

**CALC: A COGNITIVE ARCHITECTURE OF LEARNING  
AND COMPREHENSION**

by

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## Abstract

Cognitive architectures and unified theories of cognition have the potential to offer significant insight into the process of student learning. This dissertation proposes a cognitive architecture which defines how the mind integrates information into meaningful expressions through the acts of comprehension and learning. The proposed Cognitive Architecture of Learning and Comprehension (CALC), a Situated Model of Comprehension (SMC), and a Socially Situated Model of Comprehension (SSMC), integrate theoretical and empirical evidence from cognition, psychology and semiotics into a coherent model of how the mind comprehends and learns.

A research study on how the mind comprehends new information was performed to identify relevant cognitive correlates of how individuals make sense of nonsense sounds and pictures. Two groups were presented with both reference and relational information (Relational group), or only reference information (Reference group) based on the SMC. It was hypothesized that the Relational group would have higher performance scores (how many they match) and confidence scores (how confident they were in their choice) on all measures. The Need for Cognition assessment was hypothesized to correlate with performance on the task. In the first experiment, a re-interpretation of Bouba-Kiki experiment, the Relational group scored statistically significantly higher than the Reference group for performance ( $p = .021$ ), but not for confidence ( $p = .316$ ). In the Alien Language test, where users had to match sounds and images of an unknown language, MANOVA found that the Relational group scored statistically significantly higher than the Reference group for performance ( $p < .0005$ ), but not for confidence ( $p = .651$ ). In the Alien Language Post-test, where users had to generate the sound for a given alien shape, ANOVA found a statistically significant difference between the groups ( $p = .003$ ). The Need for Cognition assessment had insignificant correlation with the dependent variables and therefore was dropped as a covariate from the analysis. The finding that effortful cognition and confidence in answer choice did not correlate with performance calls into question how information is comprehended and acted upon outside of conscious awareness.

**Keywords:** CALC; Cognitive Architectures; Comprehension; Learning; Bouba-Kiki;

## **Dedication**

This dissertation is dedicated to Dr. Jillianne Code, my best friend, wife, and perpetual ass-kicker — you make me a better man.

## **Acknowledgements**

“all good science begins as an imaginative excursion into what might be true” – Peter Medawar, Nobel Laureate 1960

To my mother Lowell Nimac, you instilled in me the importance of education and imagination, which set me on the trajectory to where I am today. I would not be the person I am, or the person I’m going to become, without those values. It was your constant support of my crazy plans and ideas over the years that gave me the courage to complete a dissertation like this. To my advisors, Dr. John Nesbit and Dr. David Kaufman, thank you for supporting me through this endeavour. I know my work has been challenging, but it was your critical questions and feedback that brought my work to a different level. To my mentor, Dr. Stephen Campbell, thank you for all your encouragement, support, and friendship over the years. Working with you in the ENGRAMMETRON, our long probing discussions about life and politics, and your inquisitive questioning and challenge, helped shape this dissertation and made my experience at SFU fun and meaningful. Finally, to my colleagues and peers in the PhD program here at SFU, you made my time at SFU an experience to remember.

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## Glossary

*Cognitive architecture.* Cognitive architectures attempt to model the components and mechanisms of human cognition, including the functions of control, learning, memory, adaptability, perception, and action.

*Comprehension.* The ability to link discreet pieces of information into patterns that form the discourse of thought and understanding.

*Stimuli.* A detectible change in the internal or external environment, which influences or causes a temporary increase of physiological activity or response in the whole organism or in any of its parts, which can evoke a response or has an influence on a system to act.

*Attention.* Alerting, orienting, and executing recognition of an internal or external stimuli.

*Perception.* The identification of relevant, distinctive, and apparent qualities of objects, symbols, and stimuli that allows us to distinguish the characteristics of items for their recognition.

*Functional memory.* The active assembly of situated stimuli and past experience in the pursuit a particular action or goal. A type of ‘working memory.’

*Long-term memory.* The articulation of experience through expression, whether mental, physical, or behavioural.

*Conceptual stimuli.* Stimuli with attached attributes. Attributes are features that are used to describe or define stimuli. The attributes reflect our subjective comprehension and rationalization of what the stimuli means or represents

*Contextual stimuli.* The pattern or environment in which stimuli are situated.

*Reference stimuli.* Stimuli related to another for associative equality.

*Relational stimuli.* Stimuli with shared mediating information. The mediating stimulus provides the association that links the stimuli.

## **CHAPTER ONE: INTRODUCTION & OVERVIEW**

Cognitive architectures and unified theories of cognition have the potential to offer significant insight into the process of student learning. Cognitive architectures attempt to model the components and mechanisms of human cognition, including the functions of control, learning, memory, adaptability, perception, and action (Oltremari & Lebiere, 2011). Such models have the potential to provide a framework in which clinicians and educators can both evaluate and assess how learning succeeds, and where it may fail. Modelling how students integrate external stimuli into coherent expressions in memory, across a diverse set of tasks and domains, allows for a clearer understanding of how learning occurs. Using psychological constructs to model how the whole brain system integrates experience is one of the fundamental goals of the learning sciences (Bransford, Brown, & Cocking, 2000). Sun (2007) argues that psychologically oriented cognitive architectures are particularly important in that they:

- shed new light on human cognition and therefore serve as useful tools for advancing the understanding of cognition,
- may (in part) serve as a foundation for understanding collective human behaviour and social phenomena, and
- can be used in ‘intelligent’ systems that are cognitively realistic and therefore allow for human-like performance.

Although cognitive architectures have the ability to explain many cognitive, psychological, and neurological processes central to human learning, they are not sufficiently represented in the literature in educational psychology or the learning sciences.

The classification and reduction of cognition and learning into sub-fields of unrelated disciplines has led to a fragmented and disjointed view of the cognitive act of learning. A review of the chapter headings in textbooks on cognition and educational psychology, such as the textbook *Cognition* (Matlin, 2008) or the *Handbook of Educational Psychology* (Alexander & Winne, 2006), reveals a variety of topics including, but not limited to, attention, visual and auditory recognition, perception, working memory, long-term memory, language, problem solving, decision making, and creativity. Missing from this list is any concept of holistically relating these categories into an assembly of cognitive action, comprehension, and learning. The holistic view of cognition has been largely relegated to philosophers, neurologists, and computing scientists; a realization that ought to be challenged.

The unification of cognitive principles into coherent models of how the mind works is not a novel concept. John Anderson, the developer of the ACT-R cognitive architecture, and Allen Newell the author of *Unified Theories of Cognition*, both conclude that there is enough evidence accumulated in cognitive science over the past 60 years to propose unified theories of cognition (J. R. Anderson, 1983; Newell, 1990). Although cognitive architectures have been used in artificial intelligence, machine learning, and cognitive systems that mimic human intelligence and behaviour, few

cognitive architectures bridge the disciplines of human psychology, cognition, and learning.

The purpose of this chapter is to review current cognitive architectures as they relate to cognition and learning, to review the use of cognitive architectures in education, and to establish the need for a new cognitive architecture of learning and comprehension in the learning sciences.

### **Cognitive Architectures and Unified Theories of Cognition**

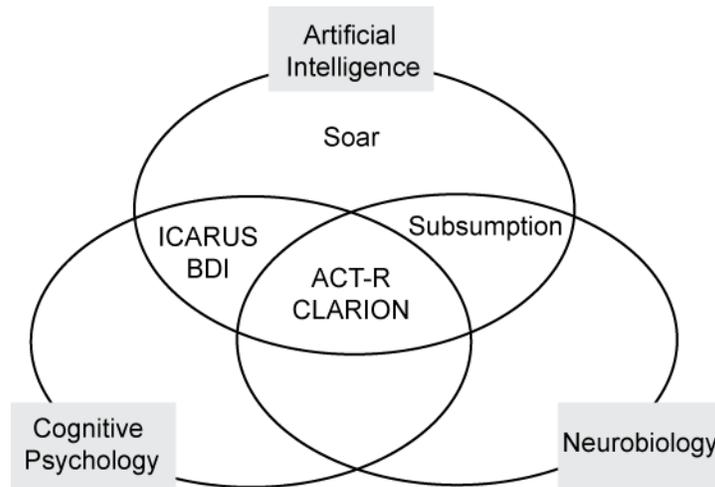
“To understand the mind, we need an abstraction that gets at its essence. The cognitive architecture movement reflects the realization that this abstraction lies in understanding the relationship between structure and function rather than focusing on either individually” (J. R. Anderson, 2007)

The integration, synthesis, and explanation of cognitive action are the goals of cognitive architectures. Cognitive architectures aim to answer questions of trying to understand human cognition in a dynamic changing environment. Allen Newell who coined the term cognitive architecture as an analogy to computer systems (Bell & Newell, 1971) defined it as “the fixed (or slowly varying) structure that forms the framework for the immediate processes of cognitive performance and learning” (Newell, 1990, p. 12). Langley, Laird, and Rogers (2009) in a recent review outline the typical elements of cognitive architectures which include:

- short-term and long-term memories that store content about the agent's beliefs, goals, and knowledge;
- the representation of elements that are contained in these memories and their organization into larger-scale mental structures; and
- the functional processes that operate on these structures, including the performance mechanisms that utilize them and the learning mechanisms that alter them.

The assumptions of how the above elements interact form the base of how the architecture supports intelligent cognitive action. In his book *Society of Mind*, Marvin Minsky (1988) outlines how each element of an intelligent system, and the diversity of mechanisms within that system, can bring about intelligent action from mindless subsystems. It is through the interaction and diversity of the interactions and functional components that intelligence emerges. The questions asked about what constitutes intelligent action dictate the outcome and structural relationship of the architectural elements. Similar to how an office building and a car garage have different functions that dictate their structure, the structures of cognitive architectures build theory and models to explain observable outcomes of cognition function.

Chong, Tan and Ng (2007) in a survey of integrated cognitive architectures compare six cognitive architectures and their application in artificial intelligence, cognitive psychology, and neurobiology (see Figure 1). In the review, the authors look at the cognitive architectures Soar, ICARUS, BDI, Subsumption, ACT-R, and CLARION. The two cognitive architectures that offer the most significant bridge between cognition, neurobiology, and artificial intelligence are ACT-R and CLARION.



*Figure 1.* Overview of six cognitive architectures. From “Integrated cognitive architectures: A survey,” by Chong et. al., 2007. Copyright 2007 by Springer. Reprinted with permission.

## **ACT-R**

The Adaptive Control of Thought – Rational (ACT-R) cognitive architecture aims to generalize and extrapolate human intelligence and behaviour. Created by John Anderson (J. R. Anderson, Bothell, & Byrne, 2004; J. R. Anderson & Lebiere, 1998; J. R. Anderson, 1983), ACT-R is implemented in a vast array of areas including perception, attention, learning, memory, problem solving, decision-making, language processing, and cognitive development (see ART-R, 2012). The ACT-R architecture consists of modules, buffers, and a pattern matcher (see Figure 2).

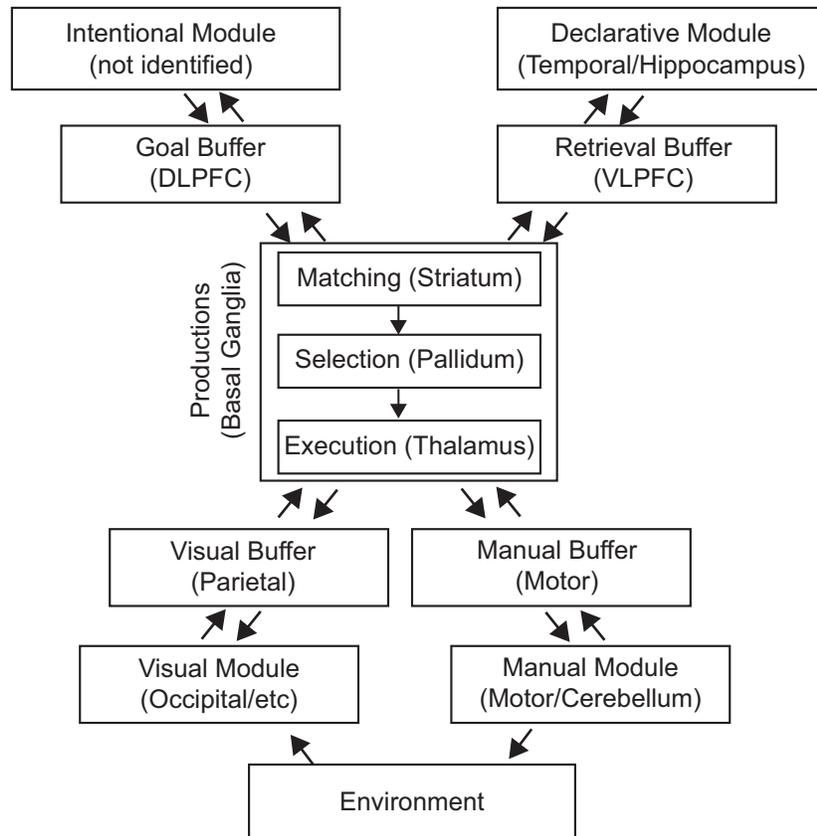


Figure 2. The ACT-R cognitive architecture. From “Integrated cognitive architectures: A survey,” by Chong et. al., 2007. Copyright 2007 by Springer. Reprinted with permission.

Each module within the ACT-R system is associated with a specific brain region, which reflects their function. The modules of ACT-R are visual, manual, intentional, declarative, and procedural. The perceptual-motor module is the interface to the external world through the visual and manual modules. The declarative memory module is specialized for the storage of knowledge and facts into component *chunks*, while the procedural module is specialized for knowledge on how to do things, known as *production rules*. The intentional module is responsible for the current goal state, which controls the order in which productions are fired.

The buffers of the ACT-R architecture interface with the modules and hold in memory any given state within the system. The production system of ACT-R proposes that cognitive function is composed of a series of inter-related conditional statements known as *production rules*. These production rules, or *condition-action pairs*, of matching, selecting, and execution are similar to *if-then* statements in a computer program. Cognitive tasks are executed when production rules are applied in working memory. The pattern matcher searches for conditions that match the state within the buffers. When a production rule matches the state within a buffer, it is fired and a cognitive action is initiated as a succession of production firings that spread activation (ART-R, 2012). The symbolic processes of pattern matching and the subsymbolic system of paralleled processes, which reflect past use, allows the system to put weight on any particular match and the speed of retrieval and action. Learning and the automation of tasks takes place by the strengthening of production paths (Sorden, 2005).

In the book chapter *Implications of the ACT-R learning theory: No magic bullets* (J. R. Anderson & Schunn, 2000), Anderson and Schunn review ACT-R's application in the learning sciences. Pointing out that ACT-R has been promoted as a "simple theory of learning and cognition" (p. 2), the authors propose that "all complex cognition is composed of relatively simple knowledge units which are acquired according to relatively simple principles" (p. 2) and that the complexity of learning is reflected in the complex aggregate of action and behaviour within the system.

Knowledge acquisition within ACT-R takes place either through passive receptive encoding from the environment or active constructive encoding from past mental operations. Procedural knowledge or production rules are learned through a

process of *analogy*. An analogy is composed of two elements: 1) a goal and 2) an example solution for such a goal. Procedural learning is “acquired by making references to past problem solutions while actively trying to solve new problems” (p. 5). Chunks of declarative information and productions of procedures are “all-or-nothing” systems, where new symbolic information is either permanently added or forgotten. The development of knowledge or learning is determined by the activation and use of the material that strengthens with its use over time.

The activation process, the information-processing step in ACT-R, takes place when a production rule is fired and some declarative information is retrieved and used to solve a particular goal. The speed at which the declarative or procedural task is analysed and implemented is based on the activation level of the chunk or strength of the production rule. This strength is reflected in the fluency or performance of the procedure, which is a reflection of learning. The strength or weakness of activation is reflected in a number of Bayesian probabilities of chunk retrieval and use. The Bayesian equations, which can be seen in the *Implications of the ACT-R learning theory: No magic bullets* paper, represent accuracy, latency, and activation within the system. The probability resultants of these equations reflected in a number of psychological experiments on learning and forgetting (for a review see J. R. Anderson, 1995) and leads to a number of stated laws within the theory (J. R. Anderson & Schunn, 2000, p. 8):

- 1) Power Law of Learning: As a particular skill is practiced there is a gradual and systematic improvement in performance.
- 2) Power Law of Forgetting: As times passes performance degrades.

- 3) **Multiplicative Effect of Practice and Retention:** There is a multiplicative effect relation between the combined variables of amount of practice and duration over which the information must be maintained.

What the laws state is that performance continuously improves with practice and continuously degrades with time. This means that increased practice will improve performance and also combat declarative and procedural knowledge attrition.

Understanding or comprehension within ACT-R is represented by having a large number of declarative chunks and a large number of procedural units on how the knowledge can be used. Complex concepts are nothing more than complex schema of related chunks. Procedural knowledge on how to use these chunks is a set of conditions in which the information can be used. A large number of these procedural condition-action pairs, allows for a wide range of production firings, or cognitive actions. The goal structures within the ACT-R system decomposes any goal into sub-sequences of subgoals, which act on the procedural and declarative information they are trying to solve. The strategy of how the information is used is based on symbolic and subsymbolic components.

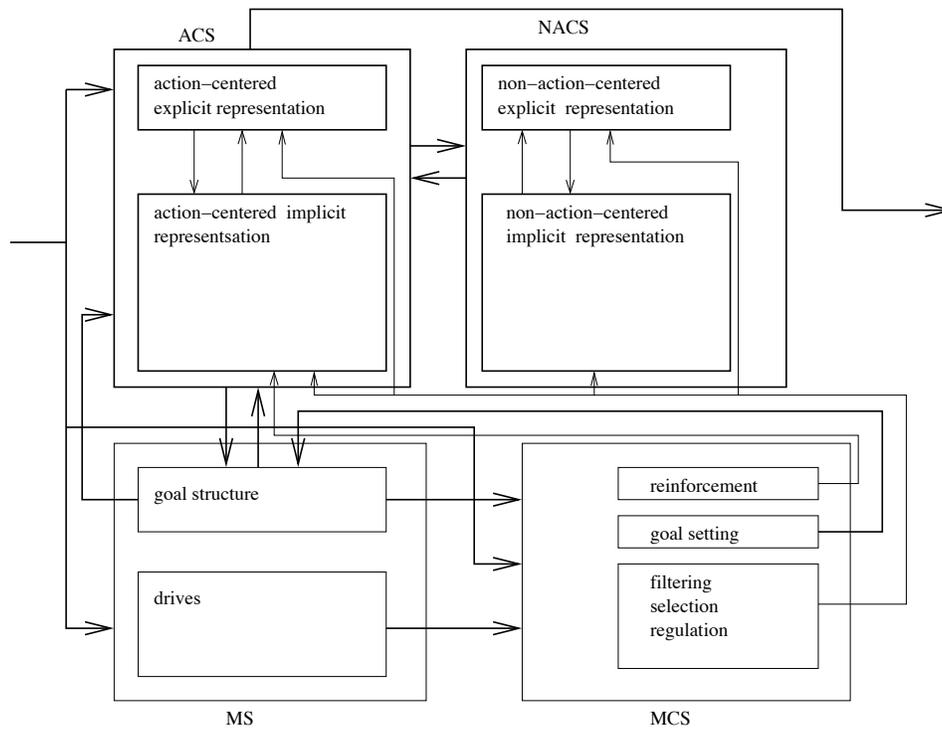
The symbolic component uses a learned set of different productions while the subsymbolic system uses the learner's self-efficacy in expected effort and expected success. The subsymbolic system is learned through a gradual use of production attempts. The learner selects productions by weighing the trade-offs between success and effort, choosing the production with the best trade-off value. These self-efficacy pairings are inline with human strategy selection and problem solving (Lovette & Anderson, 1996). Although subsymbolic system within the ACT-R architecture sets out

the motivations of the learner through production trade-offs, specific cognitive motivational production rules are not specified as they are in other cognitive architectures such as CLARION.

## **CLARION**

The Connectionist Learning with Adaptive Rule Induction ON-line (CLARION) architecture is an integrative model of agentic action. Created by a research group led by Ron Sun (Sun, 2001, 2002, 2007; Sun, Merrill, & Peterson, 1998), the model includes several functional sub-systems that aim to explain implicit and explicit agentic processes, actions, and interactions. The architecture was specifically developed to address implicit-explicit interactions, cognitive-metacognitive interactions, and cognitive-motivational interactions, which are not sufficiently represented in other cognitive architectures such as ACT-R or Soar (Sun, 2005). The CLARION architecture consists of four interrelated systems (see Figure 3):

- Action-Centered Subsystem (ACS) controls actions and decision-making.
- Non-Action-Centered Subsystem (NACS) maintains general declarative and episodic knowledge.
- Motivational Subsystem (MS) provides underlying motivations for perception, action, and cognition.
- Meta-Cognitive Subsystem (MCS) monitors, directs, and modifies the operations of all the other subsystems.



*Figure 3.* The CLARION cognitive architecture. From “Cognition and Multi-agent Interaction: From Cognitive Modelling to Social Simulation.” by Ron Sun 2006. Copyright 2006 by Cambridge University Press. Reprinted with permission.

A key assumption within CLARION is the dichotomy between implicit and explicit cognition. The dichotomy within the CLARION architecture is based on the research in implicit/explicit learning, implicit/explicit memory, and implicit/explicit perception. Implicit processes are less accessible to conscious processes yet more robust, while the explicit processes are more accessible to conscious processing (Sun, 2002).

Learning within CLARION, which significantly differs from ACT-R (J. R. Anderson & Lebiere, 1998), is innate to the agent and does not need explicit external modelling. Learning can proceed as trial-and-error, bootstrapping through “bottom-up

learning”, or through the development of explicit domain knowledge gained in a gradual and incremental fashion from external sources (Sun, 2005). Innate abilities, biases, and behaviours of the agent can also facilitate learning through their interactions with other agents and the environment. These innate behaviours can allow the agent to learn new declarative and procedural knowledge through the constraining, guiding, and facilitating the agents assimilation and interactions with the information.

CLARION has been used in a number of experiments on human learning including serial-time tasks, problem solving, and cognitive skill acquisition (Sun, 2012). And although CLARION draws attention to the dichotomy between implicit and explicit knowledge and learning, the architecture is far too complex to draw clear heuristics for instruction and for the assessment of student learning. Cognitive architectures for the learning sciences need to be developed that offer both holistic views of the cognitive act of learning that are accessible for both the development and assessment of instruction and student learning.

### **Cognitive Architectures in the Learning Sciences**

Cognitive architectures have not made a significant impact in educational theory or practice. Although used in simulating human cognitive action, intelligence, and machine learning, the generalizability for these applications to the classroom and human learning seems to be a bridge too far. The misinterpretation of what constitutes a cognitive architecture even eludes distinguished journals and researchers in the field of the learning sciences.

In a 2006 review in the *Educational Psychologist* titled *Cognitive Architectures for Multimedia Learning* (Reed, 2006), Reed provides an overview of six theories that generalize cognitive learning in multimedia environments. The theories presented are Paivio's Dual Coding Theory (Paivio, 1986, 2007), Baddeley's Theory of Working Memory (Baddeley, 1986, 1999), Engelkamp's Multimodal Theory (Engelkamp, 1998), Sweller's Cognitive Load Theory (Sweller & Chandler, 1994; Sweller & Chandler, 1991), Mayer's Multimedia Learning Theory (Mayer, 2005, 2001), and Nathan's ANIMATE Theory (Nathan, Kintsch, & Young, 1992). Although each theory contains some representative elements of cognitive architectures, most of the theories presented in the review do not constitute cognitive architectures as defined in the related literature (see J. R. Anderson, 2007; Langley et al., 2009; Newell, 1990). This misrepresentation is not surprising, as cognitive architectures have not made a significant impact in the learning sciences or related literature. There is, however, one theory that has been proposed as a cognitive theory for learning that meets most of the criteria of a cognitive architecture; Richard Mayer's Cognitive Theory of Multimedia Learning (CTML) (Mayer, 2005, 2001).

Richard Mayer in his book *Multimedia Learning* (2001) proposes a cognitive theory of multimedia learning that bridges the divide between psychology, cognition and learning design. The base assumption of Mayer's work is that learning environments designed based on how the human mind works, will more likely lead to meaningful learning than those that are not (Mayer, 1992, 2005, 2001).

The Cognitive Theory of Multimedia Learning (CTML) is an amalgamation of cognitive theories to explain how people learn from pictures and words. The CTML

references Baddeley's model of working memory (Baddeley, 1986, 1999), Paivio's Dual Coding Theory (J. M. Clark & Paivio, 1991; Paivio, 1986), and Sweller's Cognitive Load Theory (Chandler & Sweller, 1991; Sweller, Chandler, Tierney, & Cooper, 1990). The foundation in which the principles of multimedia learning are established, assume a cognitive architecture that includes dual channels, a limited capacity, and active processing (Mayer, 2005, 2001).

#### *Dual-channel assumption*

The dual-channel assumption of the CTML proposes that our information processing system contains an auditory/verbal channel and a visual/pictorial channel (Mayer, 2005, 2001). When information is presented in either a visual or auditory form, our brain processes the information in separate independent processing channels. Supporting this assumption is Paivio's Dual Coding Theory (J. M. Clark & Paivio, 1991; Paivio, 1986) with two distinct subsystems, a verbal system specialized with language and a nonverbal system specialized for dealing with imagery, and Baddeley's model of working memory (Baddeley, 1986, 1999) which includes a two-part system of a visuospatial sketchpad for visual information and a phonological loop for auditory information. Both the presentation mode, focusing on how the material is presented to the learner as either visual or auditory form, and the sensory mode, how the information is processed in the learners cognitive system, are integrated in the CTML and reflected in the principles of multimedia learning.

#### *Limited capacity assumption*

The limited capacity assumption is related to the contention that working memory has a limited capacity for processing auditory and visual information

(Baddeley, 1999; G. A. Miller, 1956) and is vulnerable to overload (Sweller, 1994).

Based on Sweller's Cognitive Load Theory (Chandler & Sweller, 1991; Sweller, 1988), the CTML suggests that by lowering extraneous cognitive load, which takes up limited resources not relevant to the task at hand, learning can be improved (Mayer, 2001).

Limitations of the working memory system for processing auditory and visual information forces designers to allocate, coordinate, and adjust multimedia to focus the learner on relevant aspects of learning. The effective design principle of only presenting what is essential for learning, promotes intrinsic and germane load, while limiting extraneous load. The principles of multimedia learning suggest that the organization and design of instruction can affect both the capacity and the amount of processing necessary for effective learning (Mayer, 2005).

#### *Active processing assumption*

The active processing assumption proposes that learners are active participants in learning and knowledge generation, rather than passive participants in knowledge acquisition. Active learners regulate and control their learning processes by selecting and organizing relevant information and building connections to relevant existing knowledge (Mayer, 1992, 2001). These processes led to the construction of mental models and knowledge structures that help learners make sense of the information presented. The implications of this assumption for the design of instruction are that (1) presented material should have a coherent structure and (2) messages should provide the learner with guidance on how to build knowledge structures (Mayer, 2005). The active processing assumption is based on Wittrock's (1990) Generative theory and Mayer's (1996) SOI model of meaningful learning.

Mayer incorporates the three assumptions of the Cognitive Theory of Multimedia Learning into a model that represents the human cognitive architecture and process of learning from pictures and words (Mayer, 2001) (see Figure 4).

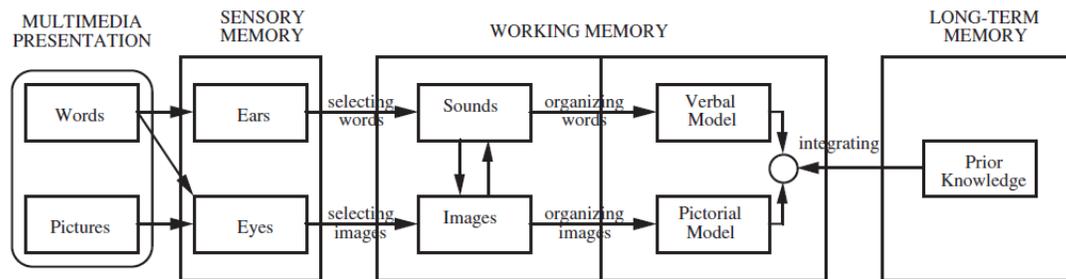


Figure 4. Cognitive Theory of Multimedia Learning. From “The Cambridge Handbook of Multimedia Learning” edited by Richard E. Mayer, 2005. Copyright 2005 by Cambridge University Press. Reprinted with permission.

Based on the assumptions of this human cognitive architecture, Mayer and colleagues have undertaken a discipline of research over the past 20 years that aims to understand the dynamics of cognition and learning. The principles of multimedia learning are a reflection of that research, which aims to summarize the research findings into instructional design heuristics or principles.

The principles of multimedia learning are based on the general assumptions of human learning and cognitive architecture. These principles aim to provide instructional design heuristics for educators when designing multimedia-learning environments. Although Mayer and colleagues have provided several studies on how these design heuristics lead to retention and transfer effects (e.g. see Mayer, Fennell, Farmer, & Campbell, 2004; Mayer & Johnson, 2008; Mayer, Mautone, & Prothero, 2002; Mayer & Moreno, 1998), they have not continued the progression of the principles to answer *why* these effects are observed using primary literature from

neuroscience, cognition, and psychology. Many of the conclusions of the studies of multimedia learning are based on the base assumptions of the cognitive theory of multimedia learning, with no reference to empirical studies in cognition, psychology, and neuroscience.

Further to the above-mentioned points, there are four very large oversights within the Cognitive Theory of Multimedia Learning that ought to be challenged. First, is the lack of explanation of how integration takes place in working memory (Reed, 2006), second, is the assumption of semantic equivalence of text and pictures when they are radically different representations (Snhnotz, 2002), third, is the lack of integration of other modalities in the theory, such as touch, taste, smell, and fourth, is the role of affect, goal orientation, and motivation in learning. Although the theory does offer heuristics for multimedia learning design, it does not generalize to all learning situations. Research in the principles of multimedia learning finds contradicting evidence (see Kalyuga, Chandler, & Sweller, 2004; Koroghlanian & Sullivan, 2000) which is not predicted by the theory and need to be revised (Moreno & Mayer, 2002). The lack of generalizability of Mayer's theory shows that "what has been learned about the principles that guide some aspects of learning do not constitute a complete picture of the principles that govern all domains of learning" (Bransford et al., 2000, p. 14).

### **Conclusion: Establishing the Need for a Cognitive Architecture for the Learning Sciences**

Current integrative cognitive theory in educational psychology, such as the Cognitive Theory of Multimedia Learning, and cognitive architectures within cognitive science, such as ACT-R and CLARION, are not sufficient for explaining human

comprehension and learning. The classical information-processing paradigm that ignores the brain, and the connectionist paradigm that ignores the mind, are not sufficient to understanding human cognition in the real world (J. R. Anderson, 2007). The information processing metaphor of cognition used in current architectures, have disembodied the internal representations of the individual to symbol processing and manipulation. This metaphor, although effective in computing, neglects the fact that signs, symbols, and representations only acquire meaning when grounded in the world in which the agent acts (Lave & Wenger, 1991). This assertion does not negate the use of these theories and architectures for understanding and explaining very real phenomena of cognition in action. Just as Behaviourism (Skinner, 1938, 1945, 1953) explains many real world cognitive acts, but not all, each component model and theory propels knowledge toward a singular unified understanding of cognition. The fact that there are so few cognitive architectures that integrate cognition, psychology, and learning in the literature, suggests that few researchers are looking at the process of learning in a unified way. The misrepresentation of cognitive architectures in the learning sciences (e.g. Reed, 2006) suggests that there is a need for the use and development of cognitive architectures in exploring human learning. A paradigm shift in the exploration of learning as a unified process could bring the fields of educational psychology, cognition, and the learning sciences into new frames of exploration and development.

### **Purpose of this Research**

The purpose of this research is to propose a cognitive architecture, which defines the cognitive elements on how the mind integrates stimuli into meaningful expressions

through the acts of comprehension and learning. The proposed Cognitive Architecture of Learning and Comprehension (CALC), a Situated Model of Comprehension (SMC), and a Socially Situated Model of Comprehension (SSMC), integrate theoretical and empirical evidence from cognition, psychology and semiotics into a coherent model of how the mind comprehends and learns. A novel experiment on how the mind integrates novel sounds and visuals, the Alien Language test, is used to explore comprehension, cognitive integration, and learning.

### **Theoretical Questions**

The architecture proposed in this dissertation attempts to address the following questions:

1. What are the cognitive components of comprehension and learning?
2. What are the cognitive correlates of symbol grounding?

### **Research Questions**

The research question addressed in this dissertation is:

1. How much information do individuals need to decode and comprehend nonsense symbols and sounds without explicit instruction?

### **Significance of the Proposed Architecture and Study**

The proposed architecture in this dissertation is significant because it aims to model the cognitive components of learning and comprehension. Building on established theoretical and empirical evidence from cognition, psychology, and semiotics, the architecture aims to explain cognitive action for learning and

comprehension. The implications in cognitive science, artificial intelligence, and educational theory are great. Similar to other integrative cognitive architectures, such as ACT-R, CLARION, and the Cognitive Theory of Multimedia Learning, the outcome and applications of these models may span a variety of disciplines beyond the scope of this study.

This study is significant because it will identify relevant cognitive correlates of how individuals make sense of nonsense sounds and pictures using an innovative paradigm of an Alien Language test. This study will be a significant contribution to the field of cognitive semiotics and cognitive architectures for learning, which are still in their infancy.

### **Dissertation Organization**

Chapter Two is an introduction to the proposed Cognitive Architecture of Learning and Comprehension (CALC). Relevant literature is reviewed and theoretic constructs are proposed that support the assimilation of sensation, perception, memory, and cognitive action into an integrated framework. Two models that support a Cognitive Architecture of Learning and Comprehension are introduced; a Situated Model of Comprehension (SMC) and a Socially Situated Model of Comprehension (SSMC). Processes and mechanisms for the integration and expression of experience in long-term memory are proposed, as well are the basic cognitive components of comprehension and learning.

Chapter Three describes the research methods, tools, instruments, data collection, and data analysis used to evaluate comprehension. A novel experiment of

the comprehension of novel words and pictures is used to evaluate how the mind comprehends and integrates cross-modal media in support of the proposed architecture.

Chapter Four presents the results and analysis of the data collected from the study.

Chapter Five discusses the analysis and results of the study in reference to established empirical research and the proposed cognitive architecture. Relevant conclusions, implications, and recommendations for further research and applications of the architecture are suggested.

## **CHAPTER TWO: A COGNITIVE MODEL OF COMPREHENSION**

Meaning is the currency of mind. The processes and mechanisms in which new information is acquired and internally represented for later use, forms the base of our ability to adapt and evolve (Byrne, 2008). The act of integrating internal and external stimuli, expressions, and experience into coherent meaningful constructions is the process of cognition. The physical, cognitive, and social elements of these adaptations are represented in our interactions within the environment and with other organisms. The recognition, recall, and instantiation of patterns within our brain and within the environment provide the base of all human cognition and memory. In the cognitive architecture elaborated in this chapter, the process and mechanisms of learning and comprehension are integrated into three components:

- A Cognitive Architecture of Learning and Comprehension (CALC)
- A Situated Model of Comprehension (SMC), and
- A Socially Situated Model of Comprehension (SSMC)

The cognitive architecture and models posits the following assumptions of human cognition:

- Stimuli from the internal and external environment are inherently arbitrary until interpreted.
- Perception is the combination of attention and functional memory.
- Attention limits perception and cognition.

- Functional memory biases perception and cognition.
- Cognition is the process of comprehension through the recognition, formation, and integration of *context*, *concept*, *reference*, and *relational* patterns of information. These patterns are called *Semantic arrays*.
- The use of *semantic cues*, *semantic leaps*, and *frame-shifting* augment comprehension.
- Long-term memory is the articulation of experience through expression, whether mental, physical, or behavioural. The expressions from long-term memory can be *constructive*, *selective*, or *generative*.
- Learning is the reinforcement of expression.
- Learning takes place through the four processes of *selection*, *interpretation*, *integration*, and *expression*.
- Pattern *recognition*, *recall*, and *instantiation* are the primary mechanisms of comprehension, cognition, and memory.

My approach in developing a cognitive architecture is to outline and address the basic elements and mechanisms of the human experience. How we comprehend the world, how we learn, and how we use that information for later use, is paramount to understanding human psychology. My explanation of this architecture presents the necessary elements of an integrated holistic view of human cognition and intelligence. How information is perceived, interpreted, integrated, and expressed, are all articulated from abstractions within the proposed architecture. Figure 5 is a diagram that visually models the structures and process of the Cognitive Architecture of Learning and

Comprehension (CALC). Although the visual model assumes a linear form, and is intended to depict a path by which information is processed, it is not intended to require serial processing. The visual model is a way of presenting the elements in an abstract form to articulate their functional relationships. Stimuli informers ( $S_a$ ,  $S_b$ ) are information that is used as determinates of goals, motivation, action (N. H. Anderson, 1996, 2013, 2014) and comprehension. These stimuli informers come from either the external environment or the internal environment of the mind, and can be a variety of things including images, sounds, touch, taste, smell, or even emotion and thought.  $S_a$  are the primary stimuli perceived, and  $S_b$  are secondary stimuli informers that are used for the interpretation, integration, and comprehension of the primary stimuli.

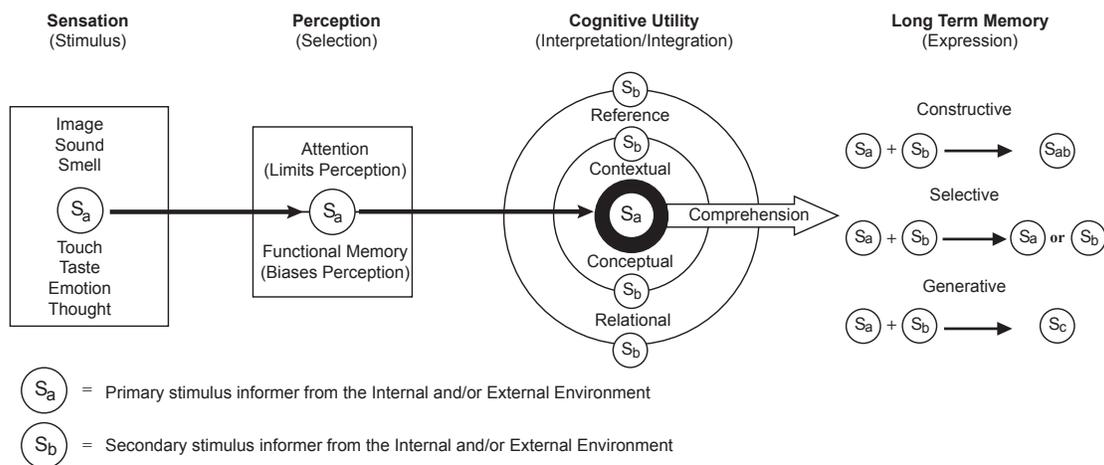


Figure 5. A Cognitive Architecture of Learning and Comprehension (CALC).

CALC borrows elements from empiricism (Hume, 1967; Locke, 1690), nativism (Chomsky, 1967; Fodor, 1975; Pinker & Jackendoff, 2005), embodiment (Varela, Thompson, & Rosch, 1991), evolutionary psychology (Darwin, 1872; James, 1884), and gestalt theory (Koffka, 1935; Wertheimer, 1923). CALC does not fully conform to any of these prior theories and may contradict them on particular points. Instead, it borrows

elements that naturally cohere to form a new synthesis. A wide range of research from cognition, psychology, and neuroscience is used to support the functional components of CALC. A full exploration of any one of these research areas' relevant empirical, theoretical, or philosophical evidence is not within the scope of this dissertation. Selected empirical evidence and theoretical justifications are presented that offer insights into the structure and function of the architecture and its models. Neuroscience research is used as a bridge to link the cognitive components of CALC with neurological and physiological support. The importance of making this bridge cannot be understated. Early pioneers of cognitive architectures, such as Alan Newell and his Soar architecture, support a unembodied view of cognition as symbol manipulation with a complete independence from modal content and no neuroanatomical overlap with sensory-motor systems (Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012). Architectures such as ACT-R and CLARION start to bridge the gap between cognitive, neurological, and sensory-motor systems (Chong et al., 2007), but do not address the sociocultural component of cognition. CALC furthers this evolution by linking the functional relationship of social, cognitive, neurological, and sensory-motor systems and supporting the convergence of an unembodied, embodied, and sociocultural view of cognition.

This dissertation aims to present and explore a cognitive architecture that provides a parsimonious account of the steps and mechanisms in which the mind selects, interprets, integrates, and expresses experience through the acts of comprehension and learning.

### **Sensation and Stimuli: The Media of Cognition**

The brain is not inert or passive, waiting for the sensory apparatus to come in contact with external stimulation in order to initiate brain activity. The brain is active, is operative prior to birth, and initiates activity by ordering the sensory network to respond to certain structures of information (Gregg, 1984, p. 30)

Stimuli from the internal and external environment of human brain provide the building blocks for human cognition. It is recognized that the term stimuli has a historical definition from classical psychology as events in the environment that influence behaviour (Gibson, 1960), however leading figures in medicine and neuroscience have extended this definition to include activity in the brain.

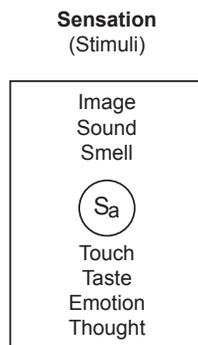
Georg Northoff, the Canadian Research Chair of Mind, Brain Imaging, and Neuroethics, and Michael Smith Chair of Mental Health and Neuroscience, uses the term stimuli extensively in publications to denote intrinsic activity in the brain. Terms such as intrinsic stimuli (Northoff, 2009), neural stimuli (Northoff, 2012), and self-referential stimuli (Northoff & Bermpohl, 2004), are used in the literature to represent intrinsic activities such as self-awareness, emotions, thoughts, and ideas. It is these intrinsic stimuli that are used for such processes as representation, monitoring, evaluation, integration, self-awareness, unity, agency, emotion, and autobiographical memory (Northoff & Bermpohl, 2004). It is worth noting that this is not a new definition of the term, as there are publications in physiology going back to the 1960s that use the term “intrinsic stimuli” to represent thought and emotion. Missiuro (1961)

in his paper *The influence of environmental stimuli and of intrinsic stimuli on the working capacity and on resistance to fatigue*, uses the term intrinsic stimuli to represent the influence of emotions on the functional efficiency of the body. The paper concludes that the central nervous system and the brain are important factors in influencing physiological processes. The differentiation of stimuli into interoceptive, stimuli produced within an organism, exteroceptive, stimuli external to an organism, and what could be called neuralceptive, stimuli produced within the brain, are not differentiated in CALC as it is the functional relationships of the elements that denotes their importance for comprehension.

CALC uses the term stimuli to denote both information perceived from the external environment such as tastes, smells, and images as well as information from within the internal environment of the mind such as thoughts, ideas, and emotions. Although using the term stimuli to denote a thought, emotion, or ideas in the brain may seem idiosyncratic from a classical psychology point of view, the addition of intrinsic brain activity to the definition of stimulus fits with the current definition from physiology. Using a physiological definition, stimuli are defined as:

- 1) a detectible change in the internal or external environment
- 2) which influences or causes a temporary increase of physiological activity or response in the whole organism or in any of its parts
- 3) which can evoke a response or has an influence on a system to act (Leidlmair, 2009).

This definition supports that stimuli do not simply elicit a response, but are the building blocks of a feedback-response loop that influences the individual to act, interpret, and respond. Figure 6 outlines some of the various primary stimuli informers ( $S_a$ ) such as images, sounds, smells, or thoughts that can be interpreted by the brain for comprehension.



*Figure 6.* The components of internal and external environmental stimuli.

The modalities of stimuli from the external environment, such as light, touch, and sound, although perceived through special organs such as the eyes, nose, and skin, are not perceivable to the brain in their original form. Physiologically the brain as an electro-chemical system only responds and acts on stimuli from either the internal or external world in which it exists (Ng, 2009; Ratey, 2002). The sensory receptors from the eyes, nose, and skin relay a detectable change in the environment and send a message to the brain through sensory transduction. The brain then interprets this sensory informer as an image, sound, or temperature change. Similarly, stimuli can originate from the internal environment of the individual.

Homeostatic imbalance, such as thirst, hunger or temperature change, blood pressure, and emotional responses such as fear, all elicit physiological responses for the

individual to act. Internal stimuli are perceived through receptors, sensors, and the central nervous system within the body and translated by the brain for action. The brain as part of the central nervous system does not only translate stimuli, but can also produce stimuli such as emotion and thought.

Induced activity in the brain is spontaneous oscillations that are not directly related to external stimuli. These “oscillations are induced because their self-organized emergence is not evoked directly by the stimulus but induced vicariously through nonlinear and possibly autonomous mechanisms” (David, Kilner, & Friston, 2006, p. 1580). It is the intrinsic stimuli in the brain that provides the neural context for how the brain can encounter, get excited by, engaged, in, and approach external stimuli (Northoff, 2009). Research supports that these intrinsic spontaneous oscillations are related to higher-order complex brain functions such as perception, the willing execution of movement, storage in memory, and pattern recognition (Basar & Bullock, 1992). It is the reciprocal relationship of internal and external stimuli in the brain, which influences how each is perceived. On-going spontaneous intrinsic neural activity is comparable in magnitude and complexity to activity evoked by sensory stimuli (Abbott, Rajan, & Sompolinsky, 2011). These responses differ in temporal activation whereas the induced-response is spontaneous and non-temporal. Where *evoked responses* are stimulus-locked in a time-frequency space, *induced oscillation* are generation by higher-order processes from within the brain (David et al., 2006). The brain is constantly active with both intrinsic and stimulus-induced activity. The differentiation of *evoked response*, which is the brains response to stimulus-related activity, and *induced response*, which is the brains spontaneous activity without external

stimuli, is important for understanding how the brain works (S. Campbell, personal communication, September 6, 2013).

Stimuli as the ‘media’ of cognition can be defined as any means in which the human brain receives communication. The external sensory organs, such as the eyes, nose, and skin, as well as the internal sensors, receptors, and central nervous system provide a conduit to relay information from the internal or external world to the brain. These sensing organs can be defined as a medium of communication to the brain as they are “a substance that makes possible the transfer of energy from one location to another” (The American Heritage Science dictionary, 2008). As these stimuli excite receptors, the information is relayed through the perceptual system for action. The threshold in which stimuli are perceived differs based on either the strength of the stimuli to pull attention (Eccleston & Crombez, 1999) or with the shift in attention to focus on the precept (Corbetta & Shulman, 2002; Posner, 1980; Posner & Petersen, 1990). This does not mean that all stimuli are allocated equal cognitive processing resources. The modalities of stimuli, such as sight, smell, and touch, vary radically in the amount of information that they relay to the cognitive system. For example, the human sense of vision, provides far greater information than other senses (Medina, 2008). Similarly, emotion may have the strongest influence on human perception and behaviour (Rolls, 1999, 2005). The influence of emotion affects memory, cognition, perception, and the physiological response (Corson & Verrier, 2007; Paas, Renkl, & Sweller, 2002; Phelps & Carrasco, 2006; Zeelenberg, Wagenmakers, & Rotteveel, 2006). The differences in how these stimuli are perceived and acted upon are based on the linking and interpretation of the stimuli, which produce meaning.

Sensations are the building blocks for cognition. Whether they are evoked by external images, sounds, or smells, the internal stimuli of a racing heart, or the recollection of an emotional encounter, stimuli provide three gauges for perception.

Stimuli can be perceived as:

1. categorical stimuli informers (information),
2. qualitative mediating stimuli informers (valence), and
3. quantitative mediating stimuli informers (arousal)

For example, emotion as stimuli informer can be defined based on these criteria.

Affect-as-information is the categorization of an emotional experience (Clore et al., 2001; Schwarz & Clore, 1983, 1988). Happy, sad, and scared are all subjective categorizations of emotional experiences that can be used as information for judgment and choice. Affect-as-valence is the subjective interpretation of experience that effects the attractiveness, averseness, or ambivalence of any emotion. Affect-as-arousal defines how much that emotion is felt (Lang, 1994; Russell, 1980). Emotions have strong effects on the interpretation, experience, and perception of stimuli informers (Phelps & Carrasco, 2006; Zeelenberg et al., 2006) and directly affects thought and action (Lerner & Keltner, 2000). For example, riding a rollercoaster generates information that can bring about an experience of fear. However, how strongly or weakly that fear manifests (arousal) and whether we like it or not (valence), determines whether we ride the rollercoaster again or swear off riding it ever again. The use of affect as stimuli informers also directly effects an individual's goals, judgments, and choice (for a review see Forgas & Bower, 1988). For example, the physical and mental pain of running a marathon is offset by the expectancy valence of happiness from the accomplishment.

The ability to recognize, manipulate, and instantiate affective stimuli informers of information, arousal, and valence, can radically change how we act, interpret, and experience the world. The interpretation of arousal of specific stimuli links information as important both implicitly, through physiological actions and reactions, and explicitly through subjective valuations of importance (Clore & Storbeck, 2006). Which stimulus we experience, how much we feel that stimulus, and whether we enjoy that stimulus, directly affects how we experience the world.

Stimuli within CALC, whether being the stimuli of pleasure, pain, emotion, sight, taste, smell, or touch hold no inherent meaning and are arbitrary until interpreted. What smells bad to one person may bring about great pleasure to another. A stimulus that may be painful to one individual may be immensely pleasurable to another. How these discrepancies manifest their meaning to each individual through the linking of contextual, conceptual, reference, and relational information is a central construct within CALC. The importance of the differentiation of stimuli into the components of contextual, conceptual, reference, and relational information provides a model on how stimuli are comprehended and how they can produce meaning. The exploration of the complexity of stimuli and comprehension, are investigated through the sensation of pain, the volitional control of sensory response, and sensory substitution in the brain.

Eating spicy foods, running a marathon, or having your back scratched maybe interpreted as painful events; yet we seek them out. The reason we can allow these events to be transposed from something that is not enjoyable to something that is agreeable, is due to the differentiation between pain that is life-threatening and pain that is not (Ratey, 2002). It is this differentiation that allows us to understand the differences

between torture and sadomasochism. The psychophysical components of pain, such as the neurophysiological and behaviour response, which is the main contributor to behaviour in animals, varies greatly in humans as it is the subjective interpretation of pain that influences outcome.

Humans seek out and consume foods that produce physiological consequences that are not, at their face value, desirable (Rozin, 2007). The physiological response to alcohol and drugs is that of being poisoned and the response to hot chilli peppers and spicy foods is that of being burned. The inflammation response caused by hot chilli peppers activates the same capsaicin receptors as those that react to the venom of spiders, snakes, cone snails, or scorpions (Siemens et al., 2006). The discrepancy on how this inflammatory response is interpreted based on context, beseeches the question on how capsaicin receptor pain from bites or stings are interpreted as bad, yet capsaicin receptor pain from spicy hot sauce is interpreted as good. Although some researchers explain the enjoyment of spicy food for its effects in releasing endorphins, the promotion of cooling by sweat or salivation, or for antimicrobial properties (Carstens et al., 2002), this is not sufficient to explain the massive individual differences in the attraction or repulsion of peoples taste preferences to spicy foods (Rozin, 1990). Even those who have eaten the hottest peppers in the world, when asked which heat level they liked best, chose the highest level they could stand – just below the level of unbearable pain (Gorman, 2010). Although enculturation and habituation influence preferences to spicy foods, neuroscience supports that our response to pain maybe somewhat volitional. Peyron, Laurent, and Garcia-Larrea (2000) in a meta-analysis of functional imaging of the brain in response to pain using both positron emission tomography

(PET) and functional magnetic resonance imaging (fMRI) conclude that the “hemodynamic responses to pain reflect simultaneously the sensory, cognitive and affective dimensions of pain, and that the same structure may both respond to pain and participate in pain control” (p.263). This supports that both physiological response and volitional control work in consort on how pain is experienced. Individuals cannot only control their subjective interpretation of pain, but can also change the bodies’ physiological response through volitional control.

Mindfulness training for the cognitive modulation of pain offers significant insight into the volitional malleability of stimuli. The Mindfulness-Based Stress Reduction program (MBSR), where individuals are taught how to maintain focus on both autonomic and dynamic stimuli in the body, is one of the most used meditation interventions for treating both physical and emotional pain (Zeidan, Gordon, Merchant, & Goolkasian, 2010). This type of training has been applied to patients with cancer (Ledesma & Kumano, 2008; Musial, Bussing, Heusser, Choi, & Ostermann, 2011), chronic pain (Astin, 2004), as well as loneliness (Creswell et al., 2012), and depression (Hofmann, Sawyer, Witt, & Oh, 2010) with positive results. A meta-analysis of MBSR training for clinical effectiveness found a significant effect size of  $d = 0.5$  (Grossman, Schmidt, Niemann, & Walach, 2004). And although a majority of this research uses self-reports, such as the Kentucky Inventory of Mindfulness Skills (Baer, Smith, & Allen, 2004) and the Freiburg Mindfulness Inventory (Buchheld, Grossman, & Walach, 2001; Walacha, Buchheldb, Buttenmüllerc, Kleinknechte, & Schmidta, 2006), to gain an understanding of the effects of MBSR training and pain management (for an

integrative review see Teixeira, 2008), biological tests have also been used to support the patient's subjective reports of pain reduction.

Zeidan, Grant, Brown, McHaffie, and Coghill (2012) in a review looking at the brain mechanisms involved in mindfulness meditation-related pain relief across different meditative techniques, expertise and training levels, experimental procedures, and neuroimaging methodologies, found significant effects in a number of studies. A number of the studies reviewed using functional magnetic resonance imaging (fMRI) found that cognitive factors such as contextual shifting and appraisal in the prefrontal and cingulate cortices are also intimately involved the modulation of pain. This research supports that how the brain reacts to physical and emotional pain stimuli can be manipulated through volitional control. This is inline with a number of studies finding that attention, beliefs, conditioning, predictive cues, expectations, mood, placebo, stress, anxiety, hypnosis, emotional state, and self-regulatory perception can contribute to either the increase or decrease in pain-related brain activation (Zeidan et al., 2012). A number of studies support that our interpretation of pain is largely regulated based on expectation and experience (Zeidan et al., 2010). Placebo research on the psychobiological effects of expectation and treatment effects offers further support to how the mind can effect stimuli interpretation and response.

Placebo and pain research finds that the endogenous response, also known as the *meaning response*, supports that “the psychological meaning of the treatment induces shifts in cognition, emotion, and corresponding brain and nervous system activity that produce a palliative effect” (Zeidan et al., 2012, p. 201). Using objective physiological measures such as fMRI, PET, EEG, and blood pressure, researchers find that patient's

beliefs about treatment can have significant effects on the outcome (Koyama, McHaffie, Laurienti, & Coghill, 2005; Ploghaus et al., 1999; Wager et al., 2004). The research on mindfulness training and placebo effects not only offers significant insight into the power of perception, but also showcases the malleability of stimuli informers. The power to shift the physiological response of stimuli, such as pain in the brain, supports that it is not the stimuli in-and-of-itself that produces meaning, but the subjective interpretation and linking of stimuli informers that produces comprehension. Similar to Pavlov's dog, who salivated at the sight of food, the unconditioned biological responses also responded to series of conditioned associated stimuli such the lab assistant opening the door, white lab coats, or a bell (Pavlov, 1927). The association and interpretation of these conditioned stimuli, which to the dog meant he was going to be fed, was a subjective interpretation as it was not taught or reinforced. Some of the most compelling evidence for the arbitrary nature of stimuli informers is in the transposition of stimuli from one modality to another in the brain through sensory substitution.

Sensory substitution is the ability of the brain to translate information in one sensory domain (e.g. visual information via the eyes) by means of the receptors, pathways, and brain projection, integrative and interpretative areas of another sensory system (e.g. "visual" information through the skin and somatosensory system) (Bach-y-Rita, 1987). Paul Bach-y-Rita pioneered the concept of sensory substitution in the 1960s with his work on the Tactile Vision Substitution System (Bach-y-Rita, 1967; Bach-y-Rita, Collins, Saunders, White, & Scadden, 1969) and the BrainPort device which allows users to 'see' with their tongue. Bach-y-Rita stressed that senses do not come from the organ themselves, which simply sends electrical impulses to the brain,

but it is the brains interpretation of those impulses which give us the sense of vision, taste, touch, or smell.

Sensory substitution devices have taken advantage of the malleability of stimuli in the brain to allow the deaf to ‘hear’ and the blind to ‘see’. An array of electrodes on a blind persons tongue that allows them to perceive spatiotemporal information (Danilov, Tyler, & Kaczmarek, 2008; Kaczmarek, 2011), a jacket that allows the deaf to perceive auditory information through vibrations on their torso (Eagleman, 2012), and a head mounted TV camera that translates visual patterns into sound (Capelle, Trullemans, Arno, & Veraart, 1998) are just a few examples of how sensory substitution can augment perception. The BrainPort device is one example, which allows the blind to ‘see’ through the use electrodes on their tongue. The system transforms images from a camera into pulses that can be felt on the user’s tongue. Each electrode acts as a ‘pixel’ where an image is felt on the tongue.

Other examples of sensory substitution include echolocation, the ability to perceive objects with the use of sound, and haptic perception, where visual or auditory perception is mediated through touch. The flexibility of the brain to respond to and transpose stimuli from one modality to another, such as transposing touch-to-sound or touch-to-image, shows the arbitrariness and malleability stimuli informers for comprehension. The ability of the brain for transposing one stimuli to another through sensory substitution, allows the brain to both manipulate and comprehend stimuli that extends and augments the individuals perceptual space. These processes however are not tacit, as the person must consciously translate the pattern of impulses from one sense

to another, such as impulses on the tongue into an idea of an object, until they become fluent and sensory substitution becomes automatic (Collins, 2009).

Brain imaging studies using fMRI support that sensory substitution is not merely the conscious perception of stimuli, but that individuals brains actually recognize sounds-as-images (Amedia et al., 2007), touch-as-images (Kim & Zatorre, 2011), and touch-as-sound (Levanen & Hamdorf, 2001). Similarly visual perception, the perception of depth, space, and perspective which is thought to be a function of sight (Kaufman, 1974), is actually a comprehension of space irrespective of vision.

Esref Armagan is a Turkish artist who can paint in perfect perspective; which would not be that amazing if it wasn't the fact that he was born without sight. Amedia et al. (2008) in a case study used fMRI to evaluate how Armagan could draw with such accuracy and perspective. The results showed that brain areas normally associated with vision were active during drawing as opposed to scribbling. Esref's visual cortex activity for imagined objects being drawn is as intense as when a sighted person sees that object. The visual areas of Armagan's brain, however, did not activate during verbal memory tests of objects, suggesting that images maybe stored as concepts as opposed to mental visual representations. The authors state "evidence from this case supports the hypothesis that internal mental representations of objects can be generated by haptic experiences that are readily translated into representation that can unequivocally understood by sight" (p. 6). Although many exceptionalities in extrasensory processing maybe born out of necessity, such as the heightening of auditory perception in the blind (Lessard, Paree, & Lassonde, 1998; Muchnik, Efrati,

Nemeth, Malin, & Hildesheimer, 1991), any human can accomplish such achievements with proper exposure and training.

Rojas, Hermosilla, Montero, and Espi (2009) in a study on echolocation were able to train 10 sighted individuals to use echolocation within a few days of training. Rojas et al. findings reveal that there are no special skills needed for echolocation, and that “two hours per day for a couple of weeks are enough to distinguish whether you have an object in front you, and within another two weeks you can tell the difference between trees and pavement” (Plataforma SINC, 2009). Although no studies using fMRI or other brain imaging technologies could be found on sighted individuals using echolocation, other studies have found that visually impaired individuals recognize echolocation in regions of the brain typically devoted to vision (Thaler, Arnott, & Goodale, 2011). Although researchers often explain these results as cross-modal integration, compensatory sensory substitution, or neural plasticity (see Aytikin, Moss, & Simon, 2008; Schenkman & Nilsson, 2010), it does not explain the cognitive process in which the user, through their own volition, transpose auditory, tactile, or visual stimuli into another modality in the brain. The functional aspects of memory and utility of cognition provide the mechanisms for volitional synaesthesia.

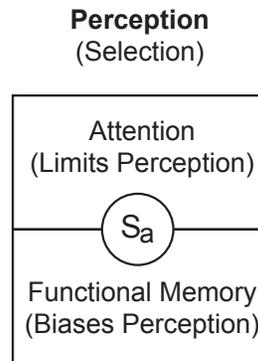
Humans have evolved to a point where we can control our comprehension of stimuli and transpose its interpretation in the brain. The main idea of the aforementioned exploration of pain and stimuli modality transposition is that our comprehension of stimuli can be radically changed based on choice. We can change our comprehension of stimuli through volitional control of what we link to those experiences. The malleability of pain interpretation, the volitional control of sensory

response, and sensory substitution in the brain, demonstrate that “we make a mistake in concentrating (too much) on senses... perception is what matters, and sensation is what accompanies it” (Durie, 2005, p. 36). Understanding that cognition is not the function of independent senses, but is the composure of senses within an integrated perceptual system (Stoffregen & Bardy, 2001; Thomas, 2012; Walk & Pick, 1981), is important for understanding how stimuli are comprehended. How both tacit and volitional control changes the way we experience stimuli in the mind underlies the processes and mechanisms of perception.

### **Perception: The Limitation and Biases of Stimuli Selection**

Perception defines our ability to understand the world around us. As stimuli are selected, encoded, and interpreted by our senses, perception carries out the task of organizing this information into a coherent form that our brain can understand. The identification of relevant, distinctive, and apparent qualities of objects, symbols, and stimuli allows us to distinguish the characteristics of items for their recognition. The qualities of perception identified in the literature include experiential biasing (Wallis & Bulthoff, 1999), “top-down” effects due to goal orientation, motivation, and expectation (Gregory, 1990; Pomerantz & Lockhead, 1991), and “bottom-up” processing of low level stimuli (Gibson, 1960, 1966, 1972). It is also recognized that humans are perceptually selective in that they “subjectively experience and respond to only a subset of the sensory signals evoked by objects and events in the local environment” (Yantis, 2000, p. 73). The limitations and goal directed nature of perception are captured in the two intermingled processes of attention and functional memory. Figure 7 shows the

components of perception, which are attention that limits perception, and functional memory that biases perception.



*Figure 7.* The components of perception

### **Attention: The Limiting Factor of Perception**

Attention is the main limiting factor of perception, cognition, and memory. Many models of attention prescribe the ‘bottle-neck’ effect, such as Broadbent’s filter model of Selective Attention (Broadbent, 1958), Treisman’s Attenuation model (Treisman, 1964), and the Deutsch and Deutsch Late Selection model (Deutsch & Deutsch, 1963). As attention shifts continually between the external and internal environment of the individual, it is not possible to consciously attend to all the stimuli that are present at any one moment (McLeod, 2008). The brain selectively filters what is attended to, based on the threshold in which stimuli are perceived based on either the strength of the stimuli to pull attention (Eccleston & Crombez, 1999) or with the shift in attention to focus on the precept (Corbetta & Shulman, 2002; Posner, 1980; Posner & Petersen, 1990). The processes of stimulus threshold activations (bottom-up) and goal-directed cognitive control (top-down) are the mechanisms of attention.

Alerting, orienting, and executing attention are primary for survival. As attention is both outwardly bound to the changing stimuli of the external environment and inwardly bound to the changing stimuli of the body and brain, attention must continually shift to ensure an organisms safety and security. The exogenous orientation of attention, which is sensory and unconscious, takes priority over endogenous orientation, goal-directed processing, as it serves to protect (Posner & Snyder, 1975). Research supports that “unexpected, novel, salient and potentially dangerous events take high priority in the brain, and are processed at the expense of on-going behaviour and neural activity” (Corbetta & Shulman, 2002, p. 201).

Corbetta and Shulman (2002) in a comprehensive review of visual attention propose that there is a defined neural segregation of attention in the brain into top-down and bottom-up control centres. Using neurological research they find evidence that supports that the intraparietal cortex and superior frontal cortex are involved in preparing and applying goal-directed (top-down) selection and that the temporoparietal cortex and inferior frontal cortex are specialized for the detection of behaviourally relevant stimuli (bottom-up), particularly when they are salient or unexpected. Sensory cues, which are unexpected, facilitate discrimination and detection faster than cognitive cues and prolonged inhibition of processing at cued locations (Klein, 2000; Muller & Rabbitt, 1989; Posner & Petersen, 1990). It is these differences that have facilitated the differentiation of attention into sensory (exogenous) and cognitive (endogenous) orienting systems (Jonides, 1981). Although these components of attention are treated as distinct and separate in most empirical studies, the question of how goal-directed

constraints influence attention, offers greater insight into the process of perception (Yantis, 2000).

Conscious and unconscious goal-directed attention serves to prioritize stimuli for the performance of goal-directed action. This endogenous-orienting attention system works by biasing the bottleneck of attention to focus on particular stimuli. Discerning relevant from irrelevant stimuli in the environment based on goal-directed cues discriminates what is attended to. The biasing of perception and attention through goal-orientation and expectancy is the foundation for the functional aspects of memory and perception.

### **Functional Memory: The Biasing Factor of Perception**

Functional memory is the active assembly of situated stimuli and past experience in the pursuit a particular action or goal. The theory of Functional memory, based on Norman Anderson's *Functional Theory of Cognition* (1996), is a departure from traditional models and theories of reproductive working or short-term memory (see Atkinson & Shiffrin, 1971; Baddeley, 1986; G. A. Miller, 1956). Where the normal paradigm of memory research has been to evaluate the accuracy of remembering or forgetting digit-spans (Gregoire & Van der Linden, 1997), word lists (Lumiley & Calhoun, 1934) or the serial recall of non-words (Ebbinghaus, 1913) the utility of such research cannot be recognized in everyday life. Functional memory, in contrast, is judgement and goal-directed. The prototypical functional memory task involves the valuation of present stimuli in the environment together with integration informers from past experience to arrive at a goal-directed response.

Support for a functional theory of memory evolved from Anderson's work on person cognition where the traditional model of verbal memory led to a failed hypothesis (N. H. Anderson & Hubert, 1963). N. H. Anderson and Hubert (1963) using an experiment that combined a verbal recall task with an integrated judgement task, found that the long taken for granted memory hypothesis of the recency and primacy effects were not supported. Subjects in the study heard a serial list of adjectives that describe a person. After hearing the list, the subjects were asked to judge how much they would like that person and to recall the adjective. With the aim to compare primacy-recency in person judgement, Anderson found that goal-directed judgement informers affected memory more than where the people were placed in the list. The findings in this research, as well as other discrepancies in memory research, led Anderson to re-evaluate the reproductive models of memory and to propose a functional theory of memory that incorporates goal-oriented thought and action.

Functional memory, a system of 'working memory' or 'short-term memory', is distinct from other models such as those proposed by Baddeley (Baddeley, 1986, 1999, 2007) as it does not map to a particular modality of representation in the brain such as a visio-spatial sketchpad or phonological loop, but is stimulus agnostic similar to the Atkinson-Shiffrin model (Atkinson & Shiffrin, 1971). Functional memory, in contrast to current working and reproductive memory models, is goal-directed and modality agnostic. The two basic operations of functional memory are valuation and integration.

Valuation assesses the significance of external and internal stimulus informers relative to a particular goal. Where the goal is held in memory, the actions of informers are in utility to the pursuit and resolution of that goal. The goal activates associated

information from long-term memory, including both procedural and production cues, which informs action. External informers are evaluated based on the similarity to items in memory. It's worth noting that "similarity is different from recall...in its dependence on interaction among informer, the memorial material, and the goal" (N. H. Anderson, 1996, p. 363). Internal informers from memory are also evaluated based on their ability to meet a particular goal. The valuation of external and internal informers, with procedural and production cues from memory, with the goal, lead to the integration of this information into a goal-directed response.

Integration, within functional memory, incorporates multiple memory informers to arrive at a unified goal-directed response. Knowledge, procedural, and production cues are integrated in memory to inform action. The assembly, organization, and operation of goal-directed response happen within integration. Where valuation is susceptible to the biasing effects of expectancy and experience, integration is the manifestation of those biases through goal-directed action. The integration and manifestation of goal-directed actions do not need to be conscious. A number neurologically-based studies support that goal-based brain events bringing about voluntary control can happen without conscious intention (Libet, 2004). "It is concluded that [the] cerebral initiation of a spontaneous, freely voluntary act can begin unconsciously, that is, before there is any (at least recallable) subjective awareness that a 'decision' to act has already been initiated cerebrally" (Libet, Gleason, Wright, & Pearl, 1983, p. 623). The tacit goal-directed response of functional memory allows for many cognitive and physical voluntary responses and biases to fall outside of conscious perception.

Functional memory as a part of the perceptual system with attention is concurrent with other models of working memory, such as the cognitive model of working memory proposed by Cowan (Cowan, 1995, 1999) and Anderson (J. R. Anderson, 1983) and is consistent with experimental research on working memory in cognitive neuroscience. Kok, Jehee, and de Lange (2012) in a study looking at the neural mechanisms of visual perception, find that expectation facilitates the sharpening of sensory representations. Using functional magnetic resonance imaging (fMRI) and multivariate pattern analysis (MVPA), the researchers found that top-down expectations of the environment facilitated the biasing of sensory experience by dampening and suppressing certain sensory perceptions while sharpening others. The experiment showed neurological evidence for a sharpening account of expectation, in which overall neural activity is reduced; yet the stimulus representation is enhanced by expectation. The biasing of perception and goal-directed response can also be seen in cognitive and psychological research on expectancy bias and inattention blindness.

Expectancy from past experience, projected anticipation, or beliefs, colours and biases our perception. The integration of these expectations into perceptual experience exemplifies the subjective nature of how we experience the world. There are many studies on how expectancy biases perception including food tastes (Yeomans, Chambers, Blumenthal, & Blake, 2008), object perception (Puri & Wojciulik, 2008), and pain reception (Atlas & Wager, 2012). What many of these studies find is that perception is highly malleable and that perception is an interpretation of sensory experience (bottom-up) and expectation (top-down) (Gregory, 1990). The interaction

between expectation and experience and the results on perception are so strong, that there are many instances where first-hand experiences cannot be trusted.

Eating and drinking are multimodal perceptual experiences that incorporate all human senses. Researchers have found that food names (Crisinel & Spence, 2010; Okamoto et al., 2009), colour (Spence, Levitan, Shankar, & Zampini, 2010), sound (Spence & Shankar, 2010; Woods et al., 2011), and presentation (Zampollo, Wansink, Kniffin, Shimizu, & Omori, 2012) all change our perceptual experience of food and drink. Many studies have shown that the colour of food alone greatly affects the perception of odour and taste (see Dematte, Sanabria, & Spence, 2006; Gilbert, Martin, & Kemp, 1996; Gottfried & Dolan, 2003). Morrot, Brochet, and Dubourdieu (2001) in a study that looked at the perception of wine based on colour, found that when white wines were coloured red, experts described the wines using adjectives for red wine. The results suggest that wine experts primarily use visual information over olfactory senses in describing the odour of wine. Other studies have shown when beverages or foods do not match flavour-colour expectations, such as yellow-cherry cola or blue-lemon Jell-O, subjects cannot tell the flavour (DuBose, Cardello, & Maller, 1980; Philipsen, 1995; Stillman, 1993). Similarly, the sound environment in which food or drink is consumed affects its taste. Heston Blumenthal's molecular gastronomy restaurant *The Fat Duck* uses the features of sound to radically change the dining experience. One example is the dish 'Sounds of Sea' that uses an mp3 player playing sounds of the ocean while patrons eat seafood. Patrons report that the seafood tastes saltier and stronger with the sounds of the ocean in the background (BBC, 2007). The bulk of this research supports that our sensory experience is greatly influenced by environmental and expectancy cues

that hold far greater influence on our perception than the information itself. And although there are 100's of published papers on the influence of colour on flavour, based on the principle of multisensory integration in the brain, few have looked at the cognitive influences of expectation and cued associations (Shankar, Levitan, & Spence, 2010). Beyond skewing our experiences of sensory information, expectation and goal direction can render the user inattentioanly blind to sensory information right in front of their face.

In the book *The Invisible Gorilla* (Chabris & Simons, 2009), Christopher Chabris and Daniel Simons discuss their research on inattention blindness (IB) and how our expectations and intuitions are deceptive. Inattention blindness, which is also called selective attention, is when an individual who is focused on performing a task, can be virtually blind to stimuli that are presented right before their eyes. Simons and Chabris (1999), in their famous “The invisible ape” experiment, had participants watch a video of students in black and white shirts passing around a ball. The users are asked to count how many times the white shirts pass the ball. In the middle of the clip a person in an ape costume walks to the centre of the frame, bangs their chest, then walks out of the frame (see Figure 8).



*Figure 8.* Still clip from Simons and Chabris (1999) selective attention test. From “Selective Attention test”, <https://www.youtube.com/watch?v=vJG698U2Mvo>. Copyright 1999 by Daniel J. Simons.

The surprising results of the experiment are that a majority of the users who watched the clip do not see the ape. And on second viewing, once they are cued that there is an ape in the clip, cannot believe it’s the same clip. This is also not just a phenomena of vision, but is true for all modalities of stimuli perception including touch, taste, smell, and hearing (see Bronkhorst, 2000; Shapiro, Caldwell, & Sorensen, 1997). The outcome of this research can be explained in the biasing of perception by functional memory. As subjects are misdirected with functional goal-directed memory tasks, their perception is biased to the point where irrelevant stimuli that are not part of the goal-directed task are not perceived.

Most, Scholl, Clifford, & Simons (2005) in their attempt to relate and contrast the research on inattention blindness and attention capture, conclude that the most influential factor in affecting attention is the individual’s goals. Due to the robustness of this phenomena, when attempting to draw a persons attention from one stimuli to

another, people need to use the base elements of the functional nature of attention for any measure of success. The researchers offer an number of heuristics to draw attention including using stimuli that are related to the goal, alternative modalities, faces, personal names, or stimuli that are perceived as a threat (Most et al., 2005). A critical review of *why* these heuristics work can be recognized in the proposed model of perception within CALC. As attention limits what can be attended to, functional memory biases our perception to attend to expected, cued, or associated stimuli in the environment and to filter out the rest. The functional perspective of perception supports that it is the affordances and effectiveness of the elements in the environment, which define action and meaning (Glenberg & Robertson, 1999; Greeno, 1994, 1998; Shaw, Turvey, & Mace, 1982). The process and mechanisms in which we link stimuli into meaningful forms is the utility of cognition.

### **Cognitive Utility: Cognition as the Process of Comprehension**

Comprehension is the process and product of cognition. The ability to link discreet pieces of information into patterns forms the discourse of thought. Comprehension and meaning, two of the most important constructs in cognitive psychology for communication, learning, and memory, are surprisingly ill-defined in the literature (Kintsch & Rawson, 2005). Many of the models within comprehension are defined based on the content in which comprehension is utilized. For example, there are different theories and models for text comprehension, reading comprehension, language comprehension, and math comprehension, but very few content-agnostic models. A cognitive model of comprehension would address *what* comprehension is and *how* comprehension takes place using subject agnostic constructs. Such a model could be used

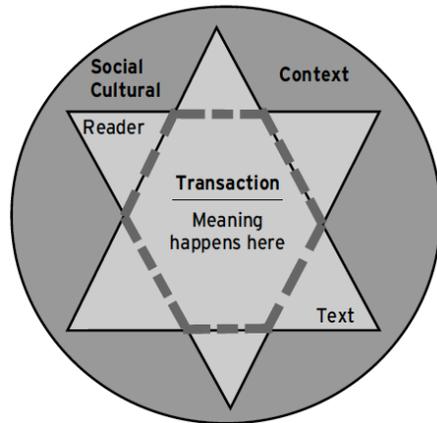
to look at the cognitive correlates of comprehension. The issue of defining what comprehension is, among all the subject-specific models and definitions, can be daunting; even standard dictionaries are little help.

The Merriam-Webster dictionary defines *comprehension* as “the act or action of grasping with the intellect: understanding” (Merriam-Webster, 2012a). What the act or actions are, however, are not defined. To follow this further is to look up the word *understanding*. The definition of understanding is defined as “the capacity to apprehend general relations of particulars” (Merriam-Webster, 2012b). What those particulars are, however, are not defined. The categorization of comprehension into domain-specific models such as reading comprehension, mathematics comprehension, and language comprehension, further blurs the definition of the components necessary for the construction of meaning; as there is no agreement of what the elements of comprehension or meaning are. The essential properties of most of these comprehension models include the same underlying strategies of tapping prior knowledge, questioning, inferring, visualizing, summarizing, synthesizing, monitoring, and repairing understanding (Siena, 2009). Although these strategies are useful for offering some framework for self-regulation for understanding, they do not explicitly address the structure of information that is necessary for understanding and comprehension to take place.

Walter Kintish in his book *Comprehension* (1998), presents a construction-integration (CI) model of comprehension as a constraint satisfaction process. The theory posits that “comprehension occurs when and if the elements are meaningfully related to one another and other elements that do not fit the pattern of the majority are

suppressed” (p. 4). The principle characteristics of the model are to integrate the fusion between the to-be-comprehended object, and the general knowledge and experience of the individual. Knowledge is represented as an associative network of nodes, which are concepts, and propositions, which are linked into frames and schemata. The model however, does not define how these patterns are manifest.

Pardo (2004) in her article *What every teacher needs to know about comprehension* presents a model of text comprehension that includes social cultural, contextual, and transactional elements (see Figure 9).



*Figure 9.* Pardo (2004) model of text comprehension. From “What every teacher needs to know about comprehension.” by Laura S. Pardo 2004. Copyright 2004 by John Wiley and Sons. Reprinted with permission.

Pardo defines comprehension as a process in which readers construct meaning by interacting with text through the combination of prior knowledge and previous experience, information in the text, and the stance the reader takes in relationship to the text. The transaction process, where meaning takes place, is where the user decodes words and propositions into mental images. These images then bring forth ideas and

information from long-term memory to assist in building connections. The user furthers their understanding by making more connections by making inferences on how the information is related. The elements of the information in the text and in the reader's mind and the structures that facilitate understanding, however, are not defined. CALC, in contrast, defines the structure and the elements as contextual, conceptual, reference, and relational patterns of information. It is the interpretation and integration of these structures, which define meaning. The structural elements of meaning and comprehension are captured in a Situated Model of Comprehension.

### **A Situated Model of Comprehension: The Elements of Meaning**

Comprehension is not arbitrary; our perceptions of stimuli in the external world and in our minds are highly structured. The semantic relationship of these perceptions defines the how they are understood. The icons, signs, and symbols that we interact with, gain their meaning through the correlation between what the sign is, what it signifies, and how we interpret it. Semiotic theory, which is the study of how signs and symbols gain their meaning, offers some insight into how meaning is constructed.

The two major theories and models in semiotics from C.S. Peirce (1839-1914) and Ferdinand de Saussure (1857-1913) offer an abstracted view of how meaning is constructed (see Figure 10). Saussure's model is composed of a *signifier* and the *signified*. The relationship between the elements is arbitrary until there is an acquired linkage and use between the elements. It is the system of use of the signifier and the signified that provides its utility (e.g. the word cat to signify the animal object cat). The issue with this model becomes evident comes when a signifier refers to many signified

items. The ambiguity of how signifier and signified elements can share many interpretations is addressed in C.S. Peirce's model of semiotics.

Peirce's triad model proposes the elements of *sign*, *object*, and *interpretant*, as influential entities in which signs gain meaning. The sign is what represents the relational object (e.g. the word cat), the object is represented by the sign (e.g. the object cat), and the interpretant is the interpretation or translation of the relationship between the sign and object (e.g. does the word cat mean lion or a house cat). This extra element of interpretant in the model suggests that many interpretations are possible for any particular sign. Within both theories the effectiveness of any particular sign is based in the knowledge of the individual and how they are situated in any particular language, culture, or time. This introduces the idea of conceptual and contextual variables in the nature of meaning, which are incorporated into the Situated Model of Comprehension (SMC) proposed in this dissertation.

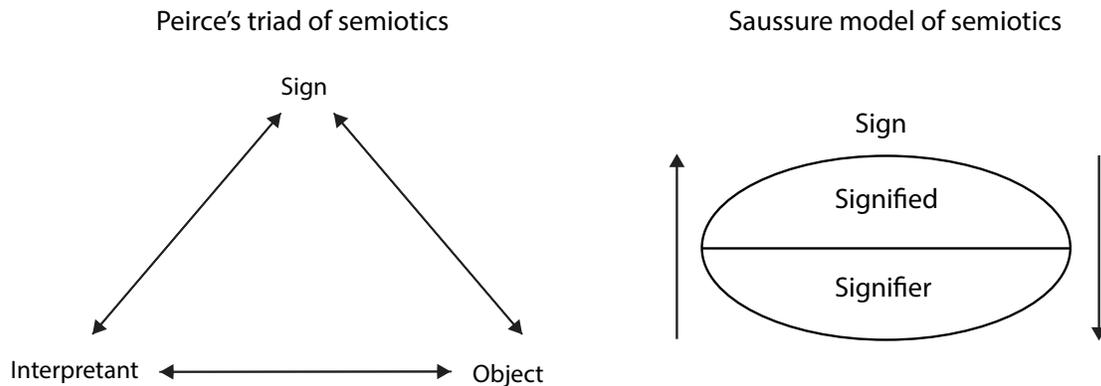
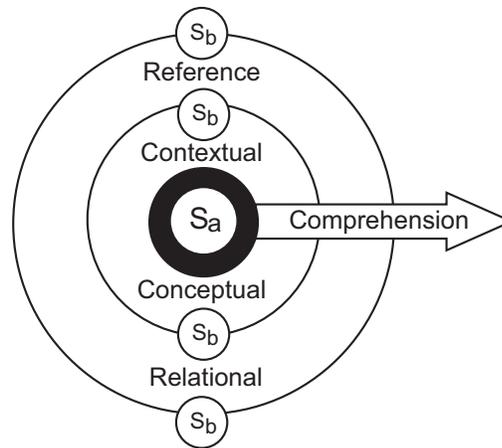


Figure 10. Peirce's and Saussure's models of semiotics.

The Situated Model of Comprehension extends Peirce's and Saussure's models to address the variable nature that conceptual and contextual elements add to the

structure of meaning (see Figure 11). The conceptual element addresses the knowledge of the individual in the interpretation of the sign, based on the conceptual understanding of language, culture, or society. The contextual element addresses the variable nature of the internal and external factors that change a sign's meaning based on time, place, and use. It is the patterns of contextual, conceptual, reference and relational information from either the external environment or the internal environment of the mind, which provide the building blocks for comprehension and meaning.

The stimuli at the centre of the model ( $S_a$ ) can be anything, a word, an image, or a sound, and can come from the external environment or the environment of the mind. By themselves, however, stimuli are difficult to comprehend. A loud noise, without other information such as relationship to where it came from or what it is, is just a noise. A smell without reference is just a smell. It is not until stimuli are linked with other elements that they make sense. The other elements in the model of contextual, conceptual, reference, and relational information are also just patterns of stimuli, which can come from the external environment or the environment of the mind. The linking of conceptual, contextual, reference, and relational patterns facilitates comprehension. Figure 11 shows a Situated Model of Comprehension. At the centre is a stimulus ( $S_a$ ), which by itself is very hard to comprehend, represented by the black ring. When that stimulus is linked with other patterns of stimuli such as contextual, conceptual, reference, and relational information ( $S_b$ ) the process of comprehension can take place.



*Figure 11.* A Situated Model of Comprehension (SMC)

### *Concepts*

Concepts are stimuli with attached attributes (see Figure 12). Attributes are features that are used to describe or define stimuli. The attributes reflect our subjective comprehension and rationalization of what the stimuli means or represents. The attributes can reflect objective observations, such as physical attributes (fur, whiskers), subjective affective attributes (mean, funny), abilities (language), or mediating propositions (belief, desire). Concept structures within CALC, that are defined based on attributes and categorization, are consistent with the literature on Concept Learning (Bruner, Goodnow, & Austin, 1967; Feldman, 2003; Medin & Smith, 1984).

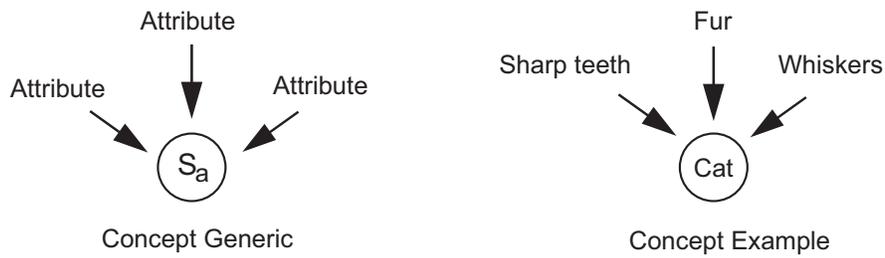
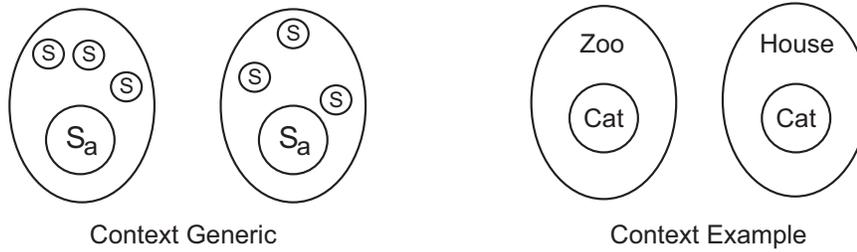


Figure 12. The relationship of attributes to stimuli in defining a concept.

### Contexts

Context is defined as a pattern of stimuli that situates information. Recognizable patterns in the environment or in our minds allows us to ground novel stimuli in what's deemed a context. A word (stimuli) within a sentence (context), a sound bite (stimuli) from an interview (context), a cat (stimuli) in a zoo (context), are all examples of how contexts ground the stimuli in which they are situated. Context-dependent categorizations change the meaning of how an item is understood (Labov, 1973).

Figure 13 shows how the same stimuli, for example the word cat, change based on the context in which it is situated. In the context of a zoo, it could mean a lion or a tiger, but in a house, it is most likely a house cat and not a lion or a tiger.



*Figure 13.* The relationship of situated stimuli in defining context.

Context-dependency effects are supported in the literature with the situated effects on memory, learning, retrieval, and comprehension (Eich, 1980; Grant et al., 1998; Smith & Vela, 2001; Wagner, Desmond, Glover, & Gabrieli, 1998).

### *References*

References are defined as stimuli related to another for associative equality. A reference derives its comprehension from the strength of the association between the two or more stimuli. The reference between the stimuli can be location, time, duration, context, or conceptual information. Figure 14 shows that the word cat (reference) can refer to many instances of cat, all which differ greatly in their presence. The reference of cat is used for a cartoon character that looks nothing like a real cat (Garfield), a house cat (Tabby), and for a very large wild cat (Lion).

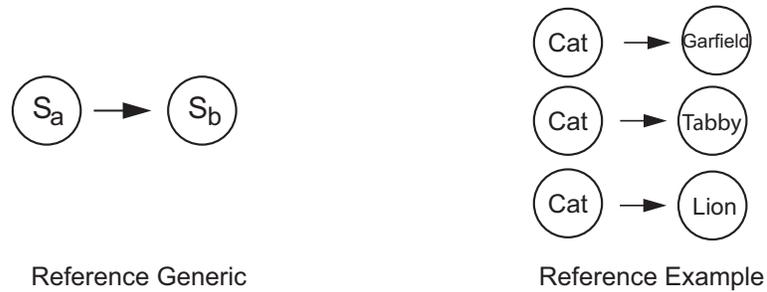


Figure 14. The relationship in defining reference.

*Relationships*

Relationships are defined as stimuli with shared mediating information. The mediating stimulus provides the association that links the stimuli. This mediating variable defines *why* the stimuli are related. Relationships can be referential, but is not always the case as can be seen in Figure 15. In Figure 15, the objects Tabby and Lion do not refer to each other but do have a relationship. What defines that relationship is the mediating quality of cat. A relationship can also be defined as the location, time, duration, context, or concept in which the stimuli are embedded. It is the relationship between the elements that defines how the stimuli or concepts are associated.



Figure 15. The association of stimuli with a mediator defining their relationship.

The double arrows define that relationships are not always bidirectional. Unidirectional relationships include terms such as installed on, installed with, contains, member of,

starts from, resides on, succeeded by, and preceded by (IBM, 2011). An example would be a lion is a member of a pride, but a pride is not a member of a lion.

The uncertainty of comprehension diminishes as each element of contextual, conceptual, reference, and relational information are linked. Uncertainty reduction theory (URT) recognizes that a central motivation of communication is to reduce uncertainty (Berger & Calabrese, 1975). Uncertainty in communication is when there are high variability and possibilities of interpretation for any given event or situation (Shannon & Weaver, 1949). The SMC predicts that it is the structure and addition of the elements of comprehension that facilitate the reduction of uncertainty. This does not mean that *more* information facilitates comprehension, but the elements of information that are available to the user. It is the addition of conceptual, contextual, reference, or relational information that facilitates comprehension.

Comprehension as a mental act can be exclusive to the individual, with interpretation and meaning being subjective. The issue with comprehension being solely an individual act, is that it does not consider the relation between the socio-historical-cultural roots in which signs and symbols gain their meaning. Symbols and signs are socio-historically produced from interactions and are transmitted as cultural artifacts (Engeström, 2014). “The real knowledge of a word comes through practice of appropriately using it within a certain situation. The word, like any man-made implement, becomes significant only after it has been used and properly used under all sorts of conditions” (Malinowski, 1923, p. 325). The interaction with other individuals, societies, and cultures challenges subjective comprehension. Extending this model to

include other individuals, groups, or cultures provides a model on shared, mediated, and socially situated comprehension.

### **A Socially Situated Model of Comprehension**

Shared cognitive acts of comprehension form the base of all social and cultural interactions. The proposed Socially Situated Model of Comprehension (SSMC) (see Figure 16) outlines how the sharing of stimulus informers along with contextual, conceptual, reference, and relational information supports shared comprehension. It is the shared comprehension of stimuli in the forms of signs, symbols, and cues, which define cultures, societies, and social groups. It is worth noting that this model suggests an objective agreement of comprehension, not the subjective interpretation of meaning. Although the stimuli of contextual, conceptual, reference, and relational information are shared, they are *interpretations* of shared information. In the model  $S_a^1$  and  $S_a^2$  represent the stimuli or event each individual experiences.  $S_b^{1,2}$  are the shared contextual, conceptual, reference, and relational information that suggests that both individuals share comprehension of the stimuli or the event. It is the shared objective contextual, conceptual, reference and relational information that suggests objective agreement of comprehension. It is the subjective individualized contextual, conceptual, reference, and relational information that defines meaning. For example, if two individuals see a car accident they both comprehend that an accident has taken place based on shared contextual, conceptual, reference, and relational information. However, one of the individuals recognizes the car as his daughters. Although both share comprehension of the event, the meaning for one is radically different with having other

contextual, conceptual, reference, and relational information that are confined to the individual.

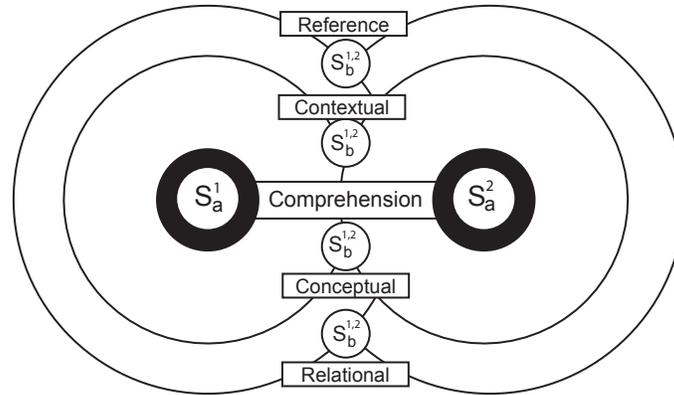


Figure 16. A Socially Situated Model of Comprehension (SSMC).

The social elements of cognition are represented in the literature in various theories such as distributed cognition (Hutchins, 1995), social cognition (N. E. Miller & Dollard, 1941), and situated cognition (J. S. Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991). The fundamentals of these theories suggest that cognition is not an individual act, but is an amalgamation of elements from the environment and interactions with other individuals. It is the shared interpretation, action and affordances of these shared elements that allow individuals to see the unity of cooperative understanding. The shared linking of these elements also defines the structure of cultures, sub-cultures, and communities. These elements, however, are not set and change based on the contextual, conceptual, reference, and relational information of the individual in their surroundings. For example, hand gestures hold multiple meanings based on the context of use and the reference and relational patterns that are held in the culture in which they are used. Winston Churchill can be seen in

many images raising his index and middle finger into the sign of a “V” one with his palm inward another with his palm outward. The difference in meaning based on the context of use, however is great. The “V” sign with palm out in North America and the U.K. means victory, defiance, and most usually peace. The same sign, however in Australia, Ireland, New Zealand, and the U.K means the derogatory “up yours”. The same is true for the thumbs-up sign. In the North America the sign means a positive, everything is okay, or everything is good. However, the same sign in Latin America, West Africa, Greece, Russia, and Italy this means the derogatory “up yours” (Axtell, 1997). The subjective interpretation of these gestures and comprehension is based on the cultural linkages to these signs, which allows for multiple meanings. The contextual, conceptual, reference, and relational patterns within and amongst cultural, social, and individual boundaries are highly malleable and allow multiple meanings. These multiple meanings happen when individuals hold multiple contexts, concepts, reference, and relational patterns for any particular stimulus. These highly dynamic polymorphous *Semantic arrays* in the mind change the interpretation and use of signs and symbols.

### **Semantic Arrays: Addressing the Symbol Grounding Problem**

Semantic arrays are highly malleable patterns of stimuli that are interpreted according to situated internal and external environmental stimuli. The structure of Semantic arrays based on contextual, conceptual, reference, and relational information, is an amalgamation of elements from models and theories of thought. Associationist models such as those proposed by Aristotle, Locke, Hobbes, and James introduced the idea of linked conceptual and referential entities for understanding (J. R. Anderson &

Bower, 1980), Shannon’s Information theory (Shannon & Weaver, 1964) introduced elements of context and self-reference, Newell and Simon (1972) the idea of relationships as the model to link symbols, Prototype theory (Rosch, 1975, 1977) introduce the structure of concepts as the linking model of comprehension, and Semiotic theory introduced the concept of relational and referential signifiers for meaning (Peirce, 1839-1914; Saussure, 1857-1913). It is these elements in the form of contextual, conceptual, reference, and relational patterns which form semantic arrays. The novelty and unity of semantic arrays is in the formation of mental structures that are coherent yet highly malleable. The overall structure of semantic arrays allows seemingly unrelated arbitrary stimuli to form polymorphous arrays of meaning. These structures, although may seem similar to the construct of schema, are different in their application, definition, and utility. Table 1 outlines the differences between Semantic arrays and Schema

Table 1. Comparison of the utility, structure, and mechanisms of Schema and Semantic arrays.

	Semantic arrays	Schema
Utility	Comprehension	Knowledge
Structure	Highly fluid	Rigid
Mechanisms	Recognition, recall, instantiation	Assimilation, accommodation

The reinforcement of semantic arrays may lead to the formation of schema, and schemas are used as contextual, conceptual, reference, and relational information in utility of comprehension. The structure of semantic arrays serves to ground icons, symbols, and signs, in a highly variable environment.

Symbol grounding is concerned with how signs and symbols acquire their meaning. The investigation of symbol grounding in linguistics, semiotics, cognition, and psychology hold the theory that “meaning arises from the syntactic combination of abstract amodal symbols that are arbitrary related to what they signify” (Glenberg & Robertson, 2000, p. 379). The current information processing or computational theory of mind posits that it is the linking of these signs, symbols, and icons that forms meaning. Current theories of symbol grounding such as those proposed by Harnad (1990), Landauer and Dumais (1997) and Burgess and Lund (1997) that start with already temporal, cultural, and societal symbols, signs, and icons do not address how ambiguous stimuli gain meaning. Where these theories start with already defined signs, they ought to start where no prior symbols exist (Saraswat, 2006). Starting with situated stimuli in which signs, symbols, and icon can be formed, presents a novel model and theory in which symbol grounding can be formulated.

How stimuli are transposed into symbols, icons, and signs is a central question of CALC. The contention of CALC is that symbol grounding is not formed in an abstract connectionist framework such as those proposed by the Latent Semantic Analysis model (Landauer & Dumais, 1997) or Hyperspace Analogue to Language model (Burgess & Lund, 1997), but are “formed in relation to the life-world of agents, through the perceptual/motor apparatuses of agents, lined to their goals, needs, and actions” (Sun, 2000, p. 150). CALC proposes that symbol grounding is the recursive linking of internal and external stimuli with contextual, conceptual, reference, and relational patterns of information into polymorphous *semantic arrays* based on an agents needs, goals, and actions. *Semantic cues* from the environment and from within

the individual, perpetuate how meaning is in constant flux as the individual searches for comprehension. *Frame-shifting* between the contextual, conceptual, reference, and relational cues in the environment to the internal cues of the individual, facilitates dynamic understanding (Coulson, 2001). The constant recursive checking of internal and environmental cues, through frame-shifting, facilitates dynamic symbol grounding. Similar to Andy Clark and David Chalmers hypothesis of the extended mind (A. Clark & Chalmers, 1998), with dynamic loops through which the mind and world interact through the cycle of activity from brain through body and world and back again, the mind extends beyond the confines of biological organism into the environment. When information is incomplete, not fully represented, or evident to the individual through environmental cues, the individual will make guesses as to the missing contextual, conceptual, reference or relational information. These *Semantic leaps* allow the individual to continue the interpretation with only tangential meaning (Coulson, 2001). The processes of *frame-shifting*, *semantic cues*, and *semantic leaps* facilitate dynamic symbol grounding. How the relationship of these elements brings about the ability to ground stimuli into meaningful forms, which facilitates understanding, can be understood through the exploration of research and heuristics of short-term memory.

The components of ‘chunking’ of information are a heuristic and theory of how memory becomes more efficient through the association of elements. G. A. Miller (1956) coined the term ‘chunk’ in his famous paper *The Magical Number 7, Plus or Minus 2 – Some limits on our Capacity for Processing Information* as a means to differentiate between a bit of information and an organized grouping of information. Miller explains how when bits are ordered into larger patterns of chunks that more

information can be processed and remembered. The recoding of digits experiment, quoted in the paper, supports chunking as a heuristic for memory by adding relational elements between the digits. Taking abstract single digits and placing them in referential arrays of 2 or 3 digital spans are comprehensible because of the established pattern. Assuming that these chunks are arbitrary is not cogent, as a pattern has been placed on the information, which facilitates comprehension. Related research in chunking shows that it is the prior associations of contextual, conceptual, reference, and relational patterns which define whether chunks are effective or not. For example, in Figure 17 there is a random set of letters, which at face value, would be very difficult to remember. However, if this list is rearranged into recognizable ‘chunks’, the information they can readily be recalled and articulated. The chunking of the letters into the component acronyms of BMW, RCA, AOL, IBM, and FBI in this example only makes sense if you have the prior knowledge of what these acronyms represent. Any subjective chunking of information will be limited to the abilities of the user to find and relate abstract symbols into coherent wholes.

Random Letter Sequence	Chunked Sequence
W M R C A A O L I F M B B I B	BMW RCA AOL IBM FBI

*Figure 17.* An example of letter span chunking.

Although many of the experiments in chunking add relational or referential information or subjective mnemonics, the innate ability of chunking relational patterns is seen in children as young as 7-months old (Moher, Tuerk, & Feigenson, 2012) which suggests

that pattern instantiation is innate to the human brain. The structure of how memories are encoded, stored, and retrieved, can also be realized in memory heuristics.

Memory heuristics offer insight into the structural elements of comprehension and memory. Mnemonists, individuals who have seemingly super human abilities to remember long lists of names, numbers, or random information, use specific heuristics of memorizing material in a very short period of time. Using heuristics such as the *Method of Loci*, mnemonists link information into meaningful forms. This includes linking new information to places on their body or to places or furniture in their house. By encoding and linking new information to already established conceptual, contextual, reference, and relational information, they can perform amazing memory feats. Research supports that this ability is not innate to the individual, but can be taught and reinforced to mastery through training (Ericsson, 2003). It is the addition of information, most notably context, concept, reference, and relational information that facilitates individuals' comprehension of information therefore supporting expression in long-term memory.

### **Long-Term Memory: The Expression of Experience**

Long-Term memory is the expression of experience; whether real, imposed, or created. The functional recursive nature of memory allows us to change its expression through life's experience. The term *expression* is purposely chosen as it encompasses the *biological*, *physiological*, and *behavioural* manifestations of long-term memory. These expressions happen both physically through the connecting of neurons in the brain and brain plasticity, and through the actions and behaviours those connections instantiate. Activity-controlled gene expression in the nervous system supports synapse

formation, synaptic growth and stabilization, synaptic transmission, axonal and dendritic outgrowth, and circuit formation, which are the underlying mechanisms of learning and memory in the brain (Loeblich, 2009). In fact, Eric Kandel received the Nobel Prize in 2000 for his work in identifying the process of memory storage as a dialog between gene expression and synaptic growth (Kandel, 2001). The manifestations of these expressions are seen in more-or-less developed areas of the brain in overall structure and synaptic density. Woollett and Maguire (2011) in their landmark study *Acquiring “the knowledge” of London’s layout drives structural brain changes*, show compelling evidence that there is a direct cause-and-effect relationship between learning, memory, and brain structure. In the study the researchers looked at taxi drivers over 4 years while training to become licensed taxi drivers. While at the start of the study all trainees had similar memory skills and normal sized hippocampi, after 4 years those who completed their licenses had significantly larger hippocampi and improved cognitive skills. The authors conclude “specific, enduring, structural brain changes in adult humans can be induced by biological relevant behaviours engaging higher cognitive functions such as spatial memory, with significance for the “nature versus nurture debate” (p. 2109). Similarly, physiological expressions of memory can be recognized in muscle memory which are largely unconscious (Shanks & St. John, 1994; Xu et al., 2009) and behavioural expression can be recognized in the conscious recall of experience (Endel Tulving & Craik, 2005).

The operations of memory in CALC as *constructive*, *selective*, or *generative* are based on how memories are articulated (see Figure 18). Constructive memory is the linking of two or more conceptual, contextual, reference, or relational stimuli into a

component expression. For example, the linking of a face with name would be a constructive memory. Selective memory is when two or more conceptual, contextual, reference, or relational stimuli are available in declarative memory, but only one is expressed. For example, knowing the sequence of how to ride a bike or drive a car, but not being able to actually perform the skill. The information is there in declarative memory, but is not expressed due to insufficient reinforcement and expression.

Generative memory is the emergence of a new conceptual, contextual, reference, or relational stimuli based on linked semantic arrays. New knowledge and skills are articulated that are greater than the sum of the parts. These new expressions emerge and bring new patterns of knowledge and skills into consciousness. The complexity and diversity of semantic arrays facilitates generative expression. It is generative memory that brings previously unrelated information into new forms of art, technology, and innovation. The diagram in Figure 18 represents the three types of memory expression. Given two stimuli or semantic arrays,  $S_a$  and  $S_b$ , the outcome of each expression is demonstrated as constructive ( $S_{ab}$ ), selective ( $S_a$  or  $S_b$ ) or generative ( $S_c$ ).

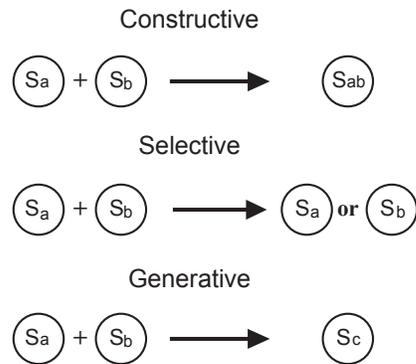


Figure 18. Constructive, selective, and generative memory expressions.

Many theories of how memory is encoded in the mind, such as chunking (G. A. Miller, 1956), schemas (Bartlett, 1932), implicit memory (Schacter, 1987), declarative memory, procedural memory, episodic memory (E. Tulving, 1983, 2002), and semantic memory (E. Tulving, 1972), each condone a black-box faith of the brain as an information storage locker of differing types of memories. What each of these operations articulates is ways in which long-term memory is *expressed*. Terms such as episodic, semantic, declarative, and procedural articulate categorizations on how long-term memory is instantiated when used.

Similar to the structure and function of DNA, that of the encoding and expression of genes, the brain is the structure for the encoding and expression of memory. Similar to genes, the expression of memory is malleable and varied in its use and expression. With some genes being expressed all the time, some with generative expression where more than one gene brings about a particular outcome, to selective gene expression where only partial expression is encoded, memory acts the same. The brain, similar to genes, holds the structure in which different expressions can be promoted or suppressed. The reinforcement of any particular expression strengthens its

potential instantiation. This reinforcement of expression in memory is how learning takes place. The movement from conscious-effortful work to tacit expression occurs through the reinforcement of a particular expression. The functional nature of working and long-term memory support the tacit expression of declarative, procedural, and strategic memory is based on the context of use. Using semantic cues from the environment and context in which the memory is expressed, a reconstruction of elements of conceptual, contextual, reference, and relational information are articulated. Frame-shifting from contextual cues in the environment, our expression, and the narrative we are weaving in our minds, is how memories are actively constructed and expressed. It is the active construction of memory by agents through their interaction with the world, through their perceptual and motor apparatuses, and their goals, needs, and actions in which experience is produced whether real, imposed, or created. Evidence from research suggests “there are no invariant knowledge structures in memory. Instead, people continually construct unique representations from loosely organized generic and episodic knowledge to meet the constraints of particular contexts” (Barsalou, 1988, p. 236). The functional nature of memory permits a very malleable long-term memory based on the context of expression. Reframing long-term memory as expression provides clues on how false memories, imagination inflation, impossible memories, and false eyewitness testimonies are possible.

Elizabeth Loftus, the famous memory researcher, remembers the vivid drowning of her mother at the age of fourteen in her book *The Myth of Repressed Memory* (Loftus & Ketcham, 1994). Loftus describes how at a family gathering, some thirty years after her mother’s death, an uncle recounted how she was the one who discovered her

mother's body in the pool. And although she believed that she never saw her mother's body prior to the gathering, following the revelation from her uncle she remembered the incident in vivid detail. "The memories began to drift back, like the crisp, piney smoke from evening camp fires. I could see myself, a thin dark-haired girl looking down into the flickering blue-and-white pool. My mother dressed in her nightgown, was floating face down...I started screaming. I remember the police cars, their lights flashing, and the stretcher with the clean, white blanket tucked in around the edges of the body" (p. 39). The problem with this memory however, is that Loftus was not the one who found her mother's body. A few days after the family gathering her brother notified her that in-fact the uncle was mistaken and that it was her Aunt who had found her mother's body. Other relatives confirmed that she did not find her mother in the pool and was not even at home at the time; yet her memory seemed as vivid as any real event in her life. Loftus explains that all "it took was a suggestion, causally planted, and off I went eagerly searching for supporting information" (p.40). This antidote shows how the search for meaning and the construction of meaning in the brain can be expressed as instantiations that do not reflect experience. Many studies in false memory, including many from Loftus herself, support that memory is a reconstruction of experience from many fragmented and often ambiguous pieces of information and memories (Loftus, Coan, & Pickrell, 1996; Loftus & Pickrell, 1995). Research shows that even events that are highly emotional, such as the assassination of JFK, the Challenger Space Shuttle Disaster, or September 11, 2001, which are thought to be better represented in memory, many times do not represent accurate reflections of reality (Bohannon III, 1988; R. Brown & Kulik, 1977). Flashbulb memories and autobiographical memories, which can

feel like photographic-like or movie like experiences in the individuals head, are easily manipulated and many times do not represent reality (Curci & Lanciano, 2009; Lanciano, Curci, & Semin, 2010; Talarico & Rubin, 2007). Subjects are many times so confident that their memories are correct and accurate, that they will contradict direct evidence to the contrary (Talarico & Rubin, 2003). Even the recall of first-hand experience is highly fallible. A prime example of this is in eyewitness testimony and police line-ups.

Memory research demonstrates that first-hand experience is many times distorted and inaccurate. This fact however, has not diminished the fallacy of eyewitness testimony and police line-up identification in the conviction of innocent people (Tversky & Fisher, 1999). Case studies and DNA testing in the US and Canada now show that mistaken eyewitness testimony has led to more wrongful convictions than any other cause of false sentences (Yarmey, 2001). Douglas and Steblay (2006) in a meta-analysis of feedback effects on police line-up identification found large effect sizes for confirmatory feedback. The simple confirmation of choice was enough for people to reaffirm their confidence in their choice; whether correct or not. In both recall tasks (e.g. eye witness testimony) and recognition tasks (police line-ups) memory is highly fallible. As individuals create new conceptual, contextual, reference, and relational patterns they recreate their experience. The reinforcement of this experience through memory reconstruction, misinformation, questioning, or feedback, all support that memory is an expression of meaning. This construction and reinforcement of meaning, however, can be used in constructive ways, such as the use of mental practice and imagery in sports psychology.

Long-term memory as the expression of experience also incorporates physical, procedural, and strategic manifestations. Many of the methods in sports psychology such as mental practice, cognitive rehearsal, and strategic mental imagery, manifest in improved athletic performance. Driskell, Copper, and Moran (1994) in a meta-analysis of the literature on the effects on mental practice on performance, conclude that mental practice has a significant positive effect on athletic performance. The type of task performed, the interval between practice and performance, and the duration of the mental practice, moderate the effectiveness of the mental practice. The fact that mental imagination of action manifests in actual performance gains re-enforces that the expression of experience does not have to be necessarily experienced first-hand. It is the reinforcement of expressions, whether real, imagined, or created, that facilitate learning.

### **Semantic Learning: The Reinforcement of Meaningful Expression**

Learning is the reinforcement of expression. The rehearsal of expressions promotes the ability to express those skills more readily, whether they are procedural, declarative, affective, or strategic. The interpretation and integration of past, present, and future stimuli reinforce these expressions with goal-directed and motivational outcomes. The basic pattern of selection, interpretation, integration, and expression, as outlined in Cognitive Architecture of Learning and Comprehension (CALC), explain many experiments and theories in the learning sciences from classical conditioning and behaviourism to constructivism. Semantic learning outlines the basic processes necessary for successful learning. These basic elements of learning, regardless of their underlying theory and application are the same; what information to learn, how we

comprehend that information, how do we make that information meaningful, and how do we express that information for later use.

Learning theories such as behaviourism, classical conditioning, operant conditioning, cognitivism, constructivism, humanism, and transformative learning are all frameworks, which define how information and skills are integrated into knowledge or behaviour. Although the components of each theory are different, all have the same goal of trying to tease out the mechanisms in which new information and skills are incorporated for later use. The factors that are necessary for successful learning within each of these theories define their focus. Table 2 outlines the factors of learning in behaviourist theory, cognitive theory, constructivist theory, social cognitive theory, connectivist theory, humanist theory, transformative theory, and semantic learning theory (Culatta, 2011; Olson & Hergenbahn, 2012).

Table 2. Learning theories and the factors that influence learning

Learning Theory	Factors Influencing Learning
Behaviourist theory	Environmental conditions, stimuli, reinforcement, positive and negative reinforcement
Cognitive theory	Organization, linking of information, meaningfulness, elaboration
Constructivist theory	Situations, real contexts, discovery, collaborative, task-based, self-directed, problem based
Social Cognitive theory	Social interactions, observation, collaboration, intrinsic reinforcement
Connectionist theory	Connection between ideas, concepts and knowledge, social connections
Humanist theory	Student choice, control, interests, self-evaluation, feelings
Transformative theory	Perspective taking, critical self-reflection, self-actualization in belief and behaviour
Semantic theory	Comprehension and meaning, goal-directed action, reinforcement through mental, physiological, or behavioural expression

Many of the elements in semantic learning are similar to factors defined in other theories for successful learning. N. E. Miller and Dollard (1941) Social learning and Imitation theory identify the four factors of drives, cues, responses, and rewards as the components of learning. Stimulus sampling theory includes the reinforcement of stimulus-response pairings and the accumulation of learning which fluctuates based on internal and environmental factors (Estes, 1950, 1970; Niemark & Estes, 1967).

Cognitive flexibility theory supports that learning should have multiple representations, that knowledge is context-dependent, and that knowledge should be connected (Spiro, Coulson, Feltovich, & Anderson, 1988). Transformational learning defines that it is the

change in meaning structures through the use of reflection about content, process or premise (Mezirow, 1991). These factors for successful learning are reflected in the four operations of are selection, interpretation, integration, and expression.

### **Selection**

The presentation and selection of relevant stimuli is paramount for successful learning. This includes cuing the learner to what they are going to learn, setting and choosing expectations, and setting the context of learning for enhance selection. Understanding the limitations of attention and the biasing of functional memory, learning should be focused, goal-directed, significant, and value-based. The information must also supply or cue the learner to relevant contextual, conceptual, reference, and relational information either from their experience or in the environment. The selection of stimuli must also align and support expression. For example, many students learn through rote declarative learning but are expected to apply this to a new context and procedure of an exam. The stimuli and the expression are not aligned.

### **Interpretation**

Interpretation is the use of stimuli informers from the external environment in conjunction with informers in memory to comprehend the information. The users must make the information comprehensible by linking conceptual, contextual, reference and relational information. Ensuring that the student situates the information so that it is comprehensible in the present is paramount. Learners must consciously make sense of information in the present context with the goal of future contextual expressions in mind and application.

## **Integration**

Integration is the formation and construction of meaning. Using information from the past, present, and future, users link with affective, goal-directed, and motivational factors. Integration is enhanced when learners are supplied or cued to these patterns of information in any learning context. What they know from the past, how that affects the present, and how it will affect the future is established. Value and outcome informers are important for understanding and evaluating how the outcome is meaningful.

## **Expression**

Expression is both the instantiation of experience in the brain and the implementation of that experience. The reinforcement of expression in the brain and the product of that expression, whether it is written, spoken, performed, or explained are paramount. How the information, procedure or skill is learned, must also be reinforced through active expression. The expression must also be situated and expressed in the context of use.

The elusive transfer effect in learning is due to the inherent complexity that context and application adds to the comprehension process. As context changes, so does the structure in which that information is represented and expressed in the brain. It is not until new contexts are introduced that the true malleability of semantic arrays are realized. The constant construction of stimuli into semantic structures is vital to understanding the mechanisms of learning, cognition, and memory. This active expression promotes adaptation. Activity-dependent plasticity is the mechanism in which expressions are reinforced in the brain.

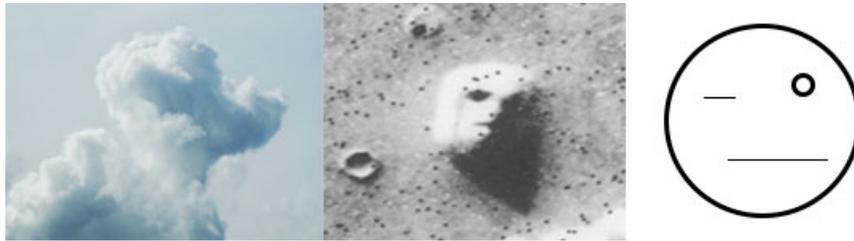
## **Pattern Recognition, Recall, and Instantiation: The Mechanisms of Cognition and Memory**

“Patternality with its affordances shapes how we and all creatures make sense and meaning of the environment within which we exist and the world in which we live. At a biological level, it drives survivability. At the cognitive and social levels, it drives learning and meaning-making for humans and many other social species” (Jordan, 2013, p. 193)

Pattern recognition, recall, and instantiation are innate to the human brain and are the primary mechanisms of cognition and memory. The human brain, as both the product of and the producer of patterns, has an infinite ability to detect, recall, and produce pattern arrangements. CALC posits that pattern recognition, recall and instantiation are the primary mechanisms in which the mind encodes, stores, and organizes information. The mechanism in which patterns of stimuli are encoded and recognized are in the form of semantic arrays of contextual, conceptual, reference, and relational patterns of information. The dynamic interpretation of semantic arrays allows many meanings to be interpreted based on changing patterns. The polymorphic nature of semantic arrays permits infinite variability in both the interpretation and instantiation of meaning. The fundamental mechanism of pattern recognition, recall and instantiation is the reason that humans find such comfort and meaning in the organization, categorization and differentiation of people and things. Pattern finding is the innate way that we make sense of the world.

Apophenia, which is the tendency to interpret random patterns as meaningful, is a universal trait of the human species. Our brains naturally look for meaningful patterns

from the chaos of everyday life. Confirmation bias, clustering illusions, and gambler's fallacy are just a few examples. Pareidolia, which is the perception of images in random stimuli, is also innate. Humans ability to see animals in clouds, the face on Mars, or a face amongst shapes, are a few examples of how the human mind searches for recognizable patterns (see Figure 19). The phenomena of Pareidolia, although varies in the reference that is used in the recognized in patterns, is universal regardless of society or culture.



*Figure 19.* Three examples of Pareidolia. From “Poodle Cloud”.

<https://www.flickr.com/photos/southeasternstar/>. Copyright 2010 by Southeastern Star. and “Unmaking the face of Mars, [http://science.nasa.gov/science-news/science-at-nasa/2001/ast24may\\_1/](http://science.nasa.gov/science-news/science-at-nasa/2001/ast24may_1/). Copyright 2001 by NASA.

The famous astronomer Carl Sagan in his book, *The Demon Haunted World* states, “the pattern recognition machinery in our brains is so efficient in extracting a face from a clutter of other detail that we sometimes see faces where there are none. We assemble disconnected patches of light and dark and unconsciously see a face” (Sagan, 1995, p. 45). The Rorschach test takes advantage of this phenomenon to test people's perceptions, personality, or mental disorders. Evolutionary psychologists posit that the reason for this ability is to improve evolutionary fitness (Jordan, 2013). The ability of the mind to recognize, recall, and instantiate patterns, whether is a lions face in the woods or the sound of a human is distress, directly improves our ability to survive.

Pattern finding has also led to human socialization and survival. The ability of a social group to share patterns of sounds (language) that represents stimuli in their minds and the environment (objects, thoughts) has also led to improved survival through social and cultural exchange. Although there is agreement that patterns form a base of survival, there is some debate on whether some sound patterns hold greater evolutionary significance than others.

Music is the universal language. Every known society has had music that is as diverse as the cultural rituals, beliefs, and customs that surround its performance (Blacking, 1995). The universality goes beyond performance, but is reflected in our innate interpretation of how music affects us. Fritz et al. (2009) in a study looking at the universality of music perception of basic emotions of happy, sad, and scared found that participants from a native African population and Western participants could identify these emotions in the music of each respective culture. Results support that the basic emotions that music convey are universal. Our physiological reaction to music is also universal. Music induces changes in heart rate, respiration rate, blood flow, and skin conductance outside of conscious awareness (Trainor & Schmidt, 2003). This recognition of beat, tempo, and rhythm and its effects on the brain does not have to be taught; neither does the expression of musical recognition.

Infants prior to the age of one-year-old have almost all the faculties and skills of music perception (Kogan, 1997). A search on YouTube for “dancing baby” will result in over a million hits accentuating this fact. A particular clip, *11-Month-Old Twins Dancing to Daddy’s Guitar*, which has reached over 11 million views, reinforces the universality of pattern recognition and expression (see Figure 20). In the clip two

11-month-old twin babes are sitting in their high chairs eating peas. Off camera their father starts to play the guitar. The twins look at each other, smile, and start to sway in unison. There is nothing special about these babies as there are numerous other babies who are able to match movement with sound or music without modelling or instruction to do so. We as human do this naturally. Dance is a form of pattern matching to show our recognition and comprehension of beats, timing, and rhythm. We move our bodies to the music to show we know the pattern. The instinctive recognition of patterns brings about emotions of happiness as the brains recognition, recall, and instantiation of patterns are innately rewarding.



*Figure 20.* YouTube video still from "11 month old twins dancing to daddy's guitar." From "11 month old twins dancing to daddy's guitar", <https://www.youtube.com/watch?v=to7uIG8KYhg>.

Not all mind theorists however, support that the recall, recognition, and expression of music leads to improved evolutionary fitness.

Steve Pinker, the famous Harvard Professor in Psychology and the author of books *How the Mind Works* (1997), argues that in relation to “biological cause and

effect, music is useless. It shows no signs of design for attaining a goal such as long life, grandchildren, or accurate perception and prediction in the world” (p. 528). Pinker goes on to call music “auditory cheesecake, an exquisite confection crafted to tickle sensitive spots” (p. 534). His conjecture about music, however does not take into account the innate ability of the human mind to recognize patterns that directly attribute to evolutionary fitness. The patterns in music, like the patterns of a human or lions face are no different. The glaring contradiction to Pinker’s theory is his view that language, another form of sound, is a basic human instinct (Pinker, 2007). This instinct, which Pinker describes as inherent to the human brain, however can be lost without use (see Seliger & Vago, 1991). Defining one pattern of sound as a basic human instinct (language) and another as ‘mental cheesecake’ (music) is not a cogent theory and makes the mistake of projecting too much significance on a particular pattern of expression.

The brain, needing constant stimuli, is constantly searching for patterns. The cross-wiring between both visual and auditory and emotional centres ensures “that the very act of searching for the solution [in patterns] is pleasing...it’s about generating as many “a-ha’s in your brain as possible” (Ramachandran, 2003, p. 51). The patterns that are formed, reinforced, and emerge, provide the building blocks for cognition, memory, and learning.

### **Conclusion: Establishing a Cognitive Architecture of Learning and Comprehension**

Charles Spearman (1923), the father of modern intelligence testing, proposed that there are three fundamental qualitative principles of cognition and intelligence. The first, is the *apprehension of experience*, which is the encoding of stimuli from the

environment, the second, *education of relations*, is the inference of the relationship between two concepts or stimuli, and the third is the *education of correlates*, which is the application of these relationships to new situations (cited in Sternberg & Pretz, 2005). These principles, proposed by Spearman as the basic components of human intelligence, are articulated in the cognitive architecture and models proposed. The mechanisms in which the mind uses stimuli from the internal and external environment to facilitate comprehension through the linking of contextual, conceptual, references, and relational patterns of information into semantic arrays, forms the base of how we make sense of the world. The social linking and recursive checking of semantic arrays allows the formation of contextually, culturally and socially based signs, symbols, and cues. The reinforcement of expression through learning and memory support the expression of experience. The ability of the human mind to recognize, recall, and instantiate patterns as an innate property of the mind, allows for infinite expressions of thoughts, ideas, abilities.

CALC and supporting models and mechanisms offer explanatory insight into a number of well-established psychological observations that lack sufficient theory for explanation. Selective attention, mindfulness meditation therapy, and false memories, are just a few observations that can be decoded using the proposed architecture. It is through the exploration and explanation of psychological phenomena using grounded theory that allows new questions and explorations to take place.

CALC satisfies the criteria of a cognitive architecture, as having a short-term and long-term memory stores, representational elements that are contained in these memories, their organization into larger-scale mental structures, and the functional

processes that operate on these structures, including the performance mechanisms that utilize them and the learning mechanisms that alter them (Langley et al., 2009). The cognitive architecture and models presented in this dissertation offer new ideas and frameworks in which psychologists, researchers, and educators can predict, explore, and evaluate the phenomena of learning and comprehension.

### CHAPTER THREE: RESEARCH METHOD

Comprehension underlies intelligent action. The cognitive correlates of comprehension, however, are not clearly defined in the literature. The Situated Model of Comprehension (SMC), presented in the Cognitive Architecture of Learning and Comprehension (CALC), specifies the factors of comprehension as *contextual*, *conceptual*, *reference*, and *relational* information. It is the use of these patterns that facilitates how individuals make sense of information. Due to the breadth and depth of the topics addressed in CALC, this study was devised to empirically evaluate only one of many implications of the Situated Model of Comprehension. This study tested how individuals make sense of nonsense symbols and sounds without explicit instruction. The paradigm proposed in this study provided a novel way in which to study comprehension outside of subject-specific domains. The use of nonsense sounds and symbols, although a novel experiment for assessing comprehension, is not a new paradigm in psychological research.

Hermann Ebbinghaus (1913), the father of memory research, used nonsense sounds and symbols to evaluate memory. In his book *Memory: A contribution to experimental psychology*, he outlines how he devised a list of 2300 nonsense syllables having the structure of consonant-vowel-consonant (e.g. Caj, Nog, Baf). The use of nonsense words acted as a control for the experiment as they were thought to be free of memory associations. Ebbinghaus, using himself as the primary subject of the experiment, learned the list of syllables over a number of trials and periods of time until

he had reached perfect recall. The outcome of the experiments led to many groundbreaking insights into learning and memory including the learning curve, forgetting curve, memory decay, spaced practice, and the primacy effect (Boneau, 1998). Many researchers followed Ebbinghaus' experiments using nonsense syllables to evaluate a number of psychological areas including memory (Carson, 1926), reading disabilities (Stanovich, 2000), dyslexia (Rack, Snowling, & Olson, 1992), and phonetic decoding (Treiman, Goswami, & Bruck, 1990). What many researchers found, however, was that even when using the strictest criteria for selecting nonsense words most subjects projected and imposed meaning onto them (see Carson, 1926). J. Arthur Glaze proclaims in his study *The Associate Value of Non-Sense Syllables* (Glaze, 1928), "our subjects were doubtless looking for associations... given enough time, almost anyone will be able to read into most syllables some form of association" (p.266). Other researchers follow this assertion that "it appears to be a fundamental element of the 'human condition' that, in our natural state, we do typically seek to impose meaning upon events taking place in our environment" (Foster, 2009, p. 11). The finding that subjects impose meaning onto nonsense syllables suggests that comprehension is an innate process. The Bouba-Kiki experiments have extended this research, attempting to answer the questions of the universality of linking nonsense sounds and shapes.

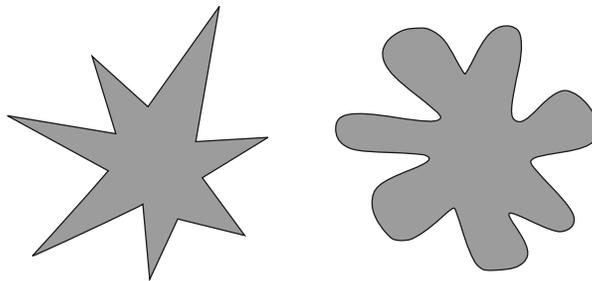
### **Making Sense of Nonsense: The Bouba-Kiki Experiment**

The mapping of sounds to objects is largely arbitrary and varies greatly based on language and culture (Maurer, Pathman, & Mondloch, 2006). Shared signs and symbols and the sounds that are attributed to those objects, are largely defined based on the society and culture in which they are defined. The Takete-Baluba (Kohler, 1929, 1947;

Werner, 1934; Werner & Wapner, 1957) and Bouba-Kiki experiments (Ramachandran & Hubbard, 2001), however, call these assertions into question.

The Takete-Baluba and the Bouba-Kiki experiments aimed to show that there is non-arbitrary link between sounds and shapes. Using one shape that is round and another shape that is jagged, with corresponding sounds such as Takete-Baluba (Kohler, 1929), Takete-Maluma (Kohler, 1947), or Bouba-Kiki (Ramachandran & Hubbard, 2001), users were asked to match sounds to shapes. Figure 21 shows the basic elements of the Bouba-Kiki experiment.

Which is Bouba? Which is Kiki?



*Figure 21.* The Bouba-Kiki experiment.

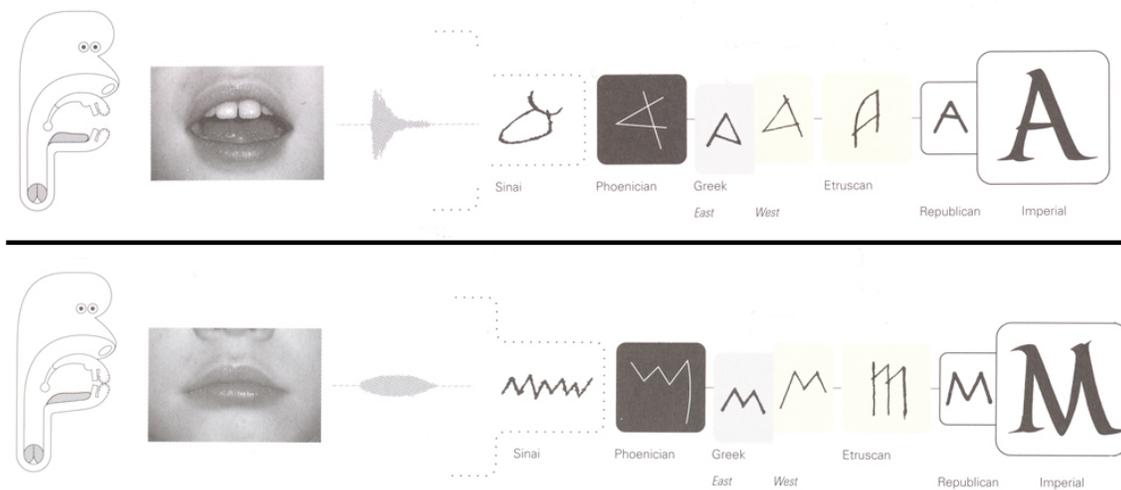
The experiments found that, regardless of cultural background, subjects almost universally chose the rounded shape for the rounded sound (Bouba, Baluba, Maluma) and the jagged shape with the sharp sound (Kiki, Takete). The experiment has been tested on native English speakers, Spanish speakers, and Tamil speakers with 95%-98% overlap in users responses (Ramachandran, 2003). The effect has also been observed in children as young as two-and-a-half years old, to demonstrate that it is not reading or language ability that facilitates the effect, but is a universal trait of the human brain (Maurer et al., 2006).

Ramachandran and Hubbard (2001) explain the Bouba-Kiki effect as cross-modal synesthetic abstraction in the brain. They posit that the brain naturally links soft sounds with rounded shapes and sharp sounds with jagged shapes. Ramachandran (2003) furthers this conjecture with evidence from brain lesion studies where patients with damage in angular gyrus of the left hemisphere are not able to reproduce this effect. “This makes perfect sense because the angular gyrus is strategically located at the crossroads between the parietal lobe (concerned with touch and proprioception), the temporal lobe (concerned with hearing) and the occipital lobe (concerned with vision). So it is strategically places to allow a convergence of different sense modalities to create abstract, modality-free representations of things around us” (p.74). He goes on to say the crossroads of the angular gyrus facilitates the abstraction of how we link stimuli. Although it is a cogent argument, it does not presuppose that an individual would automatically come up with a soft sound or a jagged sound given the abstract shapes of the experiment.

### **An Alternative Explanation of the Bouba-Kiki Experiment using a Situated Model of Comprehension and Onomatopoeia**

The process of deciphering the Bouba-Kiki experiment on how individuals link sound with shape is currently explained as an innate type of cross-modal synesthetic abstraction in the brain (Ramachandran, 2003; Ramachandran & Hubbard, 2001). The assumption that the mind makes the simple link between sound and shape, without extraneous cues, however, is a misnomer. A critical look at the experiment reveals that there are fundamental cues that guide the user into choosing one image or the other.

Timothy Donaldson in his book *Shapes for sounds* (2008) describes why alphabets look the way they do, their evolution, and how sounds are linked to alphabet shapes. An analysis of mouth shape, lips, tongue, and sounds produced, reveal that many letters resemble a form of onomatopoeia of sound and shape; that the naming of the letter, its sound, and its shape are linked. We develop visual images that represent “a delicate visual structure of small shapes, representing sounds that come out of our mouth to express the thoughts in our heads” (p.20). Although most alphabets are not truly phonetic, and it is difficult to map and assign a grapheme to a single phoneme, many letter shapes do map onto mouth shape, feel, or sound texture. Figure 22 shows the mapping of sounds, mouth shape, tongue placement, and vibration, to an evolving alphabet.

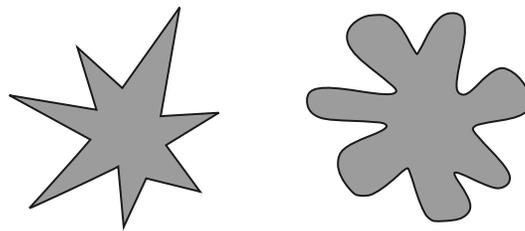


*Figure 22.* The mapping of sound, mouth shape, and sound texture to letter shape. From “Shapes from sounds” by Timothy Donaldson, 2008. Copyright 2008 by Timothy Donaldson. Reprinted with permission.

Information provided to the user through the experience of sound, mouth shape, and sound texture allows them to link sound and shape.

Further deciphering this experiment using a Situated Model of Comprehension, it can be seen that the structure of the information, along with the onomatopoeia of the shapes, provides enough information for the individual to comprehend the linkage between shape and sound. Breaking the Bouba-Kiki experiment into the components of a Situated Model of Comprehension, of contextual, conceptual, reference, and relational information, an alternative explanation of the results can be proposed (see Figure 23).

Which is Bouba? Which is Kiki?



Situated Model of Comprehension Components			
Context	Concept	Reference	Relationship
Question	Differentiation (Which)	Images Sounds	1 Image = 1 Sound 1 Image = 1 Sound

*Figure 23.* The Bouba-Kiki experiment broken into the components of the Situated Model of Comprehension.

Breaking the Bouba-Kiki experiment into the components of a Situated Model of Comprehension shows that the information presented holds structure that facilitates comprehension. Cross-modal synesthetic integration or onomatopoeia alone, may explain simple sound-shape pairs, but the hypothesis of this study suggest there is more to the story. How individuals link stimuli into comprehensible forms may be facilitated by the structure of the information they are presented with. My research tested four hypotheses on how participants comprehend nonsense words and symbols by differing

the presentation of either reference or relational patterns of information without explicit instruction.

### **Participants**

A total of 46 students from the general Simon Fraser University population participated in the study. The number of participants in the study was based on a Power analysis for a multivariate analysis of covariance (MANCOVA) with two levels and two dependent variables. G-POWER was used to determine a sufficient sample size using an alpha of 0.05, a power of 0.80, and a medium effect size ( $f^2 = 0.25$ ) (Faul, Erdfelder, Buchner, & Lang, 2008). Based on the aforementioned assumptions of power, effect size, and alpha, the desired sample size was 42. All subjects were English speakers, with normal or corrected-to-normal vision and hearing. All subjects were asked to provide written informed consent prior to the study in accordance to the Tri-Council Policy Statement, Ethical Conduct for Research Involving Humans (Panel on Research Ethics, 2010). Participants were randomly assigned to either the *Reference group* or *Relationship group* prior to the *Need for Cognition* assessment. Participants were compensated for their time in this study with the payment of \$15 cash for approximately 1 hour of their time.

### **Research Design**

This study tested four hypotheses on how participants comprehend nonsense words and symbols by differing the presentation of either *Reference* or *Relational* patterns of information. Participants were never explicitly informed about the association between the symbols and sounds, but used the information presented to

make probabilistic inferences about how the shapes and sounds match. Participants ( $N=46$ ) were randomly assigned into two groups: *Reference group* ( $N=23$ ) or *Relational group* ( $N=23$ ) by selecting a piece of paper with either test name on it. Participants' answer choice (*DV: Performance score*) and confidence of answer choices (*DV: Confidence score*) were measured. The *Need for Cognition* assessment was used as individual difference measure to control as a possible confounding variable (*CV: Need for Cognition*). A multivariate analysis of covariance (MANCOVA) was performed to see if there were significant differences between the groups controlling for the *Need for Cognition*.

A Post-test assessment was administered to both groups to see if there was a learning effect from the presentation of the sequences of either reference or relational information. The participants were presented with 10 nonsense symbols, some from the test and some new. The qualitative answers were scored by two independent raters on a scale from 0 to 2: 0 for no match (no matched sounds), 1 for partial match (2-3 sounds match), and 2 for a close match (3+ sounds match). Cohen's kappa was run to determine inter-rater reliability. An analysis of covariance (ANCOVA) was performed to look at the learning effect across the two groups: *Reference group* and *Relational group* (IV), their Performance score on matching nonsense symbols (DV), while controlling for *Need for Cognition* (CV).

## **Hypothesis**

*Hypothesis I.* The *Relationship group* will choose the matching symbol statistically significantly more for the Bouba-Kiki question than the *Reference group*.

*Hypothesis II.* The *Relationship group* will match statistically significant more nonsense symbols to sounds than the *Reference group*.

*Hypothesis III.* The *Relationship group* will have statistically significant more confidence in their answer choice than the *Reference group*.

*Hypothesis IV.* The *Relationship group* will have statistically significant more ability to assess the 10 nonsense symbols in the post-test more accurately than *Reference group*.

### **Materials**

The *Demographic Survey*, *Need for Cognition*, *Alien Language test*, and *Alien Language Post-test* were completed using pen and paper. The assessments were originally supposed to be done with a Flash-based computer program, but due to glitches found prior to the experiment, the computer assessment was cancelled.

#### *Demographic Survey*

The demographic survey consisted of 12 questions to gather general information about the subjects and their language learning experience (see Appendix D). The demographics survey aimed to gain a general overview of who was participating in the study and how much experience and exposure they had to second languages.

#### *Need for Cognition Assessment.*

The Need for Cognition assessment was administered to the subjects as a possible correlate of performance (see Appendix E). The instrument, which was developed by Cacioppo and Petty (1982), assesses participants' motivation and extent in which they engage in effortful cognitive activities (Petty, Brinol, Loersch, & McCaslin,

2009) a critical aspect of comprehension. The instrument consists of 34 questions, which ask the subjects to rate on a scale of 9, from very strong agreement to very strong disagreement, the extent in which they enjoy engaging in thinking. The assessment was later revised into a shortened form of 18 questions and 5 selections for how well the statements identify their preference for thinking (Cacioppo, Petty, Feinstein, & Jarvis, 1996; Cacioppo, Petty, & Kao, 1984). The shortened form is what was used for this study (see Appendix C). The Need for Cognition assessment appears to both valid and reliable, with a Cronbach's alpha coefficient of +.90 for the 18-item NCS and +.91 for the longer 34-item NCS (Cacioppo et al., 1984). The measure has been shown to be an efficient way to measure participants' enjoyment of thinking (Cacioppo & Petty, 1982; Cacioppo et al., 1996; Sadowski, 1993; Sadowski & Gulgoz, 1992).

### *Alien Language Test*

Using the idea of onomatopoeia, where a word or shape phonetically imitates, resembles, or suggests the source of the sound it describes, a novel 'alien' alphabet was devised for this task and 'words' created based on phonetic complexity and repetitiveness. Due to the complexity of devising these sound shape links, only 22 sounds of the 44 total International Phonetic Alphabet (IPA) phonetic sounds of the English language were invented for this experiment. The chart of the 22 sounds with their IPA phonetic symbols can be seen in Figure 24.

 æ cat, apple	 b board, tab	 k cord, kard	 d dog, add	 i: we, tree	 f fool, enough
 g grass, agree	 h hat, happy	 l kit, symbol	 dʒ jungle, judge	 ɪ laugh, legal	 m mother, monkey
 n note, know	 u: fool, rule	 p parking, open	 r random, race	 s sister, sunday	 t trunk, test
 j yet, you	 v vocal, vote	 w what, window	 z zebra, xenon		

Figure 24. Base symbols and sounds of the alien alphabet.

By combining the alien alphabet symbols into four-sided shapes, novel sound symbols are formed. Using combinatorics with a sample space of ( $N = 22$ ), choice of ( $r = 4$ ), order not important, and no repetition allowed, there are 7315 combinations that can be made from the alien alphabet. The novel sound symbols when combined form a word, and are read starting at the top moving to the right clockwise around the shape. Figure 25 shows three examples of alien word shapes in a range of complexity and arrangement. Very simple sound shapes will only differ in a single changing consonant sound, while more complex shapes will differ in both consonant and vowel shape and sound based upon a similar consonant-vowel-consonant-vowel pattern described by Ebbinghaus (1913). The most complex will have no repetition of vowels and use the shapes to make whole words. To assess comprehension within a novel context, a sequence of 30 symbols was presented; 10 of simple sound-shape forms, 10 sound-

shape forms of medium complexity, and 10 more complex sound-shape forms (see Figure 25 for examples).

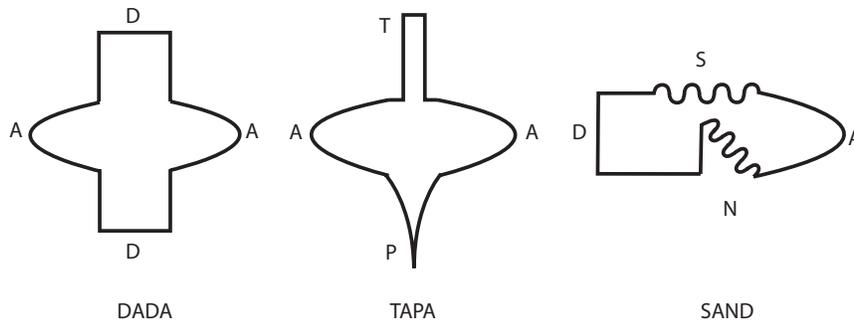
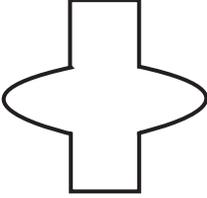


Figure 25. Example four-sided sound-shapes (words) of the alien alphabet from simple to complex.

The *Reference group* was presented with the shapes and sounds in serial form, which only supplied reference but not relational information (see Appendix H), while the *Relationship group* was presented with the shapes and sounds in parallel, supplying them with both reference and relational information (see Appendix G). Ignoring the differential provision of information in the treatments and the accumulated experience of participants as they progress through the session, both groups had a 50% chance of guessing the correct or incorrect answer in their selection. No feedback was given about correctness of response at any point in the session.

The *Reference group* was presented with one sound and one image. The question asks the participant if the sound and shape match with a choice of *Yes* or *No*. Following their answer choice, subjects were asked to rank the confidence in their answer on a 4 point Likert scale from being very confident, confident, somewhat confident, or not confident. Figure 26 shows an example of the *Reference groups'* assessment question.

Is this PAPA?



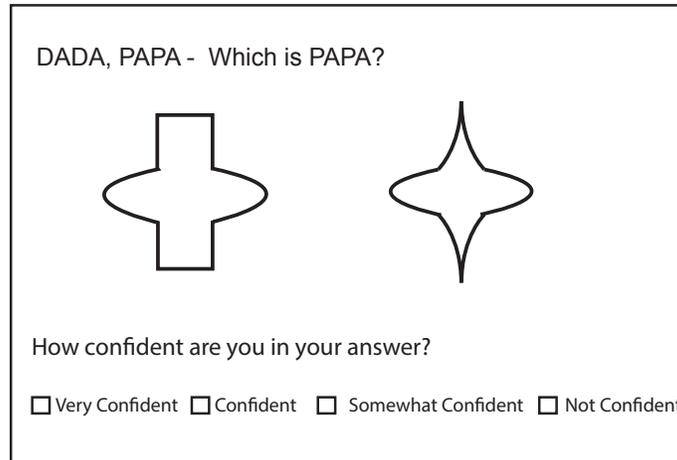
YES  
NO

How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

*Figure 26.* Example question from the Alien Language test for the Reference group.

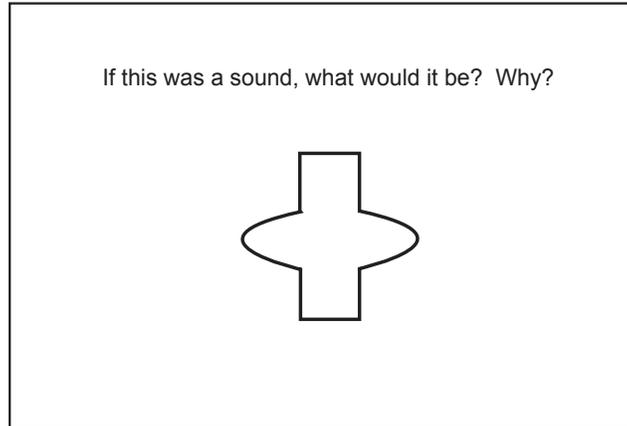
The *Relationship group* was presented with two sounds and two images at the same time, providing both reference and relational information. Following a participant's answer choice they were prompted to rank their confidence in their answer on a 4-point Likert scale, from being very confident (1), confident (2), somewhat confident (3), to not confident at all (4). Figure 27 shows a presentation slide with questions for the *Relationship group*.



*Figure 27.* Example question for the Alien Language test for the Relationship group.

### *Alien Language Post-test*

After subjects were exposed to the novel alien ‘words’ in the Alien Language test, they were presented with ten ‘word’ shapes, one at a time, and asked “If this was a sound what would it be” and “Why”. The post-test was administered to assess whether participants recognized the patterns of the alien words, and if they could verbalize the relationship between sound and shape. Figure 28 shows a question slide from the Alien Language Post-test. All 10 shapes used in the Post-test can be seen in Appendix I.



*Figure 28.* Example question from the Alien Language post-test.

### **Procedure**

A classroom at Simon Fraser University was used for this study. Volunteers were asked to sign-up via an online web form. On the form participants were able to sign-up and choose a date and time-slot for test administration. An email was automatically generated telling both the researcher and the participant the date and time they signed up for along with the research room number.

### *Volunteer Informed Consent*

Participants were given the *Letter of Informed Consent* (see Appendix B) to read prior to the Demographic survey and Need for Cognition assessment. Participants were asked to sign two copies, returning one to the researcher, and keeping the other for their records. Any questions in regards to the experiment were answered before the study began.

### *Demographics Survey*

The Demographics survey was administered following the Letter of Informed Consent. The results of the demographic survey were entered into SPSS for descriptive analysis.

### *Need for Cognition Assessment*

The Need for Cognition assessment was administered to the subjects as an individual differences questionnaire. The results were entered into SPSS for analysis. Cronbach's alpha was performed on the *Need for Cognition* assessment to assess internal validity of the assessment. Following the assessment, participants were given directions to begin the *Alien Language test*.

### *Alien Language test*

The quantitative assessment of comprehension was administered via pen and paper with the participants either selecting their *shape choice* or the word choice *Yes* or *No* to identify the matching shape and sound (see Figure 26 and Figure 27). Following their selection they chose how confident they are in their choice, very confident, confident, somewhat confident, or not confident. Following the test phase, participants were given directions to begin the *Alien Language Post-test* with the researcher. The results of the test were entered into SPSS statics for analysis. A multivariate analysis of covariance (MANCOVA) was performed with an alpha of 0.05, a power of 0.80, and a medium effect size ( $f^2 = 0.25$ ) to see if there were significant differences between the groups. The *Reference group* ( $N = 23$ ) or *Relational group* ( $N = 23$ ) (IV), participants' answer choice (DV) and confidence of answer choices (DV) were measured. The *Need*

*for Cognition* assessment was used as individual difference measure to control as a possible correlate of performance.

#### *Alien Symbol Post-test*

The qualitative assessment of participants' comprehension was administered via pen and paper with the researcher present, recording the audio of the participants to comprehension of 10 alien shapes. Each shape was presented one at a time. The qualitative answers were scored by two independent raters on a scale from 0 to 2: 0 for *no match*, 1 for *partial match*, and 2 *close match* into SPSS. Inter-rater reliability was calculated to evaluate the consistency among observational ratings using Cohen's kappa. An analysis of covariance (ANCOVA) was performed to look at the learning effect across the two groups: *Reference group* and *Relational group* (IV), their score on matching nonsense symbols (DV), while controlling for *Need for Cognition* (CV). The qualitative answers were also scored based on their overall general strategy in how they came up with a sound for the chosen object.

## CHAPTER FOUR: RESULTS

This chapter presents the results of the study. First, subject characteristics and demographics are presented to give an overview of the participants of the study. The results of Bouba-Kiki test questions are presented with a Mann-Whitney test. The results of the Need for Cognition test, which is used as a covariate in the study, are presented with reliability measures to assure internal consistency. The results of the Alien Language test phase of the experiment are presented next using MANOVA. The Alien Language Post-test results are then presented last using ANOVA.

### **General Subject Demographics**

All participants of this study were drawn from the general student population at Simon Fraser University. Participants completed the demographic survey prior to beginning the Need for Cognition assessment and experimental tests.

A total of 46 participants took part in the study, 16 males (34.8%) and 30 females (65.2%). The participant age range was from 18 to 65 years old with an average age of 24.47 ( $SD = 7.23$ ) years. Only 15 (32.6%) of the participants were native English speakers, with a majority, 31 (67.4%), of the participants having English as a second language. There were 16 different first languages represented in the participants surveyed (see Table 3). A majority of the participants 40 (87%) speak more than one language with 22 (48%) speaking two languages, 12 (26%) speaking three languages, and 6 (13%) speaking 4 or more languages. All of the participants, 46 (100%), identified having studied a second language formally in school. Table 3 shows

the results of all of the questions from the demographics survey and Table 4 shows second language study demographics.

Table 3. General Participant Demographics

<b>Variables</b>	<b>Answers</b>	<b>Results</b>
Average Age (years)		24.47
Gender	Male	16 (34.8%)
	Female	30 (65.2%)
Native Language	English	15 (32.6%)
	Cantonese	7 (15.2%)
	Mandarin	4 (8.7%)
	Spanish	3 (6.5%)
	French	2 (4.3%)
	Hindi	2 (4.3%)
	Urdu	2 (4.3%)
	Nepali	2 (4.3%)
	Korean	2 (4.3%)
	Thai	1 (2.2%)
	Vietnamese	1 (2.2%)
	Japanese	1 (2.2%)
	Lithuanian	1 (2.2%)
	Russian	1 (2.2%)
Speak other Language	Farsi	1 (2.2%)
	Tagalog	1 (2.2%)
Speak other Language	Yes	40 (87%)
	No	6 (13%)
Number of Languages Spoken	1	6 (13%)
	2	22 (48%)
	3	12 (26%)
	4+	6 (13%)

Table 4. Participant Demographics for Second Language Learning

<b>Variable</b>	<b>Answer</b>	<b>Results</b>
Studied other Languages	Yes	46 (100%)
	No	0 (0.0%)
Years of Second Language Training	0-5	10 (21.7%)
	5-10	8 (17.4%)
	10-15	12 (26.0%)
	15-20	5 (10.9%)
	20+	11 (24.0%)
Second Language Studied	English, French, German, Russian, Taiwanese, Dutch, Latin, Punjabi, Arabic, Japanese, Spanish, Hindi, Urdu, Cantonese, Mandarin, Farsi, Malaysian, Thai, Finish	
Second Language Proficiency	Expert	4 (8.7%)
	Very Proficient	13 (28.3%)
	Proficient	17 (37.0%)
	Somewhat Proficient	7 (15.2%)
	Not Proficient	5 (10.9%)
Enjoyment of Learning a Second Language	Very Enjoyable	19 (41.3%)
	Enjoyable	16 (34.8%)
	Somewhat Enjoyable	8 (17.4%)
	Not Enjoyable	3 (6.5%)
Reasons for Studying Second Language	School	24 (52.2%)
	Work	1 (2.2%)
	Immigration	1 (2.2%)
	Family	3 (6.5%)
	Curiosity	5 (10.9%)
	Enjoyment	4 (8.7%)
	Most Common Language	8 (17.4%)

### **Bouba-Kiki Pre-test Question**

The Bouba-Kiki experiment question was administered as a pre-test question to both groups prior to the Alien Language test. In the Reference group, 16 of the 23 ( $M = 0.696$ ) participants chose the matching shape-sound pair based on current published studies (Davis & Tsang, 2008; Nielsen & Rendall, 2011; Ramachandran & Hubbard, 2001), while 22 of the 23 participants ( $M = .957$ ) in the Relationship group chose the matching shape-sound pair (see Figure 29). A Mann-Whitney test, used due to non-normal distribution of the dependent variables, indicated that the Relational group choose the matching shape in the Bouba-Kiki experiment ( $M = .957$ ) statistically more times than the Reference group ( $M = 0.696$ ),  $U = 195.5$ ,  $z = -2.31$ ,  $p = .021$ ,  $r = -0.34$ .

The Confidence scores of the groups were not statistically significantly different based on a Mann-Whitney test; Reference group ( $M = 2$ ), Relational group ( $M = 3$ ),  $U = 220.5$ ,  $z = -1.004$ ,  $p = .316$ ,  $r = -0.15$ . A Box-plot of the Confidence scores can be seen in Figure 30.

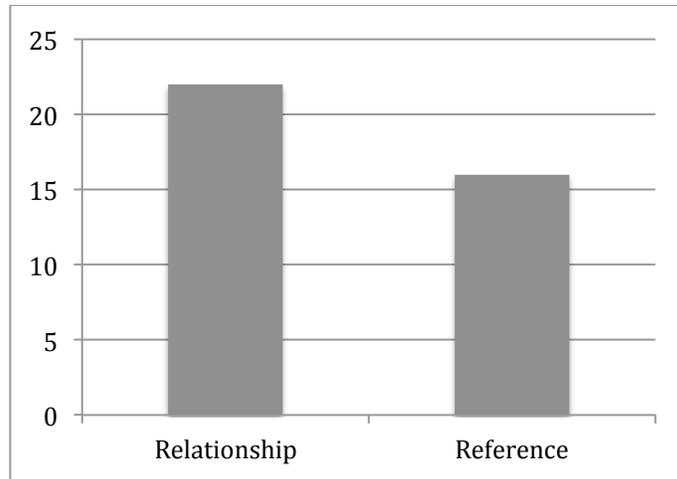


Figure 29. Number of matching answers in the Relational and Reference groups in the Bouba-Kiki experiment.

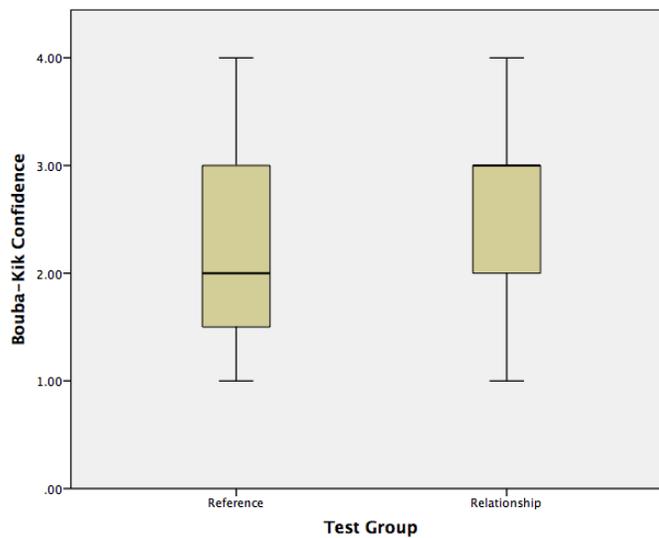


Figure 30. Boxplot of the Confidence scores of the Reference and Relationship groups for the Bouba-Kiki pre-test.

### Need for Cognition Assessment

The Need for Cognition test was employed as a possible covariate in the Alien Language test and Post-test assessments. A reliability test was run and the scale was

found to have a high level of internal consistency as determined by a Cronbach's alpha of .816.

### Alien Language test

The descriptive statistics of the Reference and Relational groups for the dependent variables, Performance score, Confidence score, and covariate, Need for Cognition, can be seen in Table 5.

Table 5. Descriptive statistics for the Alien Language test

Group		Dependent Variables				Covariate	
		Performance Score		Confidence Score		Need for Cognition Score	
	N	M	SD	M	SD	M	SD
Reference	23	14.870	2.096	69.826	17.639	57.913	15.398
Relationship	23	20.261	3.957	67.391	18.605	65.261	13.091

Note: N = number of participants, M = Mean, SD = Standard Deviation, Reference = Reference test group, Relationship = Relationship test group.

A MANCOVA [between-subject factor: Groups (Reference, Relationship); covariate: Need for Cognition; dependent variables: Performance score, Confidence Score] was planned to be run for the Alien Language test but failed preliminary assumption checking. Preliminary assumption checking found there was no statistically significant correlation between the covariate and the dependant variables of Performance score ( $r = .226$ ) and Confidence score ( $r = .191$ ). The covariate was dropped from the analysis and the preliminary tests for MANOVA were performed. There were no univariate outliers in the data as assessed by inspection of a boxplot for both Performance Scores and Confidence Scores (see Figures 31, 32, 33).

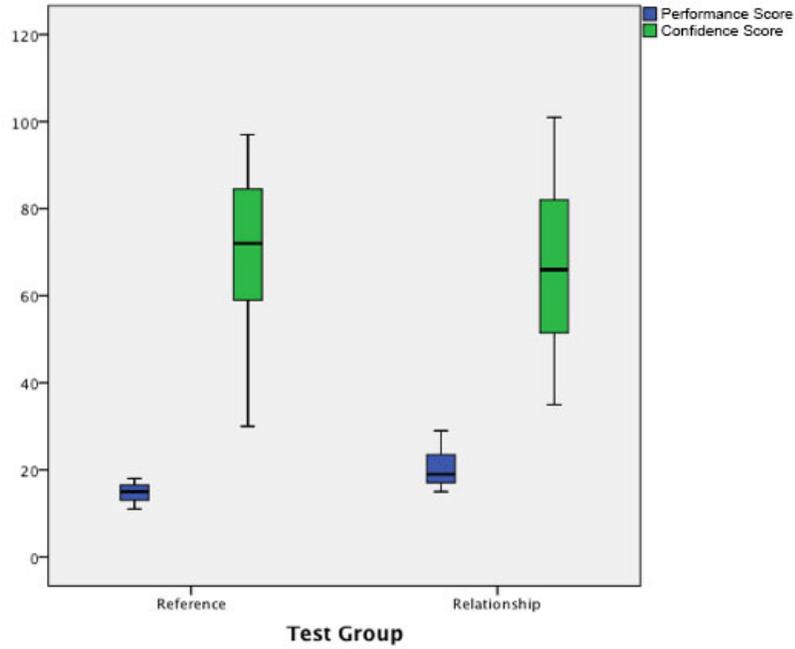


Figure 31. Boxplot of Performance scores and Confidence scores for each test group.

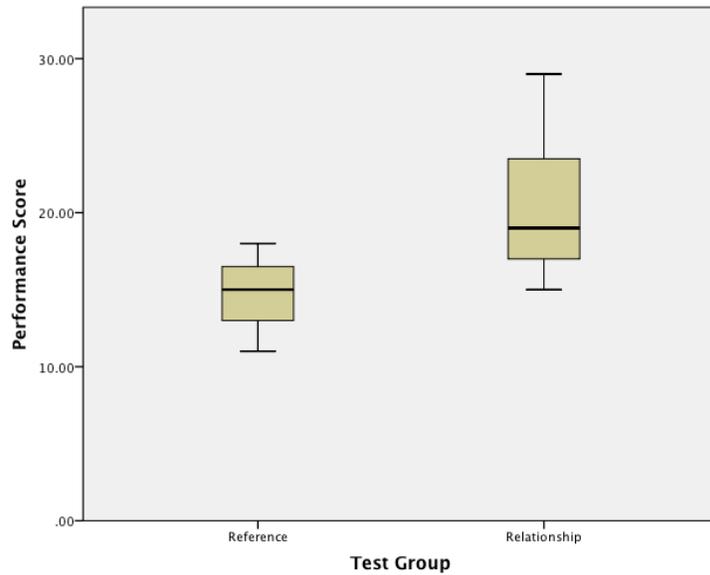


Figure 32. The Reference and Relational group Performance scores boxplot.

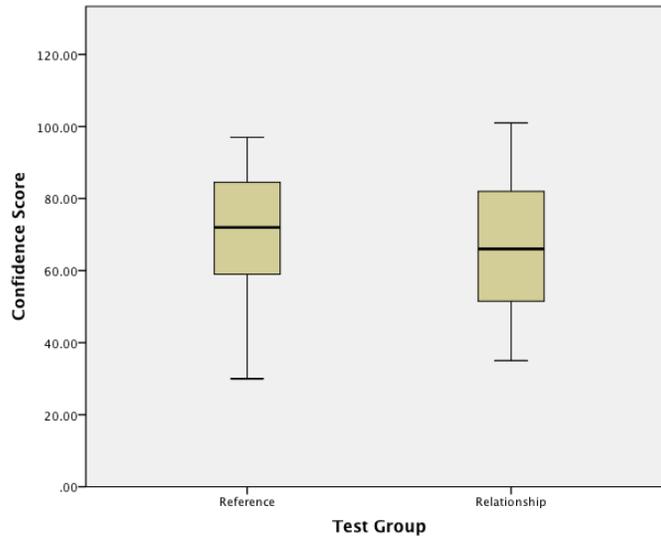


Figure 33. The Reference and Relationship group Confidence scores boxplot.

The data were normally distributed as assessed by a Shapiro-Wilk test ( $p < .05$ ), for Confidence score for Reference group ( $p = .605$ ), Relationship group ( $p = .435$ ), and the Performance score for the Reference group ( $p = .155$ ), but was not normally distributed for the Relationship test scores ( $p = .027$ ). It was decided due to the robustness of one-way MANOVA to continue regardless of the deviation from normality. There were no multivariate outliers in the data, as assessed by Mahalanobis distance ( $p > .001$ ) and there was homogeneity of variance-covariance matrices, as assessed by Box's M test of equality of covariance matrices ( $p = .046$ ). There was a statistically significant difference between the groups on the combined dependent variables,  $F(2, 43) = 17.141$ ,  $p < .0005$ ; *Pillai's Trace* = .444; *partial*  $\eta^2 = .444$ . Separate ANOVAs found there was a statistically significant difference in test scores between the groups,  $F(1, 44) = 33.347$ ,  $p < .0005$ ; *partial*  $\eta^2 = .431$ . There was no statistically significant difference in confidence scores between the tests groups,  $F(1, 44) = .207$ ,  $p = .651$ ; *partial*  $\eta^2 = .005$

## Alien Language Post-test Assessment

All the participants were presented with 10 shapes and asked what they think the shape sounded like. Two independent-raters listened to the recordings and scored the produced sounds as *no match* (no sound match), *partial match* (1-2 sounds match), or *close match* (3+ sounds match). Cohen's kappa was run to determine inter-rater reliability in the judgment of how close participants matched sound to shape. Over the 10 questions there was substantial ( $k = 0.61$  to  $0.80$ ) to almost perfect agreement ( $k = 0.81$  to  $1.0$ ) between the raters' judgements on many of the questions (Landis & Koch, 1977). Table 6 shows the inter-rater agreement with Cohen's kappa, the confidence interval and p-value for each question.

Table 6. Inter-rater reliability on the Alien Language Post-test questions.

Question Number	Cohen's kappa, Confidence Interval, and p-value
1	$\kappa = .746$ , CI[.556, .936], $p < .001$
2	$\kappa = .778$ , CI[.611, .945], $p < .001$
3	$\kappa = .706$ , CI[.522, .890], $p < .001$
4	$\kappa = .634$ , CI[.444, .824], $p < .001$
5	$\kappa = .644$ , CI[.464, .824], $p < .001$
6	$\kappa = .814$ , CI[.661, .967], $p < .001$
7	$\kappa = .859$ , CI[.728, .990], $p < .001$
8	$\kappa = .670$ , CI[.484, .856], $p < .001$
9	$\kappa = .675$ , CI[.473, .877], $p < .001$
10	$\kappa = .732$ , CI[.552, .912], $p < .001$

Table 7. Intervention means and variability for Alien Language Post-test score and Need for Cognition assessment as a covariate

Group	N	Dependent Variable		Covariate	
		Performance Score		Need for Cognition Score	
		M	SD	M	SD
Reference	23	6.13	5.05	57.913	15.398
Relationship	23	10.63	4.51	65.261	13.091

Note: N = number of participants, M = Mean, SD = Standard Deviation, Reference = Reference test group, Relationship = Relationship test group.

An ANCOVA was originally going to be run to determine the effect of the test group assignment to either the Reference or Relational test group on the Alien Language Post-test after controlling for the Need for Cognition covariate, but was changed to ANOVA based on preliminary assumption checking. There was a linear relationship between the Alien Language Post-test and the Need for Cognition as assessed by a visual inspection of a scatterplot (see Figure 34). Although the Relational group scored higher on the NfC test ( $M = 65.261$ ) than the Reference group ( $M = 57.913$ ), the homogeneity of regression slopes as the interaction term was not statistically significant,  $F(1,42) = .146, p = .704$ . The finding that there was little interaction between the covariate and the dependent variable means they are independent. For this reason the analysis using the covariate was dropped and a one-way ANOVA was performed on the data.

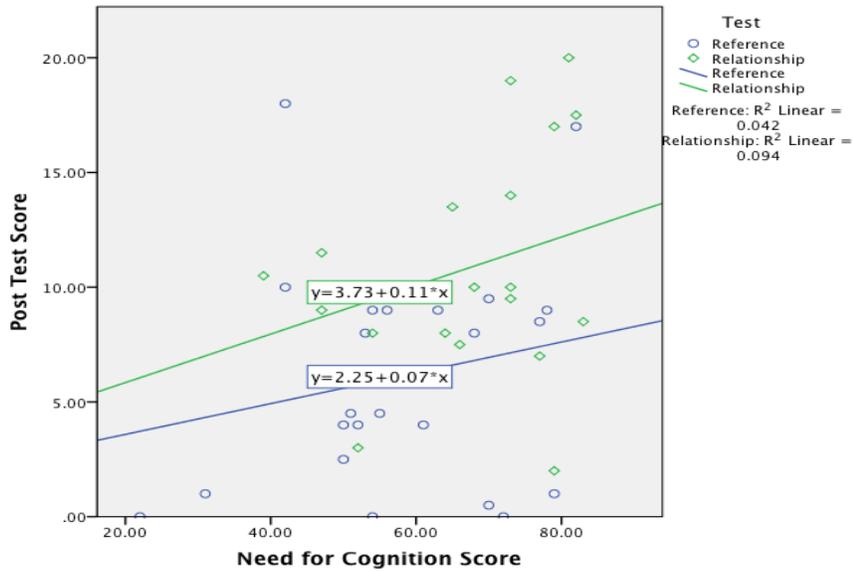
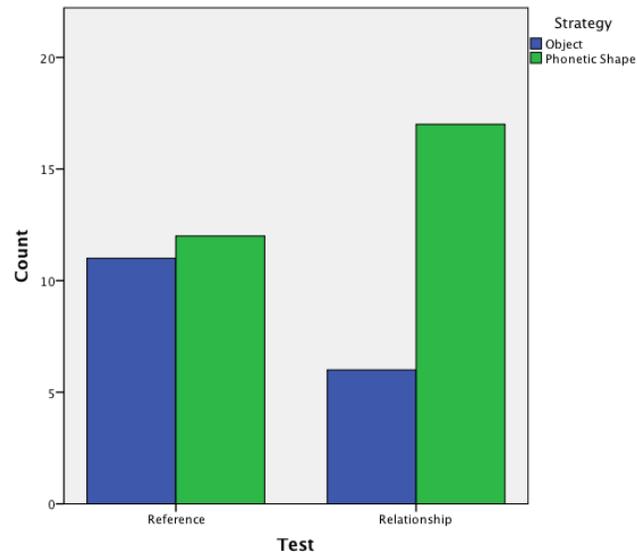


Figure 34. Scatterplot of the covariate Need for Cognition and post-test scores.

Standardized residuals for the interventions and for the overall model were normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ). There was homoscedasticity and homogeneity of variances, as assessed by visual inspection of a scatterplot and Levene's test of homogeneity of variance ( $p = .355$ ). There were no outliers in the data, as assessed by no cases with standardized residuals greater than  $\pm 3$  standard deviations. There was a statistically significant difference in Alien Language Post-test between the Reference and Relational groups,  $F(1,44) = 10.163, p = .003$ ,  $partial \eta^2 = .188$ .

The qualitative analysis of the results from the Post-test revealed two overall strategies in regards to how users answered the questions. The users answered the questions based on either what object they thought the Alien shape looked like, for example a top, a shark, or a cross, or they identified the Alien shape as a phonetic object, identifying sounds with the outline that made up the shape. Figure 35 shows

each test groups strategy for selecting the shapes sound. In the Reference group, 11 (47.8%) identified the Alien shape as an object and 12 (52.2%) identified the Alien shape as a phonetic shape. In the Relationship group, 6 (26.1%) identified the Alien shape as an object and 17 (73.9%) identified the Alien shape as a phonetic shape.



*Figure 35.* The qualitative strategy for how users deciphered the shapes as either object or phonetic shape.

## **CHAPTER FIVE: DISCUSSION**

This chapter presents a general discussion of the proposed cognitive architecture and results of the study. This chapter is organized into three main sections. First, implications of the study results are discussed in reference to the proposed Situated Model of Comprehension and prior research. Second, limitations of the study, its methods, and instrumentation are discussed. Third, recommendations for further research and applications of CALC are explored.

### **Implications of the Study Results**

#### *General Subject Demographics*

The demographics of the participants in the study showed a wide range of backgrounds in both native language and language learning. The proportion of the subjects that spoke English as a second language in the study (67.4%), or those who had neither English or French as their native language (63.1%) is high compared with the rest of Canada, where only 20.6% of Canadians native tongue is neither English or French (Minister of Industry, 2012). The proportion and diversity of the native languages was also representative of Vancouver and the lower mainland, with 16 different native languages represented (Minister of Industry, 2012). The high proportion of individuals who spoke more than one language (87%), with many speaking 2 (48%), 3 (26%), or 4+ (13%) languages was exceptional for this study. These multilingual individuals better link auditory input to corresponding words in either of their spoken language, regardless to what language they are presented in or

belong (Marian & Spivey, 2003). Multilingual individuals also show superior executive processes in attention and inhibition as they are constantly maintaining a balance between their two languages (Abutalebi et al., 2008; Green, 2011). Also relevant, is the superior ability of these individuals in conflict management, inhibitory control, and task switching (Bialystok, Craik, & Luk, 2012; Prior & MacWhinney, 2010). Multilingual individuals also have improved metalinguistic awareness, meaning they have the ability to recognize, explore, and manipulate language systems (Diaz & Klingler, 1991). The findings of the study, that there was a significant difference in the performance tests for individuals who already have sophisticated cognitive abilities for languages, lends support to the idea that it is the structure of the information and not unique cognitive abilities between the groups that facilitated comprehension.

All the participants had exposure to second languages through formal studies (100%), with years of exposure varying from 0-5 years (21.7%), 5-10 years (17.4%), 10-15 years (26%), 15-20 years (10.9%), to 20+ years (24%). The participants' enjoyment of learning a second language also speaks to this demographics intrinsic motivation and pleasure in expanding their ability to recognize sound-symbol systems. A majority found learning a second language very enjoyable (41.3%), enjoyable (34.8%), somewhat enjoyable (17.4%), and a minority not enjoyable (6.5%). This intrinsic motivation affects learning achievement, focus, and effort for learning (Dornyei, 2005), which are all factors in both the test and post-test of this study.

A total of 48 people signed up for the research study with 46 (96%) successfully coming to the research room at the specified date and time. This is a high turnout for a research study and is likely due to the options for participation, compensation, and short

study duration. Participants had the ability to sign-up via an online web form for a date and time of their choosing, in one-hour segments from 9am-to-5pm within a two-week block. The web form sent the users a confirmation and reminder email with date, time, and location information. Users also had the ability to drop their appointment or reschedule for another date or time. Participants commented that the flexibility of dates and times were factors in their ability to participate. The compensation of \$15 cash for approximately 1 hour of participation time is significantly higher than the minimum wage in British Columbia (\$10.25/hour) (Employment Standards Branch, 2014), which may also be a factor in the high turnout.

### *Bouba-Kiki Experiment*

The Bouba-Kiki experiment has long been explained as a phenomena of synaesthesia-like mappings where the brain automatically links round shapes with soft sounds and jagged shapes with harsh sounds (Ramachandran & Hubbard, 2001). The question of this experiment was whether it is an implicit brain phenomenon that leads to these mappings, or if the structure of the information facilitates comprehension. An analyses of the Bouba-Kiki question using the Situated Model of Comprehension shows that all of the elements necessary for comprehension are present; most notably the users are presented with *contextual*, *conceptual*, *reference*, and *relational* information (see Figure 23). The experiment manipulated the Bouba-Kiki question by removing the relational information where the users were presented with one sound (soft Bouba sound) with one jagged shape, instead of two sounds and shapes. Based on the Situated Model of Comprehension, it was hypothesized that the Relational group, who were

presented with the all four key elements of comprehension, would score higher than the Reference group for whom relational information was removed.

The results of the study support the hypothesis and show a significant difference between the groups with the Relational group scoring statistically significantly higher than the Reference group ( $p = .021$ ). The percentage that chose the theoretically matching sound-shape pairs in the Relational group (95.6%) follows closely the results of other studies that found between 95% to 98% matching the selection (Ramachandran & Hubbard, 2001). The results of the study call into question the influence on the synaesthesia on matching sound-shape pairs versus the structure of the question. It would be assumed that the theoretical explanation would still hold up if the users were presented with a *single* mismatched sound and shape like in this experiment; the results however do not support this assumption. Although neither the Bouba-Kiki experiment nor the subsequent Alien Language experiment rule out synaesthesia-like-mapping, sound symbolism, or onomatopoeia for linking shapes and sounds, this study shows that the compositional elements of how the stimuli that are presented, most notable the contextual, conceptual, reference, and relational information, also facilitates comprehension. The explanation of the linkage between sound-shape mappings and the brain needs more study given these new study results.

It was also found that the Confidence scores, on how confident the participants were of their answers, did not differ between the groups ( $p = .316$ ) even with statistically significant different performance outcomes ( $p = .021$ ). This finding brings to light the question of the role of conscious awareness in comprehension. The

discussion of conscious versus unconscious perception, cognition, and comprehension are discussed in the Need for Cognition and Alien Language test sections below.

### *Need for Cognition Assessment*

The Need for Cognition assessment was hypothesised to be a possible covariate in the study. Although the test was found to have a high level of internal consistency for this research group, as determined by a *Cronbach's alpha* of .816, it did not have a statistically significant correlation with the dependent variables the Alien Language test ( $r_{\text{performance}} = .226$ ,  $r_{\text{confidence}} = .191$ ) or Alien Post-test dependant variables. The preliminary assumption checking in the Alien Post-test ANCOVA found that the homogeneity of regression slopes between the Post-test score and Need for Cognition was not statistically significant ( $p = .704$ ). Due to a lack of correlation between the covariate and the dependant variables, the covariate was dropped from the analysis in both the Alien Language test and Alien Language Post-test analysis.

The Need for Cognition (NfC) was hypothesized to correlate with performance in this research because it measures how inclined individuals are to engage in *effortful* cognitive activities (Cacioppo & Petty, 1982; Cacioppo et al., 1996; Cacioppo et al., 1984). The association of NfC with epistemic curiosity, which is the “desire for knowledge that motivates individuals to learn new ideas, eliminate information-gaps, and solve intellectual problems” (Litman, 2008, p. 1586), was thought to be directly related to the tasks of the study; deciphering the linkages between sounds and shapes. The lack of correlation between performance and the NfC assessment maybe due to the threshold in which conscious versus unconscious comprehension and cognitive effort takes place. The tasks of the Alien Language test, although seeming to require

conscious effort, are more likely based on the type of unconscious information processing that is identified as intuition in the cognitive psychology literature (Bowers, Regehr, Balthazard, & Parker, 1990; Shirley & Langan-Fox, 1996).

“Intuition denotes the ability to make judgements about stimulus features or discriminate between stimulus categories better than chance without being able to describe the basis of those judgements” (Annette Bolte & Goschke, 2008, p. 608). Many studies have found increasing evidence that individuals are able to use pre-existing knowledge activated from memory to make decisions outside of conscious awareness (Kahneman, 2003; Volz & von Cramon, 2006). Research has shown evidence of unconscious object perception of semantic representations for images and objects (Biederman, 1987), as well as word fragments (A Bolte, Goschke, & Kuhl, 2003) and verbal problems (Jung-Beeman et al., 2004). These experiments show that pattern finding and “gestalt judgements can be mediated by unconscious activation of semantic object representations” (Annette Bolte & Goschke, 2008, p. 615). The process outlined in CALC also supports the notion that many of these complex processes can take place outside of conscious awareness.

Perception, as defined in CALC, allows for both conscious and unconscious goal-directed attention, which serves to prioritize stimuli for the performance of goal-directed action. Functional memory, which drives goal-directed behaviours, facilitates goal-directed responses that may or may not fall outside of conscious perception. This allows us to make decisions, both trivial and complex, without conscious introspection of what, why, or how that choice is made. Comprehension takes place through the tacit selection of semantic patterns. The user perceives semantic cues from contextual,

conceptual, reference, and relational patterns from the environment and from long-term memory, which helps answer the question. The users saying the words out loud while looking at the shapes, reinforced the pattern and contrast of sounds-shapes linkages. The innate mechanism of pattern recognition, whether it's mediated by sound symbolism, synaesthesia, or onomatopoeia, allows us to make selections without conscious effortful contemplation.

### *Alien Language test*

I hypothesized on the Alien Language test that the Relational group would score statistically significantly higher than the Reference group on both performance and confidence measures. A MANOVA found a statistically significant difference between the groups on the combined dependent variables ( $p < .0005$ ). Separate ANOVAs found there was a statistically significant difference in test scores between the groups ( $p < .0005$ ) with the Relational group scoring higher. There was no statistically significant difference in Confidence scores between the test groups ( $p = .651$ ). Similar to the results of the Bouba-Kiki experiment, users were able to statistically significantly identify the matching sound-shape pairs with little metacognitive awareness of the accuracy of their choice. The finding that the Relational group scored statistically significantly higher than the Reference group for performance supports the hypothesis that it was the structure of the information that facilitated comprehension.

The Alien Language study, by differentiating the selection of non-sense sounds and shapes, with the subject's conscious confidence in their choices, supports that there is a significant amount of comprehension that happens outside of conscious awareness.

Timothy D. Wilson in his book *Strangers to Ourselves: Discovering the Adaptive*

*Unconscious* (2002), theorizes that a majority of our cognitive processes, both trivial and sophisticated, are a part of an adaptive unconscious. The adaptive unconscious, being outside of introspection, is far more efficient, pervasive, adaptive, and complex than conscious thought. The efficiency of the adaptive unconscious allows, “the mind [to] operate most efficiently by relegating a good deal of high-level, sophisticated thinking to the unconscious, just as a modern jumbo jetliner is able to fly on auto pilot with little or no input from the human, “conscious” pilot. The adaptive unconscious does an excellent job of sizing up the world, warning people of danger, setting goals, and initiating action in a sophisticated and efficient manner (p.6).” The ability of both the conscious and adaptive unconscious to work in unison, allows our conscious mind to be occupied, while our adaptive unconscious can still interpret, evaluate, and select information for action. Examining the adaptive unconscious can be deduced by looking at the behaviours of the individuals and coming up with a “good narrative” on how the behaviours are manifest outside of conscious awareness. This point is exemplified in this experiment where we find individuals making choices (performance scores) that do not correlate with their metacognitive awareness of those choices (confidence scores). Many neurological studies have found that participants’ subjective awareness of a stimuli can be outside of conscious perception, while still affecting a goal-directed response (Sundermeirer, Virtue, Marsolek, & van den Broek, 2005).

#### *Alien Language Post-test*

It was hypothesized that the Relational group would score statistically significantly higher than the Reference group in naming Alien Language symbols. The results of the study support this hypothesis, using ANOVA a statistically significant

difference between the groups was found ( $p = .003$ ). The implicit learning that took place during the Alien Language test was obviously more effective for transfer when all four elements of comprehension are present. This included both correct user identification of the Alien sound, and how users deciphered the Alien language shapes. Participants, in trying to decipher what the Alien shapes sounded like, used two overall strategies. They answered based on what they thought the object looked like, a shark, a cross, a top, or they identified the object as a phonetic shape, identifying the outlines as sounds. The Reference group used each strategy in almost equal proportions (*Object* = 47.8%, *Phonetic shape* = 52.2%), while the Relational group identified the object as a phonetic shape far more than as an object (*Object* = 26.1%, *Phonetic shape* = 73.9%). This supports that implicit learning was more effective for transfer with having all the elements of comprehension present. The Reference group, whose participants were missing elements of comprehension, showed evidence of making *semantic leaps* in trying to fill in the information not present. *Semantic cues* from the environment, the shapes of the objects, as well as the users interpretation of the shapes, allowed participants to interpret the shapes with only tangential meaning. The process in which participants' implicit learning was facilitated can be explored with the model of Semantic learning as proposed in CALC.

Semantic learning, as defined in CALC, posits that comprehension facilitates transfer. The processes of selection, interpretation, integration, and expression facilitate learning and reinforce transfer. In the Alien Language test, transfer was statistically significant for the Relational group in the Post-test ( $p = .003$ ) due to the elements of comprehension. The implicit learning that was reinforced more effectively in the

Relational group and not the Reference group can be explained with the steps within Semantic learning.

First, relevant stimuli are selected from the environment either through overt or covert semantic cues. The compare-and-contrast relationship of two sounds and shapes, and the selection of a shape for the Relational group served to prioritize stimuli for goal-directed action. As stated in Chapter 2, “discerning relevant from irrelevant stimuli in the environment based on goal-directed cues discriminates what is attended to.” Functional memory reinforced transfer through the valuation of the stimuli in regards to correct choice of shape-sound matches for the Relational group, rather than a Yes/No answer choice for the Reference group. This is important, as integration within functional memory reinforced the linkage of sound and shape to arrive at a unified goal-directed response. The repeating of the patterns of sound-and-shape linkages strengthened newly created semantic arrays.

Interpretation of the stimuli was facilitated through contextual, conceptual, reference, and relational cues. The context of the shapes within a question, the attributes of the shapes and sounds, the reference of two sounds and shapes, as well as relational information of sound-shape correspondence, provided the means in which implicit semantic learning could be assisted.

Integration was supported by the repeating patterns of sounds and shapes. The value of selecting the ‘correct’ matching sound-shape pair, versus a Yes/No answer, further reinforced the integration of how these patterns manifest.

Expression was supported through both repetition of behaviour and repetition of interpretation and integration. This allowed the participants to strengthen the semantic

relationship between shapes and sound though correcting and reintroducing sound-shape corresponding relationships. The Alien Language post-test exemplified this reinforcement by introducing a new context to the assessment. As stated in Chapter 2, “it is not until new contexts are introduced that the true malleability of semantic arrays are realized.” The change in format in the post-test, from the sound being given to the participant, to having to supply the sound themselves, was enough of a contextual change for half the Reference group to abandon the Alien Language test objects as phonetic shapes and to interpret them as objects.

### **Limitations of the Study**

The limitations of the study include the validity of the instruments and measures used, uncertainty of construct operationalization, identification and measurement of possible confounding variables, and generalizability of the results.

The instruments and measures that were used to evaluate comprehension have uncertain validity and reliability. The Alien Language test was devised as a measure of comprehension where users pre-existing knowledge would have minimal effect on the outcome. This method was chosen to control for prior knowledge as a possible confound. The test was devised to look at sound-symbol correspondence at the level of grapheme and phoneme rather than semantic representation. With no standardized measure of comprehension as a cognitive construct, the Alien Language test aims to remove semantic and knowledge representation from the assessment. Comprehension is currently measured within the context of subject domains such as mathematics, reading, and language. Until the Alien Language test has been studied more widely using other

types of participants and under varying contexts, interpreting the data it generates will be subject to some ambiguity.

The SMC theorizes that uncertainty diminishes with the addition of each element of comprehension. Based on Uncertainty reduction theory (URT), the central motivation of communication is to reduce uncertainty and make sense of the information provided (Berger & Calabrese, 1975). It is not clear from the results on confidence scores in the study if the construct of metacognitive uncertainty is what's measured. This is not unusual in psychological research, where self-assessments using Likert-like scales or percentage scales ranging from *impossible* to *certain* are used to measure uncertainty. "There seems to be an implicit assumption that the consequences of measuring uncertainty one way versus another are generally not significant. The predominant method for measurement of psychological uncertainty involves the solicitation of subjective probability estimates" (Windschitl & Wells, 1996, p. 343). The issue with these verbal measures is that many times decisions are made based on associations, assumptions, and intuition rather than conscious effortful thought. The measure that was used, a self-assessment of certainty of performance, may not be the best operationalization of this construct. A measure of uncertainty that would more closely match the hypothesis of SMC, would be the serial addition of information elements with the measure of metacognitive uncertainty at each juncture. Starting with a stimulus that has high ambiguity, contextual, conceptual, reference, and relational information would be added serially, with a measure of metacognitive uncertainty with each addition.

The hypothesis that the Need for Cognition would be a correlate of performance on the learning task was not evident in this study. The assumption that the deciphering of the Alien Language symbols would precipitate effortful cognitive task maybe correct, but the measure of this confound maybe the issue. There may be more correlation between the Alien Language task and the deciphering of natural language, which can be more intuitive and dynamic, than cognitive effort that would be seen in solving a puzzle. Other studies suggest that age of exposure to a second language and proficiency in a second language maybe predictors of performance on the Alien Language task (Robinson, 2012).

The generalizability of the results is a limitation based on the demographics of the research participants and sample size. Using university students, who have all studied a second language (100%), with many speaking more than one language (87%), represents a unique population. As mentioned in the discussion above, individuals who are bilingual show improved cognitive abilities that may affect the outcomes of the assessments. In order to make more substantial claims in regards to results, a more diverse population and larger sample sizes would have to be used. Using students in K-12 and earlier, would better substantiate and validate the results of the Bouba-Kiki and Alien Language Experiments.

### **Implications and Applications of CALC**

CALC provides a narrative to the functional components of comprehension and learning. From the selection of the stimuli to the expression of learning, the architecture binds together a breadth of processes into a coherent model. The unification of perception, functional memory, attention, comprehension, and memory, provides a

single model in which to study and question the relationship between cognitive function and learning.

The study and establishment of comprehension as a cognitive construct is central to the CALC. The development of the Alien Language test, aims to provide a framework in which to study comprehension outside of subject domains.

Semantic arrays offer a new cognitive construct in which to study the interface between comprehension and knowledge. Similar to the differentiation between the domains of complex problem solving, which is time dependant, and problem solving which is not time dependent, the differentiation and contrast between semantic arrays and schema will open new avenues of research.

The evaluation of student learning, where it succeeds and where it may fail, is currently a passive assessment. Understanding what students are linking to content, most notably conceptual, contextual, reference, and relational information will allow educators to see why their lessons resonate with some students and not with others. It is the missing pieces of comprehension that hinder learning and can be addressed in design.

Instructional design is one of the main areas where CALC can be utilized. Message design using conceptual, contextual, reference, and relational information can ensure a higher probability of successful learning. The SMC can also be used in the process of a needs analysis to understand in which areas of comprehension are lacking for any particular audience.

Artificial Intelligence and machine learning are also two areas where CALC may offer some insight. Semantic representation of objects in computers and on the web is a highly sought-after goal. The elements of SMC offer a model in which these representations could be built.

### **Recommendations for Further Research**

The Alien Language task as an experimental paradigm for studying implicit (unconscious) comprehension and learning is of paramount importance for supporting a Situated Model of Comprehension. The measure of comprehension using ambiguous images and sounds, outside of subject-specific domains such as reading, and mathematics, provides a novel prototype for understanding comprehension. The use of non-sense sounds and shapes, which is a well-supported method of exploring psychological phenomena (Carson, 1926; Ebbinghaus, 1913), is a sound way of testing comprehension as it diminishes other influences on outcome and user choice. For example, Item Response Theory (IRT) could be used to evaluate questions and question types on the continuum of difficulty using Alien Language symbols. The identification of comprehension as a cognitive construct with development of a sound instrument for the measurement of comprehension would be a major contribution to educational psychology.

The measure and prediction of explicit conscious or implicit uncertainty is also a component of contention that needs further study. The Situated Model of Comprehension predicts that uncertainty would diminish as each element of comprehension, context, concept, reference, and relational information, is provided to the user. The issue of whether this concept of uncertainty or certainty is tacit and outside of

conscious awareness is of paramount importance for understanding the elements of comprehension. One of the possible ways to study conscious and unconscious uncertainty, awareness and processing is to use neurological and biological feedback.

Electroencephalography (EEG), electrocardiography (EKG), electromyography (EMG), eye-tracking (ET), skin conductance response (SCR), positron emission topography (PET), and functional magnetic resonance imaging (fMRI) are a few of the tools that can be utilized to look at unconscious and pre-conscious processes. In studies looking at the moment of insight, or the “ah ha” moment, research has found that these measures are effective in deciphering conscious versus unconscious comprehension (Aziz-Zadeh, Kaplan, & Iacoboni, 2009; Kounios & Beeman, 2014). Luria’s brain functioning theory (1973) may also serve as a model to look at brain processing patterns for the constructive process of comprehension. The three functional units defined in Luria’s theory of arousal and attention, sensory input and integration, and executive planning and execution are all related to the components of CALC. Using topographical models during cognitive tasks such as comprehension may differentiate differences between individuals beyond performance. Associating task performance with brain processing patterns may bridge the gap between educational psychology and cognitive psychophysiology (Languis & Miller, 1992).

Mathematical models of comprehension based on the Situated Model of Comprehension are also an area worth exploring. Similar to Clark L. Hull (1935) and William Kaye Estes (1950) work on mathematical models of learning and memory, a mathematical probability chain can be used to predict comprehension. Using Bayesian models such as Markov probability chains, statistical models of comprehension can be

developed using the components of comprehension. These models would augment the predictive power of using the Situated Model of Comprehension in both human and machine learning.

Cognitive and neurological semiotics can be studied using the Alien Language task as a paradigm for exploration. How the mind, encodes, comprehends, and deciphers new information that marries cognition and neuroscience, is a field that is paramount for understanding language, psychology, and cognition.

### **Conclusion**

Malcolm Gladwell in his book *What the dog saw and other adventures* (2009), distinguishes the differences between problems that are *puzzles* and those that are *mysteries*. He contends that this fundamental differentiation between problems that are puzzles or mysteries drastically affects their approach and possible solution. Problems that are puzzles do not have sufficient information for their resolution. The addition of labour and analysis does not lead to resolution, as it is the missing information that is critical. Mysteries, in contrast, are made more confusing with the addition of information. The abundance of information leads to contradictions, confusion, false assumptions and dead ends. For mysteries, it is the lack of analysis, and not information, which hinders resolution. The fundamental difference between problems and mysteries whether more information or more analysis will bring about clarity and resolution. Cognitive science and educational psychology, similar to the dilemmas faced by the intelligence and spy agencies discussed in Gladwell's book, are generally approached as puzzles. There are plenty of agents in the field gathering data, but not enough analysts or general theorists looking at the data for connections that lead to

novel insight. The outcome of this view has led to an abundance of empirical data with insufficient theory to explain the findings. The cognitive architecture movement and the proposed Cognitive Architecture of Learning and Comprehension (CALC) aims to address this need.

CALC was born out of the recognition in the relationship between the structure and function of the components of cognition. How stimuli from the internal or external environment are selected, interpreted, integrated, and expressed for later use provides a model in which to understand the components of learning. Amalgamating and interpreting both theoretic and empirical evidence into a coherent narrative of cognitive function aims to aid both the prediction and explanation of cognitive phenomena. The experimental questions and measurements used in this dissertation were synthesized through the use of CALC.

The results of the Bouba-Kiki experiment, showing that the structure of the information provided facilitates comprehension, challenges the singular theoretical explanation of synaesthesia-like mappings in the brain. It was the evaluation of the Bouba-Kiki experiment using SMC that facilitated the development of the Alien Language test. The assumptions and elements of CALC and SMC allow researchers to evaluate research and theoretical explanations with a different perspective. Many other experiments and theoretical explanations, including the Stroop test (Stroop, 1935), and Inattentional Blindness (Chabris & Simons, 2009; Simons & Chabris, 1999), can be re-interpreted using these models.

The Alien Language test was proposed as a novel way to measure comprehension outside of subject-specific domains. Similar to the Bouba-Kiki

experiment, this novel experiment offers insight into the psychological phenomena of comprehension outside of conscious awareness. The significant results for performance score, but not for confidence score, calls into question how much, and at what point, does comprehension reach into conscious perception. The framework of this test may serve as a new paradigm for studying comprehension and learning.

The two research questions addressed in beginning of this dissertation 1) What are the cognitive components of comprehension and learning and 2) What are the cognitive correlates of symbol grounding, are not fully addressed in the research or architecture in this dissertation. Although CALC and the Alien Language test provide a new paradigm in which to evaluate how signs and symbols are composed and comprehended, the body of research in this dissertation is just the beginning of an opportunity and attempt at answering these questions. Evaluating, testing, and revising CALC and the Alien Language test to continue to study these questions and extending this research into the domains of Cognitive and Neural semiotics, are exciting avenues of inquiry that I hope to continue throughout my career.

The outcome of developing CALC, its applications and influence are unknown. Similar to other cognitive architectures such as ACT-R and CLARION, whose development started in one domain but went on to influence many of areas including artificial intelligence, neuroscience, and cognition, the future trajectory and impact of CALC are unknown. The implications of CALC in the philosophical and methodological paradigms of radical embodiment (see Heidegger, 1927; Merleau-Ponty, 1945), embodied cognition (see Maturana & Varela, 1980), and the second cognitive revolution (see Bruner, 1990; Wittgenstein, 1953), address the application of

cognitive architectures in cultural and societal interactions. Although addressing the philosophical applications of CALC are beyond the scope of this text, it is recognized that it is the amalgamation of ideas from these philosophies that focus the conclusions of CALC; the conclusion that meaning is both *embodied* in our use and interaction in the world and *embedded* in the language and culture in which we exist. The inspiration to integrate psychological, cognitive, and neurological research and theories into a coherent model is fundamental to the exploration and development of new paradigms, tools, and methodologies for studying the processes of mind and meaning.

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doi: 10.1016/j.neulet.2012.03.082

## Appendices

### Appendix A: Ethics Approval



Street Address  
Simon Fraser University  
Discovery 2  
Room 230, 8900 Nelson Way  
Burnaby, BC Canada V5A 4W9

Mailing Address  
8888 University Drive  
Discovery 2  
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Manager 778.782.3447  
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<http://www.sfu.ca/vp-research/ethics/>

#### Minimal Risk Approval

**Study Number:** 2014s0277

**Study Title:** CALC: A Cognitive Architecture of Learning and Comprehension

**Approval Date:** 2014 June 30

**Expiry Date:** 2015 June 30

**Principal Investigator:** Zaparyniuk, Nicholas

**Faculty Supervisor:** Nesbit, John

**SFU Position:** Graduate Student

**Faculty/Department:** Education

**SFU Collaborator:** n/a

**Research Personnel:** n/a

**Funding Source:** n/a

**Grant Title:** n/a

#### Documents Approved in this Application:

- Study Detail, uploaded 2014 June 24
- Research Poster, uploaded 2014 June 24
- Participant Demographics, uploaded 2014 June 24
- Need for Cognition Assessment, uploaded 2014 June 24
- Consent Form, uploaded 2014 June 24

I am pleased to inform you that the above referenced study has been approved by the Associate Director, Office of Research Ethics, on behalf of the Research Ethics Board in accordance with University Policy R20.01 (<http://www.sfu.ca/policies/research/r20.01.htm>). The Board reviews and may amend decisions or subsequent amendments made independently by the Associate Director, Director, Chair or Deputy Chair at its regular monthly meeting.

The approval for this protocol expires on the **Expiry Date**, or the term of your appointment/employment/student registration at SFU, whichever comes first. **An annual renewal form must be completed every year prior to the anniversary date of approval. Failure to submit an annual renewal form will lead to your study being suspended and potentially terminated.** If you receive any grant for this protocol in addition to any funding listed above, please email [dore@sfu.ca](mailto:dore@sfu.ca) stating the funding source, the term of approval of the funding source and the title of that funding application if it differs from the title of your ethics application. If you intend to continue your protocol to collect data past the term of approval, you must contact the Office of Research Ethics at [dore@sfu.ca](mailto:dore@sfu.ca) and request an extension at least 6 weeks before the expiry date.

The Office of Research Ethics must be notified of any changes in the approved protocol. If you wish to revise your study in any way, please send an email requesting an amendment addressed to [dore@sfu.ca](mailto:dore@sfu.ca). In all email correspondence relating to this application, please reference the application number shown on this



OFFICE OF RESEARCH ETHICS

letter, which should be included in square brackets at the beginning of the Subject Line; this will ensure that all correspondence is saved to the electronic study file.

Your application has been categorized as “Minimal Risk”. “Minimal Risk” occurs when potential participants can reasonably be expected to regard the probability and magnitude of possible harms to be no greater than those encountered by the participant in those aspects of his or her everyday life that relate to the research. Please note that it is the responsibility of the researcher, or the responsibility of the Student Supervisor if the researcher is a graduate student or undergraduate student, to maintain written or other forms of documented consent for a period of 1 year after the research has been completed.

The REB assumes that investigators continuously review new information for findings that indicate a change should be made to the study protocol or consent documents and that such changes will be brought to the attention of the ORE in a timely manner.

If there is an adverse event, the principal investigator must notify the Office of Research Ethics within five (5) days. An Adverse Events Form is available electronically by contacting [dore@sfu.ca](mailto:dore@sfu.ca).

All correspondence with regards to this application will be sent to your SFU email address.

Please notify the Office of Research Ethics at [dore@sfu.ca](mailto:dore@sfu.ca) once you have completed the data collection portion of your project so that we can close the file.

**This Notification of Status is your official ethics approval documentation for this project. Please keep this document for reference purposes and acknowledge receipt of this Notification of Status by email to [dore@sfu.ca](mailto:dore@sfu.ca) and include the study number in square brackets as the first item in the Subject Line.**

Best wishes for success in this research.

Sincerely,

A handwritten signature in black ink, appearing to read "Holly Longstaff".

Holly Longstaff, PhD  
Acting Associate Director  
Office of Research Ethics

## Appendix B: Participant Informed Consent



Application ID: 2014s0277

### Participant Consent Form

**Study Title:** CALC: A Cognitive Architecture of Learning and Comprehension.

**Study Team:** *Who is conducting this study?*

*Principal Investigator:* Nicholas Zaparyniuk      *Phone:* 778.988.5888  
*Faculty:* Faculty of Education      *Email:* nick\_zap@sfu.ca  
*Co-Investigator:* Dr. John Nesbit      *Phone:* 778.782.7123  
*Faculty:* Faculty of Education      *Email:* nesbit@sfu.ca

This study is a part of the Primary Investigators PhD dissertation research. By participating in this study you agree that individual as well as grouped data may be used in a graduate dissertation (public document) and may also be used in book chapters, journal articles, and conference presentations (semi-public documents).

**Purpose of the Study:** *Why should you take part in this study? Why are we doing this study?*

We are doing this study to learn about how people make sense of new information. The information you will see in this study, both images and sounds, will be totally new to you. Understanding how people make sense of new information may help us understand the components of how we learn new things.

**Voluntary Participation:** *Do you have to participate in this study?*

Your participation is voluntary. You have the right to refuse to participate in this study. If you decide to participate, you may still choose to withdraw from the study at any time without any negative consequences to the education, employment or other services to which you are entitled or are presently receiving.

**Study Procedures:** *What if you say "Yes, I want to be in the study"? What happens to you in the study? How is the study done?*

If you say "Yes", here is how the study will be done:

The study will take approximately 1 hour to complete and has 4 Sections. All the sections will be done on a laptop computer supplied by the researcher with a standard mouse and keyboard. A set of computer headphones with a microphone will be used to record your answers in Section 4 of the research.

*Section 1)* At the beginning of the study you will be asked general information about yourself. What is your gender, age, educational background, what your native language is, how many languages you speak, and if you like learning languages.

*Section 2)* You will be asked a series of 18 questions about how much you like to solve problems. You will click on the most appropriate answer.

*Section 3)* A series of 30 sounds and shapes will be presented to you. You will choose which sound matches each shape by clicking on the most appropriate

answer. You will then be asked to click on how sure you are that you answered the question correct.

*Section 4)* A series of 10 shapes will be presented. You will say out loud what you think that shape sounds like.

As the Post-test procedure is necessary to see if there are effects of the test phase, the recording of your voice is necessary for this research. If you do not agree to have your voice recorded, please do not participate in this study.

**Storage of Data:** *How will the data we stored? Will your name or other information be linked to the answers?*

All answers you give in the study will be coded information, only identified with a Participant ID not linked to your first or last name. The audio recordings tied to the Participant ID's will be anonymized by coding them numerically. These recordings will be deleted after they are coded and transcribed, removing all direct identifying information. The primary investigator and two assistants will code and transcribe the audio recordings. The assistants will only have access to the raw audio and Participant ID to ensure confidentiality. All code information from the study answers will be stored on a password-protected database on a secure server in Canada. The data in the study will be transferred to the Primary Investigators password protected encrypted computer for transcription and analysis in SPSS then deleted. No personal information of the participants will be stored in the database or on the computer used in the study. All results will be transferred to an encrypted external hard drive and locked in a safety deposit box at the Royal Bank of Canada following the study.

**Potential Risks of the Study:** *Is there any way being in this study could be bad for you?*

We do not think there is anything in this study that could harm you or be bad for you. Some of the questions maybe difficult to answer and may be puzzling, but you simply give your best guess for those you are not sure about.

**Potential Benefits of the Study:** *Will being in this study help you in any way? What are the benefits of participating?*

We do not think taking part in this study will help you. However, in the future, others may benefit from what we learn in this study.

**Payment:** *Will you be paid for your time/taking part in this research study?*

You will receive \$15 cash for your participation in this research study for approximately 1 hour of your time. You will receive the cash payment whether you complete all the sections of the study or withdraw from the study at anytime.

**Confidentiality:** *How will your identity be protected? How will your privacy be maintained?*

All documents and data collected will be identified only by Participant ID number and kept on a secure server in Canada, an encrypted hard drive, or a locked cabinet. Informed consent forms will be kept in a locked cabinet that the Primary investigators personal residence, then locked in a safety deposit box at the Royal Bank of Canada following the study. Participants will not be identified by name in any of the reports of the completed study.

**Withdrawal:** *What if I decide to withdraw my consent to participate?*

Refusal to participate or withdrawal after agreeing to participate will have no adverse effects on your organization, institution, education, or employment. You may withdraw from this study at any time without giving reasons and you will still be compensated the \$15 for your time. If you choose to enter the study and then decide to withdraw at a later time, all data collected about you during your enrolment in the study will be destroyed.

**Organizational Permission:** *Who has given permission to conduct this study?*

Permission to conduct this research study has been approved by the Office of Research Ethics at Simon Fraser University.

**Study Results:** *How will the results of this study be used?*

The results of this study will be reported in a graduate dissertation and may also be published in book chapters, journal articles, and conference presentations. The main use of the study findings will be for the completion of the Primary Investigators graduate dissertation. Participants may contact the Primary Investigator to get access to the results of their tests.

**Contact for Information about the Study:** *Who can you contact if you have questions about the study?*

If you have any questions about the study, the methods used, how the data will be used or for how the study turned out, please contact the Primary Investigator of the study Nicholas Zaparyniuk [nick\\_zap@sfu.ca](mailto:nick_zap@sfu.ca).

**Contact for Complaints:** *Who can you contact if you have complaints or concerns about the study?*

If you have any concerns about your rights as a research participant and/or your experiences while participating in this study, you may contact Dr. Jeffrey Toward, Director, Office of Research Ethics [jtoward@sfu.ca](mailto:jtoward@sfu.ca) or 778-782-6593

**Future Use of Participant Data:** *How will the data of this study be used?*

By participating in this study you agree that individual as well as grouped data may be used in a graduate dissertation and may also be used in book chapters, journal articles and conference presentations.

**Participant Consent and Signature:**

All participants in this study must be 18 years old or older to participate.

Taking part in this study is entirely up to you. You have the right to refuse to participate in this study. If you decide to take part, you may choose to pull out of the study at any time without giving a reason and without any negative impact or consequence.

- Your signature below indicates that you have received a copy of this consent form for your own records.
- Your signature indicates that you consent to participate in this study.

---

Participant Signature  
(or Parent or Guardian Signature)

Date (yyyy/mm/dd)

---

Printed Name of the Participant (or Parent or Guardian) signing above

## Appendix C: Research Poster



Application ID: 2014s0277

# How can your mind make sense of an **ALIEN LANGUAGE?**

A research study in the Faculty of Education at Simon Fraser University is looking at how the mind links sounds and shapes into sound-symbol pairs.

Testing will take approximately **1 hour** to complete, and all participants will be compensated **\$15 cash** for their time.

For more information or to participate, please go to:

<http://www.sfu.ca/~nezapary>  
or contact  
**Nicholas Zaparyniuk**  
Faculty of Education  
[nick\\_zap@sfu.ca](mailto:nick_zap@sfu.ca)

The plan for this study has been reviewed for its adherence to the ethical guidelines and approved by the Office of Research Ethics (ORE) at Simon Fraser University. For questions regarding participant rights, ethical conduct of research, concerns, or complaints can be addressed to the Director of the Office of Research Ethics: Dr. Jeffrey Toward, Director, Office of Research Ethics [jtoward@sfu.ca](mailto:jtoward@sfu.ca) or 778-782-6593, Simon Fraser University, Burnaby, B.C., Canada, V5A 1S6. Application number [2014s0277] - Version: 2014 June 23  
Study Title: CALC: A Cognitive Architecture of Learning and Comprehension

<b>Alien Language Study</b> Contact: Nicholas Zaparyniuk <a href="mailto:nick_zap@sfu.ca">nick_zap@sfu.ca</a> <a href="http://www.sfu.ca/~nezapary">http://www.sfu.ca/~nezapary</a>
<b>Alien Language Study</b> Contact: Nicholas Zaparyniuk <a href="mailto:nick_zap@sfu.ca">nick_zap@sfu.ca</a> <a href="http://www.sfu.ca/~nezapary">http://www.sfu.ca/~nezapary</a>
<b>Alien Language Study</b> Contact: Nicholas Zaparyniuk <a href="mailto:nick_zap@sfu.ca">nick_zap@sfu.ca</a> <a href="http://www.sfu.ca/~nezapary">http://www.sfu.ca/~nezapary</a>
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<b>Alien Language Study</b> Contact: Nicholas Zaparyniuk <a href="mailto:nick_zap@sfu.ca">nick_zap@sfu.ca</a> <a href="http://www.sfu.ca/~nezapary">http://www.sfu.ca/~nezapary</a>
<b>Alien Language Study</b> Contact: Nicholas Zaparyniuk <a href="mailto:nick_zap@sfu.ca">nick_zap@sfu.ca</a> <a href="http://www.sfu.ca/~nezapary">http://www.sfu.ca/~nezapary</a>
<b>Alien Language Study</b> Contact: Nicholas Zaparyniuk <a href="mailto:nick_zap@sfu.ca">nick_zap@sfu.ca</a> <a href="http://www.sfu.ca/~nezapary">http://www.sfu.ca/~nezapary</a>

## Appendix D: General Subject Demographics Survey



Application ID: 2014s0277

### CALC: A Cognitive Architecture of Learning and Comprehension

#### Participant Demographic Survey

*Please take a few minutes to complete the following survey*

Age: \_\_\_\_\_ Gender: Male / Female

What is your native language? (the first language you learnt): \_\_\_\_\_

Do you speak any other languages?: Yes / No

If Yes, how many languages do you speak?: 1 2 3 4 5

Have you studied any other languages?: Yes / No

If Yes, what other language(s) have you studied?: \_\_\_\_\_

If Yes, how many years did you study a second language?: \_\_\_\_\_

How would you rate your proficiency in your second language?

Not Proficient  Somewhat Proficient  Proficient  Very Proficient  Expert

How would you rate your enjoyability of learning a second language?

Not Enjoyable  Somewhat Enjoyable  Enjoyable  Very Enjoyable

What is the reason you studied a second language? \_\_\_\_\_

---

---

If you have NOT studied a second language, can you tell us why?: \_\_\_\_\_

---

---

---

## Appendix E: Need for Cognition Assessment



Application ID: 2014s0277

### CALC: A Cognitive Architecture of Learning and Comprehension

#### Need for Cognition Assessment

Instructions: For each of the statements below, please indicate to what extent you agree with the statement. Please use the following scale:

- 1 - Extremely uncharacteristic
- 2 - Somewhat uncharacteristic
- 3 - Uncertain
- 4 - Somewhat characteristic
- 5 - Extremely characteristic

1. I would prefer complex to simple problems.
2. I like to have the responsibility of handling a situation that requires a lot of thinking.
3. Thinking is not my idea of fun.
4. I would rather do something that requires little thought than something that is sure to challenge my thinking abilities.
5. I try to anticipate and avoid situations where there is likely a chance I will have to think in depth about something.
6. I find satisfaction in deliberating hard and for long hours.
7. I only think as hard as I have to.
8. I prefer to think about small, daily projects to long-term ones.
9. I like tasks that require little thought once I've learned them.
10. The idea of relying on thought to make my way to the top appeals to me.
11. I really enjoy a task that involves coming up with new solutions to problems.
12. Learning new ways to think doesn't excite me very much.
13. I prefer my life to be filled with puzzles that I must solve.
14. The notion of thinking abstractly is appealing to me.
15. I would prefer a task that is intellectual, difficult, and important to one that is somewhat important but does not require much thought.
16. I feel relief rather than satisfaction after completing a task that required a lot of mental effort.
17. It's enough for me that something gets the job done; I don't care how or why it works.
18. I usually end up deliberating about issues even when they do not affect me personally.

*Note.* From "The Efficient Assessment of Need for Cognition," by J. T. Cacioppo, R. E. Petty, and C. F. Kao, 1984, *Journal of Personality Assessment*, 48, pp. 306-307. Copyright 1984 by Lawrence Erlbaum

## Appendix F: Bouba-Kiki Test Questions for Reference and Relational Group

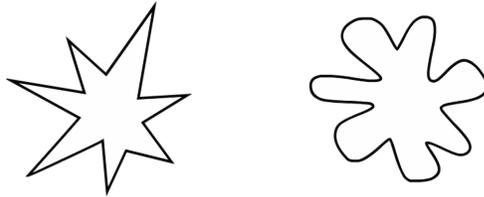
**Instructions:** You will be given a SOUND and a SHAPE. It is your task to evaluate if the sound matches the shape or not.

a. Say the words **out loud** while looking at the shape before making your choice. Circle the correct answer.

b. You will also specify how confident you are in your answer. Please check the box next to how confident you are in your answer.

**Reference Group Question:**

**BOUBA, KIKI – Which is BOUBA?**



**3b. How confident are you in your answer?**

Very Confident    Confident    Somewhat Confident    Not Confident

**Relational Group Question:**

**BOUBA – Is this a BOUBA?**



**YES**

**NO**

**3b. How confident are you in your answer?**

Very Confident    Confident    Somewhat Confident    Not Confident

## Appendix G: Alien Language - Relational Group Test

PART 2: REL-TEST

ID: \_\_\_\_\_

**Instructions:** You will be given TWO SOUNDS and TWO SHAPES. It is your task to evaluate if the sound matches the shape or not.

- a. Say the words **out loud** while looking at the shapes before making your choice. Circle the correct answer.
- b. You will also specify how confident you are in your answer. Please check the box next to how confident you are in your answer.

Few Examples to get started:

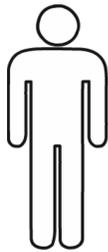
### 1a. CAR, PLANE - Which is CAR?



### 1b. How confident are you in your answer?

- Very Confident    Confident    Somewhat Confident    Not Confident

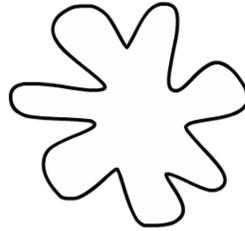
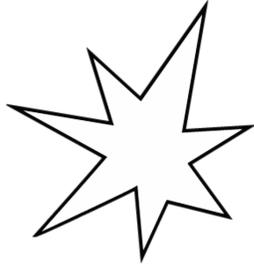
### 2a. WOMAN, MAN – Which is WOMAN?



### 2b. How confident are you in your answer?

- Very Confident    Confident    Somewhat Confident    Not Confident

**3a. BOUBA, KIKI – Which is BOUBA?**



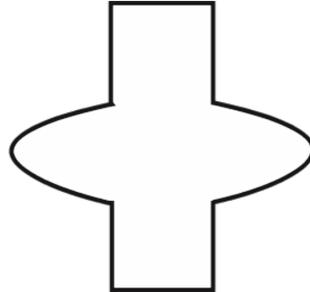
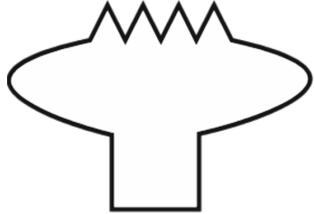
**3b. How confident are you in your answer?**

Very Confident    Confident    Somewhat Confident    Not Confident

**----- IF YOU HAVE ANY QUESTIONS OR CONCERNS PLEASE ASK THE RESEARCHER NOW -----**

**\*\* PLEASE DO NOT GO BACK ONCE YOU'VE ANSWERED A QUESTION\*\*\*\***

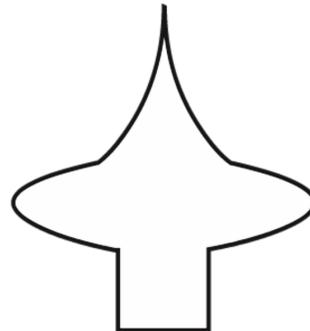
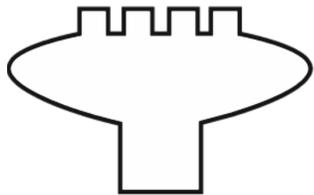
1a. DADA, ZADA – Which is DADA?



1b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

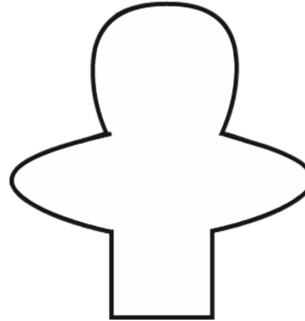
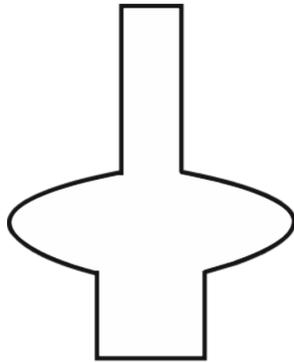
2a. PADA, RADA - Which is RADA?



2b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

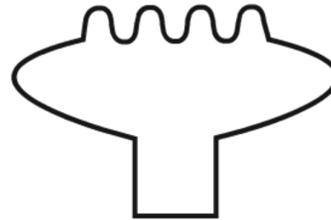
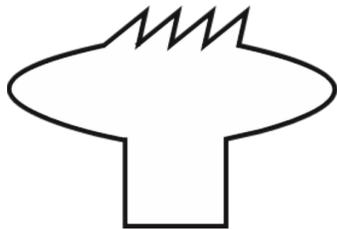
3a. TADA, HADA – Which is HADA?



3b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

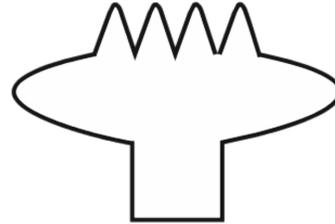
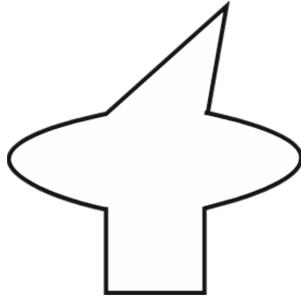
4a. SADA, FADA - Which is SADA?



4b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

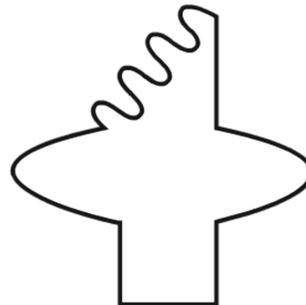
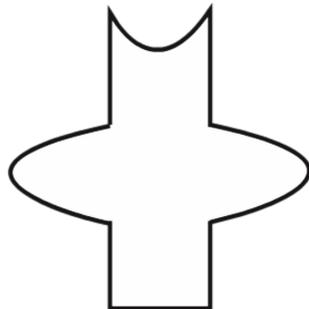
5a. LADA, KADA – Which is LADA?



5b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

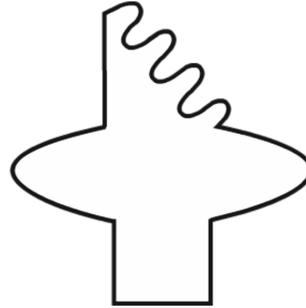
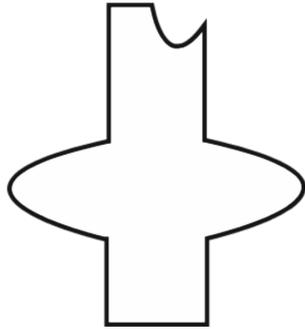
6a. MADA, BADA – Which is BADA?



6b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

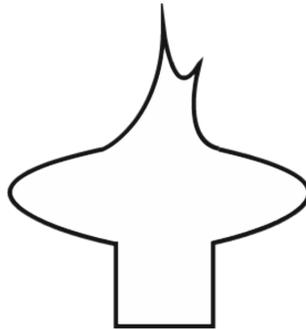
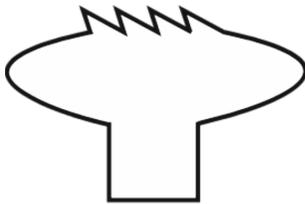
7a. GADA, NADA - Which is GADA?



7b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

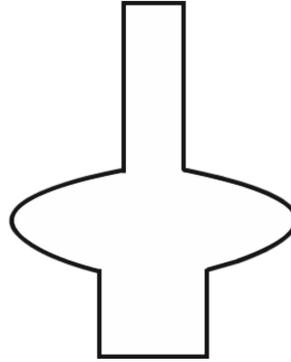
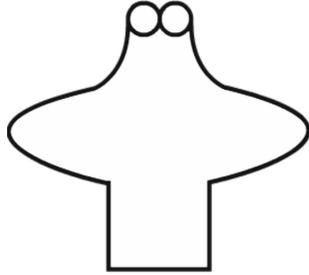
8a. JADA, VADA - Which is JADA?



8b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

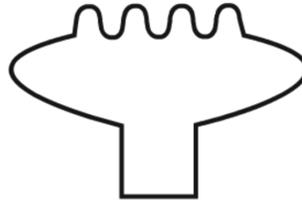
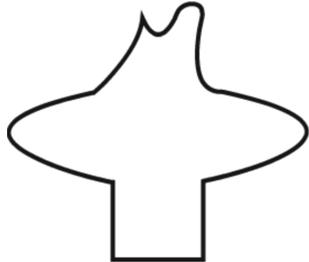
9a. TADA, WADA - Which is WADA?



9b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

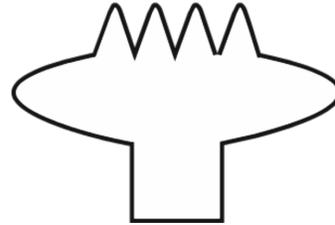
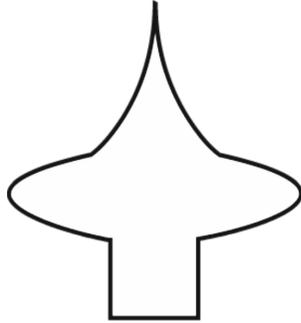
10a. SADA, YADA - Which is YADA?



10b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

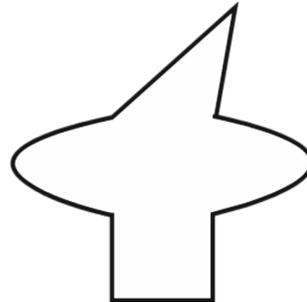
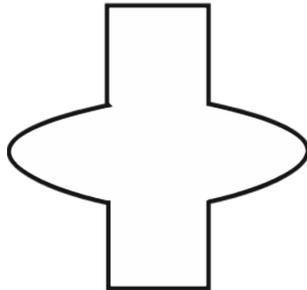
11a. PADA, LADA - Which is PADA?



11b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

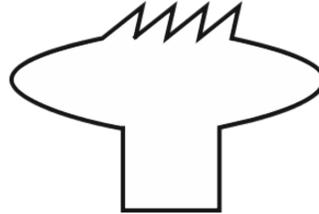
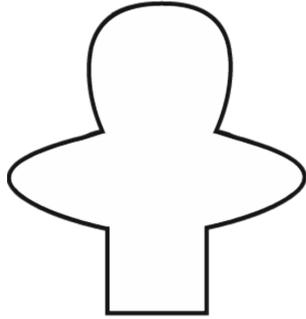
12a. KADA, DADA - Which is DADA?



12b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

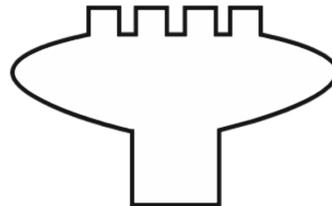
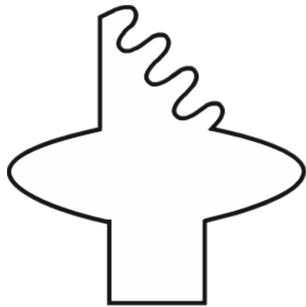
13a. FADA, HADA – Which is FADA?



13b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

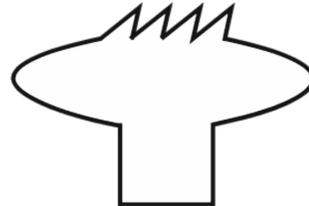
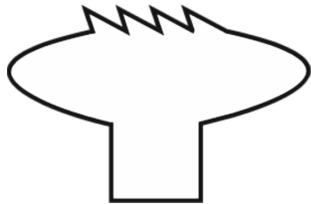
14a. RADA, NADA - Which is RADA?



14b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

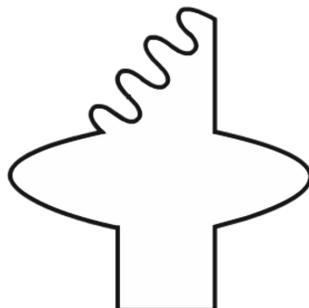
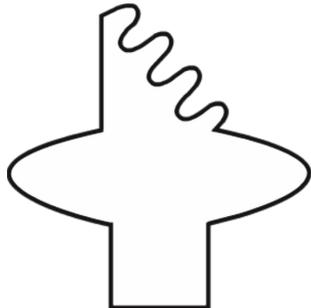
15a. FADA, VADA - Which is FADA?



15b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

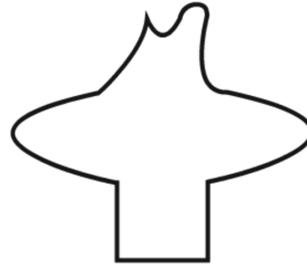
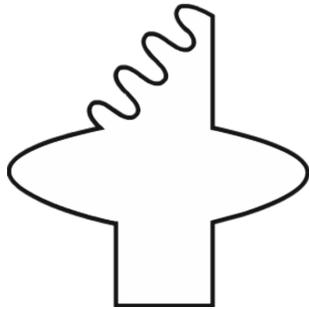
16a. MADA, NADA - Which is MADA?



16b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

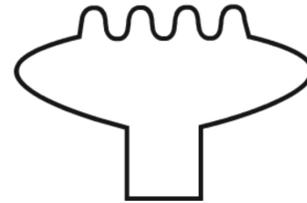
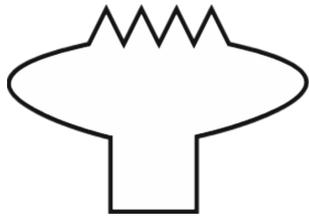
17a. MADA, JADA – Which is JADA?



17b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

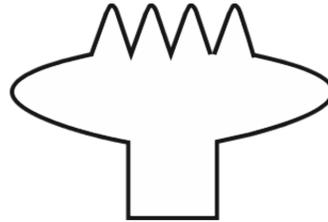
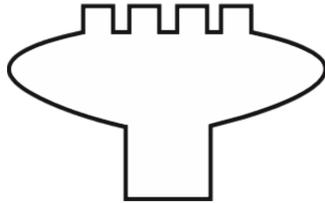
18a. ZADA, SADA – Which is ZADA?



18b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

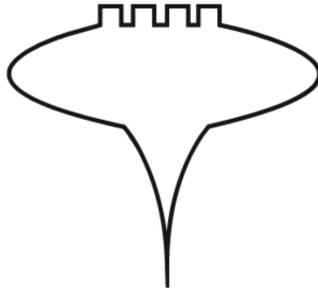
19a. LADA, RADA - Which is LADA?



19b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

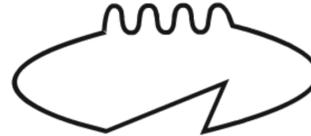
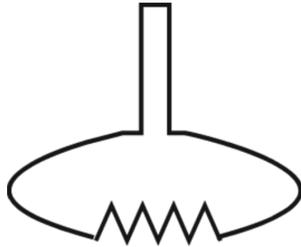
20a. LAMA, RAPA - Which is RAPA?



20b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

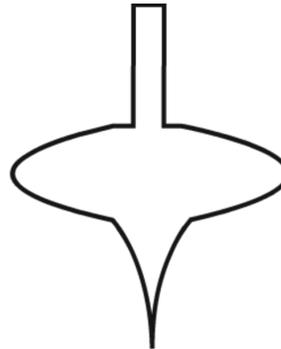
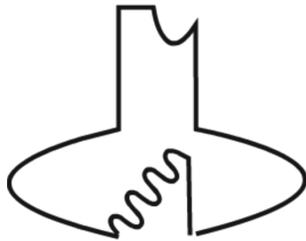
21a. SAKA, TAZA - Which is TAZA?



21b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

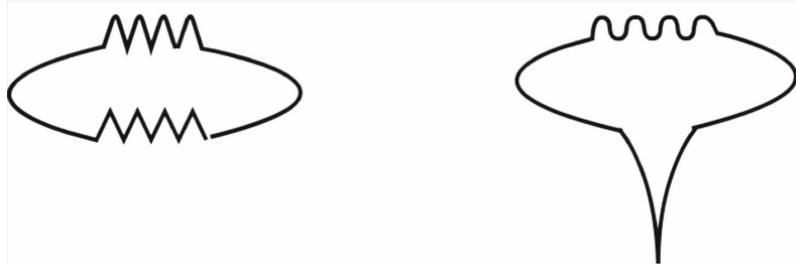
22a. TAPA, GAMA - Which is GAMA?



22b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

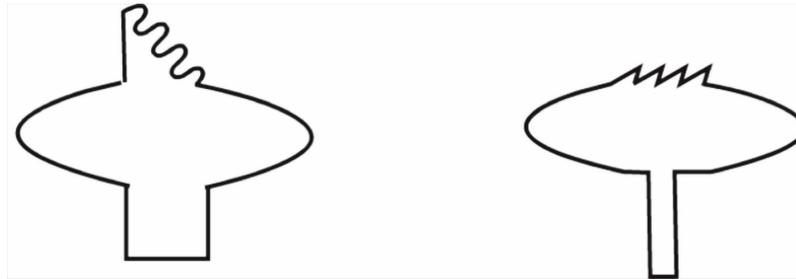
23a. SAPA, LAZA – Which is SAPA?



23b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

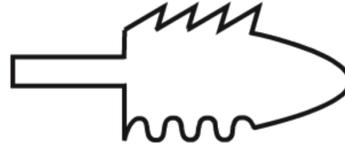
24a. NADA, FATA - Which is FATA?



24b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

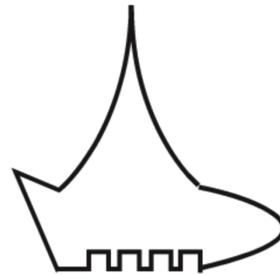
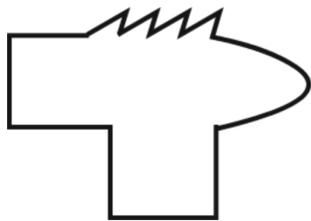
25a. FAST, SAND - Which is SAND?



25b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

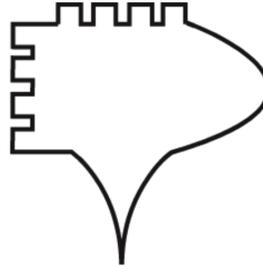
26a. FADD, PARK - Which is PARK?



26b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

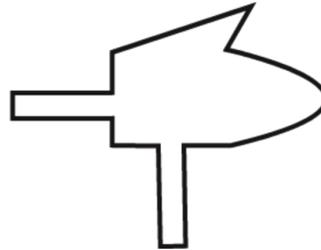
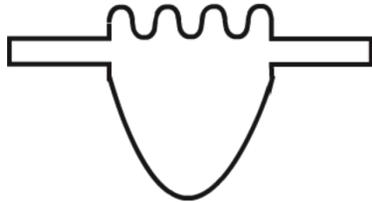
27a. RAPR, RAFT - Which is RAFT?



27b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

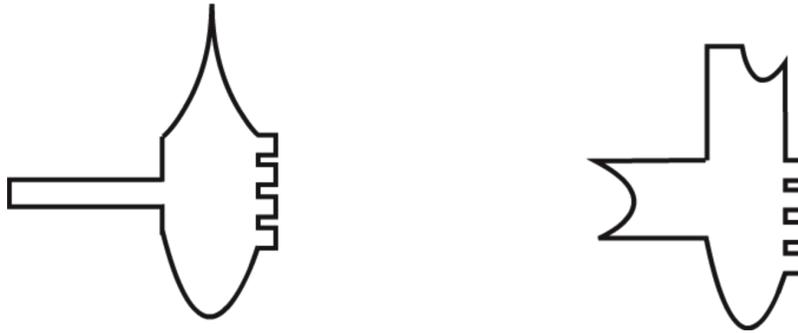
28a. STAT, KATT - Which is KATT?



28b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

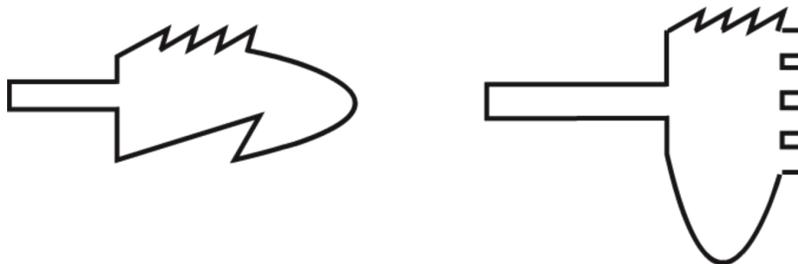
29a. GRAB, PRAT - Which is PRAT?



29b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

30a. FAKT, FRAT - Which is FRAT?



30b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

## Appendix H: Alien Language - Reference Group Test

PART 2: REF-TEST

ID: \_\_\_\_\_

**Instructions:** You will be given ONE SOUND and ONE SHAPE. It is your task to evaluate if the sound matches the shape or not.

a. Say the word **out loud** while looking at the shape before making your choice. Circle the correct answer.

b. You will also specify how confident you are in your answer. Please check the box next to how confident you are in your answer.

Few Examples to get started:

**1a. PLANE - Is this a PLANE?**



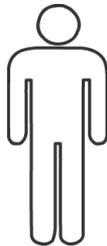
YES

NO

**1b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**2a. MAN – Is this a Man?**



YES

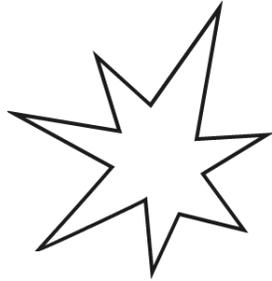
NO

**2b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

1 of 17

**3a. BOUBA – Is this a BOUBA?**



**YES**

**NO**

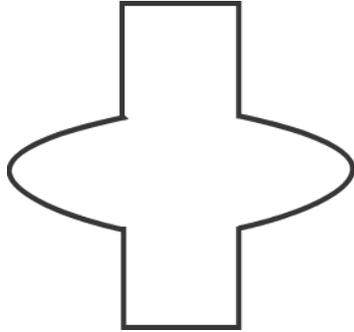
**3b. How confident are you in your answer?**

Very Confident    Confident    Somewhat Confident    Not Confident

**----- IF YOU HAVE ANY QUESTIONS OR CONCERNS PLEASE ASK THE RESEARCHER NOW -----**

**\*\* PLEASE DO NOT GO BACK ONCE YOU'VE ANSWERED A QUESTION\*\*\*\***

**1a. ZADA – Is this a ZADA?**



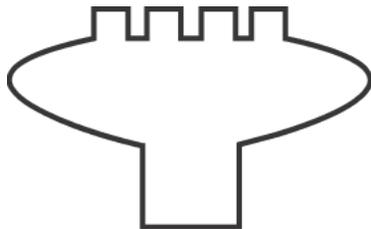
**YES**

**NO**

**1b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**2a. RADA - Is this a RADA?**



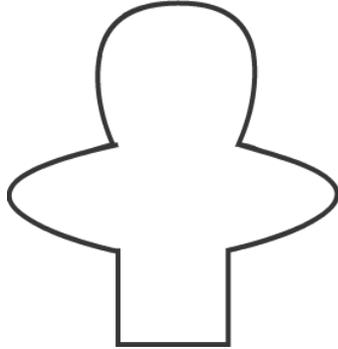
**YES**

**NO**

**2b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**3a. HADA – Is this a HADA?**



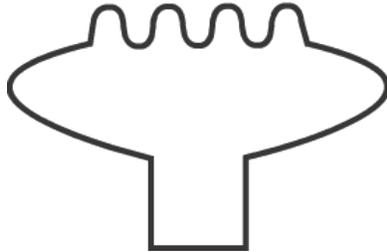
**YES**

**NO**

**3b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**4a. SADA - Is this a SADA?**



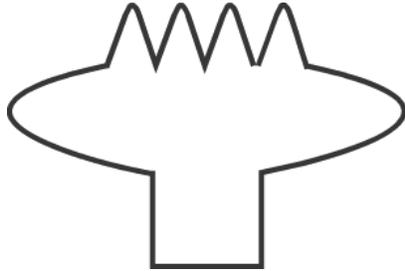
**YES**

**NO**

**4b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

5a. KADA – Is this a KADA?



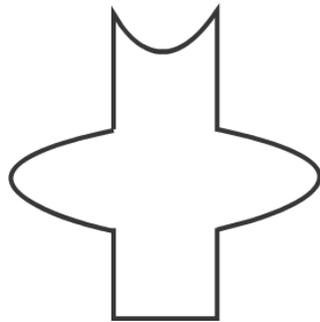
YES

NO

5b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

6a. MADA – Is this a MADA?



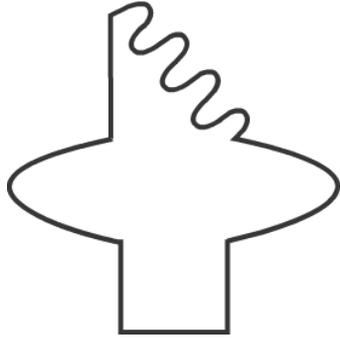
YES

NO

6b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

7a. NADA - Is this a NADA?



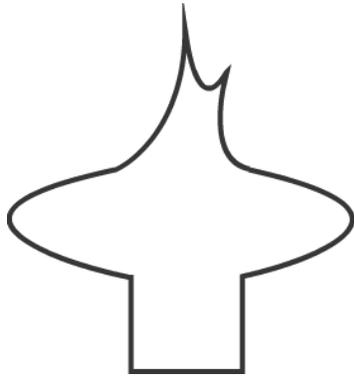
YES

NO

7b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

8a. VADA - Is this a VADA?



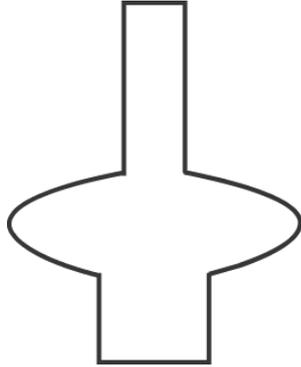
YES

NO

8b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

9a. TADA - Is this a TADA?



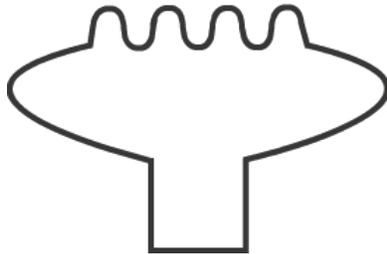
YES

NO

9b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

10a. YADA – Is this a YADA?



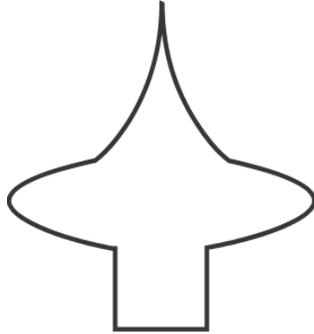
YES

NO

10b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

**11a. PADA - Is this a PADA?**



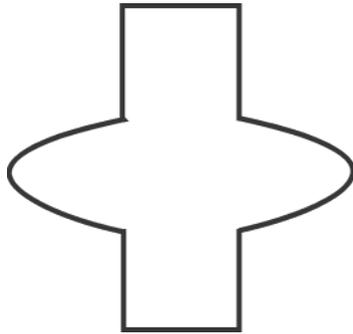
**YES**

**NO**

**11b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**12a. DADA - Is this a DADA?**



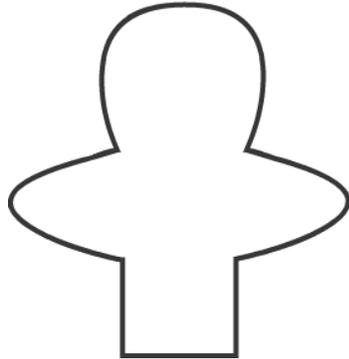
**YES**

**NO**

**12b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

13a. FADA – Is this a FADA?



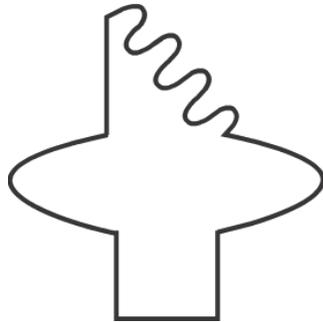
YES

NO

13b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

14a. RADA - Is this a RADA?



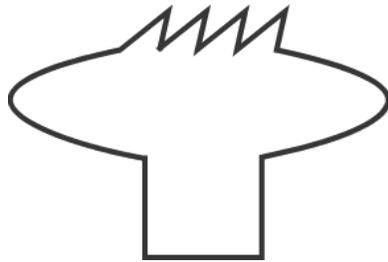
YES

NO

14b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

15a. VADA - Is this a VADA?



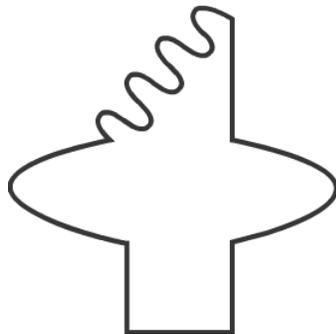
YES

NO

15b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

16a. NADA – Is this a NADA?



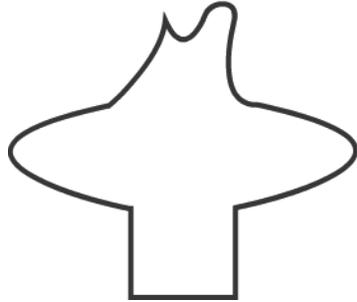
YES

NO

16b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

**17a. JADA – Is this a JADA?**



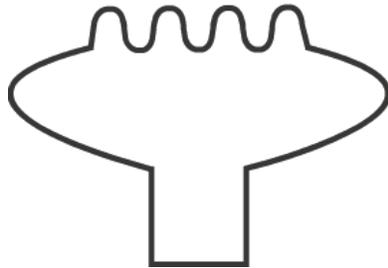
**YES**

**NO**

**17b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**18a. ZADA – Is this a ZADA?**



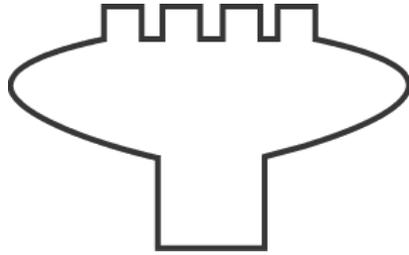
**YES**

**NO**

**18b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

19a. LADA - Is this a LADA?



YES

NO

19b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

20a. RAPA - Is this a RAPA?



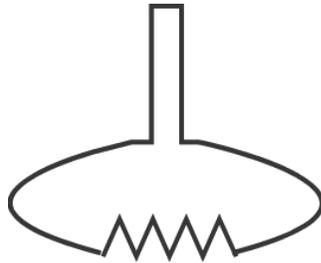
YES

NO

20b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

21a. TAZA - Is this a TAZA?



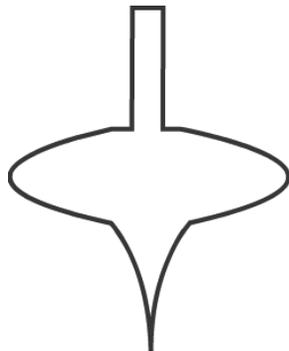
YES

NO

21b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

22a. GAMA – Is this a GAMA?



YES

NO

22b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

23a. LAZA – Is this a LAZA?



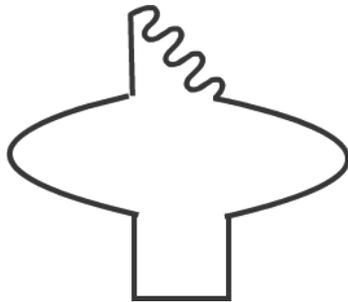
YES

NO

23b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

24a. NADA - Is this a NADA?



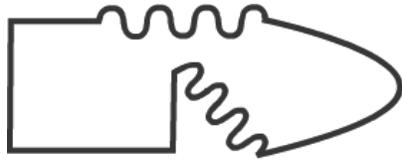
YES

NO

24b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

25a. SAND - Is this a SAND?



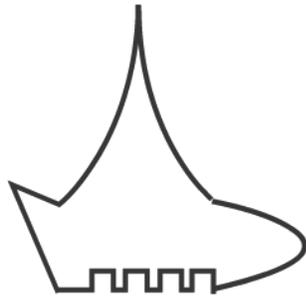
YES

NO

25b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

26a. PARK - Is this a PARK?



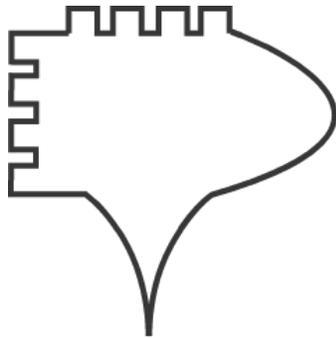
YES

NO

26b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

27a. RAFT - Is this a RAFT?



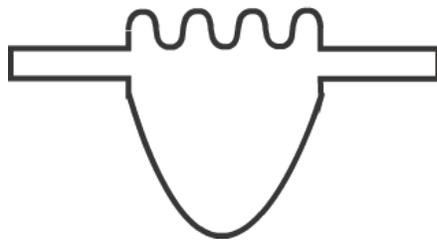
YES

NO

27b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

28a. STAT - Is this a STAT?



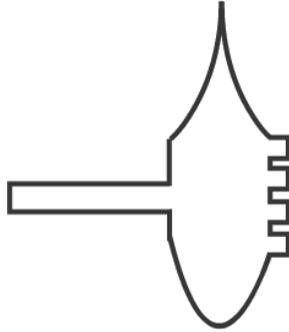
YES

NO

28b. How confident are you in your answer?

Very Confident  Confident  Somewhat Confident  Not Confident

**29a. PRAT - Is this a PRAT?**



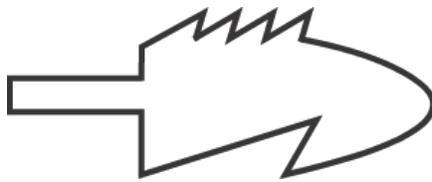
YES

NO

**29b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

**30a. FRAT - Is this a FRAT?**



YES

NO

**30b. How confident are you in your answer?**

Very Confident  Confident  Somewhat Confident  Not Confident

## Appendix I: Alien Language Post-Test

**Instructions:** You will be shown a number of shapes. Your task is to **SAY OUT LOUD** what you think that shape sounds like.

If you don't know a sound, say the first sound that pops into your head or work through the shape. Guessing is not a bad thing. Your verbalization of the shapes will be recorded.

If this shape were a sound, what would it be? Why?

