JPP. Some departures from the JPP are notorious for the unfortunate outcomes that resulted.

In 2002, as a subordinate operation to Operation Enduring Freedom, Operation Anaconda sought to destroy Taliban and al-Qaeda forces near the Shahi-Kot Valley in Afghanistan (Naylor 2005). This complex operation involved conventional US forces, US special operations forces (SOF), the Afghanistan National Army, and paramilitary forces. A projected three-day battle of light combat turned into an intense seven-day battle with heavy combat, resulting in 58 US military member casualties and eight deaths (Lyle 2009). Afghan forces suffered numerous wounded with three deaths. Estimates on the number of enemies killed range from 50 to 500 (Kugler et al. 2009). Analyses of the operation later identified several shortcomings that incurred unnecessary risk. There was a lack of coordination regarding fire support priority between the conventional and paramilitary forces, an absence of unity of command on the battlefield, and the hasty infiltration of SOF elements compromised their location (Naylor 2005). Many of these shortcomings were ultimately attributed to poor planning and inadequate communication of those plans. According to Lyle (2009), "there is no direct mention of anyone but the JTF staff participating in the formulation of JTF mission analysis products, course of action development, or course of action analysis." The absence of decision-maker participation in the JPP undermined the value it could have provided to inform sound decisions.

Therefore, the structure of the JPP provides a challenge. At its best, it can provide

decision-makers with useful information. At its worst, it can overwhelm decision-makers, causing them to set it aside, along with the information it could provide. Core to resolving this conundrum is for the JPP to enable the clear communication of a large volume of information to a decision-maker. How to effectively do so is the focus of this work.

In addition to concerns regarding the volume of information in the JPP are issues regarding the manner in which it is conveyed. Written documents both inform and result from the JPP. As a type of bureaucracy, a commander's staff ingests written documents, and their orders are communicated in writing as well. Visual communication of information (e.g., via PowerPoint presentations) provides an alternative to narrative exposition; however, since it can be imprecise in its meaning(s), such communication must be used judiciously. Even when visual presentations are used to convey information, military planners default to written documents to communicate orders, frequently in large volume, thereby extending the challenge of information overload to subordinate units. Also prevalent is the round table discussion, in the form of back-and-forth deliberation from military planners to pass information to inform decisions and strategies. This communication method is a purely audio one, where an individual relies on hearing and little to no visual triggers exist to process information.

Given the synchronous, simultaneous challenges regarding the amount of information and its communication, it is worth examining Mayer's (2009) concept of multimedia learning. Supported by extensive research, the author explains that the human information-processing system consists of *dual channels*: a visual channel and an auditory channel. When adopting the sensor-modality perspective, whether the decision-maker receives information by observing a visual presentation or reading written documents, it is processed via the visual channel. After processing, informa-

tion is brought into working memory to help develop mental models and corresponding strategies. The visual channel, like the audio channel, has a limited capacity for information processing.

In the JPP context, having a decision-maker who is limited regarding the amount of information they can process visually, as well as the abundance of round table discussions limiting the information being processed from an auditory manner implies that a reliance on visual-only or audio-only stimuli may correspond with unused capacity to inform decision making. Whereas Mayer's models present experimental results supporting his postulates regarding information processing via dual channels, it has not been determined whether-and-how leveraging those channels affects the quality of strategic decisions made within a competitive environment. Accordingly, this research examines and quantifies the degree to which both the method a strategic situation is presented, as well as the complexity of the situation, affects individuals' ability to process the presented information and determine an effective strategy.

1.2 Problem Statement

This research seeks to explore how the communication modality used to communicate information about a competitive situation affects a sample population's ability to reach sound, strategic decisions. The communication modalities considered will be auditory, visual and a combination of auditory and visual. In contrast, analysis of the participants' decisions will be evaluated both with and without the use of non-equilibrium structural models. That is, categorical data analysis techniques will first be utilized on raw response information to determine associations between selected actions and communication modalities. Subsequently, the Cognitive Hierarchy model will be utilized to characterize changes to the population's average depth of strategic thought (Camerer, Ho & Chong 2004). We will also explore the effect of the situa-

tion's complexity (as measured by the size of the game's action space) on the quality of the decisions. In so doing, we further the behaviorist approach to military operations planning (see Caballero et al. 2020, Caballero & Lunday 2020) by ascertaining how the modality of inter- and intra-staff communication affects strategic decision making.

1.3 Organization of the Thesis

The organization for the remainder of this paper is as follows. Chapter 2 formally reviews the pertinent literature related to information processing, game theory, behavioral game theory, and cognitive hierarchy models. Chapter 3 presents the designed experiment and methods of analysis for the results, whereas Chapter 4 presents the results and analysis. Chapter 5 concludes with a summary of results and proposes extensions to this research endeavor.

II. Literature Review

This research focuses on whether and to what degree different communication modalities used to present information affect a person's ability to analyze a competitive situation and make sound strategic decisions for problems having varying levels of complexity. Prior to reviewing the broader literature that informs this research, it is first necessary to examine the definitions of *learning*, both in the pedagogical and game theoretic sense. Subsequently, a review of the relevant pedagogical literature discusses different styles of information processing and how it affects an individual's ability to reason and commit new information to memory for application in new situations. The review concludes with a two-part discussion of game theory that informs the testing in this study. After reviewing the the structure of complete, normal-form games, this section discusses related works from behavioral game theory and, more specifically, the related theories used to evaluate and quantify the strategic soundness of game theoretic decisions.

2.1 Learning in Education and Game Theory

The term *learning* has distinct meanings within the disciplines of educational psychology and game theory, each of which informs this research. The initial focus of this literature review pertains to the former framework; however, because much of the testing herein relates to decisions within game theoretic frameworks, it is important to present and discuss the definitions of learning from both disciplines before finalizing the terminology utilized. Mayer (2009) defines learning within educational psychology as the "change in knowledge attributable to experience" and partition learning via changes to three components: change in the learner, change in the learner's knowledge, and changes attributed to experience in the learner's environment. Within game

theory, learning consists of the evolution of a player's preferred decision(s) in a competitive context (i.e, a game) that occurs through repeated play (Fudenberg & Levine 2016). Beyond these primary definitions, other specialized denotations for *learning* abound. From a philosophical perspective, learning is defined as how someone processes information in a pedagogical framework with documented principle traits like "learning is change", "learning refers to both a process and a product", and "learning is different at different points in time", to name a few (Alexander et al. 2009). Within the educational psychology discipline, specialized terms like *latent learning* (i.e., changes induced at a later time due to experiences (De Houwer et al. 2013)) pertain to specific aspects of the general terminology.

In this research, we adopt a perspective aligned with the educational psychology literature, specifically focusing on *generative cognitive processing*; that is, the learner's understanding of material presented, assuming cognitive capacity is available (Mayer 2010). Hereafter, unless otherwise noted, *cognitive processing* refers to a subject's comprehension of new information as an attempt to complete tasks or develop reasoning to a strategic solution for problems of varying levels of complexity.

2.2 Cognitive Processing within the Pedagogical Literature

Within this section only, we refer to cognitive processing as *learning* to be consistent with the pedagogical literature.

2.2.1 Theory of Multiple Intelligences

The theory of learning and being able to define the act of learning itself has taken root in the field of psychology. Psychometrics, the study of physiological measurements, often uses the concept of general intelligence, which measures one's cognitive ability and human intelligence. Spearman (1904) first proposed the idea of a $g\ factor$

(i.e., general intelligence) in the early 20th century when observing a positive correlation in children's performance across seemingly unrelated school subjects. Spearman reasoned this correlation was due to an underlying factor in the children's general mental ability and suggested all mental performance could be categorized by a combination of a single general ability factor, g, and selected other ability factors that are discipline-specific. Thomson (1916) later presented evidence that such interconnectivity between tests could exist, even without the existence of a $g\ factor$.

Cattell (1963) suggested that general intelligence (g) could be subdivided into fluid intelligence (g_f) and crystallized intelligence (g_c), two subcategories of ways to process learning and apply gained knowledge. Fluid intelligence, the ability to solve problems in new situations with logic, refers to analytical learning, where one needs to solve cognitive problems through reasoning. Crystallized intelligence, the ability to use knowledge previously acquired through experience and education, is measured with general information, linguistic, and verbal reasoning tasks (Horn 1968).

Other variants of learning theory evolved that divide human intelligence into subcategories. Gardner (1983) proposed The Theory of Multiple Intelligences wherein intelligence is divided into seven different modalities in lieu of a single general intelligence factor. The intelligence modalities are (1) linguistic intelligence, (2) musical intelligence, (3) logical-mathematical intelligence, (4) spatial intelligence, (5) bodily-kinesthetic intelligence, and the personal intelligences, (6) interpersonal, and (7) intrapersonal. Individuals with high linguistic intelligence were adept at reading, writing, and storytelling, thereby displaying a talent with words and languages. Musical intelligence is exhibited by people able to play and compose music with a keen sense to pitch, harmony, and sound. Learners with high logical-mathematical intelligence excel with numbers, logic, and problem-solving. Spatial intelligence relates to one's ability to visualize with the mind's eye. Bodily-kinesthetic intelligence

represents someone's control of body motion. Interpersonal acumen refers to one's social intelligence characterized by other people's feelings, behaviors, and group working ability. Intrapersonal intelligence measures one's ability to self reflect and understand their weaknesses and strengths (Gardner 1983).

After its initial development, Gardner (1995) would add naturalistic intelligence, an eighth intelligence modality to the model; it characterizes the ability to be nurturing and relate information to one's natural environment. Gardner (2000) also suggested the existence of an existential intelligence (i.e one's spiritual connection) but did not commit it as a formal component of the model. Additional educational researchers have investigated and debated the idea of such intelligence (e.g., Tupper 2002, Simmons 2006).

Each of the proposed intelligences was validated against eight criteria established by Gardner (1983). These criteria established independence among the different intelligences and consist of (1) potential isolation by brain damage, (2) existence of savants or exceptional people, (3) an identifiable core set of operations, (4) distinctive developmental history, (5) evolutionary history or plausibility, (6) support from experimental psychological tasks, (7) support from psychometric findings, and (8) the intelligence is capable of being represented symbolically.

Although Gardner (1995) argued otherwise, the theory of multiple intelligence (MI) is sometimes referenced as pseudoscience due to lack of evidence. Additionally, the field of neuroscience does not support the idea of multiple intelligences. "Neuroscience researchers have not claimed that individual human perceptual processes such as taste or vision are intelligences or that innate skills, such as spatial navigation, or learned skills, such as music composition, are intelligences" (Waterhouse 2006). Setting aside any debate over the existence of specific intelligences, it is worth considering the theories and empirical support specific to learning.

2.2.2 VARK

Whereas Garner's research sought to understand and evaluate one's intelligence, selected pedagogical research (e.g., Jung 1921, Myers 1962, Fleming & Mills 1992) postulated the concept of learning styles to characterize *how* an individual learns. Specifically, a person's learning style is their preferred method of information processing. Learning styles take root from personality types explored originally by Jung (1921), who separated them into four groups: (1) extroversion/introversion, (2) sensation/intuition, (3) thinking/feeling, and (4) judging/perceiving. This taxonomy was later integrated into the well known Myers-Briggs Type Inventory (Myers 1962).

Learning styles were researched by Fleming & Mills (1992), who discovered that different methods of presenting material (i.e., styles) could affect student's understanding of the material. This motivated the concept of a teacher embracing their students' preferred learning styles to support better attainment of educational outcomes. The authors developed a taxonomy of learning styles and an instrument to assess the relative preference of an individual over those styles. The acronym VARK represents four learning styles: (1) Visual (V) - graphical and symbol information, (2) Aural (A) - heard information, (3) Read/Write (R) - printed information, and (4) Kinesthetic (K) - practice and experience.

The VARK questionnaire determines which of four learning styles a subject prefers for processing information. Beyond its aforementioned use by teachers, the result of a VARK assessment can also be used by a learner to improve information processing should there be a misalignment between their preferred learning style and a learning environment; if the learner cannot change the environment, they can at least be more cognizant of the misalignment and commit additional effort to successfully process information via their lesser-preferred style (Fleming & Mills 1992). The VARK assessment has a relatively short completion time, and responses have shown to help

overall learning when adjusting and using new study skills. A VARK learning style relies on neither natural intelligence nor inherent skill; instead, it focuses on how one can absorb, acquire, and process new information or knowledge (Othman & Amiruddin 2010). The VARK construct of learning styles, as well as variants thereof, is not without controversy. Many researchers and educators (e.g., Black 2016, Newton & Miah 2017, Felder 2020) contest their validity and use. As such, we set aside consideration of learning styles for this research and examine more empirically grounded theories relating to the information processing component of learning.

2.2.3 Dual Coding Theory, Dual Channel Theory, and Multimedia Learning

Whereas learning styles attempt to categorize people based on different abilities to learn new information, Paivio (1969) propounded an alternative approach known as dual coding theory. According to dual coding theory, a person uses both visual and verbal information to represent knowledge. Visual and verbal information are each respectively received and processed within two "cognitive subsystems." These subsystems are used to process incoming information from non-verbal occurrences (analog codes) and language (symbolic codes). Analog codes store images, and symbolic codes are used to store images of letters and words. Paivio (1969) studied a learner's ability to recall images and words in sequential order and found participants could recall the sequential order of words more readily than the ordering of images. This experiment supports dual coding theory's hypothesis that verbal and visual information are processed differently.

The idea of two cognitive subsystems processing new information, one verbal and one nonverbal, gave rise to Mayer's (2009) cognitive theory of multimedia learning. According to Mayer (2009), "the cognitive theory of multimedia learning assumes that

the human information-processing system includes dual channels for visual/pictorial and auditory/verbal processing, each channel has limited capacity for processing, and active learning entails carrying out appropriate cognitive processing during learning." The two channels within Mayer's research extend the concept of two cognitive subsystems from Pavio's theory.

The broader cognitive theory of multimedia research holds three assumptions to be true: (1) dual channels, (2) limited capacity, and (3) active processing. Dual channels reference dual coding theory (Paivio 1990); learners use two separate channels for processing visual and auditory information. Limited capacity dictates that each channel has a limit to the amount of information it can process. Active processing exists when "humans engage in active learning by attending to relevant incoming information, organizing selected information into coherent mental representations, and integrating mental representations with other knowledge." Active processing conflicts with the prevailing conceptions that people record their experiences in memory to be retrieved later. The cognitive theory of multimedia learning is sequenced into five steps that must occur for meaningful learning to take place in a multimedia environment: (1) selection of relevant words for verbal working memory, (2) selection of relevant images for visual working memory, (3) organization of the selected words into mental models that are verbal, (4) organization of the selected images into visual mental models, and (5) the integration of the word-based and image-based representations (Mayer 2009).

Relative to the pedagogical VARK framework or the preceding dual coding theory, Mayer's (2009) theory of multimedia learning is grounded in several empirically supported principles. The coherence principle identifies that removing extraneous material helps people learn. The signaling principle emphasizes the use of cues that highlight essential material to assist learning. The redundancy principle indicates that

people learn better with paired graphics and narration than graphics and printed text. The spatial principle states that graphics and paired text should be printed near each other instead of apart, and the contiguity principle stresses that paired words and images should be presented simultaneously rather than successively. Whereas the previous five principles are associated with removing extraneous processing, the segmenting, pre-training, and modality principles are for managing essential processing. The segmenting principle emphasizes that people learn better when the multimedia information presented is divided into user-paced segmentation instead of continuous instruction. Pre-training indicates that people learn better from a multimedia message clearly communicating the central concept's definitions and characteristics. The modality principle refines different types of presented information; people tend to learn better from pictures paired with spoken words than printed words alone. Two more principles which foster generative processing are the multimedia principle that stresses people learn better with pictures and words instead of words alone, and the personalization principle that indicates language written in a conversational style, rather than formal, encourages better learning (Mayer 2009).

There are limitations to the cognitive theory of multimedia learning; it has been shown to be more beneficial when the learner has a lower level of prior knowledge about the subject. However, the theory proves most effective when the material is complex and presented at a rapid pace or to a large quantity for the learners (Mayer 2009). For the military planning challenges that motivate this study, the latter point is essential when considering both the large amount of information that planners need to process and the level of risk involved when learning is not effective. Multimedia learning stresses the importance of using both visual and verbal media to inform learners. The assumptions establish how working memory is used with the two channels that process new information. Although there is empirical evidence supporting

the principles, Mayer's theory is not yet accepted as universal truth. There is concern that the principles will not hold outside of simulated experimental conditions. For example, one study found that, if the material was of interest to the learners, extraneous material did not significantly affect performance (Muller et al. 2008).

2.2.4 VARK versus Multimedia Learning

While learning styles are commonly embraced for use in educational environments, research finds its methods for determining how a learner processes and retains visual and auditory information questionable. In a study (Cuevas & Dawson 2018) involving 204 university students, no significance was identified in the correlation between the students' VARK-identified preferred learning style and their ability to learn and retain information provided via visual or aural methods. However, the study did show students receiving the information visually retained twice as much information as those receiving it via auditory means. This result strongly supports dual coding theory. Because the evidence does not strongly imply learning styles provide a viable assessment of an individual's ability to process new information, and with strong empirical evidence supporting multimedia learning, dual coding theory specifically, this research adopts a multimedia learning perspective when studying a decision maker's ability to make effective strategic decisions.

2.3 Game Theory

Classical game theory involves the identification of a prescribed action (or strategy) by each of a number of decision makers (i.e., players), wherein each player exhibits a preference over the outcomes resulting from their collective actions. Within such a context, the players seek to rationally maximize the utility obtained, as it corresponds to the possible outcomes.

Rationality is generally consistent with a player who maximizes their expected utility. In developing the axioms for utility theory, von Neumann and Morgenstern (1944) showed that, when someone's choices are structured to satisfy completeness, transitivity, substitutability, decomposability, monotonicity, and continuity, there exists utility functions that players will attempt to maximize. Player preference can be explained with the use of lotteries, which are probability distributions defining selection of outcomes. Game theory studies the interaction among assumed self-interested, rationally thinking, independent players who presume their opponents are rational as well. Self-interested players can describe possible states of the world they prefer and those they do not. Rational players have clear preferences and seek to maximize their payoffs. Independence refers to lotteries, where a player preferring choice A to B must also prefer the lottery of A to C, with probabilities p and $1-p$, respectively, to the lottery of B to C with the same probability distribution (Shoham & Leyton-Brown 2008).

2.3.1 Normal-Form Games

To assess an individual's strategic thinking, this research will examine their decisions for normal form games, also known as strategic form games or simultaneous games. Normal form games are fundamental non-cooperative games within the discipline; most representations of strategic interactions can be represented via a normal form game. Normal form games are presented by a tuple $\langle N, A, u \rangle$, where N is a finite set of players, indexed by i with $n = |N|$; A is a cross product of A_i, the respective set of actions available to each player i; and u is a vector of n utility functions (i.e., $u_i \; \forall i \in N$), each of which maps an action $a \in A$ to a real number in $\mathbb{R}$ (see Shoham & Leyton-Brown 2008).

Normal form games can be represented visually as an n-dimensional matrix. Two

player games can be represented by a matrix wherein each row corresponds to an action $a_1 \in A_1$ for Player 1 (w.l.o.g.), each column corresponds to an action $a_2 \in A_2$ for Player 2, and each element $a = (a_1, a_2)$ yields an outcome of paired utilities (u_1, u_2). Constant sum games are a type of normal form game, wherein $\sum_{i \in N} u_i = c, \forall\ a \in A$, and zero-sum games are a special case with $c = 0$. Often in normal form games, players are assumed to have complete information, such that all knowledge about a player's actions, including utilities payoffs, are known (Shoham & Leyton-Brown 2008).

Assuming complete information, normal form games solution concepts are applied to determine what player i's *best response* is to an opponents' strategy profile s_{-i}. A strategy for player i, s_i, dominates another strategy, $s_i^{'}$, when the payoff of s_i is the same or better than strategy $s_i^{'}$ no matter what action the other players choose. A strategy for player i is considered dominant when it dominates all other strategies. Conversely, a strategy is considered dominated if choosing it always yields the same or worse utility than choosing an alternative strategy, regardless of the action chosen by the opposing players. Dominated strategies can be removed from consideration, as a rational player would never select them over a non-dominated strategy. This iterative reduction can lead to reduced games with a *best response*. A player's best response is not necessarily unique, and without knowing the other player's strategy, it is not a solution concept (Shoham & Leyton-Brown 2008).

A concept of all player's mutual best response can be leveraged to define a game's Nash Equilibrium. A Nash Equilibrium (Nash 1951), known as stable strategy profile, describes a set of actions taken by all players wherein no individual player has any incentive to deviate unilaterally from the action profile. A normal form game may contain more than one Nash Equilibrium, and, assuming that only pure actions are permissible, there is no guarantee a Nash equilibrium will exist in a normal form

game. When the action space expands from pure strategies to mixed strategies, each player's strategy s_i is a probability distribution over their actions rather than a single action, and the other players' strategies are represented by s_{-i}. The combination of all players' strategies is $s = (s_1, s_2, ..., s_n)$ or, equivalently, $s = (s_i, s_{-i})$. Through Nash's theorem, every game with a finite number of players and a finite action space is guaranteed to have at least one Nash Equilibrium, when allowing for mixed strategies.

In addition to the Nash equilibrium, other solution concepts for normal form games exist, such as the maxmin strategy, where a player i, maximizes their minimum utility, assuming that all other players will collectively select the most damaging strategy to u_i. While it may seem unreasonable, as it assumes the other players are solely interested in minimizing player i's utility, this strategy is a practical approach for a player who desires to act conservatively without making assumptions about the other players. Other popular solution concepts in normal form games use the concept of regret, the difference in utility between playing an action compared to the best response. The minimax regret strategy requires the player to evaluate all alternatives' values of regret and choose the decision that yields the smallest maximum regret (i.e., minimize the worst-case regret) (Shoham & Leyton-Brown 2008). Although these solution concepts are outside to this research's scope, they offer alternative solutions dependent on a player's tolerance of regret and loss.

Whereas normal form games consider players acting simultaneously, extensive form games consider players acting sequentially. Nash equilibrium of extensive-form games can be found through its induced normal form, but can also be found by working with the extensive form directly, such as through backward induction (Shoham & Leyton-Brown 2008). Classical game theory also considers players' interactions in a hybrid of normal and extensive form games via repeated normal form games.

2.3.2 Behavioral Game Theory

Whereas standard game theory generally attempts to find saddle points in the solution spaces associated with rational players (i.e, homo economicus), behavioral game theory attempts to model the empirical behavior of human subjects. According to Camerer (2011), behavioral game theory expands on analytical game theory by including emotions, player intelligence, mistakes, limited foresight, and doubts. Behavioral game theory attempts to explain the choices made by players that classical game theory does not.

Arguably the earliest work associated with behavioral game theory corresponds to empirical evidence refuting the descriptive use of expected utility theory. Allais (1953) considered two experiments, each with two choices. Suppose experiment one contains choice A, where a person would receive one million dollars for certainty (probability 1) and choice B, where someone would receive one million for 89%, five million for 10% and nothing for 1%. Most people tended to prefer certainty, and selected choice A, implying that the person's utility, u, for choice A is greater than the utility for choice B ($1 \times u(\text{one million}) > .89 \times u(\text{one million}) + .10 \times u(\text{five million}) + .01 \times u(0)$). Recognizing the probability of 1 from choice A can be rewritten as $.89 + .11$, the relationship between the lotteries can be rewritten and simplified as $.11 \times u(\text{one million}) > .10 \times u(\text{five million}) + .01 \times u(0)$. Experiment two contains choices C, where a person would receive nothing for 89% and one million for 11%, and choice D, where a person receives nothing for 90% and five million for 10%. Here, because the chances of winning were very similar except for the greater prize, most people selected choice D, implying the utility for choice C is less than the utility for choices D ($.11 \times u(\text{one million}) + .89 \times u(0) < +.10 \times u(\text{five million}) + .01 \times u(0) + .89 \times u(0)$) which simplifies to $.11 \times u(\text{one million}) < +.10 \times u(\text{five million}) + .01 \times u(0)$; a direct contradiction to what was shown in the first experiment. This result is known as an

Allais paradox, and serves as a counterexample illustrating how people's actions can violate the independence axiom in expected utility theory.

Another axiom contradicting experiment, known as the Ellsberg Paradox (Ellsberg 1961) shows people will make choices that violate the postulates of expected utility theory when dealing with a situation of uncertainty (i.e., unknown future events without probabilistic characterization). Ellsberg (1961) conducted an experiment involving two urns and two different colored balls. Urn A contains a 50/50 ratio of red balls to black balls, but Urn B has an unknown ratio. The participant picks an urn and color, and draws a ball at random. If the color is successfully predicted, they win. Most participants picked a color from Urn A, even though it violates the axioms of expected utility theory. According to expected utility theory, if the participant believes picking a red ball from Urn A was the optimal choice, it is because they believed fewer than 50% of the balls in Urn B were red. However, this belief means that more than 50% of the balls in Urn B are black, so the participant should have selected Urn B. Ellsberg theorized this paradox exists because expected utility theory applies to player preferences in situations involving risk but not uncertainty.

Collectively, these paradoxes impel the study of behavioral game theory to examine situations wherein players make decisions to maximize their respective utilities, but their solutions deviate from those for a rational actor seeking to maximize their utility under the axioms of expected utility theory.

2.3.3 Canonical Games in Behavioral Studies

Beauty contest games were made famous by Keynes (1936), who described a newspaper contest where participants had to select the most beautiful proportion p of n individuals whose photos were depicted in the newspaper. An individual wins the contest if their answer is closest to the aggregate assessment of the group of

participants. To win, an individual must not just consider their own opinion (i.e., one-step reasoning), but the opinions of others (i.e., two-step reasoning). Keynes (1936) would note that players who are thinking at the third degree are not trying to report their score or predict the average score, but are devoting "intelligences to anticipating what average opinion expects the average opinion to be" (i.e., three-step reasoning). This strategic degree of reasoning can extend *ad infinitum*, subject to one's strategic reasoning capacity and understanding of the contest.

First presented by Moulin (1986), an alternative form to this game is referred to as a p-beauty contest games. Consider a game where each participant chooses a number between zero and 100 inclusively. Given a previously revelated parameter p, the winner of the game is the player whose number is closest to p times the average of all player's numbers. Beauty contest games can be utilized to evaluate different levels of reasoning. When experimentally studied with $p = \frac{2}{3}$ (Nagel 1995), results showed the average response was 35, with many respondents selecting 33 (one-step reasoning, as 33 equals 2/3 of the mean if selections are made via a random uniform distribution U[0,100]) or 22 (two-step reasoning, as 22 equals 2/3 of 33). The number of subjects who selected zero, the value to which the solution converges as the level of reasoning increases, was very few. Ho et al. (1998) expanded on this study by comparing values of $p < 1$ to $p > 1$ using values of 0.7, 0.9, 1.1 and 1.3. Subjects played a game ten times with a specified $p < 1$ (or $p > 1$) and subsequently played another game with $p > 1$ (or $p < 1$). This was conducted to compare individual's behavior when the Nash equilibrium was 0 (when $p < 1$) and when the Nash equilibrium was 100 (when $p > 1$). Results showed that participants who first played a $p > 1$ game tended to start with high initial guesses for $p < 1$ games, but their strategy would converge to 0 more rapidly than it had converged to 100 in the previous game, indicating they had "learned to learn" by playing both games.

Güth et al. (1982) studied the "ultimatum" game. In this two-player, extensive form game, the first player who is known as the *proposer* splits a fixed reward in two and offers one proportion $p \in [0,1]$ to the second player, the *responder*. If the responder accepts the offer, both each receive their portion of the reward; if the responder rejects the offer, they receive nothing. So long as the proposer offers some $p > 0$, the subsequent best response is to accept the offer. Using inductive logic, the best strategy for the proposer is to offer the smallest $p > 0$ possible. However, empirical evidence suggests proposers offer 40 percent of the total amount on average, and responders reject roughly half of positively-valued proposals with $p < 0.2$. (Camerer 2011). This behavioral preference was also exhibited in chimpanzees (Proctor et al. 2013), who preferred an equal split of the rewards.

A variant of the ultimatium game is known as the dictator game, wherein the responder is removed. In dictator games, the proposer chooses a proportion p of a reward to send to the other player. Rationally, to maximize utility, the proposer would send nothing (i.e., $p = 0$) and keep everything. From a behavioral perspective, whether out of fear of social rejection or an altruistic personality trait, dictators may deviate from a rational best response and propose some $p > 0$ to the other player. An experiment (Allgaier et al. 2020) conducted on children ranging from seven to eleven years of age using candy observed that children offer 40 percent of the candy in the dictator game, compared to 50 percent of their candy in the ultimatum game.

The gift exchange game is a two player game introduced by Akerlof & Yellen (1990) to model labor relationships. The two players are the employer, who first must decide to pay a higher or lower amount of wage, and the employee, who subsequently decides a level of effort put forth on work. Whereas an employer would prefer to pay a higher wage and have a high level of employee effort over any other outcome, the employee would most prefer a high wage and low effort. Knowing the employee's best response

to a high wage is not high effort, employers will pay the lower salary, creating the equilibrium for the gift exchange game to be a low salary, low effort. Fehr et al. (1993) conducted an experiment using buyers as price setters (income level) and sellers as determiners of product quality (effort). Contrary to the solutions expected via a classical game theory analysis, when the buyers set the price substantially higher than market-clearing levels, the seller would respond with high quality levels (i.e., a high income-high effort solution). In a computerized experiment involving students, Maximiano et al. (2007) observed average effort levels increase with income, and less than 25 percent of participants with a high income chose to exert a low effort. These outcomes likewise differed from the expected outcome of a classical game theoretic equilibrium informed by rational, utility maximizing decision makers.

Studied by Rosenthal (1981), the centipede game is a two player game with alternating turns until the game (finitely) ends. At each turn, a player can either "take" or "pass." If a player chooses take, they receive a large percentage (i.e., greater than 50%) of an available reward and the other player receives the remainder. Should the player pick pass, they increase the size of the net reward, and provide the other player a chance to either take or pass. Payoffs are set in such a manner that (1) a player will receive a lower amount of reward if they pass and their the opponent chooses to take in the next round, but (2) they will receive a greater amount of reward if their opponent chooses to pass and they subsequently chose to take in the following turn. The game ends on a terminal node, where the player has no choice but to take. Through backwards induction, a Nash equilibrium can be found at every node, indicating the player should always choose take, and the initial player should select take on the first turn and end the game. Ho & Weigelt (2000) performed an experiment on a four turn centipede game where the net reward would double with each turn, also noting that the terminal node was (0,0). In practice, the initial player only terminated the game

30% of the time at their first opportunity, and the second player only took the prize 50% of the time during their first opportunity, again providing evidence of individuals departing from the most strategic, utility-maximizing decisions. Contradicting the Nash equilibrium, players tend to exhibit partial cooperation in the first few turns.

2.3.4 The Cognitive Hierarchy Model

Standard analytical methods used to predict player choice such as equilibrium models, elimination of dominated strategies, and backwards inductions sometimes fail to match empirical results of actual human play. The cognitive hierarchy (CH) model is a behavioral game theory model intended to adress these shortcomings in normal form games.

As a precursor to discussing the CH model, it is important to acknowledge the competing theory of Level-k (LK) (Stahl 1993), the framework embedded within the structure of the CH model. The LK model first considers level-0 players, who choose an action without regard to other players' strategies or thought processes; most commonly assumed is that their actions are randomly determined via a uniform distribution over the possible actions. Level-1 players believe that all other players are the non-strategic thinkers at level-0, and a level-1 player will select a best response to their assumption about the others' expected actions. Level-2 players believe all other players are level-1 thinkers; level-3 players believe all other players are level-2 players, and so on. Thus, a level-k player always believes they are the most strategic player in the game, and all other players are level-$(k-1)$ thinkers. (Stahl & Wilson 1995). In a p-beauty contest game, having $p = \frac{2}{3}$, level-0 players choose a number at random. Level-1 players assume the average of all other players' choices will be 50 so they will select $\frac{2}{3}(50) = 33$. Level-2 in the same thought process will choose 22, and so on for increasingly strategic level-k thinkers.

The CH model (Camerer, Ho & Chong 2004) attempts to explain the empirical behaviors found in normal form games by offering an alternative to equilibrium theory. Similar, to LK models, the CH model looks at the hierarchical levels of iterative rationalizability for players examining k steps of thinking strategic logic. The iteration begins with the naive player, the step-0 player who makes no assumptions about their opponent and makes a choice based on a probability distribution. For sake of simplicity, Camerer, Ho & Chong (2004) assumes a uniform distribution over the action space. Differentiating itself from LK theory, in the CH model, a step-k thinker (i.e., which differs from a level-k thinker) does not assume all others are level-$(k-1)$ thinkers. Rather, a step-k thinker (with $k > 0$) assumes all other opponents are thinkers whose levels of strategic thought range from step-0 to step-$(k-1)$, where the distribution over those levels follows a normalized Poisson distribution. The Poisson CH model is advantageous as it can be easier to compute using iterative calculations, beginning with step-0 thinkers, relative to calculating Nash equilibrium for some games. The Poisson distribution exhibits parsimony with one parameter, τ, making the mean and variance the same. As τ grows large, the normalized frequencies from the step-k thinker's perspective put all the weight on $k-1$, making the model converge to a Nash equilibrium as $\tau \to \infty$ in games of iterated dominance. For a normal form game that allows for mixed strategies over the set of available actions, the formal equation for calculating the expected payoff of a step-k thinker using strategy s_i, is given by the following:

$$E_i(K) = \sum_{h=1}^{m-1} \pi(s_i, s_{-i}^h) \cdot \left\{ \sum_{c=0}^{K-1} \left[\frac{f(c \mid \tau)}{\sum_{c=0}^{K-1} f(c \mid \tau)} \cdot P(h \mid c) \right] \right\}, \tag{1}$$

where the probability that their opponents using step c levels of thought select h is $P(h \mid c)$; $f(c|\tau)$ is the frequency of players using k steps of thinking with Poisson distribution mean (τ); K is a finite upper bound for the highest step of player considered;

h is the action vector chosen by the opponents; π is the payoff for a combination of player's actions; and m is the number of actions available to player i (Camerer 2011).

The cognitive hierarchy model has proven to be effective at modeling observed empirical results. In a beauty contest data set, using the multiplier $p = \frac{2}{3}$, the median estimate for τ was 1.61, which explained the convergence to a value of 30, instead of the equilibrium of zero. High τ values were estimated (Camerer, Ho & Chong 2004) in experiments having an equilibrium of zero and subjects consisting of professional stock market portfolio managers. Other evidence showed a higher τ value estimate in subject pools composed of more analytically minded and higher educated individuals. Subjects tended to use more steps of reasoning in higher stakes games than lower stakes games (τ nearly twice as large). Across the diverse subject pool and in different experimental games, nearly half of the 90 percent confidence intervals include $\tau = 1.5$, leaving Camerer et al to suggest this value as reasonable for τ in untested games.

In an attempt to improve on the results of LK and CH, Chong et al. (2016) proposed a generalized cognitive hierarchy (GCH) model. The GCH differs from the other models regarding its assumptions for level-k thinkers' beliefs about other players; which subset of other players inform the best response of a level-k thinker; and what strategy is adopted by level-0 thinkers. GCH leverages a variant of the LK model called Level-m (LM) which, like the LK model, assumes a level-k player selects a best response to the action of a player acting at a single, lower level of strategic thought. Conversely, LM has players best responding to the *most frequently* occurring lower level, wherein the frequency of players' distribution over lower levels of thought varies based on a scenario-specific assumptions. If the modal level happens to be $k-1$, the LM framework is equivalent to the LK model.

Within the GCH model and LM framework, the frequency of the lower level

players are weighted with parameter $\alpha(\geq 1)$. An $\alpha = 1$ implies a level-$k's$ player's belief about the lower level players is equal to the its normalized true proportion. Whereas, $\alpha > 1$ concentrates the level-k player's belief about lower level players on the most frequently occurring level. In a CH model, level-0 players are assumed to select actions in a uniformly random way; in contrast, the GCH model assumes that a level-0 player will seek to avoid an action that could yield a minimum payoff. Partitioning the possible actions into two sets, a level-0 player is assumed to be β times more likely to select a action in the set of actions that never yields a minimum payoff than actions outside of this set. GCH has been shown (Chong et al. 2016) to regress empirical behavior better than CH in four data sets of $n \times m$ games, although this result is, perhaps, unsurprising since GCH contains two additional parameters, α and β. Since it is not always clear that the reduction in the model's mean squared error warrants the inclusion of the additional GCH parameters (Chong et al. 2016), we utilize the more established CH model in this manuscript.

III. Test Design and Analysis Methodology

This chapter discusses the test design and methodology underlying analytical techniques used on data gathered from participants' responses. Section 3.1 presents the test instrument's design. Section 3.2 details various quantitative analytical methodologies utilized to examine the results and garner insight with and without the use of equilibrium structured models.

3.1 Test Instrument

The problem statement was examined by designing, fielding, and analyzing the results of a computer-based survey instrument. The test instrument was an 18-question survey designed using Microsoft's Forms software. Table 1 presents the survey framework and structure including, for each question, the size of the game presented, the communication modality utilized for presentation, and relevant notes.

Question 1 presents the informed consent form per compliance with the Institutional Review Board (IRB). Appendix A and Appendix B presents the IRB application and the *Except Determination* findings. Question 2-4 are administrative in nature, preparing the participant to complete the survey. Question 2 informs the participant to refrain from revisiting previous questions and changing their answer to prevent experience gained later from interfering with earlier questions. Question 3 is an audio check, letting the individual confirm a correct audio connection. Question 4 presents a sample question for a small 2×2 game, introducing language and communication modalities used throughout the survey.

Questions 5-16 use three different communication modalities (i.e., audio-only, visual-only, and audio-and-visual) to present strategic situations of four different sizes (i.e., 2×2, 3×3, 4×4, and 5×5 normal form games). For each of these questions,

the participant is asked to select an action that maximizes their payoffs considering their opponent's payoffs (i.e, a "best response"). In scenarios of 2×2 and 4×4 size, the best response is ascertainable by iteratively considering the players' best response choices. All 3×3 and 5×5 scenarios are rationalizable by eliminating strictly dominated strategies. For the 2×2 to the 5×5 scenarios, the dominant actions are all labelled as action number 1. Although the payoffs were perturbed in each communication modality of the same game size, we number the remaining actions consistently according to their ordinal payoff structure.

To isolate communication modality effects, the twelve questions are presented in three blocks. Audio-only presentations are provided first, followed by visual-only, and subsequently audio-and-visual questions. Within each block, the questions are presented in order of increasing complexity, beginning with 2×2 scenarios and culminating with 5×5 scenarios.

To provide an additional benchmark of group performance against a commonly-studied problem in the literature, Question 17 presents a p-beauty contest scenario, for which the participant must select a number between zero and 100 in an attempt to be the closest to two-thirds of the average guess. The participant views a visual representation of the game with audio reading the words aloud. The final question serves as an integrity check on the instructions presented in Question 2; the participant answers whether they returned to any previous question and adjusted their answer. Should this occur, the participant's answers are not be included within the analysis. Such an integrity check was required for this study to ensure participants were not using gained insight from a later question to adjust previous answers.

It should be noted that all 2×2 scenario games are modeled with a prisoner's dilemma structure (Luce & Raiffa 1957), wherein they are solvable both through iteratively considering each players best response and by eliminating dominated strategies

Table 1. Test Instrument Design

Block	Question	Scenario Size	Communication Modality	Notes
Admin	1	-	-	Informed Consent
	2	-	-	Survey Instructions
	3	-	-	Audio Check
	4	-	-	Sample Game Orientation
Block 1	5	2×2	Audio	Iterative Best Response†
	6	3×3	Audio	IEDS‡
	7	4×4	Audio	Iterative Best Response†
	8	5×5	Audio	IEDS‡
Block 2	9	2×2	Visual	Iterative Best Response†
	10	3×3	Visual	IEDS‡
	11	4×4	Visual	Iterative Best Response†
	12	5×5	Visual	IEDS‡
Block 3	13	2×2	A/V*	Iterative Best Response†
	14	3×3	A/V*	IEDS‡
	15	4×4	A/V*	Iterative Best Response†
	16	5×5	A/V*	IEDS‡
Misc	17	-	A/V*	p-beauty contest style game
	18	-	-	Confirm directions followed

† Solvable by iteratively considering each player's best response(s)
‡ Solvable by iteratively eliminating dominated strategies
* Simultaneous audio-and-visual presentation

until only the dominant strategy, i.e., the best response, remains. Alternative game structures are used for the remaining game and, although the payoffs are perturbed, the payoffs have the same ordinal structure within a given game size.

3.2 Analysis Methodology

The research herein conducts several analyses on the test data. The following sections details the respective methodologies and accompanying analytical objectives.

3.2.1 GCMH Test

Applying the Generalized Cochran-Mantel-Haenszel (GCMH) test to the test results will evaluate the homogeneity of the marginal distributions associated with each communication modality. Although the GCMH test is designed for discerning conditional independence, (Agresti 2002) illustrates how it can be leveraged to answer questions regarding marginal homogeneity. If conditional independence is refuted then so is marginal homogeneity, and the communication modalities are shown to yield statistically differing response proportions.

The Cochran-Mantel-Haenszel (CMH) test is a statistical method used in the analysis of matched categorical data. It is a generalized version of the McNemer test, which only considers pairs of participant's responses. The CMH test considers an arbitrary strata size (i.e., more than two participants), K, and examines the binary association between treatment and a binary outcome.

As a generalization of the CMH test, the GCMH test compares I treatment levels with J possible outcomes from K total strata, where n_{ijk} is a quantity of responses on treatment level i of action j from participant k (Agresti 2002). Let the null hypothesis, H_0, be that conditional independence exists between the treatments, where

$$\boldsymbol{\mu}_k = (n_{1+k}n_{+1k}, n_{1+k}n_{+2k}, ..., n_{I-1,+,k}n_{+,J-1,k})'/n_{++k},$$

and the null covariance matrix of $\mathbf{n}_k$ is denoted by $\mathbf{V}_k$ having

$$cov(n_{ijk}, n_{i'j'k}) = \frac{n_{i+l}(\delta_{ii'}n_{++k} - n_{i'+k})n_{+jk}(\delta_{jj'}n_{++k} - n_{+j'k})}{n_{++k}^2(n_{++k} - 1)}$$

with $\delta_{ab} = 1$ when $a = b$ and $\delta_{ab} = 0$ otherwise.

Rows and columns are treated as unordered. Summing over the K strata yields the following calculations:

$$\mathbf{n} = \sum \mathbf{n}_k, \qquad \boldsymbol{\mu} = \sum \boldsymbol{\mu}_k, \qquad \mathbf{V} = \sum \mathbf{V}_k.$$

The generalized CMH test statistic is

$$CMH = (\mathbf{n} - \boldsymbol{\mu})' \mathbf{V}^{-1} (\mathbf{n} - \boldsymbol{\mu})$$

with associated p-value

$$p = P(\chi^2((I-1)(J-1)) > CMH).$$

3.2.2 Multiple Correspondence Analysis

Assuming marginal homogeneity is refuted, we examine the relationships between participant responses and communication modalities within each scenario size. We leverage techniques that represent the data as points in a low-dimension Euclidean space to identify possible relationships or patterns not readily observed using alternative analytical methods.

Correspondence analysis (CA) provides a graphical representation in two-way contingency tables with rows and columns of the data presented as points. The position of the points on the graphs indicate associations. Multiple correspondence analysis (MCA) is a technique used to detect underlying structures in a data set comprised of nominal categorical data. MCA is computationally equivalent to CA but allows one

to analyze a pattern over several dependent variables. MCA applies the CA algorithm to an indicator matrix or Burt table. Indicator matrices consist of binary elements showing the individual responses to particular questions, where the rows represent participants and the columns are the different categorical variables. Analyzing the indicator matrix allows direct representation of individuals as points in geometric space. Burt tables are symmetric matrices analogous to covariance matrices of continuous variances (Abdi & Valentin 2007); it equals the products of the indicator matrix with its transpose.

Assume there are K nominal variables (i.e., the number of categorical variables), with each variable having J_K levels and $J = \sum_{k=1}^{K} J_k$ holds (i.e., the categorical variable assumes a single level at each observation). With I observations the $I \times J$ indicator matrix is denoted $\mathbf{X}$. MCA can be conducted either on $\mathbf{X}$ or $B = \mathbf{X}^T\mathbf{X}$ (i.e., the Burt Matrix).

Assuming MCA is conducted on $\mathbf{X}$, the sum of all entries in $\mathbf{X}$ is calculated as N. The MCA procedure proceeds by calculating the probability matrix $\mathbf{Z}$ via $\mathbf{Z} = N^{-1}\mathbf{X}$. Two sets of factors scores result by such an analysis on $\mathbf{X}$: one for the rows and one for the columns (Abdi & Valentin 2007); however, in this research, we are mainly concerned with relationships within the column data.

Denoting $\mathbf{r}$ as the vector of row totals from $\mathbf{Z}$ and $\mathbf{c}$ as the column totals, let $\mathbf{D_r}$=diag$\{\mathbf{r}\}$ and $\mathbf{D_c}$=diag$\{\mathbf{c}\}$. MCA is then performed by computing the single value decomposition of the following matrix:

$$\mathbf{D_r}^{-\frac{1}{2}}(\mathbf{Z} - \mathbf{r}\mathbf{c}^T)\mathbf{D_c}^{-\frac{1}{2}} = \boldsymbol{P}\boldsymbol{\Delta}\boldsymbol{Q}^T$$

where $\mathbf{P}$ and $\mathbf{Q}$ are unitary matrices and Δ is the diagonal matrix of the singular values. Factor scores for the rows and columns are obtained, respectively, from the

following formulations:

$$\phi = \mathbf{D_r}^{-\frac{1}{2}} \boldsymbol{P} \boldsymbol{\Delta}$$

$$\Gamma = \mathbf{D_c}^{-\frac{1}{2}} \boldsymbol{Q} \boldsymbol{\Delta}$$

Interpretation of relationships with MCA is similar to CA and often based on the proximities between points in a low-dimensional mapping. Interpretations may vary depending upon the coordinate system utilized; however, proximities are generally only meaningful between points in the same set[1] (i.e., comparing rows to rows or columns to columns). The interpretation of an MCA plot can help identify relationships between points, either from their relative proximities or their respective proximities to the origin (Abdi & Valentin 2007, Greenacre & Blasius 2006). The identified dimensions can also be used to interpret the main sources of association in the data. Qualitative analysis can be utilized to identify the factor associated with each dimension. We note that the quality of these conclusions is related to the percentage of total inertia, i.e., the square of the data's ϕ coefficient[2], explained by the selected dimensions (Greenacre & Blasius 2006); however, when performing MCA with $\mathbf{X}$ or $\mathbf{B}$, it is well-known that the total inertia is artificially inflated via the inclusion of artificial variables and self-comparisons, respectively. As such, the calculated percentage of explained total inertia in most software packages is a lower bound on its true value. For more detail on CA and MCA, we refer the reader to Greenacre & Blasius (2006).

[1]As discussed by Greenacre & Blasius (2006), asymmetric maps can be used, in some degree, to compare row and column points.

[2]The ϕ coefficient is a measure of association in the data where $\phi = \sqrt{\frac{\chi^2}{N}}$ where χ^2 is the Pearson χ^2-statistic and N is the total number of observations.

3.2.3 τ Value Estimation

We leverage the CH model's embedded τ parameter to determine the level of strategic thought utilized by the population in the solution of the normal form game. Each question taken by all the participants has an associated τ value within the CH framework. This value represents the mean and variance of the underlying Poisson distribution for the cognitive hierarchy model, or the level of thinking the population of participants has exhibited to solve a presented problem.

Calculating τ for each question involves first determining the observational distribution of responses from the participants, i.e., the relative frequency participants selected a specific action as a response to the scenario. This distribution is compared to the one found from using Equation (1) for a range of τ values and a set value for K, the finite upper bound for the highest step of player considered. Empirical analysis identified that testing a range of τ values from 0 to 5 in increments of 0.01 provided sufficient accuracy (in terms of the upper bound on τ) and precision (in terms of granularity of the estimates). Similar analysis showed $K = 10$ is sufficient as well. The τ-value yielding the smallest mean-squared error from the experimental observation is identified as the maximum likelihood estimator for the sample's true τ-value. Camerer, Ho & Chong (2004) commented that, in games where the Nash equilibrium is reachable in finitely many iterations of weakly dominated strategies (as all question scenarios can be in the survey test instrument), the predictions of the CH model coincide with the Nash equilibrium as $\tau \to \infty$. In samples where the empirical frequencies conformed with the Nash equilibrium, the τ upper bound serves as a good approximation to the best fitting model mean.

3.2.4 τ Percentile Confidence Intervals via Bootstrapping

Since τ is estimated based off the entire population's behavior, naive utilization of Equation (1) only provides a point estimate. Conversely, it is desirable to understand the amount of variability that exists about τ for a given game and communication modality. To conceptualize this variability, we construct confidence intervals using bootstrapping techniques to generate multiple samples of the participant response data (Efron & Tibshirani 1994).

A random, uniform sampling was conducted, with replacement, on the original data set until the number of observations sampled equaled the total number of original participants. When sampled during bootstrapping, all of an individual's responses were recorded for the new sample to ensure that the individual's level of strategic thinking contributed to the calculation of the population's τ for all questions. Once enough participants' responses were sampled, τ-values are calculated for each sample question using the same technique described in Section 3.2.3. The entire list of τ values from each 10,000 bootstrapped sample served as the evaluated samples used to calculate the appropriate confidence intervals.

To gain insight into the τ-values observed in the population across the different scenarios, percentile intervals on τ were calculated for each question using the bootstrapped sample. Percentile confidence intervals will help preserve the range of observed τ values, as is a concern with the large amount of bootstrapped samples, and are less influences by skewness or bias which may occur within human subject testing data. The percentile interval is denoted

$$(\hat{\tau}_{\alpha/2}, \hat{\tau}_{1-\alpha/2})$$

where $\hat{\tau}_{\alpha/2}$ and $\hat{\tau}_{1-\alpha/2}$ is the lower $\alpha/2$ percentile and upper $1-\alpha/2$ percentile, respectively, of all τ values found in the bootstrapped sample for a particular question. Herein we utilize $\alpha = 0.1$ as demonstrated by Efron & Tibshirani (1994) and used in subsequent research by Camerer, Loewenstein & Rabin (2004).

With multiple percentile intervals being compared simultaneously comes the risk of committing a type I error (i.e., a false positive) by performing multiple hypothesis tests. To counteract the multiple comparison problem, the Bonferroni correction is applied by dividing α by the total pairs of intervals, denoted as m, being compared (Dunn 1961). For this research, $m = 3$ when comparing communication modalities within the same scenario size, and $m = 6$ when comparing across the different scenario sizes for the same communication modality.

3.2.5 p-Beauty Contest Game

The level of thinking found in this study can be compared to similar studies in the literature, benchmarking the population studied with others to conjecture if the level of thinking for the considered population was influenced by the audio-and-visual communication modality.

Question 17 on the test instrument asks players to select a number in a similar manner to the Keynes's p-beauty contest (Keynes 1936), where the multiplier is $p = \frac{2}{3}$ and the number of participants in the contest is $n = 1000$. The question is presented with a visual representation of the game such that the directions are written, and also read aloud. The Nash equilibrium for this game is zero. The responses by the survey participants informs a collective assessment of the group's level of strategic thinking within the CH framework. Given the CH assumption that Level 0 thinkers chose randomly, an average response of 33.33 corresponds to Level 1 thinking; an average of 22.22 to Level 2 thinking; an average of 14.81 to Level 3 thinking; and so on.

IV. Testing, Results, and Analysis

This chapter presents and discusses the results of the analyses described in Chapter 3 to the results of the survey. Section 4.1 presents an overview of the survey results. Sections 4.2.1 and 4.2.2 apply GCMH testing and MCA techniques to explore the relationships between the communication modality and an individual's answer choice. Multiple correspondence analysis is performed with RStudio's *ca* package. By leveraging ideas from the CH model, Section 4.2.3 investigates the level of strategic thinking exhibited by the population on each game, and identifies whether the estimated value of τ for the underlying distribution has been affected by the different communication modalities or game sizes. MATLAB scripts built using parallel *for* loops iterate through the determined range of τ to determine the best fitting model. Bootstrapping uses similar techniques with random samples from the survey. Section 4.2.4 presents the surveyed participants' results for the p-beauty contest question and compares the results to related studies in the literature. Finally, Section 4.3 explores sensitivity analysis with search ranges for values of τ and K, and Section 4.4 summarizes the research findings and discuses the relevance to military planning and decision making impacts based on communication presentation.

4.1 Survey Test Results

Over four weeks, 76 participants took part in the online survey, requiring an average of approximately 47 minutes to complete it. Three participants admitted on question 18 that they returned to a previous question and changed their answer. These responses were removed from analysis. Of the twelve questions involving a matrix style game across the three different communication modalities, the majority of respondents selected the action corresponding to the players' mutual best response

(i.e., the Nash equilibrium) for all but three questions. Two of the games wherein a majority of players selected a dominated strategy coincide with the 4×4 scenario size in the audio-only, and audio-and-visual communication modalities. In both instances, the best response was selected approximately 30% of the time, where the majority (i.e., 50-65%) selected one of the alternative, dominated actions for each question. The third game wherein such behavior was observed corresponds with the audio-and-visual method on the 2×2 scenario. Participants selected the dominated action 62% of the time, conjectured to have been influenced by the moral code defined in Air Force doctrine (US Air Force 2015). This unexpected selection is discussed in greater detail in Section 4.2.3. Discussion on the level of strategic thought for all questions, as defined by the CH model, is discussed in Section 4.2.3.

4.2 Results and Analysis

The experiment yielded the following data presented in Table 2 for the matrix games. Although the payoffs and presentation order were perturbed in each communication modality, action numbers in Table 2 have the same corresponding ordinal payoff relationships in their respective game. "Action 1" corresponds with the dominant action, otherwise refered to as the Nash Equilibrium, in each game. Descriptive statistics of the p-beauty contest results are presented in Table 3. The remainder of this section is dedicated to further statistical analysis of these results.

4.2.1 GCMH Test

Table 4 displays the calculated GCMH test statistics. In all cases, the associated p-value is less than 0.01, indicating a significant difference between how the survey participants responded between at least two of the treatments across all size scenarios.

With a significant difference found in all scenarios, the next phase was to perform

Table 2. Response Frequencies by Scenario Size and Communication Modality

Scenario Size	Communication Modality	Action 1	Action 2	Action 3	Action 4	Action 5
2 × 2	Audio	0.616	0.384			
3 × 3	Audio	0.603	0.342	0.055		
4 × 4	Audio	0.301	0.082	0.534	0.082	
5 × 5	Audio	0.616	0.027	0.260	0.096	0.000
2 × 2	Visual	0.904	0.096			
3 × 3	Visual	0.918	0.041	0.041		
4 × 4	Visual	0.890	0.082	0.000	0.027	
5 × 5	Visual	0.781	0.014	0.055	0.137	0.014
2 × 2	A/V	0.384	0.616			
3 × 3	A/V	0.945	0.000	0.055		
4 × 4	A/V	0.301	0.630	0.041	0.027	
5 × 5	A/V	0.753	0.014	0.219	0.014	0.000

Table 3. Descriptive Statistics p-beauty Contest Results

Level	Value
Maximum	69
75th Percentile	44
50th Percentile	33
25th Percentile	20
Minimum	0

Table 4. GCMH Test Statistics

2×2	3×3	4×4	5×5
45.3	190	167	111

pairwise statistical tests on the communication modalities for the different combinations of scenario sizes and pairwise modalities. Table 5 shows all of the calculated test statistics, and any corresponding p-values found to be less than 0.01 are indicated.

Comparison between the audio and audio-and-visual modalities in the 5×5 size resulted in a singular covariance matrix. The GCMH procedure described in Section 3.2.1 cannot be directly applied in such settings; a corresponding error is often reported in commercial software (SAS 2013). However, some authors (e.g., see Rayner & Best (2017), Rayner & Rippon (2018)) suggest the use of Moore-Penrose pseudoinverse as a remedy; we adopt such an approach herein for the audio and audio-and-visual comparison in the 5×5 size.

Table 5. GCMH Test Statistic of Pairwise Treatment Comparison

Pairwise Comparison	2×2	3×3	4×4	5×5
Audio | Visual	16.3	63	42.2	55.1
Audio | Audio & Visual	10.7	37.3	54.5	6.19*
Visual | Audio & Visual	34.4	68.3	64.3	62.4

*Not a statistically significant value

*Singular covariance matrix; Moore-Penrose psuedoinverse utilized

A statistically significant difference exists for how participants responded to different pairs of communication modalities, for scenario sizes 2×2, 3×3, and 4×4. When comparing the participants' selections in size 5×5, there was no significant difference found between the audio-only and the audio-and-visual modalities. For all other scenario sizes, the visual presentation, whether or not paired with audio, showed a significant difference in participant response compared to the audio-only modality questions. Within all scenario sizes, the comparison between the audio-only and visual-only modalities, as well as the comparison of the visual-only and audio-

and-visual modalities, showed a significant difference. Significant differences were observed between the audio-only and audio-and-visual modalities in all scenario sizes except the 5×5 questions. One conjecture for this counter-intuitive result derives from the large size of the scenario; that is, the problem is too difficult for the decision maker may have been overloaded with information to the point that the communication modality did not induce a difference in behavior. Test fatigue is another possible factor, as the audio-and-visual modality of size 5×5 was the final question among this block of twelve questions.

4.2.2 Multiple Correspondence Analysis

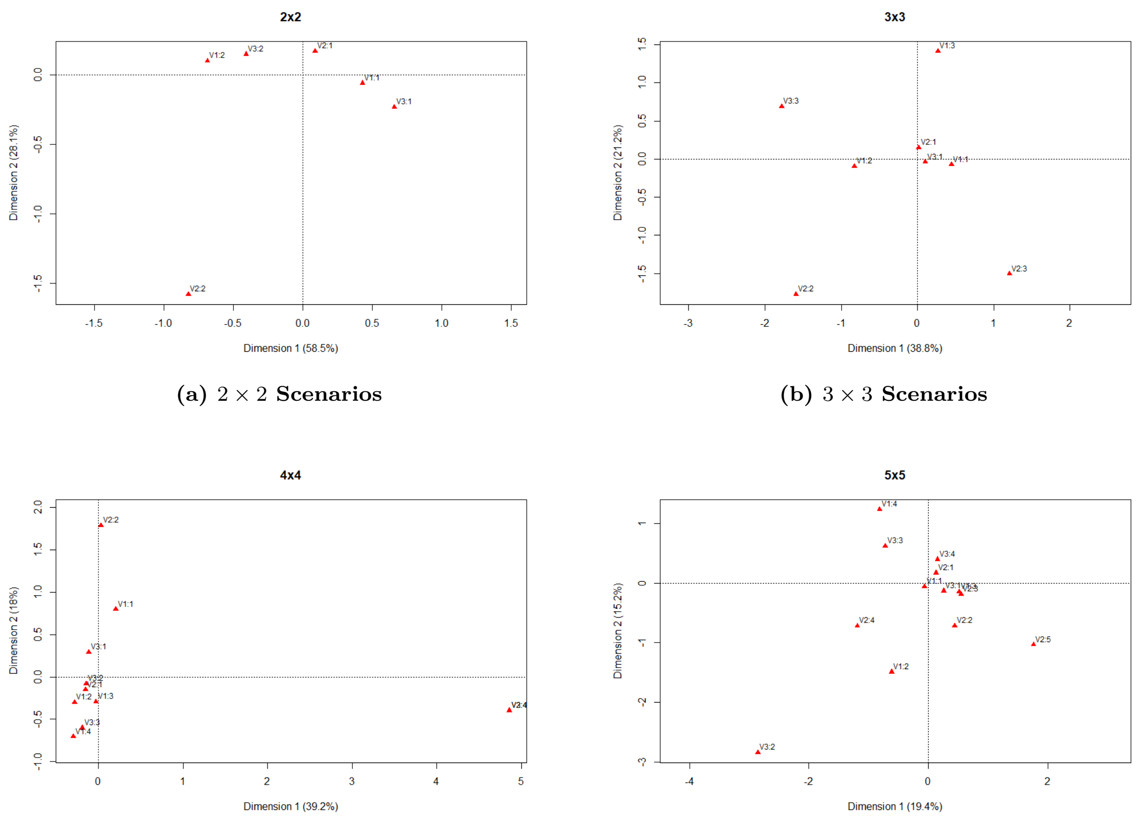
Figure 1 presents the MCA plots in principal coordinates by scenario size as calculated with the Burt matrix. Each point represents a possible response to the question. The first number is the communication modality (i.e., 1 for audio-only, 2 for visual-only, 3 for audio-and-visual), and the second number indicates a specific response from the list of possible actions for the given question. A response never chosen by survey participants is not depicted on the corresponding plot. For the 2×2, 3×3, 4×4, and 5×5 games, note that the total inertia is 86.6%, 60.0%, 57.2%, and 34.6%, respectively. Given the MCA properties discussed in Section 3.2.2, a sufficient percentage of total inertia is explained in each scenario to proceed with meaningful analysis.

Utilizing the MCA plots, we can analyze each dimension to determine what are the factors driving associations in the data. The horizontal dimensions of Figures 1a-1d can respectively be interpreted as separating actions based on modality. Scenarios 2×2 and 3×3 show a separation of Actions 1 and 2 and separation of Actions 1 and 3 from Action 2, respectively. The horizontal dimension for Figure 1c shows a separation in Action 4 for the visual-only and audio-and-visual modalities. Similarly,

Figure 1d delineates between actions in the audio-and-visual modality. The vertical dimension of Figures 1a, 1b, 1c, and 1d can be interpreted, respectively, as separating players who played Action 2 in the visual-only modality; differentiating the selection of Action 3 in the audio-only modality for size 3×3 and selection of Action 4 in the audio-and-visual modality for size 4×4.

Based on the inferred dimensions, it can be observed that behavior on the visual-only modality is central to the association observed in the data. This is further emphasized by visual inspection of the plots with respect to point proximity; doing so allows us to describe associations in the data more granularly.

In Figure 1a, notice the proximity between Points 1:2 and 3:2 as well as Points 1:1 and 3:1. This implies that participants who chose the dominant action in the audio-only modality tended to select the dominant action in the audio-and-visual modality, same with Action 2; however, this association did not translate to the visual-only modality. Figure 1b presents negative associations were present based upon player selections in the visual-only modality: selecting Action 3 in the visual-only modality suggested a tendency to not select Action 3 in the audio-and-visual modality, whereas selecting Action 2 in the visual modality implies a tendency to not select Action 3 in the audio-only modality. Figure 1c observes a similar negative association between the selection of Action 2 in the visual-only modality and Action 4 in the audio-and-visual modality, where a positive association can be observed between Action 4 between the same modalities. Figure 1d observed another negative association between selecting Action 2 in the visual-only and audio-and-visual modalities. Collectively these results imply an underlying factor influencing different responses from participants, which can be attributed to the different communication modalities.



(a) 2×2 **Scenarios**

(b) 3×3 **Scenarios**

(c) 4×4 **Scenarios**

(d) 5×5 **Scenarios**

Figure 1. MCA Plots by Scenario Size

4.2.3 τ Value Analysis

Using the techniques set forth in Section 3.2.3, Table 6 presents the participants' estimated τ value with associated mean squared error (MSE) in Table 7 for each question. Notable for each game size is the increase of τ from an audio-only to a visual-only communication modality. This increase is also seen between the visual-only and audio-and-visual modalities for scenario sizes 3×3 and 4×4. The largest MSE between the observed participants' response distribution and experimental distribution from the CH model was 0.05 from the audio-only question of size 5×5. Half of all questions yielded an MSE less than 0.005. The CH model performed well at estimating the distribution of participant responses with MSE for all 12 questions summing to 0.19.

The decrease in τ seen in the 5×5 scenario size may be a result of similar con-

Table 6. Estimated τ Values for All Questions

Communication Modality	2×2	3×3	4×4	5×5
Audio	0.27	0.52	0.48	0.74
Visual	1.65	2.09	1.92	1.29
Audio & Visual	0.00	2.50	2.02	1.18

Table 7. MSE on τ Values for All Questions

Communication Modality	2×2	3×3	4×4	5×5
Audio	0.00	0.04	0.03	0.05
Visual	0.00	0.00	0.00	0.01
Audio & Visual	0.03	0.00	0.00	0.03

jectures made in Section 4.2.1 regarding the pairwise comparisons of participants' responses. The relatively worse performance is conjectured to be caused by either the larger problem size, or by participant test fatigue.

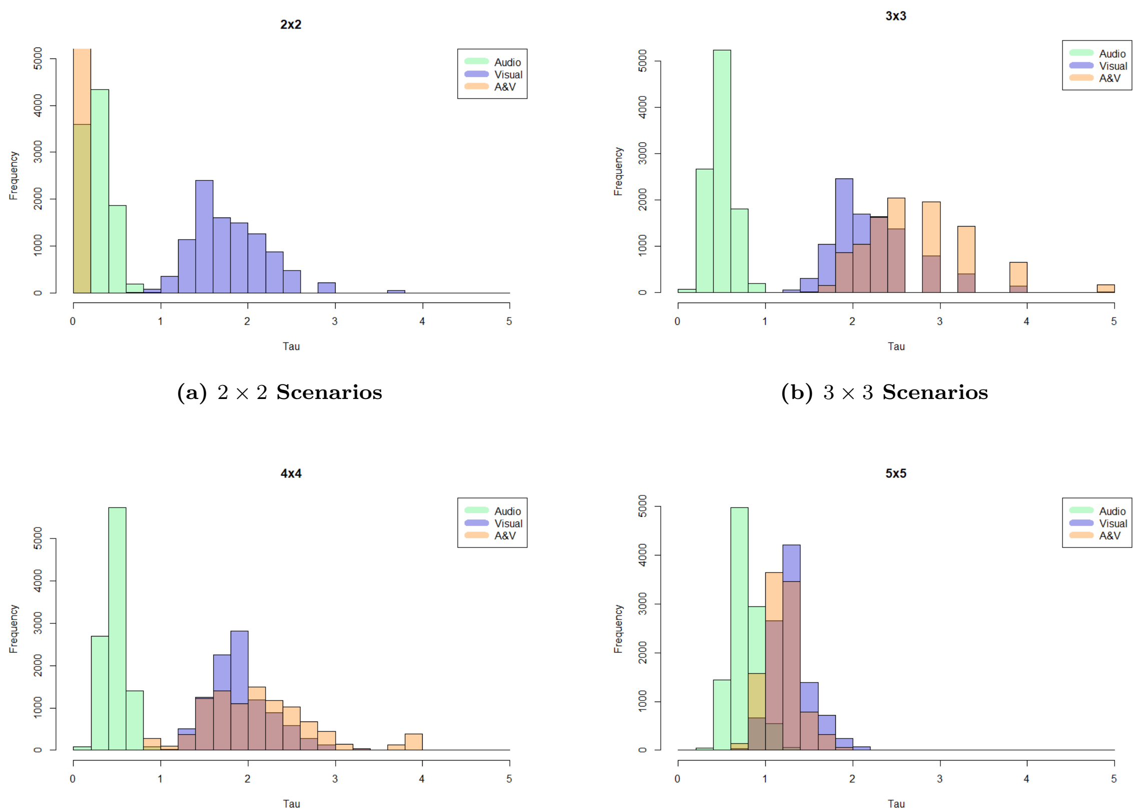
The audio-and-visual question of size 2×2 shows a notable decrease in the estimated τ-value to 0.00, a result that merits further discussion. An estimate of $\tau = 0$ indicates participants' responses are no better than an equiprobable, random guess. Because Question 13 is associated with the audio-and-visual modality, it is presented as a written scenario that was also read aloud, accompanied by a 2×2 matrix depicting player payoffs. In the audio-only and visual-only modalities associated with this scenario size, most of the participants managed to deduce the best response, indicating that some factor unique to Question 13 influenced the outlying result.

Based on a *post hoc* analysis of the test question, a common characteristic among survey participants, and informal feedback from survey participants, we conjecture that participants' ethics precluded the selection of more strategically minded actions for Question 13. This specific question involved the participant and their counterpart fixing a piece of gym equipment. A supervisor would later ask whether the individual had any help in the repair process or did the repairs alone. In this scenario, akin

to Prisoner's Dilemma (Luce & Raiffa 1957), the options were to either "tell the truth" or "lie," wherein the Nash equilibrium in dominant strategies is for both players to "lie". Results showed that 60.5% of participants elected to "tell the truth." Likely relevant to the seemingly non-strategic group performance on Question 13 is that every participant was either an active duty military or civilian employee in the Department of Defense, taking classes at the Air Force Institute of Technology, a technical graduate school run by the United States Air Force. Among the three core values of the Air Force, the first value is "Integrity First" (US Air Force 2015); honesty is valued above all else. Although "lie" is the best strategic response to Question 13, it is anathema to the explicit organizational values of the participants. Moreover, several survey participants approached one of the co-authors after completing the survey to express their angst over Question 13. Each such voluntary statement indicated that they *knew* what the utility-maximizing dominant action was, but they *did not think that "lie" is an answer they could willingly select*. Additionally, considering their honesty to influence the opposing player's payoff maximizing choice in action, participants disclosed they believed opposing players would follow a similar strategy and choose a moral action based on a similar ideology.

Figure 2 shows the frequency of all estimated τ values from the 10,000 bootstrapped samples created from the 76 participants' responses. When all sampled participant answers were the dominant action, τ was estimated to be 5.00 (i.e, the upper bound on the preset range), because the best fitting τ to the observed selection approaches infinity. In all size scenarios, the mode τ for the visual-only question was larger than the mode τ for the audio-only questions of the same size. Question sizes of 3×3 and 4×4 show the audio-and-visual questions yielding a generally higher τ value relative to audio-only questions; however, there not an extensive distinction from the visual-only questions. Scenario sizes of 5×5 have the most considerable overlap in the

τ values, showing less positive influence from the additional presentation modality as seen in the 3×3 and 4×4 scenarios. It is possible the modality had little effect on the individuals' responses due to the complexity of the problem. Alternatively, the 5×5 scenarios were positioned last in the presentation set of questions, and test fatigue may have influenced the participants' choices.



(a) 2×2 **Scenarios**

(b) 3×3 **Scenarios**

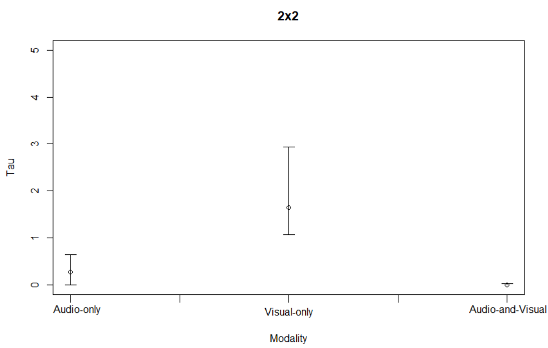
(c) 4×4 **Scenarios**

(d) 5×5 **Scenarios**

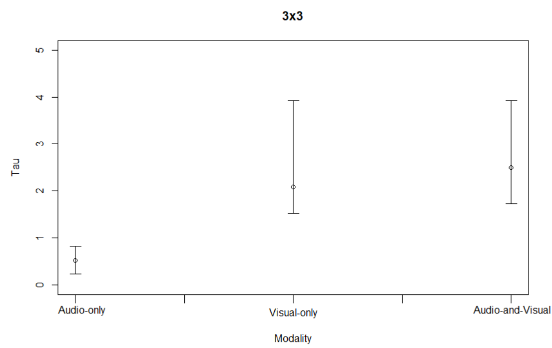
Figure 2. Frequency of Estimated τ from 10,000 Bootstrapped Samples

Figure 3 displays the percentile confidence intervals for each scenario size across the different communication modalities. In scenarios of size 2×2, 3×3, and 4×4, there is a significant difference in the intervals between audio-only and visual-only modalities, as they display no overlap. Such an overlap does appear in the 5×5 scenario, but the upper bound of the visual-only confidence interval exceeds the upper bound of the audio-only modality by over 0.6 indicating a higher likelihood of higher

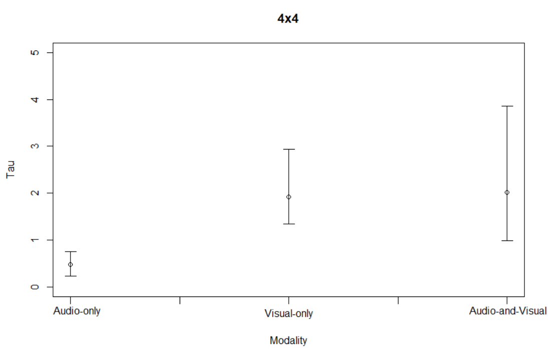
levels of strategic thought observable in the population. Similarly, the audio-and-visual modality's upper bound exceeds the upper bound of the audio-only modality in all cases but the 2×2 scenario, where the audio-and-visual modality question was affected by the participants' ethical judgements. In the 3×3, 4×4, and 5×5 scenarios, the audio-and-visual modality interval remains relatively consistent with minor variation compared to the visual-only modality.



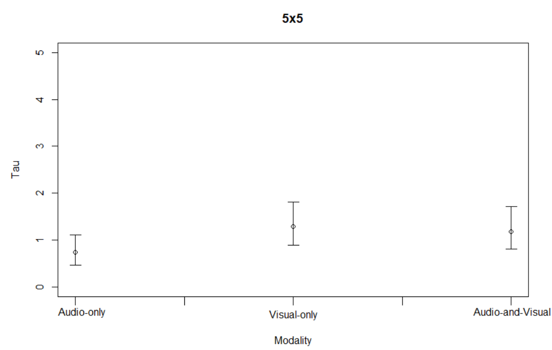
(a) 2×2 **Scenarios**



(b) 3×3 **Scenarios**



(c) 4×4 **Scenarios**



(d) 5×5 **Scenarios**

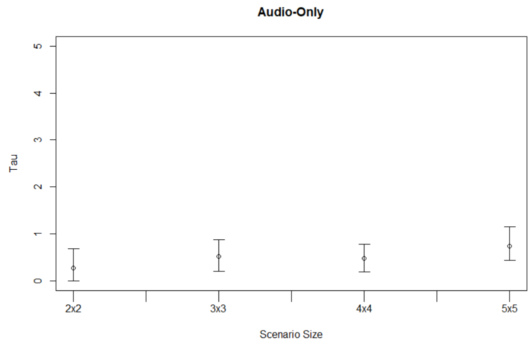
Figure 3. Percentile Confidence Intervals Across Scenario Size

Figure 4 presents the effect of increasing scenario difficulty across the different communication modalities. Although no statistical difference were observed, we note the following. In the audio-only modality, there is a steady increase in the interval's mode an upper bound. An increase in τ as difficulty increases is an unexpected outcome. One may expect the average level of strategic thought in a population to

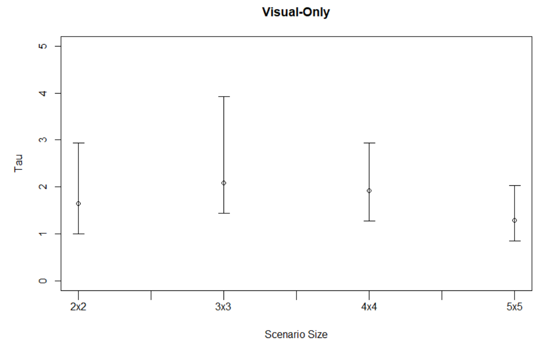
decrease and eventually reach zero as the question's size and difficulty increase. While perhaps counterintuitive, it should be noted that the largest upper bound achieved across the scenarios in the audio-only modality is similar in value to the smallest lower bound observed in the visual-only and audio-and-visual modalities. Visual-only and audio-and-visual modalities see an increase in upper bound and mode from the 2×2 to the 3×3 scenarios, but then see a steady decrease in value from the 3×3 to the 4×4 and, eventually, the 5×5 scenario. The increase is conjectured to be caused by the simplicity of the $2\times$ scenarios not requiring large amounts of mental energy, whereas the 3×3 was complicated enough to elicit a strategic response, but simple enough for good performance to be achieved. In all the 3×3 and larger scenarios, the audio-and-visual modality had non-significantly different confidence intervals to the visual-only modality but did have a larger upper bound.

4.2.4 p-beauty contest

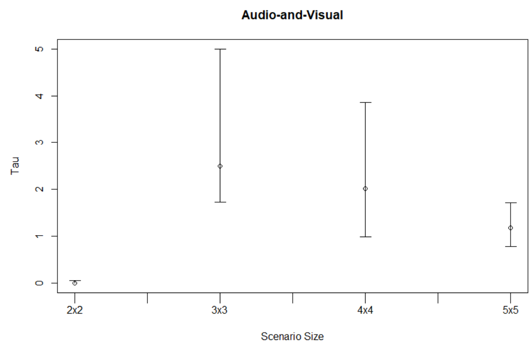
The average response for the p-beauty contest (i.e., Question 14) was 31.02. This value corresponds to $\tau \approx 1.65$. Camerer, Ho & Chong (2004) observed that, across 24 similar instances, a median estimate for τ of 1.61, indicating the observed τ for this study is similar to their results. The small difference between these numbers reveals the audio-and-visual communication modality did not exhibit a significant impact on the level of strategic thought. This corresponds with the results observed in Section 4.2.3.



(a) Audio-only



(b) Visual-only



(c) Audio-and-Visual

Figure 4. Percentile Confidence Intervals Across Modality

4.3 Sensitivity Analyses

Two sensitivity analyses were conducted that inform the preceding analysis, and each merits some discussion. To calculate τ in Section 4.2.3, a predetermined range to explore the best fitting value was set to $\tau \in [0, 5]$. Additionally, the fixed value of K, the finite upper bound for the highest step of player, was chosen arbitrarily as 10, under the presumption that double the maximum observed value would be sufficient. Various ranges for τ and values for K were explored to ensure the τ estimate's accuracy. The largest range was $\tau \in [0, 15]$ with $K = 30$. The greater value of K and wider interval of τ values considered had no impact on the analytic results; they attained the same τ-values reported in Table 6. The narrower interval for τ and lesser K-value were accordingly selected to reduce unnecessary computational

requirements to complete the analysis.

When iterating through different values of τ to determine which was the best estimate for the model, we decided to iterate by increments of one hundredth (0.01) instead of something more precise, e.g., increments of one thousandth (0.001). Much of the related CH literature present estimates of τ to the hundredth place (e.g., see Camerer, Loewenstein & Rabin (2004) and Camerer, Ho & Chong (2004)). Nevertheless, we explored the effect of estimating τ-values with this higher level of precision, for the same range of $\tau \in [0, 5]$ and with $K = 10$, and using the techniques presented in Section 3.2.3. Table 5 reports the estimated τ-values at this higher level of precision. The difference in the sum of mean squared errors between the τ-values reported in Tables 6 and 8 is 1.9×10^{-5}. The extra computational effort required to calculate more precise τ-values resulted in a negligible difference in precision. Hence, τ values were estimated to the hundredth place as demonstrated.

Table 8. Estimated τ Values to Thousandths Place

Communication Modality	2×2	3×3	4×4	5×5
Audio	0.265	0.518	0.476	0.735
Visual	1.651	2.093	1.923	1.295
Audio & Visual	0.000	2.499	2.023	1.177

4.4 Discussion

Analysis of the GCMH test indicates that communication modality has a statistically significant effect on the participant's actions. Further investigation regarding the GCMH test statistics and their associated p-values for pair-wise comparisons indicate a significant difference in participant answer selection between all other communication modalities except between audio-only and audio-and-visual communication modalities in the 5×5 scenario. The MCA analysis showed differentiation from action

choices across all scenarios dependant on an underlying factor possibly attributable to the different communication modalities. In multiple cases, the same actions were negatively associated with each other across different modalities, indicating the participant's selection of specific actions being influenced by the presentation.

Visual-only questions showed a statistically significant increase in the level of strategic thought exhibited by the population over audio-only questions. This phenomenon was also observed between audio-and-visual and audio-only modalities with some caveats in the larger, more difficult 5×5 size questions as well as the morality affected question in the 2×2 scenario. When confronted with a smaller question of size 2×2 that also involved an ethical dilemma between being honest or dishonest, participants seemed to consciously select the dominated action of "telling the truth," thereby dropping the estimated τ to zero. Although such a value of τ coincides with non-strategic choice, the truth seems more nuanced. It is likely the case that the game's payoff did not adequately represent the players' utilities. This phenomena is reminiscent of results discussed by Camerer (2011) regarding the effects of varying demographic variables on observed behavior in the Dictator, Ultimatum and Trust games.

Finally, presenting a p-beauty contest question using a combined audio-and-visual communication modality did not seem to affect or influence the population's level of strategic thinking since the average response, 31.02, was similar to average responses of participants from other experiments reported in the literature.

Multimedia learning stresses the importance of audio and visual modalities simultaneously being present to maximize cognitive processing in an individual. Research conducted here expected the audio-and-visual scenarios to perform best, i.e., compared to the audio-only and visual-only. Some outperformance indications were present in the 3×3 and 4×4 size games in the sampled populations values for τ, but

the bootstrapped samples did not find statistical significance between these communication modalities. However, a significant difference was observed in an individual's responses based on communication modality in all pairwise commissions, across all scenario sizes, except audio-only and audio-and-visual in the 5×5 questions.

4.4.1 Relevance to Military Planning

Information is shared with a commander and his staff in a myriad of manners. Much of the information given to military planners is communicated verbally in meetings and round table discussions (audio-only) or via written correspondence in reports, PowerPoint presentations, and other large written documents (visual-only). This research has shown that a higher level of strategic thought can be achieved by commanders and their staffs when audio-only communication is avoided and a visual modality is included. Additionally, when the information is presented with the audio-and-visual modality, planners' strategic thought decreases at a seemingly slower rate as the scenario's difficulty increases in comparison to the visual-only modality.

This research sought to understand how different forms of cognitive processing affects strategic decision making to enable better decision making in the military. Herein, we showed that visual-only presentation of information is more beneficial than audio-only. The combinations of audio-and-visual modalities can achieve a higher upper bound on the levels of strategic thought as difficulty increases compared to the visual-only modality. However, as the difficulty surpasses a certain threshold; the extra auditory presentation did not improve the level of strategic thinking. This result implies that information presentation should be tailored to the military operation. For moderately complex operations, there is potentially great benefit to the combined audio-and-visual presentation of information. However, for exceedingly large and complex activities at the theater-level, the verbal modality (e.g., written) dominates.

Finally, it must be highlighted that our results illustrated a fundamental character of the US military. When confronted with a morally divisive choice, our participants seemed to willing chose the “less strategic” option based upon its perceived immorality. This results suggests that the core values instilled in Air Force doctrine do indeed guide the strategic decision making of its members.

V. Conclusions and Recommendations

This chapter summarizes this research's contributions and proposes future research directions based on the limitations and methodologies. Section 5.1 reviews the study's goals, techniques used, and provides a summary of the results found. Section 5.2 presents futures considerations and alterations to the test design and methodologies from this research.

5.1 Conclusions

This research explored how cognitive processing in a competitive situation, modeled with normal form games of various difficulties (measured by the size of a scenario's action space), affects a sample's population's ability to reach sound, strategic decisions. The communication modalities considered in assessing the strategic nature of decisions, which were evaluated with and without non-equilibrium structural models, were audio-only, visual-only, and the combinations of audio-and-visual. Necessary to conduct this analysis was the measurement of the population's level of strategic thought and the evaluation of changes in strategic thought based on the different modalities and situation complexity.

The computer based test instrument consisted of 18 questions: four administrative questions; three blocks of questions accounting for each communication modality and scenario size combination, increasing in difficulty, starting with 2×2 and culminating with 5×5 for a total of 12 questions; and two miscellaneous questions including a p-beauty game and an integrity check on whether the participant followed the test's instructions. Analysis was conducted using the Generalized Cochran-Mantel-Haenszel test and multiple correspondence analysis to study associations in participant responses by communication modality and question difficulty. To evaluate a

population's average level of strategic thinking, we applied the Cognitive Hierarchy model to find a value of τ for each question. Bootstrapping was utilized to develop percentile confidence intervals on τ to examine the effect of different communication modalities and scenario difficulty on the population's average level of strategic thought. A similar methodology was used for the p-beauty contest question to determine the population's average level of strategic thinking and compare it to results in the published literature.

The analysis found that participants answered questions differently across all the different communication modalities. The only exception was the pairwise comparison made between the audio-only and audio-and-visual modalities on the 5×5 question, where participants did not respond in a statistically different manner. The average level of strategic thought (i.e., the τ-value estimated for the population) increased between audio-only and visual-only communication modalities. The value of τ increased further in the audio-and-visual modality for scenario sizes 3×3 and 4×4. The bootstrapped confidence intervals revealed similar results with a significant increase between audio-only and visual-only modalities for all scenarios, and a larger upper bound for the audio-and-visual modality compared to visual-only modality in scenarios of size 3×3 and 4×4. Visual-only and audio-and-visual modalities showed an increase in strategic thought from 2×2 to 3×3 games, attributed to simplicity of the smaller scenario requiring less cognitive processing, followed by a steady decrease as the difficulty increased to the maximum 5×5 scenario. Across all scenario sizes, a significant increase existed in the population's average level of strategic thought in the visual-only questions as compared to the audio-only. The p-beauty contest question estimated a population's τ-value to be of 1.65, comparable to literature where the median τ-value was found to be 1.61 across 24 similar test instances (Camerer, Loewenstein & Rabin 2004).

Audio-and-visually presented questions were expected to outperform audio-only and visual-only questions based on concepts from the theory of multimedia learning, indicating the additional communication modalities acting on a person simultaneously would allow more cognitive processing to occur. In scenarios of size 3×3 and 4×4, the population surveyed observed a larger level of strategic thinking, but this difference was not statistically significant. However, the analysis did show a difference in individuals' responses between different communication modalities.

During testing, an exception was discovered that significantly reduced the participants' level of strategic thought when presented a problem using the audio-and-visual modality. The 2×2 question presented a scenario with a set of actions that generated a simultaneous ethical dilemma. Most players chose to "tell the truth" over the alternative "lie." Such a choice resulted in the average level of strategic thought, τ, to be equal to zero; individuals were effectively acting non-strategically. The population observed in this question illustrated that their tendency to identify the dominant action was affected by the ethical factors.

5.2 Future Research Considerations

Future research can expand on the created test instrument and present it to participants in person instead of via the computer-based system survey. In-person proctoring could modify questions with a person verbally providing communication for audio-only questions and the different methods to consider alternative visual-only presentation techniques, such as presentation slides on a computer or drawings on a whiteboard. Such presentation will allow for analysis of conversational communication that could not be examined herein.

The population studied during this experiment could also be expanded in further research. Beyond just the graduate school members surveyed, participation could in-

clude more personnel within the Air Force, including different occupations, as a means to explore how different career specialities compare in their responses for different communication modalities and/or problem complexities. Additionally, the methods utilized herein can be utilized as a measure of effectiveness for military professional education. Military professional schools such as the U.S. Army's *School of Advanced Military Studies* and the U.S. Air Force's *School of Advanced Airpower Studies* are designed to produce strategic minded officers. By considering these schools as a "treatment", the student body's level of strategic thought can be measured upon enrollment and after graduation. The analysis presented herein can be replicated to determine what (if any) statistical increase occurred in the study body's ability to think strategically. Doing so can inform changes to officer professional development throughout the U.S. military.

Much of this research leveraged concepts from Mayer's theory of multimedia learning (Mayer 2009) to establish the type of communication modalities that would best help an individual learn and then solve a given problem. Other types of learning theories exist and could serve as a focus for further research, such as VARK learning styles (Fleming & Mills 1992).

Alternative analysis to the CH model is also of interest. Additional methods to determine whether a participant is thinking harder or using more critical reasoning than explored herein. For example, Kahneman (2011) discusses how one could measure a participant's pupil size since pupils have been observed to dilate wider when an individual is acting in critical thinking and problem-solving situations. Such a research extension is compelling, and it may be interesting to discern between *level of effort* and *successful outcomes* among participants.

Finally, one question on the test instrument unintentionally induced an ethical dilemma that limited the participant's ability to select the dominant action versus

the action that was deemed by most participants to be morally correct. The question asked participants to either tell the truth or lie, where lying was the mutual best response for the player and their counterpart. Exploring the limitations and boundaries of morally charged problems could be investigated. The question here was a small 2×2 scenario involving being honest or dishonest. However, our results imply that it is worthwhile to determine whether larger problems of a similar nature or problems under more extreme conditions, such as those involving another human's health and livelihood, cause a similar drop in the level of strategic thought. Other factors to explore include the rank, position, experience level, and seniority of the population.

Appendix A. IRB Packet

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

October 5, 2020

MEMORANDUM FOR AFIT HUMAN RESEARCH PROTECTION PROGRAM (HRPP), OFFICE OF SPONSORED PROGRAMS AND RESEARCH (ENR)

FROM: AFIT/ENS

SUBJECT: Principal Investigator Cover Letter for Exempt Determination Request for An Assessment of the Validity of Dual Channel Theory for Strategic Decision-making in Competitive Scenarios

1. Request AFIT HRPP review and approval of the Exempt Determination Request protocol named above which should be considered as a freestanding protocol.

2. As principal investigator (PI), the undersigned affirms that the protocol complies with the requirements for exempt research set forth in Federal code and the DoD, Air Force, and AFIT instructions implementing it. In addition, the undersigned agrees to:

   a. Ensure that all exempt research conducted under this protocol will conform to the written, approved document, including any restrictions imposed during the approval process. The funding and resources for this research have been procured/acquired to conduct this project as submitted in the protocol. The funding source is:

Funding Agency/Organization: n/a (no funding)	
Funding Amount: $0	JON#: n/a

   b. Personally conduct and supervise the study and be responsible for the conduct of all persons acting on behalf of the Principal Investigator.

   c. Monitor the progress of this research and notify the AFIT HRPP in writing within 24 hours of any unexpected event, unanticipated problem, safety concern or medical misadventure.

   d. Promptly notify AFIT HRPP, if either the risk or the benefit of the research appears substantially different from those represented in the protocol, or if early results clearly resolve the hypothesis.

   e. Ensure all individuals assisting in the study are adequately trained, and aware of their responsibilities.

   f. Maintain and retain all study and protocol documents as required by the protocol and DoD regulations.

   g. Conduct this research in compliance with the principles of Human Subjects Research found in the Belmont Report: 1. Respect for Persons requires that subjects, to the extent they are capable, be

AIR FORCE INSTITUTE OF TECHNOLOGY

HRPP Exempt Determination Request Form

General Instructions

NOTE Contact AFIT HRPP office (ENR) **before** completing this worksheet with questions and submit this form to: HumanSubjects@AFIT.edu. If you know your activity is not exempt, OR if the activity involves any of the following products:

a. An experimental product (any medical device, vaccine, drug, nutritional supplement or laboratory assay (In Vitro Diagnostic (IVD)) that has not been approved by the Food and Drug Administration (FDA).
b. An FDA approved product* used in accordance with its FDA approved purpose
c. An FDA approved product* NOT used in accordance with its FDA approved purpose
d. For details and guidance on appropriate Distribution Statement, please refer to: https://afit.libguides.com/STINFO

Your Exempt Determination Package must include:

1. Principal Investigator Cover Letter
2. HRPP Exempt Determination Request Form
3. CITI Training Course Complete Records for all researchers
4. CBT Training Certificate for all researchers. (Refer to AFIT HRPP Exemption Package Instructions and Checklist for links to CITI and CBT training sites.)
5. Vita / Resume for each researcher; this must include: “Last Updated DD Month YYYY” within the document, *not* the title.
6. Attach any data collection tools (e.g. surveys, questionnaires, focus group questions). If this activity is a survey, attitude or opinion poll, questionnaire, or interview, it might require approval by the Air Force Survey Office (HQ AFPC/DSYS); AFI 38-501. Contact ENR if you will be conducting a survey.

Definitions

Human Subject means a living individual about whom an investigator conducting research: (i) Obtains information or biospecimens through intervention or interaction with the individual, and, uses, studies, or analyzes the information or biospecimens; or (ii) Obtains, uses, studies, analyzes, or generates identifiable private information or identifiable biospecimens.

Research means a systematic investigation, including research development, testing, and evaluation, designed to develop or contribute to generalizable knowledge. Activities that meet this definition constitute research for the purposes of this policy, whether or not they are conducted or supported under a program that is considered research for other purposes. For example, some demonstration and service programs may include research activities. For the purpose of this part, the following activities are deemed not to be research:

- Scholarly and journalist activities, including the collection and use of information, that focus directly on the specific individuals about whom the information is collected.
- Public health surveillance activities, including the collection and testing of information or biospecimens, conducted, supported, requested, ordered, required, or authorized by a public health authority. Such activities are limited to those necessary to allow a public health authority to identify, monitor, assess or investigate potential public health signals, onsets or disease outbreaks, or conditions of public health importance. Such activities include those associated with providing timely situational awareness and priority setting during the course of an event or crisis that threatens public health.
- Collection and analysis of information, biospecimens or records by or for a criminal justice agency for activities authorized by law or a court order solely for criminal justice or criminal investigative purposes.
- Authorized operational activities (as determined by each agency) in support of intelligence, homeland security, defense, or other national security missions.
- If your proposal falls within this bulleted list, please use the Not Human Subject Research Checklist for your submission.

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Brian Lunday (ID: 8280696)
- **Institution Affiliation:** U.S. Air Force Research Laboratory (ID: 913)
- **Institution Email:** brian.lunday@afit.edu
- **Institution Unit:** Department of Operational Sciences
- **Phone:** (937) 255-3636 x4624

- **Curriculum Group:** Basic Course - Human Subjects Research
- **Course Learner Group:** Air Force Research Laboratory (AFRL)
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 32629608
- **Completion Date:** 01-Aug-2019
- **Expiration Date:** 31-Jul-2022
- **Minimum Passing:** 80
- **Reported Score*:** 100

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Conflicts of Interest in Human Subjects Research (ID: 17464)	01-Aug-2019	5/5 (100%)
History and Ethical Principles - SBE (ID: 490)	01-Aug-2019	5/5 (100%)
Genetic Research in Human Populations (ID: 6)	01-Aug-2019	5/5 (100%)
Research Involving Pregnant Women, Fetuses, and Neonates (ID: 10)	01-Aug-2019	3/3 (100%)
FDA-Regulated Research (ID: 12)	01-Aug-2019	5/5 (100%)
Research and HIPAA Privacy Protections (ID: 14)	01-Aug-2019	5/5 (100%)
International Studies (ID: 971)	01-Aug-2019	3/3 (100%)
Populations in Research Requiring Additional Considerations and/or Protections (ID: 16680)	01-Aug-2019	5/5 (100%)
Biomed Refresher 2 – HIPAA and Human Subjects Research (ID: 526)	01-Aug-2019	5/5 (100%)
DoD/AFRL Requirements for Human Subject Research (ID: 17479)	01-Aug-2019	No Quiz
History and Ethics of Human Subjects Research (ID: 498)	01-Aug-2019	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 491)	01-Aug-2019	5/5 (100%)
Basic Institutional Review Board (IRB) Regulations and Review Process (ID: 2)	01-Aug-2019	5/5 (100%)
Informed Consent (ID: 3)	01-Aug-2019	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	01-Aug-2019	5/5 (100%)
Records-Based Research (ID: 5)	01-Aug-2019	3/3 (100%)
Research Involving Children (ID: 9)	01-Aug-2019	3/3 (100%)
International Research - SBE (ID: 509)	01-Aug-2019	5/5 (100%)
Internet-Based Research - SBE (ID: 510)	01-Aug-2019	5/5 (100%)
Vulnerable Subjects - Research Involving Workers/Employees (ID: 483)	01-Aug-2019	4/4 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?kcfadfa07-0a5c-47f2-bb66-54736ed5ab1e-32629608

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

COLLABORATIVE INSTITUTIONAL TRAINING INITIATIVE (CITI PROGRAM)

COMPLETION REPORT - PART 1 OF 2
COURSEWORK REQUIREMENTS*

* NOTE: Scores on this Requirements Report reflect quiz completions at the time all requirements for the course were met. See list below for details. See separate Transcript Report for more recent quiz scores, including those on optional (supplemental) course elements.

- **Name:** Stephen Donnel (ID: 9407660)
- **Institution Affiliation:** U.S. Air Force Research Laboratory (ID: 913)
- **Institution Email:** stephen.donnel@afit.edu
- **Phone:** 7243164328

- **Curriculum Group:** Basic Course - Human Subjects Research
- **Course Learner Group:** Air Force Research Laboratory (AFRL)
- **Stage:** Stage 1 - Basic Course

- **Record ID:** 38250816
- **Completion Date:** 05-Sep-2020
- **Expiration Date:** 05-Sep-2023
- **Minimum Passing:** 80
- **Reported Score*:** 100

REQUIRED AND ELECTIVE MODULES ONLY	DATE COMPLETED	SCORE
Conflicts of Interest in Human Subjects Research (ID: 17464)	04-Sep-2020	5/5 (100%)
History and Ethical Principles - SBE (ID: 490)	04-Sep-2020	5/5 (100%)
Genetic Research in Human Populations (ID: 6)	04-Sep-2020	5/5 (100%)
Research Involving Pregnant Women, Fetuses, and Neonates (ID: 10)	04-Sep-2020	3/3 (100%)
FDA-Regulated Research (ID: 12)	04-Sep-2020	5/5 (100%)
Research and HIPAA Privacy Protections (ID: 14)	04-Sep-2020	5/5 (100%)
International Studies (ID: 971)	04-Sep-2020	3/3 (100%)
Populations in Research Requiring Additional Considerations and/or Protections (ID: 16680)	04-Sep-2020	5/5 (100%)
Biomed Refresher 2 – HIPAA and Human Subjects Research (ID: 526)	04-Sep-2020	5/5 (100%)
DoD/AFRL Requirements for Human Subject Research (ID: 17479)	04-Sep-2020	No Quiz
History and Ethics of Human Subjects Research (ID: 498)	04-Sep-2020	5/5 (100%)
Defining Research with Human Subjects - SBE (ID: 491)	04-Sep-2020	5/5 (100%)
Basic Institutional Review Board (IRB) Regulations and Review Process (ID: 2)	05-Sep-2020	5/5 (100%)
Informed Consent (ID: 3)	05-Sep-2020	5/5 (100%)
Privacy and Confidentiality - SBE (ID: 505)	05-Sep-2020	5/5 (100%)
Records-Based Research (ID: 5)	05-Sep-2020	3/3 (100%)
Research Involving Children (ID: 9)	05-Sep-2020	3/3 (100%)
International Research - SBE (ID: 509)	05-Sep-2020	5/5 (100%)
Internet-Based Research - SBE (ID: 510)	05-Sep-2020	5/5 (100%)
Vulnerable Subjects - Research Involving Workers/Employees (ID: 483)	05-Sep-2020	4/4 (100%)

For this Report to be valid, the learner identified above must have had a valid affiliation with the CITI Program subscribing institution identified above or have been a paid Independent Learner.

Verify at: www.citiprogram.org/verify/?k3a860ec1-7b77-41da-9baa-ca4e043b37b4-38250816

Collaborative Institutional Training Initiative (CITI Program)
Email: support@citiprogram.org
Phone: 888-529-5929
Web: https://www.citiprogram.org

CITI PROGRAM

Completion Date 10-Aug-2020
Expiration Date 10-Aug-2023
Record ID 37818178

This is to certify that:

William Caballero

Has completed the following CITI Program course:

Not valid for renewal of certification through CME. Do not use for TransCelerate mutual recognition (see Completion Report).

Basic Course - Human Subjects Research (Curriculum Group)
Air Force Research Laboratory (AFRL) (Course Learner Group)
1 - Basic Course (Stage)

Under requirements set by:

U.S. Air Force Research Laboratory

CITI
Collaborative Institutional Training Initiative

Verify at www.citiprogram.org/verify/?w9555b87b-34f7-4e2a-a143-6901aeed24f3-37818178

AIR EDUCATION AND TRAINING COMMAND

UNITED STATES AIR FORCE

This is to certify that

Brian Lunday (CIV - (GS13-15))

has successfully completed

Human Subjects Research Training

conferred this **4th** *day of* **August** *in the year of* **2020**

AETC FORM 109, JUL 93 (REV) FOR OFFICIAL USE ONLY

AIR EDUCATION AND TRAINING COMMAND

UNITED STATES AIR FORCE

This is to certify that

Stephen Donnel (O-2 - (1Lt))

has successfully completed

Human Subjects Research Training

conferred this **6th** *day of* **September** *in the year of* **2020**

AETC FORM 109, JUL 93 (REV) FOR OFFICIAL USE ONLY

AIR EDUCATION AND TRAINING COMMAND

UNITED STATES AIR FORCE

This is to certify that

William Caballero (O-3 - (Capt))

has successfully completed

Human Subjects Research Training

conferred this **4th** *day of* **August** *in the year of* **2020**

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Curriculum Vitae
As of: August 10, 2020

Brian J. Lunday, Ph.D.
Professor of Operations Research
Department of Operational Sciences
Graduate School of Engineering and Management
Air Force Institute of Technology
Wright Patterson Air Force Base, OH 45433-7765
brian.lunday@afit.edu
(937) 255-3636 x4624

Online Professional Presence
ORCID ID: 0000-0001-5191-4361
Google Scholar: hyperlink

EDUCATION

Virginia Tech, Blacksburg, Virginia
Ph.D. in Industrial and Systems Engineering 2010
Dissertation: "Resource Allocation on Networks: Nested Event Tree Optimization, Network Interdiction, and Game Theoretic Methods"
Advisor: Dr. Hanif D. Sherali

University of Arizona, Tucson, Arizona
M.S. in Industrial Engineering 2001
Thesis: "The Modified Covering Problem on Paths and Trees"
Advisor: Dr. Jeffrey B. Goldberg

United States Military Academy, West Point, New York
B.S. in Mechanical Engineering (Aerospace Systems) 1992
Honors: Distinguished Graduate

RESEARCH INTERESTS

My theoretical research interests lie in the areas of math programming, game theoretic models, and algorithmic design for global optimization. From an application perspective, my research interests include network design, network optimization, network interdiction, network restoration, facility/resource location, and resource location/allocation & assignment.

ACADEMIC FACULTY EXPERIENCE

Associate Professor of Operations Research, Department of Operational Sciences, Graduate School of Engineering & Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio. 2020–present

Associate Professor of Operations Research, Department of Operational Sciences, Graduate School of Engineering & Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio. 2016–2020

Assistant Professor of Operations Research, Department of Operational Sciences, Graduate School of Engineering & Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio. 2013–2016

Assistant Professor, Department of Mathematical Sciences, United States Military Academy, West Point, New York. 2010–2013

Curriculum Vitae
As of: September 11, 2020

Stephen D. Donnel
Captain, US Air Force
Graduate Student
Department of Operational Sciences
Graduate School of Engineering and Management
Air Force Institute of Technology
Wright Patterson Air Force Base, OH 45433-7765
stephen.donnel@afit.edu
(937) 255-3636

EDUCATION

Indiana University of Pennsylvania; Indiana, Pennsylvania
B.S.Ed. in Mathematics Education 2013

Westminster College; New Wilmington, Pennsylvania
B.S. in Mathematics with a minor in Economics 2011

RESEARCH INTERESTS

My research interests lie in the areas of educational psychology, learning, and strategic decision-making.

PROFESSIONAL EXPERIENCE

Graduate Student, Master of Science in Operations Research, Department of Operational Sciences, Graduate School of Engineering & Management, Air Force Institute of Technology, Wright-Patterson AFB, Ohio.	2019–present
Data Analyst, 53rd Weapons Evaluation Group, Tyndall AFB, Florida.	2016-2019
Publishing Analyst, Descartes Systems Group, Pittsburgh, Pennsylvania.	2015-2016
Substitute Teacher, Butler Area School District, Butler, Pennsylvania.	2014-2015
Support Manager/Trainer, Kings Family Restaurants, Butler, Pennsylvania.	2011-2016

CURRENT PROFESSIONAL SOCIETIES

Military Operations Research Society (MORS)

Curriculum Vitae
As of: August 10, 2020

William N. Caballero, Capt, Ph.D., USAF
Chief, Operations Assessment Team
612 Air Operations Center
Davis-Monthan AFB, AZ 85707
william.caballero@us.af.mil
(520) 202-8166

CIVILIAN EDUCATION

Air Force Institute of Technology, Wright Patterson Air Force Base, Ohio
Ph.D. in Operations Research — 2019
Dissertation: "Persuasion, Political Warfare, and Deterrence: Behavioral and Behaviorally Robust Models"

Air Force Institute of Technology, Wright Patterson Air Force Base, Ohio
M.S. in Operations Research — 2017
Thesis: "On Proportionate and Truthful International Alliance Contributions: An Analysis of Incentive Compatible Cost Sharing Mechanisms to Burden Sharing"
Honors: Distinguished Graduate

University of Houston, Houston, Texas
B.S. in Industrial Engineering — 2011
Honors: Summa Cum Laude

MILITARY EDUCATION & TRAINING

Squadron Officer School, Maxwell Air Force Base, Alabama — 2019
Honors: Distinguished Graduate

AOC Strategy Division, Initial Qualification Course, Hurlburt Field, Florida — 2019

Officer Training School, Maxwell Air Force Base, Alabama — 2012
Honors: Distinguished Graduate

RESEARCH INTERESTS

- Mathematical programming and, specifically, bilevel programming and the development of accompanying algorithms and metaheuristics.
- Game theory with an emphasis on modeling and solving frameworks representing departures from expected utility theory and rational decision makers to include cumulative prospect theory, learning in games, and mechanism design.
- Adversarial frameworks for the application of the elements of national power (i.e., diplomatic, information, military, and economic means).

ACADEMIA EXPERIENCE

Adjunct Assistant Professor of Operations Research — June 2019 – Current
Air Force Institute of Technology

Conflict of Interest (COI) Disclosure Checklist

Researcher Assigned Distribution Statement:	Distribution A: Approved for Public Release; Distribution Unlimited

General Instructions

Completion:

- The Principal Investigator (PI) must complete, sign and submit to IR with their submission packet.
- All other research personnel must complete, sign and submit to the Principal Investigator. All COI checklists shall be retained with the research records and will be made available for inspection.
- For details and guidance on appropriate Distribution Statement, please refer to: https://afit.libguides.com/STINFO

Purpose:

- To promote professional research, the integrity of a given research design [to include its resultant data] will be free of conflicts of interest. Research team members will maintain research integrity at all times.
- To timely identify, remove, and/or mitigate conflicts of interest, all members of the research community have a non-delegable duty to report known, or reasonably suspected, conflicts of interest.
- Upon being made aware of a conflict of interest, or a *perception* of a conflict, leadership shall take appropriate remedial measures to ensure the continued integrity of the research environment.

Action: Researchers shall timely disclose, in an ongoing fashion, conflicts of interest that could reasonably be seen to affect the integrity of a proposed [or ongoing] research project. If subsequent facts arise which could alter the response to one or more of the below answers, I will immediately notify the PI of the below-referenced study.

Section 1: Contact Information

Name:	Brian J. Lunday	**Official E-mail:**	brian.lunday@afit.edu
Study Role:	Principal Investigator	**Phone/DSN:**	(937) 255-3636 x4624 (DSN 785)
Rank/Title:	AD-24/Professor	**Organization:**	AFIT/ENS
Project Title:	An Assessment of the Validity of Dual Channel Theory for Strategic Decision-making in Competitive Scenarios		

Section 2: Reportable Interests

Note: Responses reflect my interest(s) along with the interests of my family members, i.e., spouse, children.

Yes	No	Reportable Interest
☐	☒	I have an equity interest, stock, stock options or other ownership interests that conflict with my role in the above-referenced study.
☐	☒	I have, or expect to receive, a gift, gratuity, or compensation from the study sponsor, third party, or agent acting by or through a representative who is external to the study team.
☐	☒	I have, or expect to receive, an agreement for future employment from one or more parties external to my role in the above named study.
☐	☒	I hold a patent, to include intellectual property rights and interest, related to the purpose of this study.
☐	☒	I hold a position as an officer, director, trustee, partner, proprietor or consultant role with a sponsor or entity that is external to the team identified by the above-referenced study.
☐	☒	I have had connections with external partners or related sponsors over the course of the previous 12 months that would alter the answer to one or more of the questions contained herein.

AIR FORCE INSTITUTE OF TECHNOLOGY

Conflict of Interest (COI) Disclosure Checklist

Researcher Assigned Distribution Statement:	Distribution A: Approved for Public Release; Distribution Unlimited

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- To timely identify, remove, and/or mitigate conflicts of interest, all members of the research community have a non-delegable duty to report known, or reasonably suspected, conflicts of interest.
- Upon being made aware of a conflict of interest, or a *perception* of a conflict, leadership shall take appropriate remedial measures to ensure the continued integrity of the research environment.

Action: Researchers shall timely disclose, in an ongoing fashion, conflicts of interest that could reasonably be seen to affect the integrity of a proposed [or ongoing] research project. If subsequent facts arise which could alter the response to one or more of the below answers, I will immediately notify the PI of the below-referenced study.

Section 1: Contact Information

Name:	Stephen D. Donnel	**Official E-mail:**	stephen.donnel@afit.edu
Study Role:	Co-Principal Investigator	**Phone/DSN:**	
Rank/Title:	Capt/Student	**Organization:**	AFIT/ENS
Project Title:	An Assessment of the Validity of Dual Channel Theory for Strategic Decision-making in Competitive Scenarios		

Section 2: Reportable Interests

Note: Responses reflect my interest(s) along with the interests of my family members, i.e., spouse, children.

Yes	No	Reportable Interest
☐	☒	I have an equity interest, stock, stock options or other ownership interests that conflict with my role in the above-referenced study.
☐	☒	I have, or expect to receive, a gift, gratuity, or compensation from the study sponsor, third party, or agent acting by or through a representative who is external to the study team.
☐	☒	I have, or expect to receive, an agreement for future employment from one or more parties external to my role in the above named study.
☐	☒	I hold a patent, to include intellectual property rights and interest, related to the purpose of this study.
☐	☒	I hold a position as an officer, director, trustee, partner, proprietor or consultant role with a sponsor or entity that is external to the team identified by the above-referenced study.
☐	☒	I have had connections with external partners or related sponsors over the course of the previous 12 months that would alter the answer to one or more of the questions contained herein.

AIR FORCE INSTITUTE OF TECHNOLOGY

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Purpose:

- To promote professional research, the integrity of a given research design [to include its resultant data] will be free of conflicts of interest. Research team members will maintain research integrity at all times.
- To timely identify, remove, and/or mitigate conflicts of interest, all members of the research community have a non-delegable duty to report known, or reasonably suspected, conflicts of interest.
- Upon being made aware of a conflict of interest, or a *perception* of a conflict, leadership shall take appropriate remedial measures to ensure the continued integrity of the research environment.

Action: Researchers shall timely disclose, in an ongoing fashion, conflicts of interest that could reasonably be seen to affect the integrity of a proposed [or ongoing] research project. If subsequent facts arise which could alter the response to one or more of the below answers, I will immediately notify the PI of the below-referenced study.

Section 1: Contact Information

Name:	William N. Caballero	**Official E-mail:**	william.caballero@us.af.mil
Study Role:	Co-Principal Investigator	**Phone/DSN:**	520-202-8166 (DSN 282-8166)
Rank/Title:	Capt/Adjunct Assistant Prof	**Organization:**	AFIT/ENS
Project Title:	An Assessment of the Validity of Dual Channel Theory for Strategic Decision-making in Competitive Scenarios		

Section 2: Reportable Interests

Note: Responses reflect my interest(s) along with the interests of my family members, i.e., spouse, children.

Yes	No	Reportable Interest
☐	☒	I have an equity interest, stock, stock options or other ownership interests that conflict with my role in the above-referenced study.
☐	☒	I have, or expect to receive, a gift, gratuity, or compensation from the study sponsor, third party, or agent acting by or through a representative who is external to the study team.
☐	☒	I have, or expect to receive, an agreement for future employment from one or more parties external to my role in the above named study.
☐	☒	I hold a patent, to include intellectual property rights and interest, related to the purpose of this study.
☐	☒	I hold a position as an officer, director, trustee, partner, proprietor or consultant role with a sponsor or entity that is external to the team identified by the above-referenced study.
☐	☒	I have had connections with external partners or related sponsors over the course of the previous 12 months that would alter the answer to one or more of the questions contained herein.

6 February 2019 1

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

Abbreviated Consent
for
An Assessment of the Validity of Dual Channel Theory
for Strategic Decision-making in Competitive Scenarios

You are being asked to participate in a research study.

Key study information you should know:

- The purpose of the study is to evaluate the effect of both the mode of communication and the complexity of a situation on the ability of humans to select the best action in a strategic, competitive situation. If you choose to participate, you will be asked to take a computer-administered survey within the next week, in the privacy of your office or home, using an Excel-based test on a computer of your choice. This will take approximately 30 minutes.

- Potential risks or discomforts from this research include eye strain from taking a computer-based test.

- The study will assess the validity of selected tenets of the dual channel theory of learning within the context of making sound decisions in a competitive scenarios.

- Taking part in this research project is voluntary. You can discontinue participation at any time without penalty or loss.

Please take time to read this entire document and ask questions before deciding whether to take part in this research project.

If you participate in this research, your individual results will neither be evaluated nor reported. Instead, the aggregate results for the study participants will be evaluated for each survey question to assess the collective level of strategic thinking of the population sample. Comparisons of results will identify whether aggregate performance differed over the scenarios presented.

The researchers will take the following precautions to maintain the confidentiality of your data: The researchers will/will not collect any identifiers linked to you. No participant identifiers will be included in any publications. Electronic data will be password-protected/encrypted.

The data may be accessed by the Department of Defense for auditing purposes.

If you have questions regarding the study, contact the Principal Investigator: Capt Stephen D. Donnel (stephen.donnel@afit.edu), Dr. Brian J. Lunday (brian.lunday@afit.edu), or Capt William N. Caballero, PhD (william.caballero@us.af.mil). If you have questions regarding your rights as a research subject, contact the AFIT HRPP: 937-255-3636 x4543 or humansubjects@afit.edu.

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

October 7, 2020

MEMORANDUM FOR AFIT HUMAN RESEARCH PROTECTION PROGRAM (HRPP), OFFICE OF SPONSORED PROGRAMS AND RESEARCH (ENR)

FROM: AFIT/ENS

SUBJECT: Copy of Survey Instrument for *An Assessment of the Validity of Dual Channel Theory for Strategic Decision-making in Competitive Scenarios*

1. The survey instrument has been created in Microsoft Forms and will be administered via Microsoft Teams. For IRB/EDO review, an exact copy of the electronic survey may be found at the following hyperlink. Note that this link is only accessible to an

   https://forms.office.com/Pages/ResponsePage.aspx?id=iwsYgAQIHkSxmFmTxyeV-GFAsbyTscRFpRwL-xDc8W9UQURQVlQ5TzJGSElYQjFSNFQwQjJBUEtFQy4u

   Note that this link is only accessible to an AFIT member with a "@afit.onmicrosoft.com" account, thereby both (a) restricting access and (b) only allowing a participant to take the survey once. The settings on the survey do not record the respondent's identifying information.

2. The POC for this action is the undersigned at brian.lunday@afit.edu or (937) 255-3636 x4624.

BRIAN J. LUNDAY, PhD
Professor of Operations Research
Principal Investigator

Appendix B. Exemption Determination Approval

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY (AETC)

HRPP Exempt Determination Form

For AFIT HRPP Use Only	
Protocol Number:	REN2020015R Lunday
Protocol Title:	An Assessment of the Validity of Dual Channel Theory for Strategic Decision-making in Competitive Scenarios

EDO Determination				
Does this submission meet an Exempt Criteria? *Select the appropriate exemption category. Categories are defined in Exemption Request Package and on Page 2 of this form.*				
☒ Yes	Which exempt category applies?	**32 CFR 219.104 (d) (3) (i)**		
	Is a limited IRB Review required to determine adequate provisions are in place to protect the privacy of subjects and maintain confidentiality of data?		☐ **Yes**	☒ No
	If a limited IRB review is required, IRB Member determined that *either*: ☐ Sufficient measures were taken to protect privacy and confidentiality. **- OR -** ☐ Insufficient measures were taken to protect privacy and confidentiality.			
☐ No	☐	The human subject research does not meet any exempt criteria. Referred to AFRL IRB Chair for IRB review.		
	- OR -			
	☐	The research uses an In Vitro diagnostic device with specimens that are NOT individually identifiable. Referred to AFRL IRB Chair to determine compliance with applicable FDA regulations.		

AFIT EDO / IRB Member Submission Analysis
EDO Reviewer Comments
The BBI will include playing an online computer game/simulation (i.e. Prisoner's Dilemma) and then answering questions about their course of action. Names will not be collected and each subject will be assigned a random identifier so they cannot be linked to their specific responses.

AFIT EDO Signature	
ELSHAW.JOHN.J.1078680454 Digitally signed by ELSHAW.JOHN.J.1078680454 Date: 2020.10.20 11:05:50 -04'00'	6/20/2019

20 June 2019 1

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REPORT DOCUMENTATION PAGE

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25 March 2021	Master's Thesis	August 2019 — March 2021

4. TITLE AND SUBTITLE

Exploring the Limits of Strategic Thought: Evaluating how different communication Modalities affect the Nature of Strategic Decision using Cognitive Hierarchy

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Donnel, Stephen D, Capt

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

This research examines and quantifies the degree to which both information communication modality and the situational complexity affect individuals' ability to process the provided information and determine an effective strategy. Human subject testing herein consists of benign benevolent intervention involving the presentation of a series of strategic situations. For each situation, a participant attempts to identify their best response for a two-player, normal-form game with complete information. In each such game, players seek to maximize their own utility while considering their own actions, their opponent's actions, and each player's respective preferences over outcomes resulting from the possible combinations of actions. Dual channel theory directly informs our experiment's design; it specifies both the manner in which humans process information and the existence of capacity limits to such cognitive mechanisms.

15. SUBJECT TERMS

Game theory, categorical analysis, bootstrapping

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
U	U	U	UU	95	Dr. Brian J. Lunday, AFIT/ENS

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