THE ROOTS OF CATEGORIZATION: 4-MONTH-OLD INFANTS EXTRACT FEATURE CORRELATIONS TO FORM AUDIO-VISUAL CATEGORIES

by

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Abstract

Is information from vision and audition mutually facilitative to categorization in infants? Ten-month-old infants can detect categories on the basis of correlations of five attributes of visual stimuli; four- and seven-month-olds are sensitive only to the specific attributes, rather than the correlations. If younger infants can detect specific attributes of visual stimuli, is there a way to facilitate the perception of these attributes as a meaningful correlation, and hence, as a category? The current studies investigate whether integrating information from two domains—speech within the auditory system together with shapes in the visual domain—could facilitate categorization. I hypothesized that 4-month-old infants could categorize audio-visual information by pairing correlation-based stimuli in the auditory domain (monosyllables) with correlation-based stimuli in the visual domain (line-drawn animals). In Experiment 1, infants were exposed to a series of line-drawn animals whose features were correlated to form two animal categories. During test, infants experienced three test trials: a novel member of a previously-shown category, a non-member of the categories (that shared similar features), and a completely novel animal. Experiment 2 used the same animals and paradigm, but each animal was presented with a speech stimulus (a repeating monosyllable) whose auditory features were correlated in order to form two categories. In Experiment 3, categorization of the auditory stimuli was investigated in the absence of the correlated visual information. Experiment 4 addressed some potential confounds of the findings from Experiment 2. Results from this series of studies show that 4-month-olds fail categorize in both visual-only and auditory-only conditions. However, when each visual exemplar is paired with a corresponding, correlated speech exemplar, infants can categorize; they look longer at a new, within-category exemplar than a new,

category violator. These findings provide evidence that infants extract correlated information from two domains, enabling cross-modal categorization at a very young age. Infants' sensitivity to correlated attributes across two domains and the implications for categorization are discussed.

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Dedication

To Grace Kathryn Nolte—my very favorite participant.

1. Introduction

Whether William James was correct in stating that infants enter the world and "…feel it all as one great blooming, buzzing, confusion," infants certainly don't remain confused for long (James, 1890, Vol. I, pg 488). When it comes to dealing with novelty, preverbal infants have us adults beat. The amount of sorting, parsing, pairing, filtering, detecting, and learning that infants do within their first years of life is phenomenal, and it goes without saying that most infants are well-equipped to handle the sort of 'confusion' into which they enter at birth (for a review on theories of perceptual development, see Aslin & Smith, 1988). That infants so readily learn the basic patterns, pairings, and categories upon which much of their later development relies (such as language development) makes the question of how they're able to initially make sense of their environment so intriguing to child development researchers. While several interesting topics of study could stem from this observation, the question of interest for the current line of research concerns whether infants can use the variation present *across domains* to learn or acquire categories.

1.1 Categories and Categorization

One of the ways in which infants (and adults) provide evidence of being able to handle variation in their natural environments is in their ability to form categories. According to Mervis and Rosch (1981), a "category exists when two or more distinguishable objects are treated equivalently" (pg 89). Implicit in the notion of a category is the act of *forming* a category, otherwise known as categorization, as well as the mental structure used to represent a category, known as a concept (Quinn, 1987). Further, Mervis and Rosch argue that

> "…this equivalent treatment may take any number of forms, such as labeling distinct objects or events with the same name, or performing the same action on different objects. Stimulus situations are unique, but organisms do not treat them uniquely; they respond on the basis of past learning and categorization. In this sense, categorization may be considered one of the most basic functions of living creatures" (pg 89) (Mervis & Rosch, 1981).

Thus, categories and the act of categorizing the environment are arguably crucial to survival, and are perhaps fundamental to organizing the vast amount variability in the environment.

Cognitive scientists have been investigating various aspects of the nature of categories for several decades. Although theorists still disagree on the representational structure of a category, three views have historically received the most support (Smith & Medin, 1981). Of these, the oldest view on the nature of categories—called the *classical view*—holds that in order to form a category, instances must share both necessary and sufficient properties. The *prototype theory*, in contrast to the classical view, assumes that various instances that form a category can vary in the degree to which they share a set of properties; however, there is a 'best example' of the category which represents a summary of the variability, otherwise known as the prototype (Rosch, 1975; Rosch *et al.*, 1976). Finally, *exemplar theories* of categorization argue that instead of forming a single representation of a category, each specific representation of the exemplars is stored; hence, no summary representation is required, instead the "category" is computed on-line during processing (Smith & Medin, 1981). While the classical view assumes deterministic categorization of instances because of its necessary and sufficient properties, both the prototype and the

exemplar views assume probabilistic categorization, where a learner does not have sufficient conditions by which to group exemplars (for a further discussion on the nature of categorical representations, see Smith & Medin, 1981). Although such different theories exist concerning the nature of categorical representations in both infants and adults, the issue of concern for the current line of research is the acquisition of categories in young, preverbal infants.

1.2 Categorization in Infancy

Much research on categorization within the first year of life has investigated infants' ability to form categories of visual stimuli (Mareschal & Quinn, 2001; Quinn & Eimas, 1986). In studies of visual categorization in infancy, infants are typically exposed to a series of instances from a category, and are later tested to see how they respond to new exemplars from within the category and exemplars from a different, novel category. Categorization is inferred if infants show different looking patterns between the new within-category instance and the category non-member; typically, studies have shown longer looking to the novel category exemplar than to the new within-category exemplar (Mareschal & Quinn, 2001). Using this visual preference paradigm, researchers have been able to assess the categorization abilities of young, preverbal infants for many kinds of visual information.

Research has shown that young infants can form perceptually-based categories of both patterns and natural kinds in the visual domain (Bomba & Siqueland, 1983; Quinn & Eimas, 1986). For example, 3- and 4-month old infants can acquire two visual form categories simultaneously, suggesting that presenting contrasting information from a separate form category does not interfere with (and may actually improve) categorization of visual forms (Quinn, 1987). Similarly, infants as young as 3 months of age can form broad

natural kind categories, e.g. that include horses but not zebras, giraffes, or cats; by 6 or 7 months, infants group (domestic) cats into categories that exclude tigers and lions (Quinn & Eimas, 1994). Before their first birthday, infants can form natural kind categories similar to those of the basic level in adults. While this research exemplifies the kinds of categories that can be formed by young infants, it doesn't concern the *learning* of a category—how the infants actually go about forming the categories.

Research concerning visual category learning has suggested that in the presence of a novel word, infants are better able to detect the properties that define a category. By labeling exemplars of a category with consistent words, infants as young as 3 months of age have shown evidence of being able to learn naturally occurring categories (Balaban & Waxman, 1997; Ferry *et al.*, 2010; Fulkerson & Waxman, 2007; Waxman & Braun, 2005; Waxman & Markow, 1995). On the basis of these findings, Waxman and colleagues have proposed that labels act as 'invitations' to form categories, highlighting the commonalities of the exemplars within a category (but for a discussion of labels as 'features of a category', see Gliozzi *et al.,* 2009; and Plunkett *et al.,* 2008; for labels as 'interfering with categorization,' see Robinson & Sloutsky, 2004, 2007).

While many categories are acquired by infants after they gain experience with various instances of a category, some kinds of categories seem to be in place during infancy without any explicit learning. The ability to categorize stimuli in the absence of explicit learning or experience is shown in a phenomenon known as *categorical perception*, a term first coined by Liberman and colleagues (1957). Categorical perception "occurs whenever perceived within-category differences are compressed and/or between-category differences are separated (relative to some baseline of comparison)" (Harnad, 1987). The nature of

categorical perception is typically considered different than that of category learning (Livingston *et al.*, 1998). The most commonly studied domains in which categorical perception has been shown include speech perception and color perception. In speech perception, when presented with sounds that vary continuously on a variety of physical dimensions (such as voice onset time), listeners treat them as discontinuous (categorically). For example, when presented with sounds varying on a continuum between /pa/ to /ba/ (which vary only in their voice onset time, where the voiceless /p/ has a longer VOT than the voiced /b/), infant and adult humans (as well as some animal species) perceive the tokens along this continuum as either /pa/ or /ba/—not as a gradual change (Eimas *et al.*, 1971; Kuhl & Miller, 1975; Liberman *et al.,* 1957). Similarly, in color perception, while colors vary continuously on a variety of dimensions (such as wavelength), they are treated discontinuously (categorically); under many testing conditions, infants, as well as adults, perceive differences in wavelength (color hue) as categorical (Bornstein *et al.*, 1976; Franklin *et al.,* 2005). Because very young, preverbal infants show categorical perception of speech sounds (Eimas *et al.*, 1971: Dehaene-Lambertz *et al.*, 2006) and of colors (Bornstein *et al.*, 1976; Franklin, *et al.,* 2005), the tendency to discriminate and categorize perceptual stimuli of these types may not need to be learned by humans. While the perception of speech sounds is reorganized (Werker, 1995) and the perception of colors is sharpened (Raskin *et al.*, 1983) during development, categorical perception by preverbal infants provides early evidence of the ability to perceive and group variation (continuous) as categorical (discontinuous) along physical dimensions.

Although stimuli like color and speech can be perceived as categories from very early in life, the process by which humans form other types of categories, such as automobiles,

fruits vs. vegetables, and gender or age in people, seems to require more than categorical perception. It has been argued that in order to *learn* a category, learners must be sensitive to some invariant structure across the instances to be grouped (Mervis & Rosch, 1981; Strauss, 1979). In this thesis, I will refer to the active process of detecting invariant structure as a form of abstraction (Gibson, 1969).

Different views on the nature of abstraction exist in the categorization literature. Common across these views is that the process of abstraction includes both learning which attributes are relevant and essential, as well as learning the logical relationship between these attributes (via creating higher order information) (Mervis & Rosch, 1981). As Mervis and Rosch (1981) describe, abstraction can be defined as "…the way in which the cognitive system acts 'creatively' on input during learning of categories and uses the resultant categorical information to classify novel items" (pg 103). Alternatively, abstraction has been portrayed as involving some compression of the psychological distance of dimensions between exemplars within a category, and expansion of other dimensions for exemplars in different categories (Livingston *et al.*, 1998). Across all of these views, the act of categorization involves dealing with variation in a manner that goes beyond initial perceptual biases, and abstracting the regularities across instances.

1.3 Learning and Abstracting Variation in Infancy

Considerable research has been conducted on infants' ability to detect regularities and handle the variability they experience in their environments. For example, infants as young as eight months of age can detect and use statistical regularities. For example, it was shown that infants can use transitional probabilities to pull out words from a string of sounds (Saffran *et al.*, 1996), to pull out patterns of sequentially-presented visual objects

(Kirkham *et al.*, 2002), and to pull out statistically more probable pairs of objects in complex scenes in vision (Fiser & Aslin, 2002). In addition, it has been claimed that following exposure to regularities such as in a set of triads, each with an ABA structure, infants are able to abstract and generalize rules (Johnson *et al.*, 2009; Marcus *et al.,* 1999), or at least summarize across the regularities (Saffran *et al.,* 2007) by 8 months of age in both speech and vision. These accomplishments reveal that preverbal infants can readily detect informative cues across a series of tokens within a domain.

By 9 months, infants can learn and extract arbitrary phonological regularities (Saffran & Thiessen, 2003). Following exposure to patterns of a specific syllable structure (either consonant-vowel-consonant-vowel (CVCV) or CVCCVC), infants were found to be able to later generalize the specific pattern on which they were trained to a set of novel words. Further, infants could also apply a specific pattern of consonant voicing[1] in bi-syllabic words, and later generalize it to novel words. These results suggest that infants can learn arbitrary phonological patterns after a brief exposure, and generalize these patterns to new words (Saffran & Thiessen, 2003). In addition, work by Chambers, Onishi, and Fisher (2003) has shown that 16-month-old infants can learn novel phonotactic regularities[2] not found in their native language. When exposed to CVC syllables in which particular consonants could only occur in either the initial (e.g., /b/, /k/, /m/ were only syllable-initial, as in "bap" and "min") or the final position (e.g. /p/, /g/, /n/ were only syllable-final, as in "kip" and "ban"), infants could generalize this phonotactic constraint to new CVC syllables (Chambers *et al.,* 2003). Together, these studies suggest that infants are able to

[1] Voiced consonants involve vocal cord vibration during production, while voiceless consonants involve no vocal cord vibration.
[2] Phonotactic regularities describe what sound combinations are likely to occur in a given language.

learn novel phonological and phonotactic regularities, and abstract them to new sets of words.

Within the first year of life, infants' ability to detect differences between phonetic categories is reorganized; infants are initially able to discriminate nonnative phonetic contrasts (a language-general pattern of discrimination), but by 10 to 12 months of age, phonetic contrast discrimination is most robust for native consonant contrasts (a language-specific pattern of discrimination) (Werker & Tees, 1984). For example, the sounds /r/ and /l/ are initially discriminated by infants learning any language. However, adult Japanese speakers are unable to tell the difference between these two sounds in words like "rake" and "lake" (where /r/-/l/ is a *non-native* phonetic contrast), while English speakers maintain this /r/-/l/ distinction (where it is a *native* phonetic contrast). Maye, Werker & Gerken (2002) showed that a sensitivity to distributional frequency information could be the mechanism that underlies this language-specific tuning. Infants between 6 and 8 months of age, who are still "universal" listeners, will either keep a non-native distinction separate or collapse it depending on whether they are exposed to a bimodal or a unimodal frequency distribution in an experimental setting. Maye and colleagues argued that infants' sensitivity to the frequency distribution of speech sounds might influence the re-organization of speech perception in infancy, such that the distribution of sounds in the input language affects infants' sensitivity to sound contrasts (Maye *et al.*, 2002).

Distributional learning may be generalizable. Maye, Weiss, and Aslin (2008) have shown that familiarizing 8-month-old infants to a bimodal statistical distribution of sounds

at one place of articulation[3] (such as a difficult velar contrast, produced with the body of the tongue at the back of the roof of the mouth) facilitates discrimination of sounds at a *different* place of articulation (such as a difficult dental contrast, produced with the front of the tongue at the teeth). These results suggest that infants can abstract phonetic (featural) information from the sounds to which they were exposed, and apply these feature-based contrasts to a different set of speech sounds (Maye *et al.,* 2008).

As a final example, research by Rost and McMurray (2009) has shown that increasing the variability of acoustic information helps infants associate minimal pair words with novel objects during an associative word-learning task. Minimal pair words are words that differ in only one sound feature; in the minimal pair 'bat' and 'pat', these differ only in initial consonant voicing (where /b/ is voiced and /p/ is voiceless). While minimal pair words are difficult to learn as object labels at 14 months of age, Rost and McMurray showed that 14-month-old infants could learn to associate minimal pair words with novel objects when the words were spoken by multiple speakers. By increasing speaker (and thus the acoustic) variability, the contrastive dimension between the two words (in "buk" and "puk", this is the difference in voicing of the initial consonants) was highlighted, and helped the infants detect and use this minimal difference.

Taken together, these studies show that young infants can readily detect regularities present in their environments. They are able to abstract from the specific stimuli on which they are trained to learn more general patterns in both vision and speech—abilities likely useful in category learning.

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[3] Place of articulation of a consonant is the place in the vocal tract where a closure occurs between a moving articulator (like the tongue) and a stationary articulator (like the roof of the mouth).

1.4 Learning Categories in Infancy

Although much research has investigated the types of categories that are learnable by young infants, as well as general learning mechanisms used by infants, the learning mechanisms that allow categorization have received less research attention. Some researchers suggest that category learning involves learning the logical relationship between the attributes that are important for category membership (Mervis & Rosch, 1981). One way to instantiate 'logical relationships' is by using correlations of attributes. Rosch (1978) argued that because categories present in the environment exhibit correlations between their various attributes, perhaps being sensitive to correlation information is important for category formation and category learning. Certain combinations of attributes are much more likely to occur than others in nature; for example, Rosch mentions that animals that have feathers typically have beaks and wings, while animals with fur typically do not, suggesting a "correlated attribute structure of the perceived world" (Mervis & Rosch, 1981, pg 92). Thus, correlation-detection may be foundational for infants' (and adults') abilities to form categories.

Younger and Cohen (1983, 1986) investigated whether preverbal infants can use correlated information to form arbitrary, artificial visual categories of animals. They found that by 10 months, infants can use the correlations of attributes of visual animal stimuli to acquire a category (Younger & Cohen, 1983; 1986). The pictures were comprised of five attributes (type of body, tail, feet, ears, and number of legs) with one of three features possible for each attribute (i.e., for body type: giraffe body, cow body, or elephant body) (Younger & Cohen, 1983). These attribute features were correlated to form different categories of animals, where three attributes were perfectly correlated, and the other two

could vary (for an example of this kind of stimuli, see Figure 2.1). To succeed in the experimental task, infants had to detect the consistent correlation-based structure while ignoring the variation in the other features. Only 10-month-olds succeeded: 4- and 7-month-olds were sensitive only to the specific attributes, rather than to their correlations (but see Mareschal *et al.,* 2005, for evidence of 4-month-olds' and Bhatt *et al.*, 2004, for 3-to-6-month olds' sensitivity to correlated information).

Younger & Cohen (1983, 1986) suggest that there is a developmental shift in an infant's sensitivity to correlational attributes of stimuli between 4 and 10 months of age. In a categorization task such as the one involving 5-featured animals, an underlying structure is present, but goes undetected by the youngest infants. Detecting the relationship among the multiple attributes requires that infants track the pattern of co-occurrence between the correlated attributes. Thus, being sensitive to and processing structures and regularities likely plays an important role in categorization.

1.5 The role of Cross-Modal Information in Infancy

The research reviewed in sections 1.3 and 1.4 suggests that infants younger than 7- to 10-months of age are unable to detect correlations and pull out regularities when stimuli are either audio-only or visual-only, but many natural categories are best defined by features in more than one modality. Work investigating the integration of cross-modal information has shown that infants as young as two days old are able to learn an arbitrary pairing of visual stimuli and auditory stimuli (Slater *et al.,* 1999). In addition, three month-old infants are able to learn arbitrary pairings of voices and faces (Brookes *et al.*, 2001). These findings show that very young infants can integrate arbitrary auditory and visual information at a younger age than they seem able to learn arbitrary correlations within a single perceptual

domain; this suggests that the linkage between information in the auditory and visual domains may be privileged from a very young age.

Facilitative effects of audio-visual information are also found in abstract rule learning research: 5-month-olds can learn abstract rules (such as an ABA structure) when presented multi-modally (Frank *et al.*, 2009). As mentioned previously, although abstract rules and regularities presented in a single perceptual domain are not learnable by infants until 7- or 8-months of age (in speech, Marcus *et al.*, 1999; and in vision, Saffran *et al.*, 2007; Johnson *et al.,* 2009), 5-month-old infants abstracted rules when bimodal patterns were presented in which visual shapes changed in synchrony with the presentation of speech sounds (Frank *et al.,* 2009). These results suggest that multi-modal presentation may facilitate the learning of abstract rules in comparison to a uni-modal presentation.

Additional evidence linking auditory (and specifically linguistic) information with visual information has shown that cross-modal associations may influence phonetic learning. Yeung and Werker (2009) showed that 9-month-old infants—who typically fail to discriminate non-native phonetic categories (Werker & Tees, 1984)—succeed at discriminating non-native phonetic contrasts when each category is synchronously presented with a distinctive visual object. The contrasts used were the Hindi phonetic contrast /da/, a dental alveolar stop consonant, and /Da/, a retroflex alveolar stop consonant. To native English speakers, this contrast is uninformative/not discriminable, as both sounds are categorized as a single /da/. Yeung and Werker found that this non-native contrast was discriminable by the 9-month-old infants who received consistent, synchronous visual cues, suggesting that the visual information helped infants classify the acoustic

information at an age when these contrasts are typically no longer discriminable (Yeung & Werker, 2009).

Together, these studies provide evidence that associating visual and auditory information can be helpful for preverbal infants when making sense of their environments, even before they begin to learn words. However, an alternative explanation for these findings is provided by the Inter-sensory Redundancy Hypothesis; this account suggests that arbitrary audio-visual pairings are only learnable by young infants when an amodal regularity, such as temporal synchrony, exists between the information in the two modalities (Bahrick & Lickliter, 2000). *Amodal* regularities present redundant information across two or more modalities (including vision and audition). In the case of the amodal regularity known as temporal synchrony, the redundant information occurs in the timing of the presentation: the onset of one stimulus (such as the onset of the presentation or movement of a visual stimulus) coincides or occurs *in synchrony* with the onset of another stimulus (such as the onset of an auditory stimulus), so that the perceiver experiences the information synchronously. *Arbitrary* intermodal relations, on the other hand, occur when there is no overlapping or redundant information across the senses; for example, although a perceiver can both see the color of a dog and hear its bark, the color of the dog and the sound of its bark are *arbitrarily* related. According to Gibson (1969; the theoretician who inspired the inter-sensory redundancy hypothesis), amodal regularities require no prior learning, and are useful to infants from the first days of life, while arbitrary relations require learning. Adherents to the Intersensory-Redundancy Hypothesis postulate that arbitrary relations (like colors paired with sounds) can be more easily learned in the presence of an amodal regularity (like temporal synchrony). Hence, although the studies reviewed above

are broadly interpreted as showing that infants can learn arbitrary audio-visual relations very early in life, in each study, the auditory and visual stimuli were presented in temporal synchrony. Therefore, it is also plausible that infants learned the auditory-visual relationship in each case not because they learned an arbitrary relation, but because the two sources of information were presented in synchrony, hence rendering them "amodal".

Many perceptual events occur to perceivers in more than one domain, and are related amodally; one can simultaneously watch the face of a person speaking while listening to the person's words; one can see a basketball bounce and hear it hit the floor. In these cases, the auditory and the visual experience are related by temporal synchrony. However, not all multi-modal experiences are related by an amodal regularity. For example, looking at a picture book and listening to the accompanying story does not have to occur in sync; the time at which one looks at a picture does not have to coincide temporally with the onset of the story. Hearing the name of an animal and seeing it run across the street do not have to occur in sync in order to learn the name of the animal. I would like to suggest that even if infants are sensitive to inter-sensory redundancies such as temporal synchrony, to be able to learn the kinds of natural audio-visual associations that exist in the world they also need to be able to pick up some arbitrary regularities that cannot be explained by amodal processes.

1.6 Cross-modal Categorization: Detecting Correlations across Two Domains

Many categories—like many perceived events—can be experienced cross-modally. For example, different kinds of dogs not only share similar visual features (such as their overall body shape, fur coats, fours legs, and tails), but they also share similar auditory features—most dogs bark. Just as learning the visual category of a dog requires the learner

to deal with variation across visual instances, variation is also present in the auditory domain. Dogs can produce many kinds of barks (varying in pitch, intensity, and quality), yet most perceivers can typically identify the sound as a dog bark. Learning the category of 'dog' occurs in two domains, where variation across instances is experienced and dealt with in both vision and audition.

Returning to Rosch's (1978) description of categories in the natural world, where she argues that correlations of *visual* attributes occur in natural categories, perhaps the simultaneous occurrence of correlations in *two* sensory domains may more accurately mimic the way information is packaged in the natural world. Hence, I argue that it may also be necessary to detect *correlational regularities* among attributes that are present across modalities. This kind of sensitivity may help facilitate learning, even when the information in each modality is not linked by synchrony or any other amodal property. The attributes coded by each modality are of different kinds. Attributes in visual stimuli, for example, can consist of lines or colors in various patterns or orientations; in audition, attributes can consist of certain sounds or frequencies. Nevertheless, if an underlying correlated structure is present among the attributes in both domains in a category-learning situation, infants may be more readily able to detect the structure and learn the category than if there is a correlated structure in only one domain.

As mentioned, Younger & Cohen (1983) asked whether infants between the ages of 4 and 10 months could detect meaningful correlations of features in order to form visual categories. Only 10-month-old infants were sensitive to the correlation structure, while 4- (and 7-) month-olds were sensitive only to the specific features. If detecting correlations is foundational for category learning, the finding that infants younger than 10 months of age

cannot detect correlations is surprising; infants as young as 3 months of age have previously been shown to be able to detect natural kind categories (Quinn & Eimas, 1994). Given the importance of detecting correlations for forming natural object categories (Younger, 1990; also see Younger, 1992 for categorizing facial stimuli), one might expect that the detection of correlations would be an earlier appearing ability. Building on the findings of Frank *et al.* (2009), where presenting (albeit synchronous) multi-modal rule-based information in both the auditory and visual domains facilitated abstract rule-learning earlier than rules presented uni-modally, I ask whether pairing correlation-based information in two domains could facilitate categorization of arbitrary features at a younger (4 months) age than previously shown. This manipulation allows an investigation of whether cross-modal correlational regularities are useful to young, preverbal infants, especially in a category-learning situation.

I hypothesize that infants can detect correlations among attributes in a category-learning task when the correlation includes attributes from two sensory domains—in this case, both vision and audition. I hypothesize that young infants are sensitive to correlations in their environments, but are first able to pick up such correlations only if there is information from more than one sensory modality specifying the correlation. It is only at a later date that they can learn correlational structures if the information is presented in a single modality. I will investigate this hypothesis by presenting infants with stimuli that preserve a correlational structure present in two domains (see sections 2.1.2 & 3.1.2). My question is whether input organized this way facilitates cross-modal categorization. Importantly, the cross-modal categorization tasks described in this thesis do not involve temporal synchrony. Hence, although the information in the auditory and visual modalities

was presented simultaneously, there was no amodal regularity of temporal synchrony between them.

1.7 Current Experiments

In this set of experiments, I test the hypothesis that infants younger than 10 months of age can detect correlations of attributes when the correlational structure is presented in two domains—vision and audition. My experiments rely on the correlation-based stimuli used by Younger & Cohen (1983); the visual stimuli used in this research are based on those animal categories. In choosing appropriate auditory stimuli for this set of experiments, a feature correlation matrix was used to organize appropriate parameters for the specific auditory attributes. However, because the current research was based on the finding of a failure to detect a correlation in the visual stimuli, auditory stimuli had to be created such that the correlation in the auditory information was also likely undetectable when presented uni-modally (see Experiment 3). Therefore, categorically perceived auditory stimuli could not be used (like those described in section 1.2); infants are sensitive to categories of speech sounds very early in life, so a more complex combination of phonetic features was necessary for the present set of studies.

Linguistic stimuli in the form of consonant-vowel syllables were chosen. This is ideal for several reasons: first, research has shown that infants are able to represent speech sounds at a syllabic level (Bertoncini *et al.,* 1988; Eimas, 1999; Jusczyk & Derrah, 1988), but can also attend to featural and segmental information (Chambers *et al.*, 2003; Maye *et al.,* 2008; Werker & Curtin, 2005). Second, syllables that require detection of an underlying correlation of *featural (phonetic)* attributes could be created (see section 3.1.2). By pairing a set of syllables with an underlying correlational structure with a set of visual stimuli with an

underlying correlational structure, the effects of cross-modal correlations in categorization could be investigated. The task for the infant, then, was to detect the correlation of attributes of a visual stimulus *as well* as the correlation of an auditory stimulus.

To investigate the impact of presenting both correlated acoustic information and correlated visual information on infant categorization, I created and implemented a series of experiments involving four-month-old infants. In Experiment 1, a replication of Younger & Cohen's (1983) findings provided a baseline of visual categorization in silence. In order to identify whether infants can form categories based on correlations of visual attributes, infants were familiarized to instances of two categories of animals which conformed to a correlation-based structure. During test, three trials were included: one stimulus had attributes that were *correlated* with a previously learned category, one stimulus had attributes that were *uncorrelated* with a previously learned category, and one stimulus was completely novel. In this kind of task, evidence of categorization exists when infants show different patterns of looking between the correlated and uncorrelated test stimuli; although both stimuli are new to the infants, if they detect the correlational structure during the familiarization phase, they would show different lengths of looking to one of these images. If, however, the correlational structure goes undetected by the infants, they should show no difference in looking between the correlated and uncorrelated stimuli, only showing longer looking to the completely novel stimulus; this is the pattern of looking I hypothesized for Experiment 1. Each follow-up experiment is based on the framework of this study, implementing a familiarization phase and a test phase (involving correlated, uncorrelated, and novel stimuli).

Experiment 2 afforded the critical test of interest: whether pairing auditory stimuli with a correlational structure with the visual categories from Experiment 1 would facilitate category learning. As described in Experiment 1, if infants are able to detect the underlying correlational structure to which they are exposed during the familiarization period, they should show different patterns of looking between the correlated and uncorrelated animal-sound test stimuli; I hypothesized that infants would exhibit this pattern of behavior when the category information was presented cross-modally.

Experiments 3 and 4 were included to account for alternative explanations for Experiment 2. Experiment 3 investigated whether the auditory stimuli could be categorized uni-modally, with no accompanying visual category information. Finally, Experiment 4 sought to determine that a *consistent* pairing of correlated auditory and visual information was necessary for detecting members of a cross-modal category.

2. Experiment 1: Visual-only Condition

In Experiment 1, infants were exposed to correlation-based category information in the visual domain, where the entire study was presented in silence. This study was a replication of Younger and Cohen (1983); 4-month-old infants' abilities to detect relationships of attributes were assessed in a visual categorization task. Based on the findings of Younger and Cohen (1983), I hypothesized that these infants would not show evidence of forming correlation-based categories in silence.

2.1 Method

2.1.1 Participants

The participants in Experiment 1 were twenty-four infants (13 male, 11 female), with a mean age of 4 months, 20 days (ranging from 4 months, 6 days to 5 months, 2 days). These infants' parents were contacted through the Infant Studies Centre at the University of British Columbia. Parents and infants were originally recruited for participation at BC Children's and Women's Hospital, after expressing an interest in being contacted for research studies. Parents gave written consent for their infant's participation before the study began. After the study, infants received a t-shirt and were awarded a certificate as a thank-you for participating. In addition to the 24 infants included in the final analyses, data from 20 infants were not included due to fussiness (11), experimenter error (2), parental interference (2), and failure to meet looking criterion (no looking during any test trial) (5).

2.1.2 Stimuli

The stimuli used for Experiment 1 were based on the visual stimuli used in Younger & Cohen (1983). These pictures were created on a computer using a design program (Adobe Photoshop CS) and consisted of line drawn animals (using black lines) on a white

background. Each animal was centered on a 34 cm x 27.5 cm computer screen. Animals were drawn in such a way that the general surface area of each creature was the same across categories, as the specific height and width varied by category. Each animal stimulus was presented individually for 20 seconds during each trial of study.

The specific animals chosen for this experiment were based on a feature correlation matrix (see Table 2.1), as found in Younger & Cohen (1983). A set of 5 attributes was chosen to create these animals: a specific body type, a specific tail type, a specific foot type, a certain number of legs, and a specific type of ear. Each of these attributes could be realized in 3 ways: a cow, giraffe, or elephant body; a fluffy, feathered, or horse tail; clubbed, webbed, or hoofed feet; two, four, or 6 legs; and round, antlered, or human ears. The features of the first three attributes listed here (body type, tail type, and foot type) were perfectly correlated within a category: these three attributes predicted category membership. The features of the last two attributes (number of legs and type of ear) could vary within a category: these two attributes were not predictive of category membership.

Based on these constraints, two separate groups of stimuli were created (see Table 2.1, Figure 2.1). In each group, four familiarization animal stimuli were constructed, with two animals each in two categories. For example, in Group A, animal tokens A and B formed category 1, and animal tokens C and D formed category 2: tokens A and B each had a giraffe-shaped body, a feathered tail, and webbed feet; whereas tokens C and D each had a cow-shaped body, a fluffy tail, and clubbed feet. Within each category, however, each token had a different number of legs and a different kind of ear: in category 1, token A had four legs and antlers, while token B had two legs and round ears. In category 2, token C had two legs and antlers, while token D had four legs and round ears. Familiarization

animals for Group B were created in a similar fashion, but the feature-values of the predictive attributes were different. In Group B, category 1 animals had giraffe bodies, fluffy tails, and clubbed feet, whereas category 2 animals had cow bodies, feathered tails, and webbed feet. Again, the number of legs and kind of ear could vary within a category. See Figure 2.1 for images of familiarization stimuli in Group A and Group B.

For both Groups A and B, one set of test stimuli was created. Two critical test animals were constructed: one that was a member of a previously learned category (shared the features of the predictive attributes), and one that was NOT a member of a previously learned category (who shared some features with previously learned animals, but not in the correct, predictive fashion). These 2 critical test animals were composed in such a way that in Group A, Token T1 was *correlated* with one of the familiarization animals, and Token T2 was *uncorrelated* with the familiarization categories. However, in Group B, Token T2 was the *correlated* test stimulus, and Token T1 was the *uncorrelated* test stimulus. This was to ensure any differences in looking time found between these two critical test stimuli was due to the learned correlation—not a general preference for one animal over the other. Token T1 had a cow shaped body, a fluffy tail, clubbed feet, antlered ears, and four legs. Token T2 had a cow-shaped body, a feathered tail, webbed feet, antlered ears, and four legs. Finally, a completely novel animal—who shared no features with any of the familiarization animal and had an elephant body, a horse tail, hoofed feet, six legs, and human ears—was included as an ultimate test of novelty. See Figure 2.1 for images of these test stimuli.

2.1.3 Apparatus

Looking time data were collected using a Tobii 1750 eye-tracking system. This eye tracker was comprised of a monitor that both presented the visual stimuli and captured the

infants' gaze information, and a PC computer that controlled the experiment. This computer used Tobii Clearview software that controlled stimulus presentation and collection of gaze data from the eye-tracking monitor. Diodes that emitted infra-red light were located in the monitor that presented the stimuli to the infant; these diodes shone infrared light on an infant's face, and this infrared light was then reflected off the infant's cornea. A camera built into the monitor collected the corneal infrared light reflection, which was then recorded as the infant's eye gaze information. This camera recorded gaze information every 20 ms, and could handle a reasonable amount of movement by the infant.

2.1.4 Procedure

Each infant participant was seated on his/her parent's lap in a dimly lit, sound-attenuated study room. The eye-tracking monitor was positioned approximately 60 cm away from the infant's face, and angled appropriately such that the monitor was roughly parallel to the infant's face. Proper positioning of the infant, as well as of the eye tracker, was evident when the infant's gaze was evenly captured. Before the study began, each infant experienced a five-point calibration, to be sure the eye tracker accurately recorded the gaze information from each infant. The experimenter controlled the study from a separate computer located behind a screen in the back of the study room, out of sight of both the infant and parent.

The study began with a brief 5-to-10 second warm-up trial, during which a colorful waterwheel was presented in the center of the screen; this was to allow the infant to become accustomed to the monitor, and to the fact that objects would be shown at the center of the screen. Following this warm-up trial, the familiarization period began. To centrally orient the infant's gaze, an attention getter (a bright, colorful, rotating ball located at the center of

the screen) preceded each trial. As soon as the infant looked centrally, the trial began. During each trial, the static animal image was presented in the center of the screen for 20 seconds. Each animal was presented in silence, and the eye tracker recorded the infant's gaze during this period. A series of eight familiarization trials included two blocks of the four familiarization animals in a pseudo-random order. After the familiarization period concluded, the test trials began, each preceded by the same attention getter as mentioned above. During each test trial, a static animal image was presented for 20 seconds while the eye tracker recorded gaze information. The total duration of the study was approximately four minutes.

To control for order effects, the 3 test trials were completely randomized across infants, resulting in 6 experimental orders. These six experimental orders were created for stimuli in both Group A and Group B, resulting in 12 possible orders for this study. Infants were randomly assigned to either Group A or Group B (12 in each), and then randomly assigned to one of the 6 orders (2 in each order in each group).

The eye tracker collected gaze information every 20 ms, and the area of interest for the following analyses included the full-screen (1024 X 768 pixels, or 34 X 27.5 cm). Thus, during each time interval, looking behavior could be classified as either 'looking on screen' or 'no gaze information.' Data from the familiarization trials and the test trials was collected in this way. The dependent measure for the following analyses was the *total looking time* during each of the eight familiarization trials and the three test trials.

2.2 Results

2.2.1 Group Differences

In order to determine whether infants who saw animals from Group A had different looking behavior than those who saw Group B, a 2 (group) X 5 (trials) mixed ANOVA was conducted. Average looking times during the familiarization trials were collapsed into two blocks for this first analysis: looking time during the first four trials were averaged into Fam1, and looking time during the last four familiarization trials were averaged into Fam2; the 3 test trials were also included in this analysis. Results showed no significant interaction between group and trials, suggesting that looking behavior across the study did not significantly differ between the two groups of stimuli. In addition, there was no main effect for group, indicating that there was no overall difference in infant looking time to the two groups of animals. Thus, all following analyses will collapse looking behavior across Groups A and B.

2.2.2 Familiarization Looking Times

Familiarization trial data and test trial data were analyzed separately. Average looking times during the familiarization trials were analyzed using two blocks in this analysis: looking time during the first two trials were averaged into Block1 and the looking time during the last two familiarization trials were averaged into Block4 for all infants. In order to see if these infants showed a decrease in looking time across the familiarization period, a 2 (familiarization block) X 2 (sex) mixed ANOVA was conducted on the looking time data. Results showed no significant interaction between block and sex. However, there was a significant main effect of block, $F(1,22)=8.353$, $p=.008$, indicating that collapsing across both genders, infants showed longer looking during the first block ($M=7140.83$ ms,

SD=4800.92) compared to the last block of familiarization (*M*=4711.67 ms, *SD*=3889.18) (see Figure 2.2). Thus, infants significantly decreased their looking to the familiarization animals from the first to the last block.

2.2.3 Test Trial Looking Times

To determine if any significant looking time differences existed between the test stimuli, the average looking times for each test trial were analyzed in a 3 (test trial) X 2 (sex) mixed ANOVA. Results showed no significant interaction between test trial and sex. However, there was a marginally significant main effect of test trial, $F(2,44)=2.834$, $p=.070$. Given the strong a priori predictions from the Younger and Cohen (1983) work, pair-wise t tests were implemented to determine if significantly different looking occurred between the different test trials. Follow-up analyses indicated no significant differences looking times between the correlated animal (*M*=5944.17 ms, *SD*=5078.52) and the uncorrelated animal (*M*=6020.00 ms, *SD*=4089.25), $t(23)=.120$, $p=.905$. However, marginally significant looking time differences were found between the novel animal (*M*=7296.67 ms, *SD*=5246.84) and the correlated animal, $t(23)=1.965$, $p=.062$, and between the novel animal and the uncorrelated animal, $t(23)=2.054$, $p=.051$, indicating longer looking times to the novel animal than both the correlated and uncorrelated animals (see Figure 2.2).

2.3 Discussion

These results provide a replication of the findings from Younger and Cohen (1983) using a different method of data collection. The 4-month-old infants showed marginally significant differences in their looking towards a completely novel animal compared to the two critical test items, indicating their interest and surprise in the seeing an animal with completely new features. As in the original work by Younger and Cohen, they failed to

form categories of animals based on a correlational structure. Because no significant interactions were found between the different groups of stimuli (Group A animals vs Group B animals) and looking time across experiment 1, all following studies used only animal stimuli from Group A.

Table 2.1. Visual Stimuli Matrices for Experiment 1.

GROUP A FAMILIARIZATION STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
A	1	1	1	1	2
B	1	1	1	2	1
C	2	2	2	1	1
D	2	2	2	2	2

GROUP B FAMILIARIZATION STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
A	1	2	2	1	2
B	1	2	2	2	1
C	2	1	1	1	1
D	2	1	1	2	2

TEST STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
T1	2	2	2	1	2
T2	2	1	1	1	2
T3	3	3	3	3	3

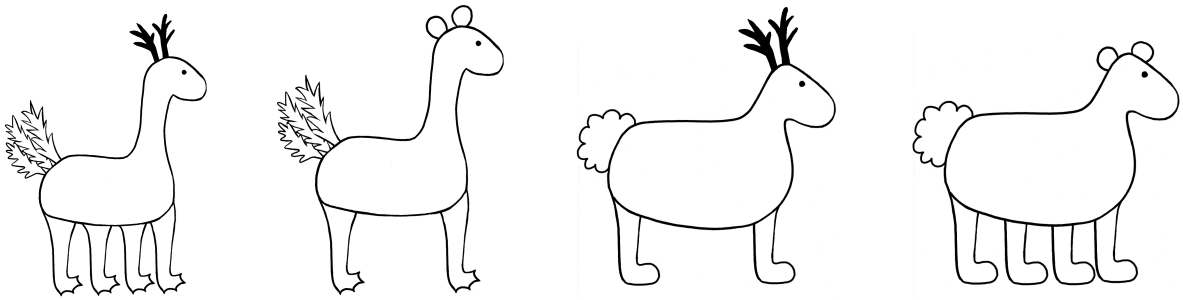
KEY:

VISUAL FEATURES

Body: 1=giraffe, 2=cow, 3=elephant
Tail: 1=feathered, 2=fluffy, 3=horse
Feet: 1=webbed, 2=clubbed, 3=hoofed
Ears: 1=antlers, 2=round ears, 3=human ears
Legs: 1=2 legs, 2=4 legs, 3=6 legs

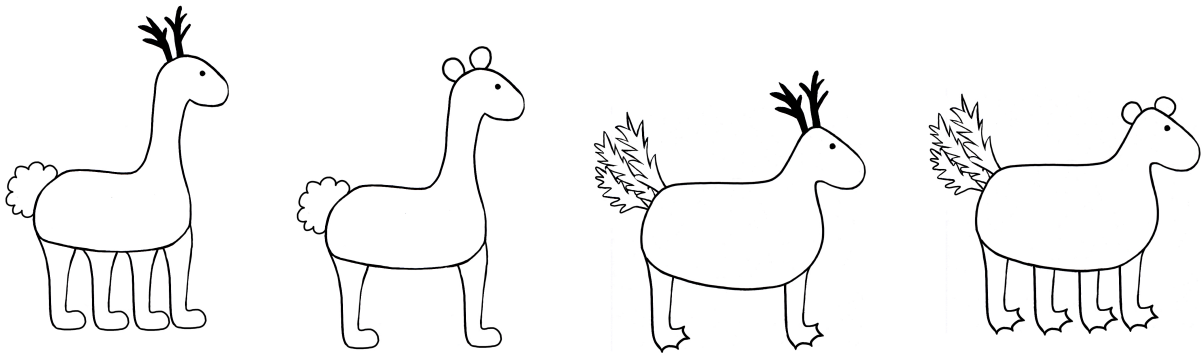
Figure 2.1. Visual Stimuli Images for Experiment 1.

GROUP A FAMILIARIZATION STIMULI



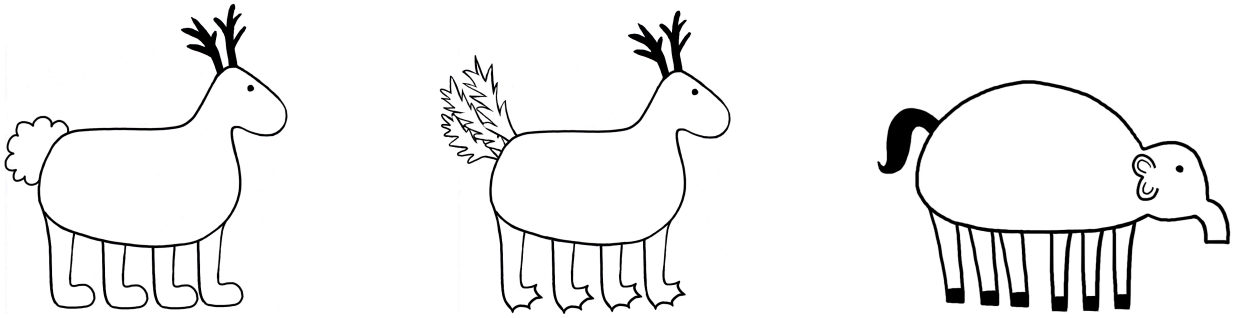
A **B** **C** **D**

GROUP B FAMILIARIZATION STIMULI



A **B** **C** **D**

TEST STIMULI

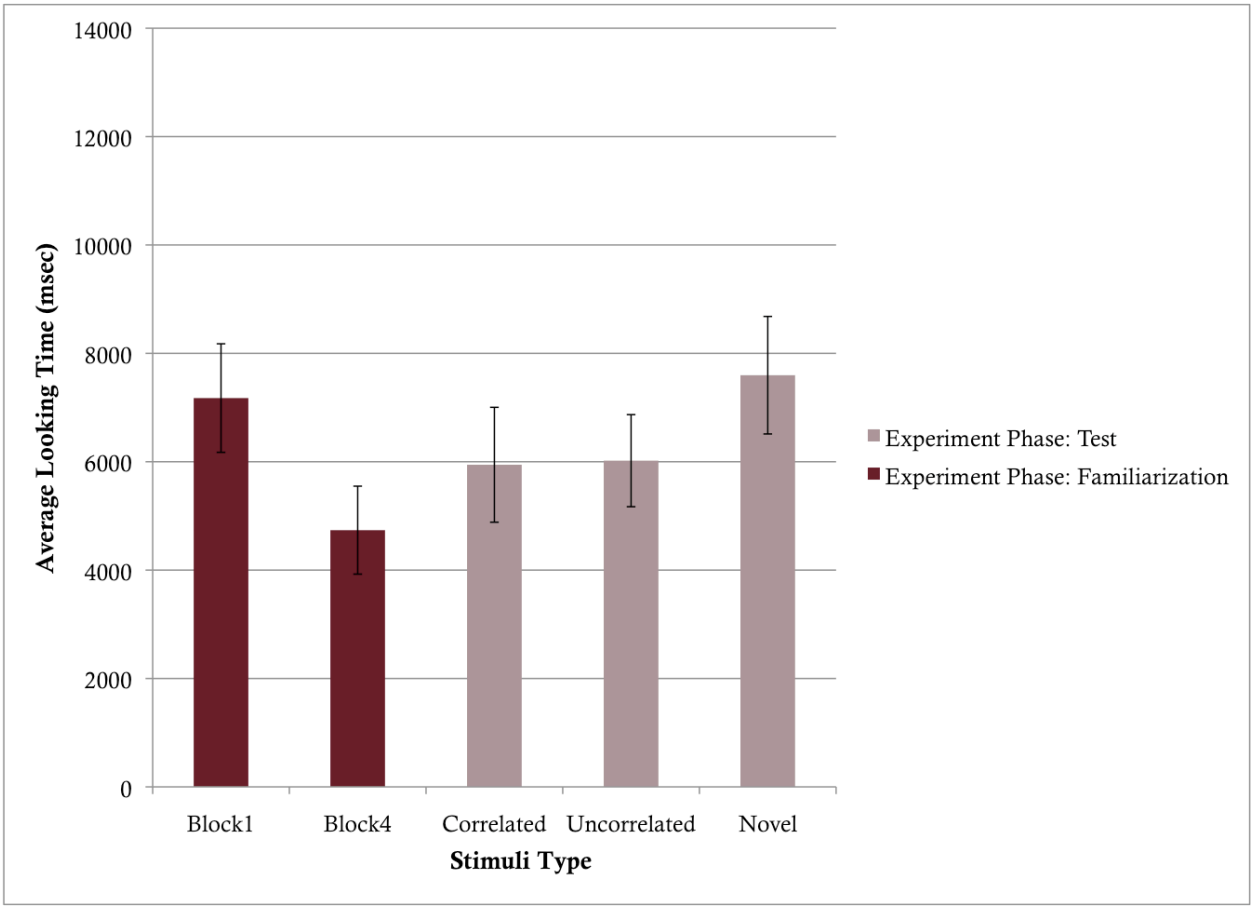


T1 **T2** **T3**

(CORRELATED GROUPA) **(UNCORRELATED GROUPA)** **(NOVEL)**

(UNCORRELATED GROUPB) **(CORRELATED GROUPB)**

Figure 2.2. Average Looking Time during Familiarization and Test Phases for Experiment 1.



3. Experiment 2: Audio-Visual Condition

Based on infants' failure to categorize the visual information in silence, the critical test of whether presenting a correlationally-based set of stimuli in a separate domain would aid in categorization remained legitimate. Experiment 2 investigated the effects of presenting correlation-based auditory (speech) with correlation-based animal stimuli, and whether this cross-modal correlational structure would facilitate categorization. If infants are able to form categories on the basis of correlated information in two domains, they should show different patterns of looking between the two critical test trials: the correlated animal-sound pair, and the uncorrelated animal-sound pair. If not, there should be no difference in looking between these two test trials, resulting in looking behavior very similar to Experiment 1.

3.1 Method

3.1.1 Participants

The participants in Experiment 2 were twenty-four infants (13 male, 11 female), with a mean age of 4 months, 13 days (ranging from 3 months, 25 days to 4 months, 25 days). Infants were recruited and contacted in the same manner as Experiment 1. In addition to the 24 infants included in the final analyses, data from 6 infants were not included due to fussiness (5), and failure to meet looking criterion (no looking during any test trial) (1).

3.1.2 Stimuli

The visual stimuli used in Experiment 2 were identical to those used in Experiment 1. As mentioned previously, because no significant interactions were found between the Group A and Group B animals and average looking times, only those animals from Group

A were used for the following study. Therefore, only one group of auditory (speech) stimuli was created for this (and subsequent) study.

The auditory stimuli were recorded using Praat 5.1 software in a sound-attenuated room by a monolingual Canadian-English female speaker. Stimuli included a set of consonant-vowel monosyllables recorded in an adult-directed voice, where each syllable was spoken within a framing sentence. Each syllable was then spliced from the audio file, and analyzed for pitch, duration, and amplitude consistency. The final audio files for the experiment each consisted of 12 repetitions of a single monosyllable (averaging between 450 and 550 ms), with an inter-stimulus interval between 1000 and 1100 ms. Each audio file was exactly 20 seconds in length, with an average amplitude of 70 dB.

The specific syllables chosen for this experiment were based on a feature correlation matrix (see Table 3.1) paralleling the matrix used for the visual stimuli in Experiment 1. A set of 5 attributes was chosen to classify these monosyllables: place of articulation of the consonant[4], vowel frontness/backness[5], vowel roundness[6], voicing of the consonant[7], and vowel height[8]. Each of these attributes could be realized in 3 ways (listed respectively): a bilabial[9], central[10], or velar[11] consonant (C-place); a front, mid, or back vowel (V-place); an

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[4] Place of articulation for consonants is the place in the vocal tract where a closure occurs between a moving articulator (like the tongue) with a stationary articulator (like the roof of the mouth).
[5] Vowel frontness/backness is the position of the tongue relative to the back of the mouth during the articulation of a vowel.
[6] Vowel roundness is defined by the shape of the lips (rounded or not) during vowel production.
[7] Consonant voicing is defined by whether the vocal cords vibrate during consonant production.
[8] Vowel height is the position of the tongue relative to the roof of the mouth during the articulation of a vowel.
[9] Bilabial consonants are produced at the lips, as in the sounds /p/ and /b/.
[10] Central consonants are formed in the middle of the mouth, as in the sounds /t/ and /s/.

unrounded, central, or rounded vowel (V-round); voiced, fricated[12], or voiceless consonant (C-voice); and high, middle, or low vowels (V-height). The features of the first three attributes listed here (place of articulation of consonant, frontness/backness of the vowel, and rounding of the vowel) were perfectly correlated within a category: these three attributes predicted category membership. The features of the last two attributes (voicing of the consonant and vowel height) could vary within a category: these two attributes were not predictive of category membership (see Table 3.1).

Based on these constraints, the specific auditory stimuli were created (see Table 3.1, Figure 3.1). Four familiarization syllables were constructed, with two syllables each in two categories. For example, syllable tokens A and B formed category 1, and syllable tokens C and D formed category 2: tokens A and B each had bilabial consonants, and front, unrounded vowels; whereas tokens C and D each had velar consonants, and back, rounded vowels. Within each category, however, each token had a different voicing of its consonant and a different height of its vowel: in category 1, token A had a voiced consonant and a low vowel, while token B had a voiceless consonant and a high vowel. In category 2, token C had voiced consonant and a high vowel, while token D had a voiceless consonant and a low vowel. These constraints formed the following monosyllabic tokens: token A was /be/, token B was /pi/, token C was /gu/, and token D was /ko/. Thus, /be/ and /pi/ formed Category 1 sounds, and /gu/ and /ko/ formed Category 2 sounds.

Relying again on a feature correlation matrix, one set of test stimuli was created. Two critical test syllables were constructed: one that was a member of a previously learned

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[11] Velar consonants are formed at the back of the mouth, as in the sounds /g/ and /k/.
[12] Fricative consonants are produced by forcing air through a constricted passage, as in the sounds /f/ or /s/.

category (shared the features of the predictive attributes), and one that was NOT a member of a previously learned category (shared some features with previously learned syllables, but not in the correct, predictive fashion). These 2 critical test syllables were composed in such a way that in Token T1 was *correlated* with one of the familiarization syllable categories, and Token T2 was *uncorrelated* with the familiarization syllable categories. Token T1 had a velar consonant, and a back, rounded vowel; the consonant was voiced, and the vowel was low, resulting in the syllable /go/. Token T2 had a velar consonant, a front, unrounded vowel; the consonant was voiced, and the vowel was low, resulting in the syllable /ge/. Finally, a completely novel syllable—that shared no features with any of the familiarization sounds—had a mid (alveolar) consonant, and a mid/central vowel; the consonant was a fricative, and the vowel was in the middle of the mouth, resulting in the consonant /sə/. This syllable was included as an ultimate test of novelty.

To create the audio-visual stimuli for Experiment 2, the visual stimuli of the animals from Experiment 1 (Group A only) were combined with the audio files of their corresponding syllables tokens. For example, visual token A was paired with audio token A, resulting in a 20 second audio-visual stimulus of a static animal and a repeating monosyllable. Visual token B was paired with audio token B, and so on for each familiarization and test stimulus. See Figure 3.1 for a visual representation of the 4 familiarization audio-visual pairs, as well as the 3 test audio-visual pairs (See Figure 3.1).

3.1.3 Apparatus and Procedure

The apparatus and procedure for Experiment 2 were identical to those used in Experiment 1. The only difference existed in the stimuli presented to the infants: each animal image was now presented with its appropriate syllable for each 20-second trial.

Sounds were presented to the infant using a pair of loudspeakers located behind the monitor, hidden from view by a black cardboard panel. Amplitude levels were adjusted so that the syllables were played at 68 dB.

Infants were randomly assigned to one of six experimental orders, as described in Experiment 1. The order of test trials was completely counterbalanced across these six orders.

3.2 Results

3.2.1 Familiarization Looking Times

As in Experiment 1, familiarization data and test trial data were analyzed separately. Average looking times during the familiarization trials were collapsed into two blocks for the first analysis: looking time during the first two trials were averaged into Block1, and the looking time during the last two trials were averaged into Block4 for all infants. In order to see if the infants showed a decrease in looking time across the familiarization period, a 2 (familiarization block) X 2 (sex) mixed ANOVA was conducted on the looking time data. Results showed no significant interaction between block and sex. However, there was an overall main effect of block, $F(1,22)=7.197$, $p=.014$, indicating that across both genders, infants showed longer looking during the first block (M=11569.17 ms, SD=4416.74) compared to the final block (M=8935.00 ms, SD=4423.98) (see Figure 3.2). Infants significantly decreased their looking to the familiarization animals from the first to the last familiarization block.

3.2.2 Test Trial Looking Times

To determine if any significant looking time differences existed between the test stimuli, the average looking times for each test trial were analyzed in a 3 (test trial) X 2 (sex)

mixed ANOVA. Results showed no significant interaction between test trial and sex. However, there was a significant main effect of test trial, $F(2,44)=11.309$, $p<.001$. Follow-up analyses indicated significantly different looking times between each test trial comparison: between the novel animal-sound (M=11110.83 ms, SD=5615.56) and the correlated animal-sound (M=8620.83 ms, SD=4726.10), $t(23)=2.912$, $p=.008$; between the novel animal-sound and the uncorrelated animal-sound (M=6850.83 ms, SD=3983.44), $t(23)=4.112$, $p<.001$; and most importantly, between the correlated animal-sound and the uncorrelated animal-sound, $t(23)=2.559$, $p=.018$ (see Figure 3.2). These findings indicated that infants looked longest to the novel animal-sound stimulus; however, infants also had longer looking times to the correlated animal-sound compared to the uncorrelated animal-sound, suggesting that these infants had become familiar to the audio-visual correlational structure during the familiarization period.

3.3 Discussion

Based on these results, four-month old infants showed evidence of forming audio-visual categories using correlation-based cross-modal information. Presenting correlation-based information simultaneously in both domains facilitated categorization, such that the infants looked longer to a correlated animal-sound token than to an uncorrelated animal-sound token. This pattern of looking indicated a sort of 'similarity' preference for the correlational structure to which the infants were familiarized in the first half of the study. Because both the correlated and uncorrelated audio-visual stimuli were new to the infants, but each contained similar features, any difference in looking between these two test items must be attributed to the underlying correlational structure found in these items. However,

these results did face alternative explanations that were considered in the final two experiments.

Table 3.1. Audio-Visual Stimuli Matrices for Experiment 2.

FAMILIARIZATION STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
A	1	1	1	1	2
B	1	1	1	2	1
C	2	2	2	1	1
D	2	2	2	2	2

	Auditory Features				
Token	C-place	V-place	V-round	C-voice	V-height
A /be/	1	1	1	1	2
B /pi/	1	1	1	2	1
C /gu/	2	2	2	1	1
D /ko/	2	2	2	2	2

TEST STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
T1	2	2	2	1	2
T2	2	1	1	1	2
T3	3	3	3	3	3

	Auditory Features				
Token	C-place	V-place	V-round	C-voice	V-height
T1 /go/	2	2	2	1	2
T2 /ge/	2	1	1	1	2
T3 /sə/	3	3	3	3	3

Table 3.1. Audio-Visual Stimuli Matrices for Experiment 2, continued.

KEY:

VISUAL FEATURES

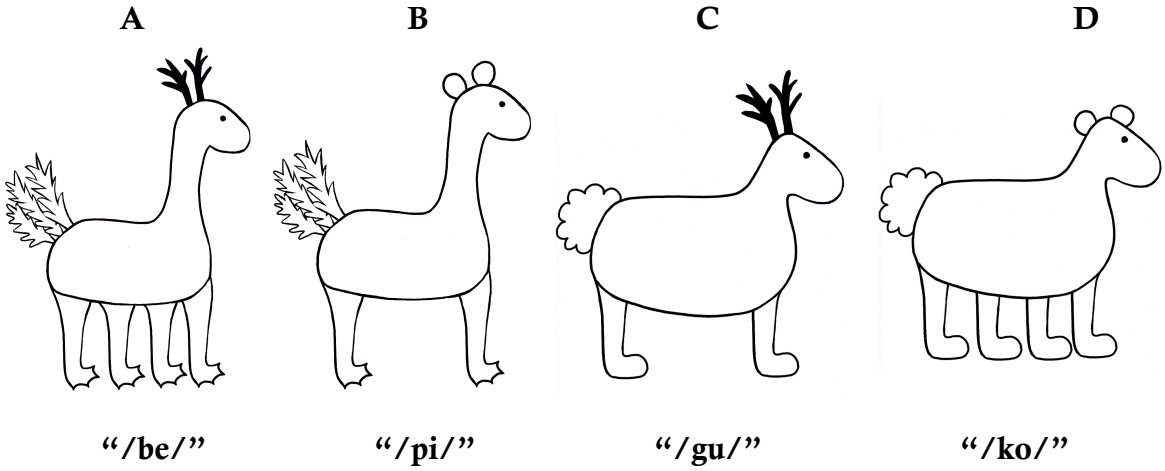
Body: 1=giraffe, 2=cow, 3=elephant
Tail: 1=feathered, 2=fluffy, 3=horse
Feet: 1=webbed, 2=clubbed, 3=hoofed
Ears: 1=antlers, 2=round ears, 3=human ears
Legs: 1=2 legs, 2=4 legs, 3=6 legs

AUDITORY FEATURES

C-place: 1=front consonant, 2= back consonant, 3=mid consonant
V-place: 1=front vowel, 2=back vowel, 3 = mid-mouth vowel
V-Round: 1= unrounded vowel, 2=rounded vowel, 3= mid-round vowel
C-voice: 1=voiced consonant, 2=voiceless consonant, 3=fricative consonant
V-height: 1= high vowel, 2=low vowel, 3=mid-height vowel

Figure 3.1. Audio-Visual Stimuli Images for Experiment 2.

FAMILIARIZATION STIMULI



TEST STIMULI

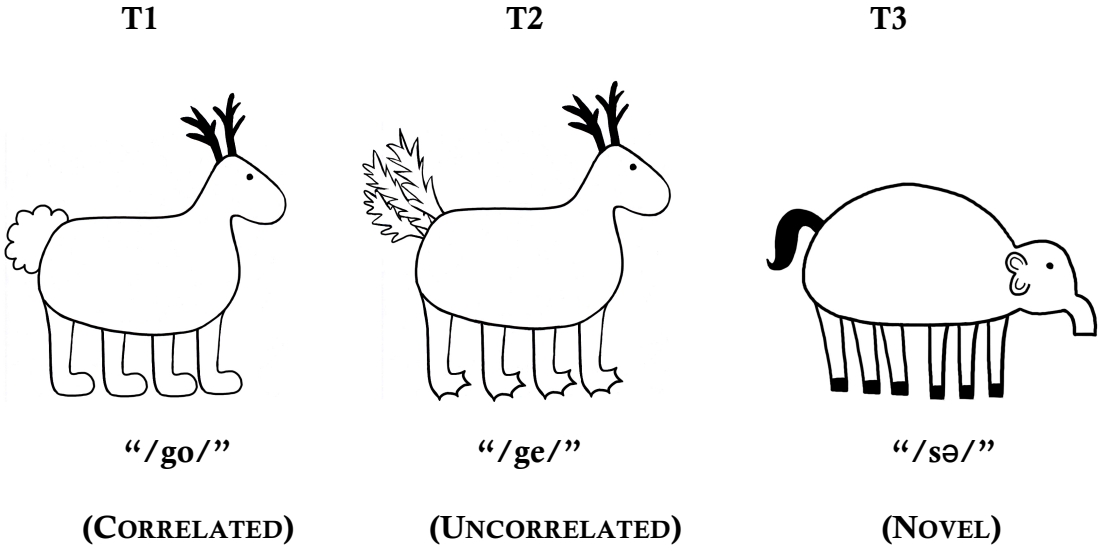
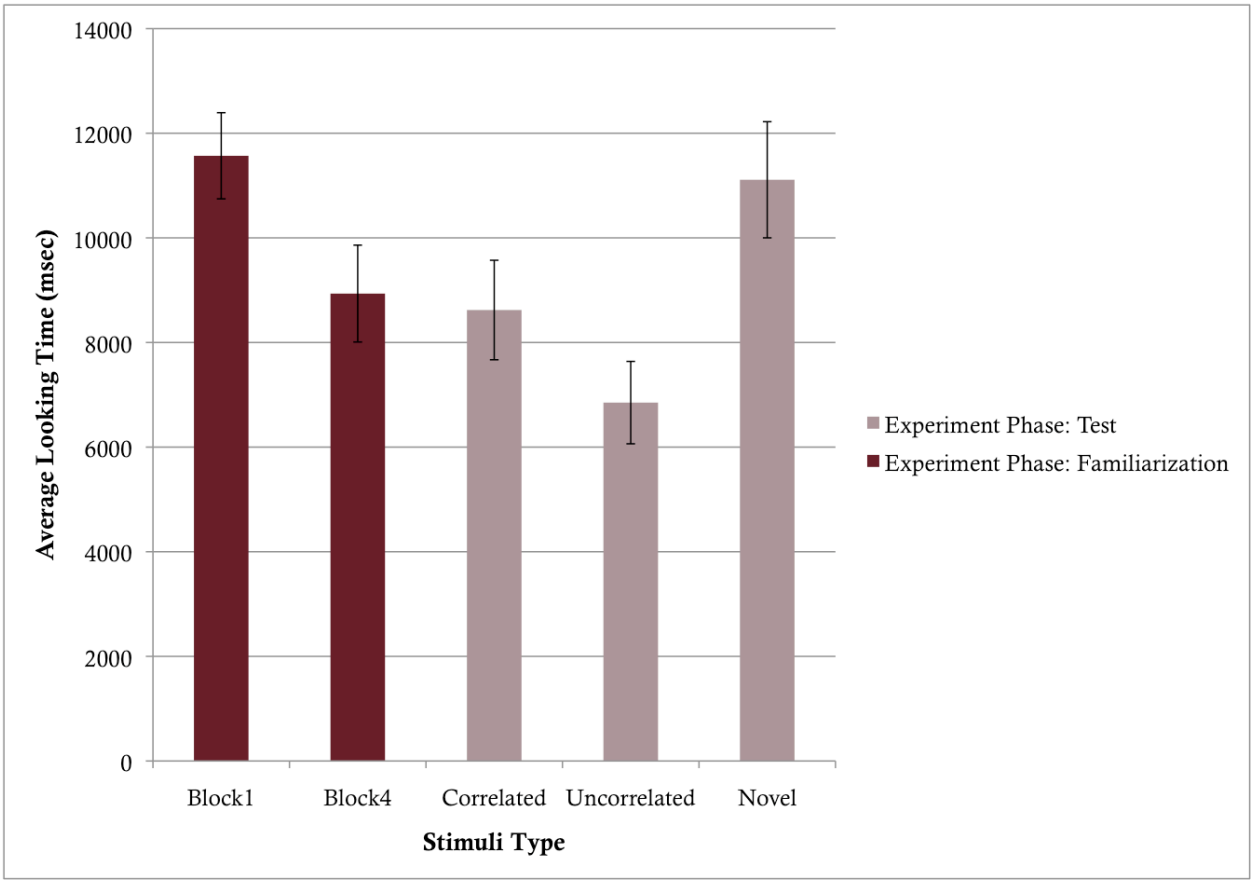


Figure 3.2. Average Looking Time during Familiarization and Test Phases for Experiment 2.



4. Experiment 3: Auditory-only Condition

Experiment 3 addressed the possibility that the infants in Experiment 2 were merely responding to, or had a preference for, the correlated sound more than the uncorrelated sound; this could have driven the pattern of looking. Further, if infants were somehow categorizing *only* the auditory information during the study, this could have also affected the test results from Experiment 2. Experiment 3 investigated whether infants could categorize the sound stimuli on their own (uni-modally) based only on the underlying correlational structure. If they could categorize the syllables in this way, they should show differences in looking behavior (similar to results from Experiment 2) during test. However, if infants are unable to detect the correlational structure of these syllables when presented uni-modally, they should have no preference for any syllable type at test.

4.1 Method

4.1.1 Participants

The participants in Experiment 3 were twenty-four infants (12 male, 12 female), with a mean age of 4 months, 18 days (ranging from 4 months, 4 days to 4 months, 30 days). Infants were recruited and contacted in the same manner as Experiments 1 and 2. In addition to the 24 infants included in the final analyses, data from 10 infants were not included due to fussiness (5), experimenter error (1), and failure to meet looking criterion (no looking during any test trial) (4).

4.1.2 Stimuli

The auditory stimuli used in Experiment 3 were identical to those used in Experiment 2; each syllable stream was the same, such that tokens A (/be/) and B (/pi) formed one category, and tokens C (/gu/) and D (/ko/) formed the second category. The

auditory test stimuli also remained the same, where token T1 was /go/, token T2 was /ge/, and token T3 was /sə/. In order to familiarize and test infants on their ability to form categories in the visual domain, an un-informative, non-object image was paired with each syllable stream; this gave the infants something to look at while the sounds were presented, allowing a measure of looking time to be collected. A static, unbounded checkerboard was paired with each of the syllable streams, resulting in 20-second trials. Each trial consisted of 12 repetitions of the syllable with the static checkerboard as the visual stimulus. Thus, the 4 familiarization and 3 test trials were created and used in Experiment 3 (see Table 4.1, Figure 4.1 for stimuli examples).

4.1.3 Apparatus and Procedure

The apparatus and procedure were identical to those implemented in Experiments 1 and 2. The only difference was in the visual stimuli, which consisted of replacing the static animal images with the static black-and-white checkerboard that was presented with each syllable stream.

Infants were randomly assigned to one of six experimental orders, as described in Experiment 1. The order of test trials was completely counterbalanced across these six orders.

4.2 Results

4.2.1 Familiarization Looking Times

Familiarization trial data and test trial data were analyzed separately. Average looking times during the familiarization trials were collapsed into two blocks for the first analysis: looking time during the first two trials were averaged into Block1, and the looking time during the last two trials were averaged into Block4 for all infants. In order to see if

these infants showed a decrease in looking time across the familiarization period, a 2 (block) X 2 (sex) mixed ANOVA was conducted on the looking time data. Results showed no significant interaction between block and sex. However, there was an overall main effect of block, $F(1,22)=30.681$, $p<.001$, indicating that across both genders, infants showed longer looking during the first block (M=9640.83 ms, SD=4233.39) compared to the final block (M=6512.92 ms, SD=4565.63) (see Figure 4.2). Infants significantly decreased their looking during the familiarization sounds from the first to the last familiarization block.

4.2.2 Test Trial Looking Times

To determine if any significant looking time differences existed between the test stimuli, the average looking times for each test trial were analyzed in a 3 (test trial) X 2 (sex) mixed ANOVA. Results showed no significant interaction between test trial and sex. Finally, there was no significant main effect of test trial, $F(2,44)=1.344$, $p=.271$. Infants showed no difference in looking behavior when the novel sounds (M=5365.00 ms, SD=4674.31), the correlated sounds (M=5090.00 ms, SD=4243.82), or the uncorrelated sounds (M=4617.50 ms, SD=4596.74) were presented at test (see Figure 4.2).

4.3 Discussion

The findings from Experiment 3 suggested that the correlational structure within the auditory stimuli was not detectable by four-month-old infants when presented unimodally. The infants responded equally to each syllable type at test (whether correlated, uncorrelated, or completely novel), indicating that the infants had not extracted the underlying structure during the familiarization phase. However, the fact that infants did not look longer during the novel sound stimulus requires some discussion. Although the phonetic features in the novel sound were completely novel to the infants, they treated this syllable in the same way

as the two syllables that were correlated and uncorrelated. This suggests that the infants not only failed to notice the *relationship* between the specific features during familiarization (and hence failed to categorize), but that they also failed to notice the particular phonetic features *themselves* in the syllables during familiarization. It seems that the infants encoded the task as one involving a series of unrelated syllables, not of two categories of syllables, and were therefore not surprised to hear *any* new syllables presented at the end of the study. Infants' inability to detect the correlational structure in the auditory stimuli rules out the possibility that the success seen in Experiment 2 stemmed from a response to the auditory categories. Thus, the results from Experiment 3 add to the argument that what the infants noticed in Experiment 2 was the correlational structure present in the *bi-modal* test stimuli, rather than a preference for any one sound during test. An issue that remained to be tested, however, was whether merely pairing visual and auditory stimuli in any way—not one that specifically satisfies the correlational structure of the sounds heard during the familiarization period—caused the difference in looking between the correlated and uncorrelated audio-visual test stimuli in Experiment 2.

Table 4.1. Auditory Stimuli Matrices for Experiment 3.

FAMILIARIZATION STIMULI

	AUDITORY FEATURES				
TOKEN	C-PLACE	V-PLACE	V-ROUND	C-VOICE	V-HEIGHT
A /be/	1	1	1	1	2
B /pi/	1	1	1	2	1
C /gu/	2	2	2	1	1
D /ko/	2	2	2	2	2

TEST STIMULI

	AUDITORY FEATURES				
TOKEN	C-PLACE	V-PLACE	V-ROUND	C-VOICE	V-HEIGHT
T1 /go/	2	2	2	1	2
T2 /ge/	2	1	1	1	2
T3 /sə/	3	3	3	3	3

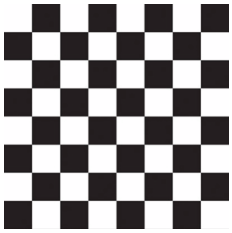
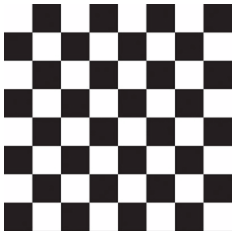
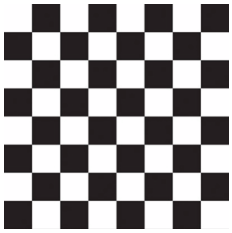
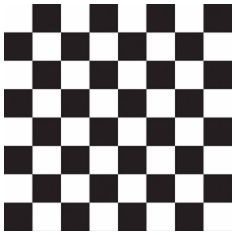
KEY:

AUDITORY FEATURES

C-place: 1=front consonant, 2= back consonant, 3=mid consonant
V-place: 1=front vowel, 2=back vowel, 3 = mid-mouth vowel
V-Round: 1= unrounded vowel, 2=rounded vowel, 3= mid-round vowel
C-voice: 1=voiced consonant, 2=voiceless consonant, 3=fricative consonant
V-height: 1= high vowel, 2=low vowel, 3=mid-height vowel

Figure 4.1. Auditory Stimuli Images for Experiment 3.

FAMILIARIZATION STIMULI

A	B	C	D
			
"/be/"	**"/pi/"**	**"/gu/"**	**"/ko/"**

TEST STIMULI

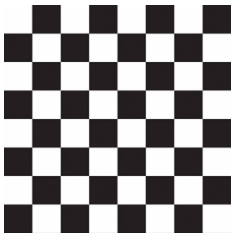
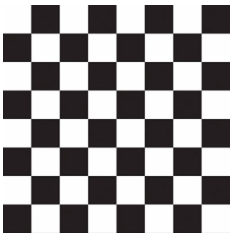
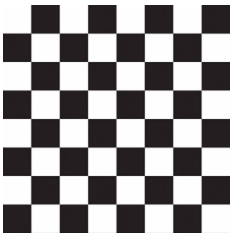
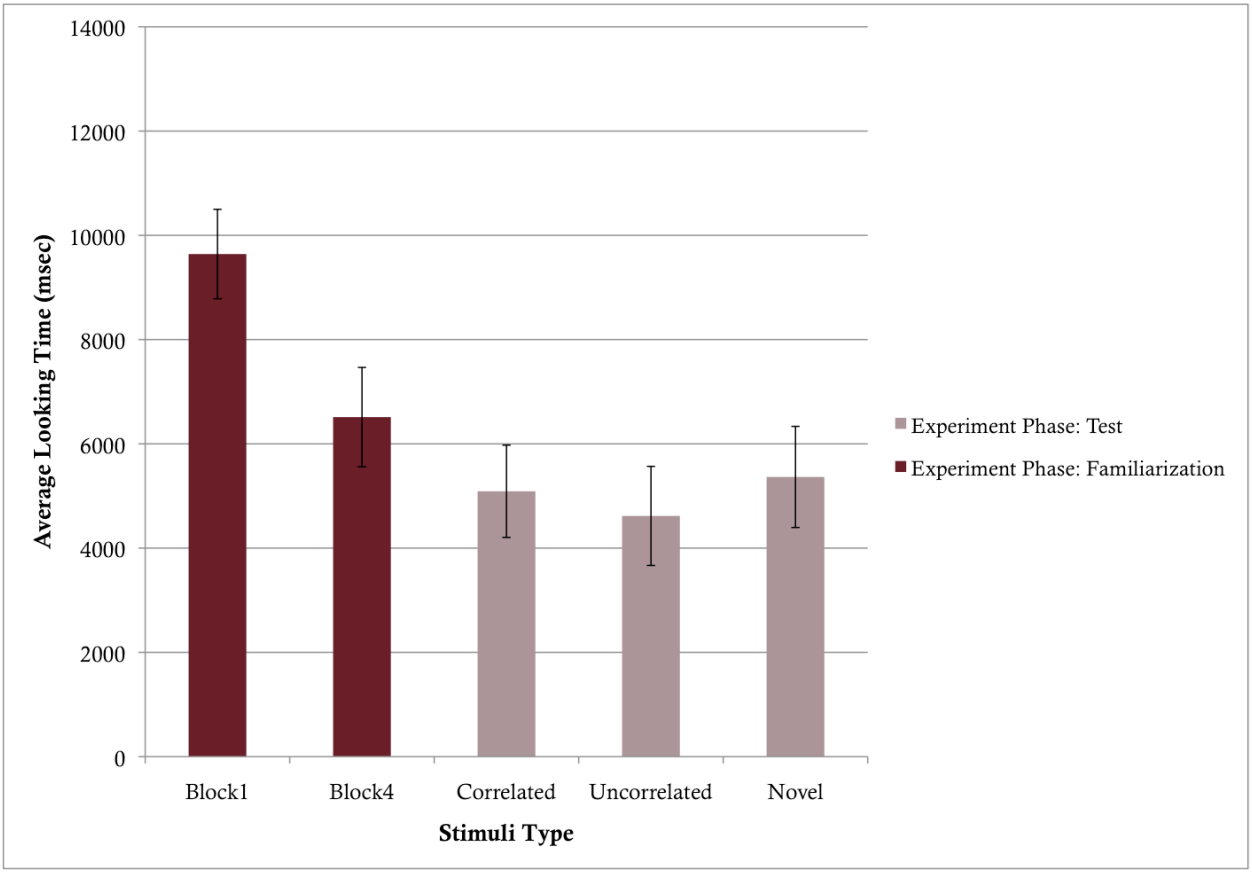
T1	T2	T3
		
"/go/"	**"/ge/"**	**"/sə/"**
(CORRELATED)	**(UNCORRELATED)**	**(NOVEL)**

Figure 4.2. Average Looking Time during Familiarization and Test Phases for Experiment 3.



5. Experiment 4: Audio-Visual Control Condition

Experiment 4 addressed the possibility that the results from Experiment 2 were driven by the infants' preference for hearing *any* sound paired with the correlated visual test stimulus, not one that specifically satisfied the correlation structure of the sounds heard during the familiarization period. In order to test this possibility, Experiment 4 was conducted in the exact manner as Experiment 2 (with the same audio-visual correlation structure to be learned), with slight—but not trivial—changes in the test stimuli. The test stimuli that were adjusted in Experiment 4 were the correlated and uncorrelated audio-visual test items (the two critical test stimuli). To determine whether pairing *either* critical sound with *either* critical picture would affect test performance, the two adjusted test stimuli in Experiment 4 involved a mis-match between the auditory and visual stimuli; the *correlated* test animal (from Experiment 2) was presented with the *uncorrelated* test sound (from Experiment 2), and the *uncorrelated* test animal (from Experiment 2) was presented with the *correlated* test sound (from Experiment 2). These mis-matched audio-visual test stimuli allowed a test of whether the correlational structure had to remain consistent between the two domains to cause a preference for the correlated animal (seen in Experiment 2). If the correlational structure must remain consistent between auditory and visual stimuli at test, the infants should show no difference in looking between the two mis-matched test items.

5.1 Method

5.1.1 Participants

The participants in Experiment 4 were twenty-four infants (12 male, 12 female), with a mean age of 4 months, 21 days (ranging from 4 months, 0 days to 4 months, 29 days). Infants were recruited and contacted in the same manner as Experiments 1, 2, and 3. In

addition to the 24 infants included in the final analyses, data from 2 infants were not included due to fussiness.

5.1.2 Stimuli

The stimuli used in Experiment 4 were identical to those used in Experiment 2, with slight, important alterations in the test stimuli. The audio-visual animal-sound pairs used in the familiarization phase in Experiment 2 were again used in Experiment 4. The only differences in stimuli existed in the test trial tokens T1 and T2. These tokens consisted of a *mismatch* between the appropriate animal-sound combinations from Experiment 2. Specifically, the audio-visual token T1 was the *correlated* animal test stimulus from Experiment 2 (a cow shaped body, a fluffy tail, clubbed feet, antlered ears, and four legs), paired with the *uncorrelated* sound test stimulus from Experiments 2 and 3 (the syllable /ge/). The audio-visual token T2 was the *uncorrelated* animal test stimulus from Experiment 2 (a cow-shaped body, a feathered tail, webbed feet, antlered ears, and four legs), paired with the *correlated* sound from Experiments 2 and 3 (the syllable /go/). The novel animal-sound pair was the same stimulus as used in Experiment 2. See Table 5.1, Figure 5.1 for images of animal-sound pairs for Experiment 4.

5.1.3 Apparatus and Procedure

The apparatus and procedure were identical to those used in Experiments 1, 2, and 3, with the previously mentioned changes in the critical audio-visual test tokens. Infants were randomly assigned to one of six experimental orders, as described in Experiment 1. The order of test trials was completely counterbalanced across these six orders.

5.2 Results

5.2.1 Familiarization Looking Times

Familiarization trial data and test trial data were analyzed separately. Average looking times during the familiarization trials were analyzed using two blocks in this analysis: looking time during the first two trials were averaged into Block1, and the looking time during the last two trials were averaged into Block4 for all infants. In order to determine whether these infants showed a decrease in looking time across the familiarization period, a 2 (block) X 2 (sex) mixed ANOVA was conducted on the looking time data. Results showed no significant interaction between block and sex. However, there was an overall main effect of block, $F(1,22)=6.749$ $p=.016$, indicating that across both genders, infants showed longer looking during the first block ($M=10600.00$ ms, $SD=4782.12$) compared to the last block ($M=7775.83$ ms, $SD=5309.57$) of familiarization (see Figure 5.2). Infants significantly decreased their looking to the familiarization animal-sound pairs from the first to the last block.

5.2.2 Test Trial Looking Times

To determine if any significant looking time differences existed between the test stimuli, the average looking times for each test trial were analyzed in a 3 (test trial) X 2 (sex) mixed ANOVA. Results showed no significant interaction between test trial and sex. However, there was a significant main effect of test trial, $F(2,44)=8.868$, $p=.001$. Follow-up analyses indicated significant looking time differences were found between the novel animal-sound ($M=10376.67$ ms, $SD=4663.07$) and the correlated animal-uncorrelated sound stimulus, $t(23)=4.081$, $p<.001$; and between the novel animal-sound and the uncorrelated animal-correlated sound stimulus, $t(23)=2.687$, $p=.013$, indicating longer looking times to

the novel animal-sound stimulus than to either of the other critical test stimuli. Most importantly, no significantly different looking times were found between the correlated animal-uncorrelated sound (M=6882.50 ms, SD=3514.34) and the uncorrelated animal-correlated sound (M=7977.50 ms, SD=4672.40), $t(23)=1.395$, $p=.176$ (see Figure 5.2).

5.3 Discussion

The results from Experiment 4 indicated that infants increased their looking time at test only to the completely novel animal, showing no preference between the two mis-matched critical test items. These findings suggest that the pattern of results found in Experiment 2—where the infants showed longer looking to the correlated animal-sound test item compared to the uncorrelated animal-sound item—were due to the consistent correlational structure being maintained across both vision and audition, rather than to some unspecified (general) preference for the picture-sound pair. By mismatching the correlated picture with the uncorrelated sound, and the uncorrelated picture with the correlated sound, the current study investigated of the importance of maintaining the correlational structure across domains in category formation.

Table 5.1. Audio-Visual Stimuli Matrices for Experiment 4.

FAMILIARIZATION STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
A	1	1	1	1	2
B	1	1	1	2	1
C	2	2	2	1	1
D	2	2	2	2	2

	Auditory Features				
Token	C-place	V-place	V-round	C-voice	V-height
A /be/	1	1	1	1	2
B /pi/	1	1	1	2	1
C /gu/	2	2	2	1	1
D /ko/	2	2	2	2	2

TEST STIMULI

	Visual Features				
Token	Body	Tail	Feet	Ears	Legs
T1	*2*	*2*	*2*	*1*	*2*
T2	*2*	*1*	*1*	*1*	*2*
T3	3	3	3	3	3

	Auditory Features				
Token	C-place	V-place	V-round	C-voice	V-height
T1 /ge/	*2*	*1*	*1*	*1*	*2*
T2 /go/	*2*	*2*	*2*	*1*	*2*
T3 /sə/	3	3	3	3	3

Table 5.1. Audio-Visual Stimuli Matrices for Experiment 4, continued.

KEY:

VISUAL FEATURES

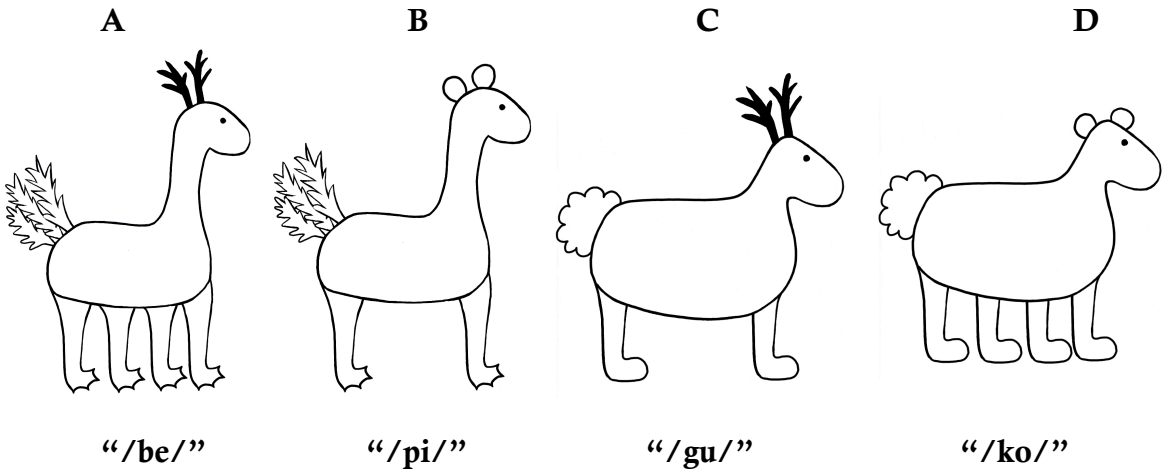
Body: 1=giraffe, 2=cow, 3=elephant
Tail: 1=feathered, 2=fluffy, 3=horse
Feet: 1=webbed, 2=clubbed, 3=hoofed
Ears: 1=antlers, 2=round ears, 3=human ears
Legs: 1=2 legs, 2=4 legs, 3=6 legs

AUDITORY FEATURES

C-place: 1=front consonant, 2= back consonant, 3=mid consonant
V-place: 1=front vowel, 2=back vowel, 3 = mid-mouth vowel
V-Round: 1= unrounded vowel, 2=rounded vowel, 3= mid-round vowel
C-voice: 1=voiced consonant, 2=voiceless consonant, 3=fricative consonant
V-height: 1= high vowel, 2=low vowel, 3=mid-height vowel

Figure 5.1. Audio-Visual Stimuli Images for Experiment 4.

FAMILIARIZATION STIMULI



TEST STIMULI

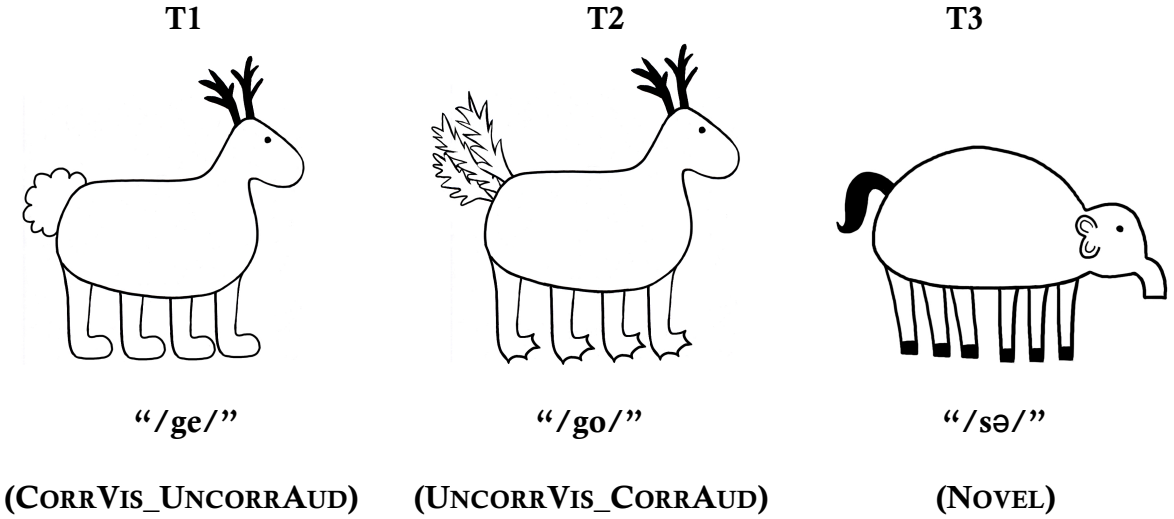
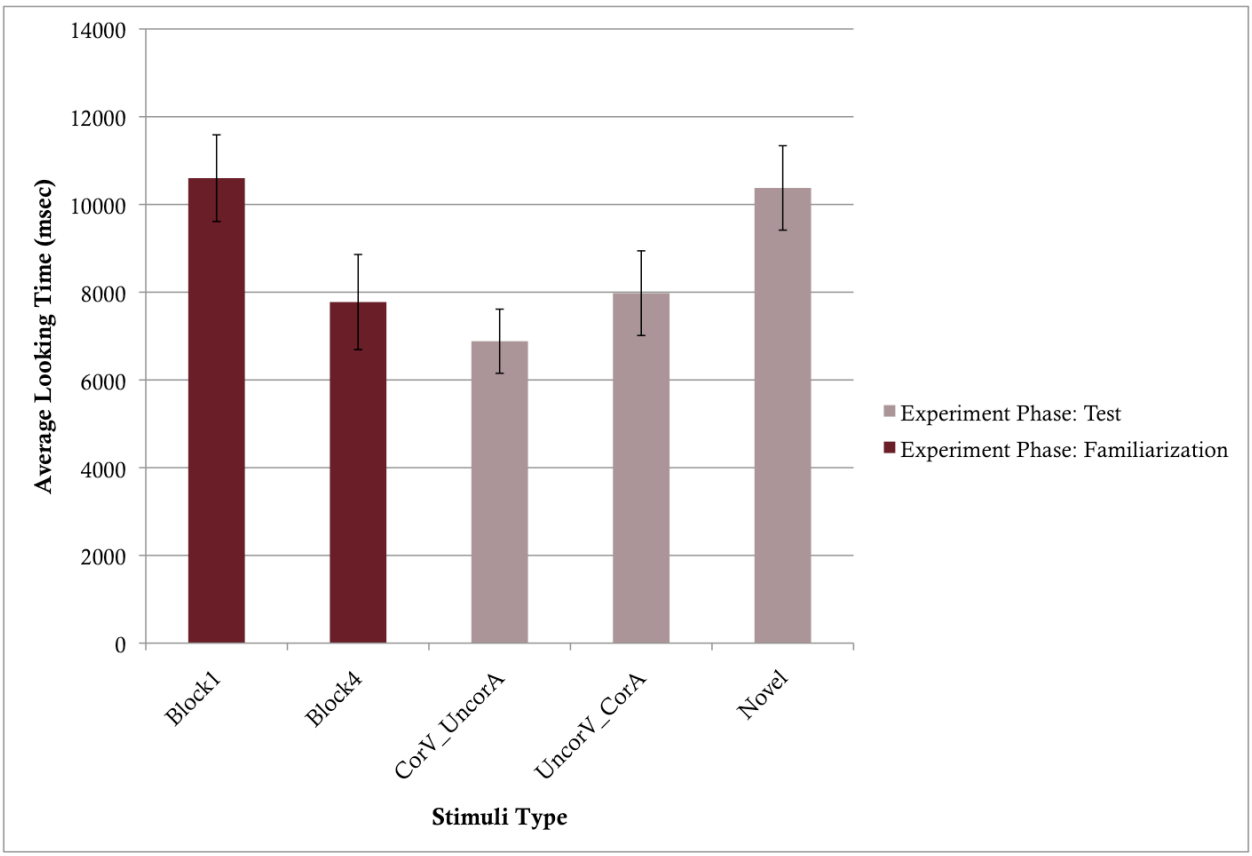


Figure 5.2. Average Looking Time during Familiarization and Test Phases for Experiment 4.



6. General Discussion

A fundamental task facing a developing infant is the ability to categorize incoming sensory input in a meaningful way. Although interest in this topic of research has received much attention within the past few decades, the nature of categorization across information presented simultaneously in two sensory domains has been largely unexplored. The goal of this thesis was to test the hypothesis that young infants are not only able to handle significant variation in their environments, but that they may also be detecting and using such variation across two domains in order to form categories. In a series of four experiments, I found that four-month-old infants can learn cross-modal categories defined by an underlying correlational structure. In contrast to the conclusions drawn by Younger and Cohen (1986), these findings suggest that infants are sensitive to correlational regularities well before 10 months of age; however, the regularities must be presented in two domains.

6.1 Detecting Cross-modal Correlations In Categorization

The findings from Experiment 1 provided a replication of the original findings of Younger and Cohen (1983) on visual categorization, such that four-month-old infants were sensitive only to the specific features of the animals presented in silence, rather than to the underlying correlational structure. The infants showed marginally longer looking times to the completely novel test stimulus, but not to either the correlated or uncorrelated test stimulus. Thus, as in the original Younger and Cohen (1983) work, they showed no difference in looking between the two critical test stimuli. That the findings were only marginally significant in the hypothesized direction was not a large concern; Experiment 1 was conducted to be sure four-month-old infants could *not* form visual categories in silence.

Thus, the predicted pattern found in Younger and Cohen (1983) was seen in these findings: when using the same general methodology with a different mode of data collection (an eye-tracking system), four-month-olds are unable to detect correlations of attributes in visual categories.

Similar results were found in Experiment 3, which investigated whether four-month-old infants would categorize monosyllables based on a correlational-structure in the auditory domain. Results showed that at test, infants did not look longer to any of the test stimuli, showing no preference between the novel, correlated, and uncorrelated test syllables. This pattern differs slightly from the findings in Experiment 1, such that there was no novelty preference for the novel test syllable (as there was for the novel animal stimulus in Experiment 1). These findings suggest that infants at this age not only failed to detect the underlying correlational structure in the auditory information, but that they also failed to notice the individual features of the sounds. Given the findings that infants may best represent speech sounds at a syllable-level (Bertoncini *et al.,* 1988; Eimas, 1999; Jusczyk & Derrah, 1988), the findings from Experiment 3 aren't surprising. The task in Experiment 3 was to learn that each set of two syllables formed a category, based on the correlational structure of their phonetic features. The fact that infants failed suggests that individual phonetic features were not encoded by the infants during the familiarization phase; infants were responding to the sounds at the whole syllable level. Therefore, at test, when the correlated, uncorrelated, and novel syllables were introduced, infants continued to respond to the stimuli at a syllable-level, rendering each type of test stimulus equally novel, and hence no more different than any other. These results showed that without accompanying

visual stimuli, four-month-old infants failed to categorize auditory (linguistic) information on the basis of correlated information among phonetic features.

In Experiment 2, I tested the critical question of whether presenting cross-modal correlations would facilitate categorization in four-month-olds. Results showed that when correlation-based visual information was paired with correlation-based auditory information, infants did detect the underlying structure. The four-month-olds looked longest to the novel animal-sound stimulus at test, but also showed longer looking to the correlated animal-sound pair compared to the uncorrelated animal-sound pair. Considering the results from Experiment 1 and Experiment 3, where the visual and the auditory categories went undetected by four-month-olds when presented uni-modally, Experiment 2 provides evidence of cross-modal, correlation-based category learning. These findings support the hypothesis that presenting four-month-old infants with correlated information in two domains facilitates categorization. Importantly, these infants are 6 months younger than the infants who succeeded in Younger and Cohen's (1983, 1986) work, challenging the idea that the ability to detect correlations is one that develops only toward the end of the first year of life. Furthermore, the four-month-old infants in Experiment 2 learned a *cross-modal* category structure; in this design, infants were exposed to a complex category structure in two domains, in which a large amount of information (and variation) was presented to the infants. In most cases, increasing variation in the input seems like it would hinder infants' ability to learn. However, given that infants are able to deal with and use variation in a single domain in various learning situations (Marcus *et al.,* 1999; Rost & McMurray, 2009; Saffran *et al.,* 1996), increasing variability is not necessarily a hindrance to learning for infants (see also Rovee-Collier & Giles, 2010). While dealing with variation in a

single domain is typically not seen in infancy until 7 or 8 months of age, Experiment 2 provides evidence that dealing with variation across two domains (with an underlying correlational structure) is shown by infants at 4 months of age. In Experiment 2, infants showed a notable ability to deal with a considerable amount of variation across two perceptual domains, detecting and using the underlying structure in order to learn cross-modal categories.

These findings require some discussion: in the pattern of looking shown by infants in Experiment 2, there seems to be both a novelty preference (for the novel test stimulus), *and* a 'similarity' preference for one of the test stimuli (for the correlated over the uncorrelated test stimulus). This pattern of results has also been seen in previous work on the type of learning exhibited by infants learning correlation-based structures. Shultz and Cohen (2004) discussed a replication of Younger and Cohen (1986), where 10-month-olds were exposed to categories of animals based on three correlated attributes (rather than five correlated attributes used in the current research). Instead of using fixed-length familiarization trials, they habituated the infants to the two visual categories until the infants' looking time decreased to a certain criterion, and then presented the three test trials. When data were divided into habituators and non-habituators, results showed that the habituators looked longest to the uncorrelated and the novel stimulus, while the non-habituators looked longest to the correlated and the novel stimulus. Cohen and colleagues argued that the non-habituators' preference for correlated test stimuli indicates shallower learning compared to a preference for the uncorrelated test stimuli. This line of reasoning would suggest that the infants in Experiment 2 showed shallow learning of the cross-modal correlations. Because the current set of experiments implemented a familiarization rather than a habituation

design, infants were not required to decrease their looking to a certain criterion before the test phase began; the infants in Experiment 2 who were familiarized to the stimuli can be compared to the non-habituator 10-month-olds described above. Further research is necessary to determine if habituating (rather than familiarizing) four-month-olds would result in a preference for the uncorrelated over the correlated stimulus at test. However, even with the fixed-length familiarization trials, it seems that infants at four-months of age are detecting the relationship between the attributes when the correlation-based information is presented cross-modally.

Experiment 4 investigated whether the results from Experiment 2 were driven by a general improvement in the ability to detect the correlations in the visual features of the test animal stimuli in the presence of *any* sound. In this experiment, the infants did not have a preference for the correlated animal stimulus when it was paired with the uncorrelated sound compared to the uncorrelated animal stimulus paired with the correlated sound. When the cross-modal correlations learned during the familiarization phase were violated at test, infants responded equally to the mis-matched critical stimuli. These results suggest that the cross-modal correlations must remain consistent across domains in order for the infants to respond to a correlated test stimulus, and thus to provide evidence of having learned the cross-modal correlational structure.

Taken together, the results from these four experiments provide the first evidence of young infants' categorization of cross-modal correlation-based information. In order to succeed in this task—and show the pattern of behavior found in Experiment 2—infants must have detected the underlying correlations in both the visual and the auditory domains. Each audio-visual test stimulus was new to the infant; while the completely novel animal-

sound stimulus was composed of completely new features, the correlated and uncorrelated animal-sound stimuli were both composed of new *combinations* of previously experienced features. However, in the case of the correlated test stimulus, the correlation remained consistent among the three defining features in each sensory domain and contained a new value of one of the two non-defining features, whereas for the un-correlated test stimulus, the defining correlation was violated. Any difference in looking between the correlated and uncorrelated items thus must be attributable to experience with—and detection of—the underlying correlations from the familiarization phase.

6.2 Correlation Detection and Category Learning

In this categorization tasks implemented in Experiments 1 through 4, the attributes and features that define the categories in both the visual and auditory domains are arbitrary and highly controlled. While natural categories arguably have some underlying correlation among their attributes (as described by Rosch, 1978), the categories created and used in these experiments were artificially created in order to test the hypothesis that young infants are sensitive to cross-modal correlations of attributes. This research can inform how infants may initially go about learning categories. The fact that infants do seem to be sensitive to correlational information across two domains from a very young age suggests that it may be a tool with which they acquire categories.

As described by Mervis and Rosch (1981), being sensitive to an invariant structure across instances is important to learning a category. Here, the invariant structure was defined by the correlations of attributes in the domains of vision and speech. To succeed in the task, infants must have abstracted the structure or the regularities across the audio-visual tokens. Interestingly, these underlying structures were not detected when the information

was presented uni-modally; further, in the auditory-only condition, the infants were not even sensitive to the specific features in the syllables. Yet, when presented together, infants abstracted the underlying structure across the two domains.

The mechanism by which infants abstract the correlational information across these two domains requires further investigation. One possibility is that some kind of transfer of information may be occurring between audition and vision, such that the underlying correlational structure in one domain becomes accessible only when a similar underlying structure is present in another domain; perceptual scaffolding may be occurring between the information in two domains. Research on the transfer of information in infancy has shown that perceptual grouping can be transferred across organizing principles. Infants utilize perceptual organizing principles from a young age to help them group and organize parts of their perceptual experiences into holistic percepts; these include the Gestalt principles such as similarity, continuation, closure, and proximity (Spelke, 1982). Although some organizing principles are not functional for infants until 6 or 7 months of age—such as form similarity—many are functional at 3 or 4 months of age—such as proximity, lightness similarity, and connectedness (Quinn, Bhatt, & Hayden, 2008). Quinn and Bhatt (2009) showed that when 3-month-old infants were trained to organize columns or rows of elements via lightness similarity, the infants could transfer the grouping principle to a new group of elements via form similarity. If perceptual scaffolding can occur *across* organizing principles, perhaps transfer of correlational information may have occurred between the visual and auditory domains in Experiment 2 in this thesis. This possibility seems unlikely, as there was no evidence that infants could categorize in either unimodal domain alone. For

transfer to have occurred, one would expect categorization in one of the modes, and only in the other modality after initial exposure to the easier modality.

In order to further investigate how the information across the domains of vision and audition are linked in this sort of categorization task, additional studies must be conducted. I have argued that the cross-modal relationship between the correlated information is bi-directional: the visual correlated information scaffolds the detection of the auditory correlated information *at the same time* as the auditory correlated information scaffolds the detection of the visual correlated information. Yet, another possibility is that the relationship may be more directional, with success being achieved by detection of the correlated structure in only one of the domains. The presence of the correlated *auditory* information may be helping the infants to detect the *visual* correlated information, hence helping them form the *visual* categories; alternatively, the presence of the correlated *visual* information may be helping the infants to detect the *auditory* correlated information, hence helping them form the *auditory* categories. The current set of studies cannot attest to either of these alternative, directional explanations. In order to test these possibilities, two extensions of Experiment 2 would be necessary, where the first extension would have the test phase occurring in silence (extension A), and the second extension would include a test phase just using auditory stimuli (extension B). In extension A, if the correlated *auditory* information facilitated the *visual* category formation, infants should show the same patterns of looking as found in Experiment 2 during a test phase in which they experience only the visual test stimuli. In extension B, if the correlated *visual* information facilitated the *auditory* category formation, infants should show the same patterns of looking as found in Experiment 2 during a test phase in which they experience only the auditory test stimuli. If, however, the

categories that infants formed in Experiment 2 are truly cross-modal in nature, then infants should show no evidence of categorization at test during either extension A or extension B (as in the pattern of results found in Experiment 4); this would suggest a bi-directional cross-modal relationship. These two follow-up studies are necessary to more fully determine how infants are using the cross-modal information in this categorization task.

6.3 Arbitrary Cross-modal Associations?

While the mechanism driving the cross-modal sensitivity to correlational information is largely unknown, amodal relations such as temporal synchrony cannot explain these results; although they co-occurred, the visual information and the auditory information were not presented in synchrony. Thus, the arbitrary relationship between the auditory and visual information, in this case, could not have been learned because of an *amodal* regularity such as temporal synchrony (Bahrick & Lickliter, 2000). Instead, the mere presence of *correlational* regularities within the two domains may have allowed the infants to learn the cross-modal categories. In Experiment 2, infants showed evidence of picking up arbitrary (yet correlational) regularities within the visual and auditory domains.

The 'arbitrariness' of the regularities within each domain requires some explanation. The fact that syllables were paired with line-drawn animals renders this relationship 'arbitrary'; just like the case of a color of an animal and the kind of sound it makes, there is no overlapping or redundant information (no amodal regularity) across the senses (Bahrick, 1992). There is, however, one way in which the specific design of the audio-visual pairings in the study—and the pairing of particular syllables/sounds with certain kinds of animals—may not have been so arbitrary. The syllables chosen for this study were based on a series of five attributes, including place of articulation and voicing of the consonant, and place,

height, and roundness of the vowel. Based on the correlation matrix used to create the auditory stimuli (which was parallel to the Group A visual correlation matrix), the syllables /be/, /pi/, /gu/, and /ko/ were chosen as the familiarization stimuli. Further, the sounds /be/ and /pi/ were paired with the animals that had giraffe body shapes, while the sounds /gu/ and /ko/ were paired with the animals that had cow body shapes. Research on the relationship between vowel sounds and visual object shapes has suggested that both children and adults match words with rounded vowels to objects with rounder shapes, and words with unrounded vowels to objects with pointed shapes (Maurer *et al.,* 2006). In the current experiments, syllables with unrounded vowels /be/ and /pi/ were paired with animals with long necks, while the syllables with rounded vowels /gu/ and /ko/ were paired with animals that were rounder in body shape. These potential sound-shape correspondences may have made the relationship between the auditory and visual information easier to learn; further research is necessary to determine this.

However, this sound-shape correspondence could not have been the only information learned by the infants; based on the findings of Experiments 2 and 4, infants must have detected the correlational information. In the test phase of Experiment 4, when the correlated sound (/go/) was mis-paired with the uncorrelated animal (an animal with a cow body), and the uncorrelated sound (/ge/) was mis-paired with the correlated animal (a different animal with a cow body), infants showed no difference in looking between these 2 test stimuli. If infants had simply learned that 'round vowels go with cow bodies' and 'unrounded vowels go with giraffe bodies', infants in Experiment 4 should have had a preference for one of the critical mis-paired audio-visual test stimuli over the other.

However, only in Experiment 2 did infants show longer looking to the (correctly paired) correlated animal-sound pair over the uncorrelated animal-sound pair.

6.4 Audio-visual Cross-modal Correlations: Linguistic or Auditory?

While the current line of research is the first of its kind showing cross-modal categorization based on correlations, many questions remain concerning the nature of these cross-modal relationships. The auditory and visual stimuli used in these experiments were highly controlled, and were of very limited kinds. Specifically, speech stimuli in the form of syllables were chosen as the auditory stimuli, and the syllables were constructed using an underlying structure of phonetic features. However, if the results from these experiments are due to the infants' sensitivity to an underlying, cross-modal correlational structure, auditory stimuli of other kinds that satisfy an underlying structure should also produce this pattern of results. An important question for future research concerns whether the auditory information must be linguistic in nature (as in the current research), or whether auditory stimuli of any kind (such as non-linguistic tones) could be categorized with visual information. Such research would not only help inform the nature of cross-modal correlation detection in infants, but could also shed light on the origins of word learning in infancy. Infants learn to associate words and objects starting around the first year of life (Golinkoff *et al.,* 1994; Schafer *et al.,* 1999; Werker & Curtin, 2005; Woodward *et al.,* 1994), but there are claims that a privileged relationship between linguistic and visual information begins much earlier. Waxman and colleagues propose that labels act as 'invitations' to form categories, highlighting the commonalities of the exemplars within a category, for infants as young as 3 months of age (Ferry *et al.*, 2010; Waxman & Gelman, 2009). If words are privileged, then cross-modal category learning might only be effective when speech sounds

such as syllables are used as the auditory stimuli. Alternatively, the sensitivity to cross-modal correlations may be more domain-general, such that *any* auditory (or other sensory) stimuli may be categorized with visual information. Further research is required to investigate these possibilities.

6.5 Concluding Remarks

Young infants are capable of detecting and abstracting rules and regularities when presented with variability in both vision and audition. As seen in the statistical learning (e.g. Saffran *et al.,* 1996) and the abstract rule learning literature (e.g. Marcus *et al.,* 1999), before the first year of life infants are equipped with tools to handle variation in their environments. The ability to detect correlational information provides another example of the ways in which young infants can handle and use the variation in their environments—and in this case, do so to learn categories.

The current experiments investigated the ability of four-month-old infants to detect correlations of attributes in two domains in a cross-modal categorization task. The results from the four experiments challenge previous findings on infants' sensitivity to correlations of attributes, such that correlations *can* be detected by four-month-olds. However, these results show that this ability is evident only when the information is presented cross-modally. Infants in these experiments were able to learn cross-modal categories in the absence of temporal synchrony (an amodal regularity), succeeding in the presence of correlational regularities. This research suggests that young infants are prepared to handle a large amount of variation from across perceptual domains, and can detect underlying structures across audio-visual instances. Further research is necessary to further probe the extent to which detecting correlations is useful in category learning.

The ability to detect and make sense of information from two domains in order to learn categories is likely a useful facility for a developing infant; naturally-occurring categories are typically experienced cross-modally. For example, not only do dogs differ from cats in some key visual traits (type of fur, overall shape), but they also make different kinds of noises: dogs bark, while cats meow. Within each of these modalities, there is variation within a category. Even though dogs come in various shapes and sizes, we, as adults, still learn to group them into the same category. In addition, even though different dogs make different sounding barks, we can still (likely) identify different barks as sounds of a dog. Perhaps even as adults we learn categories such as dogs and cats even more easily when we have the opportunity to not only see their visual features but also simultaneously hear the sounds they make. That very young infants are able to form categories when there is information from two perceptual domains suggests that human sensory systems work together from very early in life, allowing infants to rapidly learn about and categorize their world.

References

Aslin, R.N., & Smith, L. (1988). Perceptual development. *Annual Review of Psychology, 39*, 435-473.

Bahrick, L.E., & Lickliter, R. (2000). Intersensory redundancy guides attentional selectivity and perceptual learning in infancy. *Developmental Psychology*, *36*, 190-201.

Balaban, M.T., & Waxman, S.R (1997). Do words facilitate object categorization in 9-month-old infants? *Journal of Experimental Child Psychology, 64*, 3-26.

Bertoncini, J., Bijeljac-Babic, R., Jusczyk, P.W., Kennedy, L.J., Mehler, J. (1988). An investigation of young infants' perceptual representations of speech sounds. *Journal of Experimental Psychology: General*, *117*, 21-33.

Bhatt, R., Wilk, A., Hill, D., & Rovee-Collier, C. (2004). Correlated attributes and categorization in the first half-year of life. *Developmental Psychobiology, 44*, 103-115.

Bomba, P.C., & Siqueland, E.R. (1983). The nature and structure of infant form categories. *Journal of Experimental Child Psychology*, 35, 294-328.

Bornstein, M.H., Kessen, W., & Weiskopf, S. (1976). Color vision and hue categorization in young human infants. *Journal of Experimental Psychology: Human Perception and Performance, 3,* 115-129.

Brookes, H., Slater, A., Quinn, P.C., Lewkowicz, D.J., Hayes, R., & Brown, E. (2001). Three-month-old infants learn arbitrary auditory-visual pairings between voices and faces. *Infant and Child Development, 10,* 75-82.

Chambers, K.E., Onishi, K.H., & Fisher, C. (2003). Infants learn phonotactic regularities from brief auditory experience. *Cognition, 87,* B69-B77.

Dehaene-Lambertz, G., Hertz-Pannier, L., Dubois, J. (2006). Nature and nurture in

language acquisition: Anatomical and functional brain-imaging studies in infants. *Trends in Neuroscience, 29,* 367-373.

Eimas, P.D. (1999). Segmental and syllabic representations in the perception of speech by young infants. *Journal of the Acoustical Society of America, 105,* 1901-1911.

Eimas, P., & Miller, J.L. (1990). Infant categories and categorization. In G. M. Edelman, W. E. Wall, & W. M. Cowan (Eds.), *Signal and sense: Local and global order in perceptual maps*. New York: Wiley-Liss.

Eimas, P.D., Siqueland, E.R., Jusczyk, P.R., & Vigorito, J. (1971). Speech perception in infants. *Science*, *171*, 303-306.

Ferry, A.L., Hespos, S.J., & Waxman, S.R. (2010). Categorization in 3- and 4-month-old infants: An advantage of words over tones. *Child Development, 81,* 472-479.

Fiser, J. & Aslin, R.N. (2002). Statistical learning of new visual feature combinations by infants. *Proceedings of the National Academy of Sciences, USA, 99,* 15822-15826.

Frank, M.C, Slemmer, J.A., Marcus, G.F., Johnson, S.P (2009). Information from multiple modalities helps 5-month-olds learn abstract rules. *Developmental Science, 12*, 504-509.

Franklin, A., Pilling, M., & Davies, I. (2005). The nature of infant color categorization: Evidence from eye movements on a target detection task. *Journal of Experimental Child Psychology, 91,* 227-248.

Fulkerson, A.L, & Waxman, S.R. (2007). Words (but not tones) facilitate object categorization: Evidence from 6- and 12-month olds. *Cognition, 105,* 218-228.

Gibson, E.J. (1969). *Principles of perceptual learning and development*. East Norwalk, CT: Appleton-Century-Crofts.

Gliozzi, V., Mayor, J., Hu, J., & Plunkett, K. (2009). Labels as features (not names) for

infant categorization: a neurocomputational approach. *Cognitive Science, 33,* 709-738.

Golinkoff, R.M., Mervis, C.B., & Hirsh-Pasek, K. (1994). Early object labels: The case for a developmental lexical principles framework. *Journal of Child Language, 21,* 125-155.

Harnad, S. (ed.) (1987). *Categorical Perception: The Groundwork of Cognition*. New York: Cambridge University Press.

Hunter, M.A., & Ames, E.W. (1988). A multifactor model of infant preferences for novel and familiar stimuli. In L. P. Lipsitt (Ed.), Advances in child development and behavior (pp. 69-95). New York: Academic.

James, W. (1890). *The principles of psychology* (Volumes I and II). New York: Holt.

Johnson, S.P., Fernandes, K.J., Frank, M.C., Kirkham, N.Z., Marcus, G.F., Rabagliati, H., & Slemmer, J.A. (2009). Abstract rule learning for visual sequences in 8- and 11-month-olds. *Infancy*, *14,* 2-18.

Jusczyk, P.W., & Derrah, C. (1987). Representation of speech sounds by young infants. *Developmental Psychology*, *23*, 648-654.

Kirkham, N.Z., Slemmer, J.A., & Johnson, S.P. (2002). Visual statistical learning in infancy: evidence for a domain general learning mechanism. *Cognition*, *83*, B35-B42.

Kuhl, P.K., & Miller, J.D. (1975). Speech perception by the chinchilla: voiced-voiceless distinction in alveolar plosive consonants. *Science, 190,* 69-72.

Lalonde, C.E, & Werker, J.F. (1995). Cognitive influences on cross-language speech perception in infancy. *Infant Behavior and Development*, *18*, 459-475.

Liberman, A. M., Harris, K. S., Hoffman, H. S. & Griffith, B. C. (1957) The discrimination of speech sounds within and across phoneme boundaries. *Journal of Experimental Psychology, 54,* 358 - 368.

Livingston, K.R., Andrews, J.K., & Harnad, S. (1998). Categorical perception effects induced by category learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 732-753.

Marcus, G.F, Vijayan, S., Bandi Rao, S., & Vishton, P.M. (1999). Rule learning by 7-month-old infants. *Science, 283*, 77-80.

Mareschal, D., Powell, D., Westermann, G., & Volein, A. (2005). Evidence of rapid correlation-based perceptual category learning by 4-month-olds. *Infant and Child Development, 14,* 445-457.

Mareschal, D., & Quinn, P.C. (2001). Categorization in infancy. *Trends in Cognitive Sciences, 5,* 443-450.

Maurer, D., Pathman, T., Mondloch, C.J. (2006). The shape of boubas: sound-shape correspondences in toddlers and adults. *Developmental Science, 9,* 316-322.

Maye, J., Weiss, D., & Aslin, R.N. (2008). Statistical phonetic learning in infants: facilitation and feature generalization. *Developmental Science*, *11*, 122-134.

Maye, J., Werker, J.F., & Gerken, L. (2002). Infant sensitivity to distributional information can affect phonetic discrimination. *Cognition*, *82*, B101-B111.

Mervis, C.B., & Rosch, E. (1981). Categorization of natural objects. *Annual Review of Psychology*, *32*, 89-109.

Plunkett, K., Hu, J., Cohen, L.B. (2008). Labels can override perceptual categories in early infancy. *Cognition, 106,* 665-681.

Quinn, P.C. (1987). The categorical representation of visual pattern information by young infants. *Cognition*, *27*, 145-179.

Quinn, P.C., & Bhatt, R.S. (2009). Transfer and scaffolding of perceptual grouping occurs

across organizing principles in 3- to 7-month-old infants. *Psychological Science, 20*, 933-938.

Quinn, P.C., Bhatt, R.S., & Hayden, A. (2008). What goes with what? Development of perceptual grouping in infancy. In B.H. Ross (Ed.), *Psychology of learning and motivation* (Vol. 49, pp. 105-146). San Diego, CA: Elsevier.

Quinn, P.C., & Eimas, P.D. (1986). On categorization in early infancy. *Merrill-Palmer Quarterly*, *32,* 331-363.

Quinn, P.C., & Eimas, P.D. (1994). Studies on the formation of perceptually based basic-level categories in young infants. *Child Development, 65*, 903-917.

Raskin, L.A., Maital, S., & Bornstein, M.H. (1983). Perceptual categorization of color: A life-span study. *Psychological Research, 45,* 135-145.

Robinson, C.W., & Sloutsky, V.M. (2004). Auditory dominance and its change in the course of development. *Child Development, 75,* 1387-1401.

Robinson, C.W., & Sloutsky, V.M. (2007). Linguistic labels and categorization in infancy: do labels facilitate or hinder? *Infancy, 11,* 233-253.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General*, *104*, 192-233.

Rosch, E. (1978). Principles of categorization. In E. Rosch & B. Lloyd (Eds.) *Cognition and categorization* (pp27-48). Hillsdale, NJ: Erlbaum.

Rosch, E., Mervis, C.B., Gray, W.D., Johnson, D.M., & Boyes-Braem, P. (1976). Basic objects in natural categories, *Cognitive Psychology*, *8*, 382-439.

Rost, G.C., & McMurray, B. (2009). Speaker variability augments phonological processing in early word learning. *Developmental Science, 12,* 339-349.

Rovee-Collier, C., & Giles, A. (2010). Why a neuromaturational model of memory fails: Exuberant learning in early infancy. *Behavioural Processes, 83,* 197-206.

Saffran, J.R., Aslin, R.N., & Newport, E.L. (1996). Statistical learning by 8-month-old infants. *Science*, *274*, 1926-1928.

Saffran, J.R., Pollack, S.D., Seibel, R.L, & Shkolnik, A. (2007). Dog is a dog is a dog: infant rule learning is not specific to language. *Cognition*, *105*, 669-680.

Saffran, J.R., & Thiessen, E.D. (2003). Pattern induction by infant language learners. *Developmental Psychology, 39,* 484-494.

Schafer, G., Plunkett, K. & Harris, P.L. (1999) What's in a name? Lexical knowledge drives infants' visual preferences in the absence of referential input. *Developmental Science, 2,* 187-194.

Shultz, T.R., & Cohen, L.B. (2004). Modeling age differences in infant category learning. *Infancy, 5*, 153-171.

Slater, A., Quinn, P.C., Brown, E., Hayes, R. (1999). Intermodal perception at birth: intersensory redundancy guides newborn infants' learning of arbitrary auditory-visual pairings. *Developmental Science*, *2,* 333-338.

Smith, E.E, & Medin, D.L. (1981). *Categories and concepts*. Cambridge, MA: Harvard University Press.

Spelke, E.S. (1982). Perceptual knowledge of objects in infancy. In J. Mehler, M. Garrett, & E. Walker (Eds.), *Perspectives on mental representation* (pp. 409-430). Hillsdale, NJ: Erlbaum.

Waxman, S.R., & Braun, I. (2005). Consistent (but not variable) names as invitations to form categories: New evidence from 12-month-old infants. *Cognition, 95,* B59-B68.

Waxman, S.R., & Gelman, S.A. (2009). Early word-learning entails reference, not merely associations. *Trends in Cognitive Sciences, 13,* 258-263.

Waxman, S.R., & Markow, D.B. (1995). Words as invitations to form categories: Evidence from 12- to 13-month old infants. *Cognitive Psychology, 29,* 257-302.

Werker, J. F. (1995). Exploring developmental changes in cross-language speech perception. In D. Osherson (Series Ed.) & L. Gleitman & M. Liberman (Vol Eds.), *An invitation to cognitive science, Part I: Language* (pp. 87-106). Cambridge, MA: MIT Press.

Werker, J.F, & Curtin, S. (2005). PRIMIR: A developmental framework of infant speech processing. *Language Learning and Development*, *1*, 197-234.

Werker, J.F., & Tees, R.C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7,* 49-63.

Woodward, A.M., Markman, E.M., Fitzsimmons, C.M. (1994). Rapid word learning in 13- and 18-month-olds. *Developmental Psychology, 30,* 553-566.

Yeung, H.H., & Werker, J.F. (2009). Learning words' sounds before learning how words sound: 9-month-olds use distinct objects as cues to categorize speech information. *Cognition*, *113*, 234-243.

Younger, B.A. (1990). Infants' detection of correlations among feature categories. *Child Development, 61,* 614-620.

Younger, B.A. (1992). Developmental change in infant categorization: The perception of correlations among facial features. *Child Development, 63,* 1526-1535.

Younger, B.A., & Cohen, L.B. (1983). Infant perception of correlations among attributes. *Child Development, 53*, 858-867.

Younger, B.A., & Cohen, L.B. (1986). Developmental change in infants' perception of correlations among attributes. *Child Development*, *57*, 803-815.

Appendix I: UBC Research Ethics Board Certificate of Approval.

The University of British Columbia
Office of Research Services
Behavioural Research Ethics Board
Suite 102, 6190 Agronomy Road, Vancouver, B.C. V6T 1Z3

CERTIFICATE OF APPROVAL - MINIMAL RISK AMENDMENT

PRINCIPAL INVESTIGATOR:	DEPARTMENT:	UBC BREB NUMBER:
Janet F. Werker	UBC/Arts/Psychology, Department of	H95-80023

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:

Institution	Site
UBC	Vancouver (excludes UBC Hospital)

Other locations where the research will be conducted:
N/A

CO-INVESTIGATOR(S):

Laurel Fais
Whitney M. Weikum
Trisha R. Pranjivan
Padmapriya Kandhadai
Henny Yeung
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Lawrence M. Chen
Alison J. Greuel
Mark A. Scott
Tania Zamuner
Nazanin Akmal
Judit Gervain
Ladan G. G. Hamadani

SPONSORING AGENCIES:

Natural Sciences and Engineering Research Council of Canada (NSERC) - "Perceptual tuning and language acquisition"

PROJECT TITLE:
Linking Speech Perception to Language Acquisition: Biases, Mechanisms and Products

Expiry Date - Approval of an amendment does not change the expiry date on the current UBC BREB approval of this study. An application for renewal is required on or before: November 26, 2010

AMENDMENT(S):	AMENDMENT APPROVAL DATE:

Appendix I: UBC Research Ethics Board Certificate of Approval, continued.

	April 29, 2010
Updating the Funding information	

The amendment(s) and the document(s) listed above have been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approval is issued on behalf of the Behavioural Research Ethics Board

Dr. M. Judith Lynam, Chair
Dr. Ken Craig, Chair
Dr. Jim Rupert, Associate Chair
Dr. Laurie Ford, Associate Chair
Dr. Anita Ho, Associate Chair