THE NATURE OF INFANTS' EARLY SHAPE BIAS: THE ROLE OF KIND CONCEPTS, OBJECT DOMAIN, AND LEARNING

by

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Abstract

The studies in this thesis address two central issues that remain unresolved in the developmental literature. The first issue concerns the question of whether infants' earliest object labels refer to distinct shapes or distinct kinds (Study One and Two). The second issue concerns the question of the origin of infants' early linguistic sensitivity to shape, that is, identifying the potential mechanism through which a 'shape bias' may be learned (Study Three). All three studies employ the violation of expectancy looking-time method.

Study One examined whether infants expect labels for objects in different domains to have different perceptual correlates or whether they have a general expectation that object labels refer to distinct shapes. Infants were presented with food objects: an object domain in which shape is not the primary perceptual correlate of kind. The findings indicate that when the labeled objects are food, both 9- and 12-month-olds demonstrate some color sensitivity and, moreover, infants do not expect food objects differing in shape to be marked by distinct labels. These findings provide evidence that, for infants, distinct labels do not solely correspond to distinct shapes.

Study Two examined infants' expectations about internal properties of labeled objects (as opposed to external object properties, such as, shape). Findings indicate that 10-month-olds are able to use linguistic information (the number of distinct object labels applied to an object pair) in order to predict whether a particular pair of objects should make the same sound or different sounds, regardless of the object pairs' perceptual similarity or dissimilarity. These findings suggest that infants hold kind-relevant expectations about labeled objects.

Study Three examined whether 9-month-olds (the youngest age group to demonstrate a shape sensitivity in their linguistic expectations) were capable of forming overhypotheses across feature variability. An overhypothesis is a second-order induction: it allows a learner to make predictions about an entire category based on evidence from only a few category members. Findings indicate that 9-month-olds are able to form overhypotheses flexibly, over multiple property dimensions. These results suggest that infants have at their disposal a powerful learning mechanism capable of supporting the formation of strong inductive inferences.

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Co-Authorship Statement

The ideas presented in this thesis represent the work of the author, developed in discussion with her PhD advisor, Dr. F. Xu.

The experiments described in Study One were designed, conducted and analyzed by the author, in consultation with Dr. F. Xu. Participants were recruited by S. Denison and V. Waechtler. Reliability coding was provided by V. Waechtler and M. Ho. The paper reporting on these studies was written by the author, in consultation with Dr. F. Xu, and is under review.

The experiments described in Study Two were designed, conducted and analyzed by the author, in consultation with Dr. F. Xu. Participants were recruited by V. Waechtler. Reliability coding was provided by M. Ho and V. Waechtler. This study was written by the author, in consultation with Dr. F. Xu, and published in *Psychological Science* (full citation: Dewar, K. M., and Xu, F. [2009]. Do early nouns refer to kinds or distinct shapes: Evidence from 10-month-olds. *Psychological Science, 20*, 252-257.).

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Chapter 1. Introduction

1.1 The nature of conceptual development

What aspects of knowledge are constant over development from the moment that infants begin to interact with their world, and what aspects change as children grow and learn? Many theorists of cognitive development have argued for continuity in children's representation of conceptual knowledge (e.g., Carey, 2009; Carey & Spelke, 1994; Chomsky, 1980; Fodor, 1975; Gelman, 1990; Gleitman, 1986; Keil, 1989; Leslie, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992), while others have stressed discontinuity, endorsing, instead, qualitative shifts from initial to later representations (e.g., Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1996; Karmiloff-Smith, 1992; Smith, 2001)[1]. In order for development to be continuous, infants must possess the conceptual resources to represent their world in an adult-like fashion. In contrast, for development to be discontinuous, infants and adults' conceptual representations must be fundamentally different (i.e., infants lack the representational capacities of adults).

Theories of discontinuity (often labeled 'empiricist' theories) highlight the role of learning: they imbue infants with general learning mechanisms that allow them to gather information from the environment that will, subsequently, result in qualitative shifts in development. Discontinuity theories grant infants a very limited mental inventory; one that has only a few domain-general learning mechanisms and contains very little innate

[1] Here, and in the remainder of this thesis, the use of 'continuity' implies a strong correspondence between infants' and adults' conceptual representations and roughly corresponds to a nativist interpretation of conceptual development, whereas, the use of 'discontinuity' implies that the conceptual representations of infants and adults are fundamentally different and roughly corresponds to an empiricist interpretation of conceptual development.

structure and content (i.e., a general set of perceptual primitives and information-gathering abilities). By appealing only to these general processes (i.e., associative or correlational learning mechanisms), discontinuity theorists maintain that positing innate knowledge is unnecessary. The high-level concepts and domain-specific knowledge achieved later in development can emerge from perceptual primitives. For example, in the realm of language acquisition, researchers have suggested that word segmentation (e.g., Aslin, Saffran, & Newport, 1998; Saffran, Aslin, & Newport, 1996; Saffran, Johnson, Aslin, & Newport, 1999), abstract, grammar-like, rule abstraction (e.g., Gomez & Gerken, 1999), word learning (e.g., Colunga & Smith, 2005; Smith, 2000) and even grammar (e.g., Elman, 1990) can be accomplished via domain-general learning capacities.

In contrast, continuity theories (often termed 'nativist' theories) emphasize innate conceptual knowledge: they posit that infants begin the process of conceptual development with certain enabling concepts and principles. Theories of continuity endow infants with cognitive architectures filled with rich domain-specific structure and content (i.e., innate knowledge, dispositions, representations and domain-specific faculties or modules). Under the continuity stance, later development is viewed largely as enrichment and entrenchment. It has been proposed that, very early in development, infants possess systems of knowledge such as intuitive physics (e.g., Carey & Spelke, 1994; Spelke, 1998; Spelke, Breinlinger, Macomber, & Jacobson, 1992), intuitive psychology (Gopnik & Meltzoff, 1994; Leslie, 1994), and a dedicated language faculty that encompasses a universal grammar and a language acquisition device (e.g., Chomsky, 1980, Gleitman, 1986). Continuing the example of language acquisition, continuity theorists view word

learning as progressing through the operation of several biases and constraints (e.g., the whole object bias, Soja, Carey, & Spelke, 1991; the taxonomic bias, Markman & Hutchinson, 1984; the principle of mutual exclusivity, Markman & Wachtel, 1988; and, the shape bias, Landau, Smith, & Jones, 1988; see Markman, 1989 for a review). Moreover, some even postulate the operation of a dedicated word learning mechanism (e.g., Waxman, 2004).

1.1.1. Continuity and discontinuity in conceptual development?

The dichotomy between continuous and discontinuous theories of cognitive development stems from the interplay between (1) how much innate knowledge structure is granted to the infant and (2) the strength of the learning mechanisms required in order to reach a specified knowledge state. Broadly speaking, if the amount of innate representation granted to infants is significant, then the influence of learning mechanisms and input statistics in development is small. Conversely, if infants are granted little innate representation, then the role of learning mechanisms and input statistics becomes centrally important in affecting developmental change. Of course, this 'dichotomy' should be more accurately viewed as a continuum, as many theorists acknowledge the contribution of both innate representation (be it identified as 'knowledge' or 'concepts') and powerful learning mechanisms in affecting conceptual change (e.g., Gopnik, Glymour, Sobel, Schultz, Kushnir, & Dank, 2004; Xu, 2007; Xu & Tenenbaum, 2007).

1.1.2 Inductive learning and conceptual development

Whether fueled by rich innate knowledge, powerful learning mechanisms, or both, one thing is for certain: infants appear to be rapid inductive learners. They are able to make generalizations and draw conclusions based on a relatively sparse amount of

data. For example, infants are able to hypothesize the meaning of a new word with just one, or a few, exposures (e.g., Bloom, 2000; Carey & Bartlett, 1978; Markman, 1989; Quine, 1960). They are able to induce complex grammatical rules based on limited input, i.e., listening to the mature speakers around them for a couple of years (e.g., Gleitman, 1990; Pinker, 1989). Infants are also able to learn the rules of physical support based on only a few trials (e.g., Baillargeon, 2002; Wang & Baillargeon, 2005), they can use labeling information to infer the hidden properties of an object with just a few examples (e.g., Gelman, 2003) and, once preschoolers, they are able to make confident causal inferences given very sparse data (e.g., Gopnik & Sobel, 2000). Although for some tasks, children do require many repetitions and a lot of data to demonstrate learning (e.g., learning the irregular past tense forms of English, memorizing the multiplication table, or figuring out the meaning of abstract nouns such as 'mortgage' or 'justice'), in many situations, they are willing to make inductive leaps quickly based on seemingly sparse evidence. Given the rapidity and ease with which infants are able to make such generalizations, any explanatory mechanism proposed in the acquisition of concepts must account for the speed and apparent effortlessness of infants' inductive learning. Without a strong commitment to the nature of the learning mechanisms (or, lack thereof) available to the infant, it is difficult to spell out any details in answering the question of how to get from the initial state to the final state of development.

1.1.3 A case study of conceptual development

Over the last 30 years, a great deal of empirical investigation has focused on infants' representations of physical objects (see Baillargeon, 2002; Spelke, 1994 for reviews). One particular perceptual dimension of physical objects, object shape, has

received attention in both the literature on object representations and generalization (e.g., Baldwin, Markman, & Melartin, 1993; Shutts, Markson, & Spelke, 2009; Welder & Graham, 2001) and the literature on early word learning, since infants' initial vocabulary is composed predominantly of labels for objects (e.g., Nelson, 1973). What follows is a case study of a specific aspect of cognitive development: the impact of labeling on young infants' object representations and, in particular, the nature of a 'shape bias' constraining infants' early linguistic understanding. We will examine the youngest age group of infants to display sensitivity to object shape in their linguistic expectations (i.e., 9- to 12-month-olds) in order to examine whether infants' linguistic sensitivity to object shape parallels findings with older infants and children that object shape serves as a proxy for kind membership in the context of object labeling (i.e., a continuous developmental trajectory), or whether younger infants' shape sensitivity reflects a fundamentally different understanding of shape in the context of labeling than is found in older infants and children (i.e., a discontinuous developmental trajectory). In addition, we will investigate infants' capacity for an inductive learning mechanism capable of supporting the acquisition of this linguistic bias.

1.2 How are early words represented?

Infants begin to comprehend words for object categories at around 9 months of age. By their first birthdays, many infants produce their first words, the majority of which are count nouns that refer to object categories (Brown, 1957; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994; Gentner, 1982; Macnamara, 1982; Nelson, 1973; Samuelson & Smith, 1999). Determining the exact nature of these early words has been the focus of considerable empirical attention. On the one hand, it has been proposed that

these early labels are perceptually-based and refer to shapes—categories of objects organized by a unifying property (e.g., Landau, Smith, & Jones, 1988; Samuelson & Smith, 2005; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002; Imai & Gentner, 1997; Yoshida & Smith, 2001). On the other hand, it has been claimed that early words refer to kinds—to categories of objects whose members share unforeseen and nonobvious properties as well as perceptual features (e.g., Markson, Diesendruck, & Bloom, 2008; Samuelson & Bloom, 2008; Soja, Carey, & Spelke, 1991). Under this view, object shape serves as a proxy for kind membership.

1.2.1 The impact of object shape on word extension

It appears that preschool-aged children rely heavily on perceptual properties, specifically shape, when generalizing words. Many studies with young children provide evidence for a 'shape bias', i.e., an expectation that objects that share the same shape should also share a label (e.g., Landau, Smith, & Jones, 1988; Samuelson & Smith, 2005; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002; Imai & Gentner, 1997; Yoshida & Smith, 2001; among many others). When given a new count noun label that refers to a rigid object, children will extend that noun to other rigid objects of the same shape, but not to those of the same size, color, or texture (Jones, Smith & Landau, 1991; Landau, Smith & Jones, 1988; 1998; Smith, Jones & Landau, 1992; 1996). The shape bias is evident in young word learners but, with age, becomes more robust and more specific to things with the perceptual properties of artifacts (e.g., Colunga & Smith, 2005; Gershkoff-Stowe & Smith, 2004; Graham and Poulin-Dubois, 1999; Hupp, 2004; Jones, Smith, & Landau, 1991; Landau, Smith, & Jones, 1998) and to linguistic contexts

indicative of artifacts rather than of substances or animals (Booth & Waxman, 2002; Gathercole, 1997; Soja, 1992; Yoshida & Smith, 2001; 2003a).

1.2.2 Early words may be perceptually-based (refer to shapes)

The demonstration of a shape bias in preschooler's word learning has prompted the suggestion that children's object labels are, initially, perceptually based; they pick out same-shaped things regardless of the taxonomic categories to which these things belong (e.g., Imai, Gentner, & Uchida, 1994; Landau, Smith, & Jones, 1988). Thus, the word *duck*, for instance, would refer to duck-shaped things. Under this view, it is only after having learned the names of specific categories, and becoming familiar with them, are children able to learn about the specific properties relevant to those categories. According to Smith and her colleagues, shape similarity is paramount in children's early understanding of object labels and categories (e.g., Jones & Smith, 1993; Landau et al. 1988; Landau, Smith, & Jones, 1992; Smith, Jones, & Landau, 1992).

1.2.3 Kind concepts specify object categories

An alternative view on the nature of early count nouns is that they refer to kinds. Kinds[2] are categories with rich inductive potential, e.g., *dog*, *chair*, *person*, *water*, *gold* (Xu, 2005): categories united by functional/causal features as well as by perceptual features. Sortal concepts refer to kinds and a subset of these concepts, namely count sortals, such as *dog*, *cup*, or *ball*, supply the criteria for individuation (where one object ends and another one begins) and identity (whether an object is the same one as was seen

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[2] Here, and throughout this thesis, the term 'kind' is used to denote a basic-level kind (i.e., *dog* rather than the subordinate-level *Labrador* or the superordinate-level *animal*; Macnamara, 1986). Basic-level kinds have a particular psychological salience. Rosch, Mervis, Gray, Johnson, and Boyes-Braem (1976) have shown that the basic-level kind is the most inclusive kind in a hierarchy in which individuals possess many attributes in common, elicit common motor programs, and have similar shapes.

on a different occasion) (Gupta, 1980; Hirsch, 1982; Macnamara, 1986; Macnamara & Reyes, 1994; Wiggins, 1980; Xu, 1997; Xu & Carey, 1996). The count sortal *dog*, for example, provides criteria for deciding whether we see one or two dogs; it also provides criteria for deciding whether the dog we see now is the same dog encountered earlier, or whether we have seen a different dog on each occasion. In contrast to count sortals, mass sortals, such as *water* or *gold*, do not provide criteria for individuation or and numerical identity. Count sortals are lexicalized as count nouns in languages that make the count/mass distinction, whereas mass sortals are lexicalized as mass nouns.

To appreciate the conceptual role of count sortals, consider two questions. Firstly, how many are there? And, secondly, is that the same as what was here before? It is impossible to answer either question without specifying individuals-how many of *what*? One can count cups, desks, people, pages or fingers, but one cannot count the blue, the sleeping, or the metal. Only count sortals provide criteria of individuation. Similarly, 'same,' in the sense of numerical identity, indicates the *same one*, and a count sortal is required to specify the individual being traced through time. Max the puppy grows to become an adult dog, changes size, coloring, shape, and location, but is still the same dog. Max's identity is traced by the count sortal *dog*.

According to one analysis, namely psychological essentialism, members of the same kind share both internal, non-obvious properties, as well as, external, perceptual properties. The perceptual similarity reflects, and is caused by, shared deeper properties (Gelman, 2003; Medin & Ortony, 1989).

1.2.3.1 Kind membership and perceptual object properties

Adults and older children use distinct count nouns to designate different kinds of

things (i.e., objects within a kind share the same label; Bloom, 2000; Hall & Waxman, 1993; Markman, 1989). And, in general, objects that vary along a property dimension unrelated to kind membership are not marked by different labels. Given the various perceptual dimensions that objects possess, some of these dimensions are better correlated with kind membership in specific object domains than others. The property of shape is closely connected with kind membership for artifact objects (Landau et al., 1988; Rosch et al., 1976; Soja et al., 1991). Broadly speaking, artifact objects that differ in shape are usually different kinds of things and are labeled by different basic-level count nouns (Samuelson & Smith, 2005). In contrast, the property of color, for artifacts, is not closely connected with kind membership and artifact objects that differ only in color are not usually marked by different basic-level count nouns. However, while shape is a good indicator of kind membership for artifact objects, it is merely a perceptual cue: there is more to an artifact object's kind than its shape.

1.2.3.2 Kind membership and internal object properties

Members of the same kind usually share both external, perceptual properties (e.g., shape) and internal, non-obvious properties. However, because perceptual similarity reflects, and is caused by, shared deeper properties, it is vital that kind members share these 'deeper' causal/functional features. Thus, perceptual features may vary amongst kind members, as long as their causal/functional similarities are preserved. In fact, it is possible to have objects that look different to be members of the same kind (e.g., a poodle and a Chihuahua, a regular telephone and a telephone shaped like a banana) as well as to have objects that look very similar or the same to be members of different kinds (e.g., a baseball and an orange, a rock and a fake rock made of foam).

1.2.4 Early words may be conceptually-based (refer to kinds)

In contrast to this shape-based account, is the view that children's object labels refer to kinds—to categories of objects whose members share nonobvious, hidden, properties as well as perceptual features (e.g., Booth &Waxman, 2002; Cimpian & Markman, 2006; Gelman, 2003; Soja, Carey, & Spelke, 1991; Waxman & Gelman, 2009). Here, the word *duck* refers to the natural kind *duck* whose members are expected to, not only look similar, but also to share a range of behavior, internal features, etc. Under this view, even dissimilar looking things will be expected to be members of the same kind as long as they share the same object label (as a shared label is indicative of shared 'deep' causal/functional features).

There is abundant evidence to suggest that young children's understanding of category labels is decidedly kind-based. For instance, children as young as 2 years of age judge the identity of an artifact (Gelman & Bloom, 2000) or a drawing (Bloom & Markson, 1998; Gelman & Ebeling, 1998) on the basis of the intent of its creator and not just its perceptual properties (i.e., it's shape). Preschoolers are able to base their inductive inferences on an object's kind rather than its outward appearance (Gelman & Coley, 1990; Gelman & Markman 1986; 1987) and even infants as young as 14 months expect objects that share a label, but are dissimilar in appearance, to share a nonobvious property (at 14 and 20 months: Graham & Kilbreath, 2007; at 16 and 21 months: Welder & Graham, 2001). Preschoolers extend the label of a novel artifact to other artifacts that share the same salient function (e.g., Kemler Nelson, Russell, Duke, & Jones, 2000) or causal property (Gopnik & Sobel, 2000), even when perceptual similarity is in conflict with these functional or causal properties. Perceptual information can also be overridden

by creator's intent in 3-year-olds' novel word extensions (Diesendruck, Markson, & Bloom, 2003). Here, the shape bias was found to disappear when children were given explanations for why two objects were intended to be different kinds of things, even though they shared the same shape. Similarly, 3-year-olds are able to categorize perceptually identical novel objects as either animals or artifacts, depending on the conceptual information provided in the task—that is, whether the objects are described as having animal-like properties or artifact-like properties (Booth & Waxman, 2002). Moreover, recent studies provide evidence that even 18-month-old infants take into account conceptual knowledge (e.g., describing the object as "happy") in labeling (Booth, Waxman, & Huang, 2005). Such findings imply that, for young children, labels for objects (and representations of those objects) are not wholly determined by shape similarity; shape may be being used as a proxy for kind membership.

1.3 Continuity (or discontinuity) in the development of word representation?

The literature suggests that once children become rapid word learners (around 14 to 18 months of age), they seem to infer that count noun labels refer to kinds, and they hold kind-relevant expectations about the labeled objects and their properties (e.g., Bloom & Markson, 1998; Booth, Waxman, & Huang, 2005; Gelman & Ebeling, 1998; Markson, Diesendruck, & Bloom, 2008; Samuelson & Bloom, 2008; Soja, Carey, & Spelke, 1991). What remains unclear, however, is whether younger infants who are just on the cusp of learning words, represent object labels in a similar way to more experienced language learners.

1.3.1 Evidence from word learning studies

The current state of the evidence on very young infants' word comprehension is scant. To date, the evidence seems to show that as soon as children have demonstrated

clear learning of a word, they also generalize that word to new exemplars (i.e., they don't simply restrict the label to only the labeled object). By 11 months, infants appear to recognize that words refer to commonalities across categories of objects (Waxman & Booth, 2003). By 12 months, infants can be trained on a set of count noun labels and extend them to new exemplars in a comprehension task (Schafer, 2005). By 13 months, infants demonstrate their ability to map a label to an object: they extend the label beyond the target object to other members of like kind (to exemplars that differed from the target in color) and they are able to retain the label for up to 24 hours (Woodward, Markman & Fitzsimmons, 1994). Thus, once infants have embarked on the process of word learning (in, and around, their first birthdays), the evidence shows that they seem to expect that count nouns for objects refer to object categories.

Studies conducted with infants younger than 11 months of age, have not been able to demonstrate clear evidence of word learning making findings of infants' inability to generalize said labels difficult to interpret (i.e., Markman & Jaswal, 2004). Indeed, it has been suggested that it is extremely difficult for children younger than 14 months to learn novel word-object pairings under tightly controlled laboratory conditions and without the use of social or contextual information (Werker, Cohen, Lloyd, Casasola, & Stager, 1998). For a novice word learner, forging a link between a label and an object is quite a computationally demanding task (i.e., Fennell & Werker, 2003; Stager & Werker, 1997). It could be the case that young infants have expectations about count noun labels and their referents, but are not able to demonstrate these expectations in standard word learning tasks because of the processing requirements inherent in forming the initial word-object mappings.

1.3.2 Evidence from looking-time studies

A recent study circumvented young infants' mapping difficulty by examining infants' expectations about labeled objects, without requiring the infants to make specific word-object linkages. Dewar and Xu (2007) employed a novel violation of expectancy looking-time method, enabling them to test younger infants, namely, 9-month-olds. The main benefit of this design is that it examines infants' expectations about the ways in which count noun labels impact object representations, in general, as opposed to testing infants' expectations about particular word-object mappings (as in a word extension task). The looking time procedure, in question, requires that infants use labeling information to establish object representations when the objects in question are hidden from view (inside a box). In order to succeed at this task, infants must use the number of distinct object labels heard (one vs. two) in order to form an expectation of the objects they will see once the box is opened (identical objects vs. different objects).

In Dewar and Xu's (2007) design, infants watched events being presented on a puppet stage. During the familiarization trials, a box was opened to reveal two objects inside. The revealed objects were either two identical objects or two different-looking objects. The tests trials followed the same procedure and used the same objects as familiarization, except, that before the box was opened, the experimenter looked into the top of the closed box and described its contents using either two distinct object labels (e.g., "I see a wug!" and "I see a dak!") or the same label twice (e.g., "I see a zav!" and "I see a zav!"). The experimenter looked intently into the box during labeling, providing abundant intentional and referential cues. The box was then opened to reveal the object-pair outcome (either two identical objects or two different-looking objects). The question

of interest was whether the number of distinct labels would help infants determine the nature of objects inside the box. Nine-month-olds hearing the box contents described using distinct labels looked longer when two identical objects versus two different objects were revealed inside the box. In other words, when infants heard the hidden objects referred to using two distinct labels (e.g., 'wug' and 'dak'), they expected two different-looking objects to be revealed when the box door opened and were surprised if two identical objects were revealed instead. This pattern was reversed when infants heard the box contents described using a label repeated twice: they looked longer when two different-looking objects versus two identical objects were revealed inside the box. In this case, when infants heard the hidden objects referred to using the same label twice (e.g., 'zav' and 'zav'), they expected two identical objects to be revealed when the box door opened and were surprised if two different-looking objects were revealed instead.

If object labels reference kind, infants should expect that objects marked by distinct labels should not only be perceptually different from one another, but should differ along perceptual dimensions relevant for kind membership. In a second experiment, Dewar and Xu (2007) explored whether shape is central in determining kind membership for artifact objects. The second experiment was identical to the first, except that the hidden object pairs were either identical or different only in shape (as opposed to the identical and completely different-looking objects used in Exp. 1). The results of the Exp. 2 mirrored those of the first study: infants expected different-shaped artifacts to be marked by distinct labels. However, a third experiment found this expectation didn't hold for artifacts differing only in color. When the hidden object pairs were either identical or different only in color, infants did not expect the different-colored object pairs to be

marked by distinct labels. Thus, infants do not merely expect distinct object labels to refer to different objects: the way in which the objects differ is important. Nine-month-olds expect artifact objects differing in a kind relevant property (shape) to be marked by distinct labels, but they do not hold this expectation for artifact objects differing in a property unrelated to kind membership (color). Thus, the sensitivity to the perceptual dimension of shape appears to emerge at the beginning of word learning. However, these findings remain ambiguous as to whether infants who are on the cusp of learning words expect object labels to refer to kinds or, merely, distinct shapes. The results of Dewar and Xu (2007) are consistent with both interpretations.

1.4 Early words for object categories: distinct kinds or distinct shapes?

Recent findings indicate that by 9 months of age, infants demonstrate sensitivity to object shape in a linguistic context (Dewar & Xu, 2007). However, these findings are not clear as to whether, for young infants, object labels refer to distinct shapes or distinct kinds. It may be the case that infants' earliest object labels refer to distinct shapes and, later in development, shape, for objects, becomes correlated with kind membership. Or, there may be continuity in the representation of object labels: infants' representation of their earliest words may be kind-based, like that of older children and adults. Because object shape is highly correlated with kind membership for many object categories, it is very difficult to tease these interpretations apart, especially with very young word learners. However, if infants' early object labels refer to kinds, these kind representations would lead infants to form specific expectations about the labeled objects, and those objects' category; such expectations would not be predicted if infants' early words referred to distinct shapes.

1.4.1 Disentangling shape and kind membership in object categories

There are at least two ways in which to disentangle shape from object kind in order to determine whether infants interpret object labels as referring to kinds or distinct shapes. Firstly, one could examine infants' expectations about count noun labels in a domain of objects in which the property of shape is less indicative of kind membership than another perceptual dimension (e.g., as in the domain of food). Secondly, instead of focusing on visible object properties, one could examine infants' expectations about internal object properties (e.g., regardless of perceptually similarity, will infants expect two objects labeled with the same count noun to share an internal property).

1.4.1.1 The effect of object domain

One way of approaching the problem of kind versus shape is to examine a domain of objects for which shape is not the relevant perceptual dimension for determining kind membership. With older children, both corpus analyses and word learning experiments suggest that names for different domains of objects – animals, artifacts, and food objects – have different perceptual correlates (e.g., Jones & Smith, 2002). For example, children as young as 2 to 2.5 years of age have been shown to attend to different properties for different domains of objects—to the multiple similarities of animals, the shapes of artifacts, the material of substances, or the color of foods (e.g., Booth & Waxman, 2002; Imai & Gentner, 1997; Jones & Smith, 2002; Macario, 1991; Soja, Carey, & Spelke, 1991). Because count noun labels in different object domains have different perceptual correlates, there may be a domain difference in the types of perceptual features that infants use to determine an object's kind. In the domain of artifacts, shape determines kind membership: objects that differ in shape are usually different kinds of things.

However, in the domain of food, color may be a more central feature than shape in determining food kinds.

There is evidence to suggest that children and adults attend to different object-relevant properties depending on the expressed domain of the object in question. For instance, Macario (1991) asked preschoolers to categorize solid entities and found that they did so on the basis of shared shape when they were told that the entities were toys. In contrast, when preschoolers were told that these same entities were food, they categorized on the basis on color. This same pattern of results has also been found in a linguistic context. Lavin and Hall (2002) presented 3-year-olds, and adults, with a novel neutral noun ("my X") for a solid entity described either as a toy or a food. They were then asked to extend the word to one of two other solid entities, one of which differed from the standard in an object relevant property (shape) and the other which differed in a substance relevant property (color, texture, smell). Both children and adults were more likely to select the same-shaped entity if the standard was described as a toy than if it was described as a food. Thus, preschoolers' and adults' interpretation of novel labels for material entities was affected by conceptual information (the expressed domain of the entities)[3]. The question arises as to whether infants, like older children, demonstrate some sensitivity to the domain of the labeled object.

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[3] Lavin and Hall (2002) also found an effect of solidity on adults' and preschoolers' interpretation of novel labels for entities. Learners extended nouns on the basis of shape similarity more often if the entities were solid than if they were nonsolid. In addition, for adults, but not for preschoolers, when the novel noun was presented in a syntactic context that suggested the solid entity should be interpreted as an object (e.g., "an X") and the nonsolid entity should be interpreted as a substance (e.g., "some X") the effect of the entity's domain (toy, food) was largely eliminated (Exp. 3). These findings demonstrate that domain cues, solidity cues and, for adults, syntactic cues affect whether a word should be interpreted as naming an object or a substance construal.

1.4.1.2 The effect of internal object properties

An alternate way in which object shape and object kind can be separated is by investigating infants' expectations about non-obvious properties (as in: Baldwin et al. 1993; Graham, Kilbreath, & Welder 2004; Welder & Graham, 2001). If object labels reference kind, then objects that share a label should be expected to share certain non-obvious properties. Children's expectations about internal object properties are examined via an inductive inference task. In the seminal inductive inference paradigm, Baldwin, Markman, and Melartin (1993), presented 9- and 16-month-olds a pair of similar-looking toys. The infants were shown that the first toy produced an interesting nonobvious property, such as a making a distinctive sound when squeezed, while the second toy was invisibly altered such that it failed to produce the nonobvious property available in the first toy. Baldwin et al. (1993) found that infants persistently attempted to reproduce the interesting property when exploring the second toy. However, infants seldom expected toys of radically different appearance to possess the same nonobvious property.

There is evidence to suggest that older infants rely on count noun labels to make inferences about internal object properties. For example, Graham, Kilbreath, and Welder (2004) presented 13-month-olds with novel target objects with a nonvisible property, followed by test objects (altered to not produce the target property) that differed in shape similarity. Mirroring the results of Baldwin et al. (1993), when objects were not labeled, infants generalized the nonvisible property to high-similarity objects. However, when objects were labeled with the same count noun, infants generalized the nonvisible property to both high- and low-similarity objects. Graham and Kilbreath (2007) offer similar findings: when objects were labeled with the same count noun, both 14- and 22-

month-olds generalized nonobvious properties to objects that shared very minimal perceptual similarity (for similar results with 16- to 21-month-olds, see Welder & Graham, 2001). Welder and Graham (2006) examined 14- to 15-month-olds' categorization of objects on the basis of more or less obvious internal properties. Infants were familiarized with novel objects that shared either more obvious features (i.e., easily visible) or less obvious features (i.e., accessible by lifting a flap), followed by an in-category object and an out-of-category object. When only perceptual information was provided, infants formed a category on the basis of more obvious features but not on the basis of less obvious features. However, when infants were provided with object labels, they formed categories on the basis of either more, or less, obvious features.

It appears that, in the absence of linguistic information, infants rely on perceptual cues (i.e., the shape of the object) for categorization. In contrast, when a label is provided, infants infer that objects sharing a label will also share similar properties. Thus, infants as young as 13 months, who hear the same label applied to perceptually dissimilar objects, seem to assume that the objects are members of the same category, or kind, and expect those objects to share non-obvious, internal properties (e.g., Davidson & Gelman, 1990; Gelman & Coley, 1990; Gelman & Markman, 1986; Graham & Kilbreath, 2007; Graham, Kilbreath, & Welder, 2004; Kalish & Gelman, 1992; Welder & Graham, 2001).

1.5 The formation of an early 'shape bias'

If 9-month-olds' linguistic understanding is constrained by a 'shape bias', i.e., a sensitivity to object shape in a linguistic context, as is implied by the findings of Dewar and Xu (2007), it remains an open question as to how are they able to acquire this shape sensitivity, especially given their novice word learning status. It may be that infants have

an innate predisposition to expect that category labels apply to items that differ in shape. It could also be the case that infants are able to acquire this bias from the regularities present in the learning environment. However, if it is granted that the learning environment is able to support the formation of such a bias, the question arises as to how infants are able to take advantage of such regularities.

1.5.1 The attentional learning account

An existing account describes how children, considerably older than 9 months, are able to form such a bias. The Attentional Learning Account (ALA) of word learning has been used to explain preschoolers' acquisition of the shape bias. In this account, word learners' attention to shape for artifacts is the result of contextually cued attentional biases. These biases arise through three claims of the ALA (Smith & Samuelson, 2006). First, the learning environment yields correlations among linguistic devices, object properties, and perceptual category organization. For instance, in studies of babies' first 300 nouns, among the learned noun categories, artifacts tend to be rigid, solid things in categories organized by shape, while substances tend to be nonsolid and in categories organized by material (Colunga & Smith, 2005; Jones & Smith, 2002; Samuelson & Smith, 1999; Smith, Colunga, & Yoshida, 2003). Thus, there are correlations between the perceptual properties of individual things and the types of similarities characteristic in that individual's noun category.

Secondly, as children learn lexical categories, they extract these statistical regularities, and the higher-order generalizations that emerge from them, enabling more rapid learning of lexical categories. In training experiments (Samuelson, 2002; Smith, Jones, Landau, Gershkoff-Stowe, & Samuelson, 2002), 15- to 19-month-olds were taught

four novel object labels for four unfamiliar object categories well organized by shape. Children were tested on a first-order generalization task that assessed whether they would extend a trained label to a novel object that matched the trained exemplar in shape (as opposed to novel objects that matched the exemplar in color or texture). Children were also tested as to whether they were able to make the higher-order generalization that object names, in general, span categories of similarly shaped things: using new labels, they were tested with novel objects differing from the trained object categories in shape, texture, and color. Children made both first- and second-order generalizations. In addition, laboratory exposure to shape regularity and word usage induced the shape bias and, subsequently, allowed the children to learn words faster outside of the lab (relative to children in control conditions). These training studies demonstrate that highlighted attention to shape when learning names for artifacts impacts children's real-life vocabulary development.

The final claim of the ALA, is that children's learning of the statistical regularities and their application of that learning in the real-time task of generalizing a label to a new instance is mechanistically realized through learned associations that yield contextually cued shifts in attention. Children's attention is automatically directed, in the moment of learning, to similarities that have been systematically relevant in those linguistic and perceptual contexts in the child's past. Thus, the core mechanism of the ALA, is the top-down control of attention by past knowledge (e.g., Smith, 2000; Smith & Samuelson, 2006; Yoshida & Smith, 2003).

There is reason to believe that the ALA description of children's shape bias acquisition does not account for the linguistic sensitivity to shape found in 9-month-olds.

The ALA requires that children build associations between the lexical categories they have learned and the perceptual structure that exists in those object categories and these associations cue their attention for future learning. By 9 months of age, infants are just beginning the task of word learning. Indeed, the youngest age at which infants are able to segment words from a stream of natural language is 8 months (Pelucchi, Hay, & Saffran, 2009). Thus, while infants may be able to form correlations between the lexical categories and object properties they see and hear, they have not learned the amount of specific word-object pairings required by the ALA to create an attentional bias driven by their own past knowledge.

1.5.2 The mechanism of overhypothesis formation

An alternate mechanism proposed to explain how the shape bias may be learned is inductive in nature. Several researchers have applied the general idea of overhypothesis formation to account for children's acquisition of the shape bias (e.g., Smith, Jones, Landau, Gershkoff-Stowe and Samuelson, 2002; Samuelson, 2002; Kemp, Perfors, and Tenenbaum, 2007). The term 'overhypothesis' was coined by Goodman (1955) and he used the following example to illustrate the idea. Suppose you are shown a selection of identical bags. A few white marbles are drawn from the first bag. A handful of red marbles are pulled out of the second bag. Some green marbles are pulled from the third bag. If you saw a single blue marble being sampled from a new bag, what do you think the color of the next marble drawn would be? Your answer would probably be blue. The learner is making both a first- and second-order generalization. The first-order generalization concerns the contents of each individual bag. Only white marbles have been drawn from the first bag, so the next marble drawn should also be white. The learner

has also formed a second-order generalization, or overhypothesis, that "bagfuls of marbles are uniform in color," and it allows the learner to make predictions about a new bag with a new color of marbles. Since Goodman, researchers have confirmed that children (Macario, Shipley & Billman, 1990) and adults (Nisbett, Krantz, Jepson & Kunda, 1983) demonstrate the ability to form overhypotheses about feature variability, and use them to make inductive leaps given sparse amounts of data.

An example of the mechanism of overhypothesis formation in the acquisition of a shape bias can be seen in the training studies of Samuelson (2002) and Smith et al. (2002). As previously described, in order to account for the way in which children learn the shape bias, Smith et al. (2002) hypothesized that first, children acquire count nouns that refer to object categories, e.g., "cat" refers to cats; "chair" refers to chairs. For each word and each category, children form a first-order generalization, e.g., the word "cat" refers to objects that are cat-shaped; the word "chair" refers to objects that are chair-shaped. Once a number of individual words and categories are learned, the child may form a second-order generalization, or overhypothesis, that "Noun X refers to objects that are X-shaped." By making this second-order generalization, the child can now apply the shape bias to all new count nouns that he/she might learn in the future. Here, the mechanism of overhypothesis formation provides a powerful tool for future learning: the child is able to go beyond the specific words and categories they have learned in order to make principled generalizations about all count nouns that refer to object categories.

1.5.3 Is overhypothesis formation able to account for infants' shape bias?

Is overhypothesis formation a plausible mechanistic candidate for 9-month-olds' acquisition of this early shape sensitivity? The advantage of overhypothesis formation as

an inductive learning mechanism is that it is able to make meaningful and principled generalizations about an entire class of entities based on limited data. Thus, if 9-month-olds possessed the ability to generate overhypotheses, they would be able to form a second-order generalization of the kind required to support a shape bias, i.e., noun X refers to objects that are X-shaped, by making a relatively limited number of first-order generalizations. Thus, the principle advantage of overhypothesis formation is that, in contrast to the ALA mechanism, it requires the learner to make far fewer initial object-label correlations in order to form the requisite second-order generalization (i.e., the bias itself). It stands to reason that, if 9-month-olds are acquiring an early linguistic sensitivity to shape via this inductive mechanism, then they should be capable of forming overhypotheses, in general.

1.6 Rationale for the thesis

The studies in this thesis address two central issues that remain unresolved in the developmental literature. The first issue concerns the question of whether infants' earliest object labels refer to distinct shapes or distinct kinds (Study One and Two). Study One examines whether infants expect labels for objects in different domains to have different perceptual correlates or whether they have a general expectation that object labels refer to distinct shapes, independent of object domain. Study Two examines whether infants expect internal object properties to be predicted by linguistic labels. The second issue concerns the question of the origin of infants' early linguistic sensitivity to shape, that is, identifying the potential mechanism through which this 'shape bias' may be learned (Study Three). Study Three examines whether 9-month-old infants (the youngest age group to demonstrate a shape bias in their linguistic expectations; Dewar and Xu, 2007)

are able to evidence the ability to form overhypotheses.

If object labels reference kind, infants should expect that objects marked by distinct labels should not only be perceptually different from one another, but should differ along perceptual dimensions relevant for kind membership. Which features are the relevant perceptual correlates of kind membership depends on the domain of the objects being labeled. Thus, there should be a domain difference in the types of perceptual features infants use to determine an object's kind. In the domain of artifacts, shape determines kind membership: objects that differ in shape are usually different kinds of things. However, in the domain of food, color may be a more central feature than shape in determining kind. The first study uses the same methodology as Dewar and Xu (2007), except that the items presented were food objects as opposed to artifact objects. If, for food objects, infants expect that objects marked by distinct labels should differ in a kind-relevant property for the domain of food (like, color), and should not differ in a property unrelated to kind (like, shape) it would indicate that shape is not a privileged perceptual dimension for all object categories.

Because object labels reference kind, objects that share a label should also be expected to share kind-relevant internal properties. The second study examines whether 10-month-olds expect an object pair referred to using two distinct labels to possess different nonobvious properties (i.e., make different sounds) and, conversely, whether they expect an object pair referred to using one repeated label to share the same nonobvious property (i.e., make identical sounds), regardless of object pair appearance. If the application of object labels drives infants' expectations about internal object properties, it would provide evidence that, even at the beginning of word learning, infants

expect distinct labels to refer to kinds.

If 9-month-olds' linguistic understanding of artifact objects is constrained by sensitivity to shape, they must possess a learning mechanism capable of supporting the acquisition of this 'shape bias'. A third study examines whether 9-month-olds are able to demonstrate the ability to form overhypotheses using a modified, looking-time, version of the original Goodman 'bags-of-marbles' task. Here, we examine whether infants have a general ability to form overhypotheses by asking whether overhypotheses can be formed equivalently across different perceptual dimensions, namely, shape and color, respectively. For infants to be able to succeed on this task, they will have to form an overhypothesis across a relevant perceptual dimension while, simultaneously, ignoring an equally salient perceptual feature (i.e., if shape varies across boxes and color varies within boxes, the overhypothesis should be formed across shape but not color). Since the question of overhypothesis formation has never been examined using an infant population, the third study is the first to use the looking time method to address this issue empirically.

The studies in this thesis employ the violation-of-expectancy looking time methodology (Spelke, 1985) in order to assess infants' expectations regarding test events. This paradigm has been used to study infants' expectations across a wide range of phenomena, from their understanding of physical events (e.g., Baillargeon, Spelke, & Wasserman, 1985; Spelke et al., 1992), numerosity (e.g., Xu & Spelke, 2000), and statistical inference (e.g., Teglas, Girotto, Gonzalez, & Bonatti, 2007; Xu & Garcia, 2008) to their understanding of others' goals and intentions (e.g., Gergely, Nadasdy, Csibra, & Biro, 1995; Onishi & Baillargeon, 2005; Woodward, 1998). In a violation-of-

expectancy experiment, infants are shown two test outcomes, one consistent (the expected outcome) and one inconsistent (the unexpected outcome) with the expectation under investigation. Familiarization trials, which are presented prior to the test trials, serve to acquaint infants with various aspects of the test outcomes. Evidence demonstrating that infants look reliably longer to the unexpected outcome relative to the expected outcome is taken to indicate that infants (1) possess the expectation in question; (2) detect the violation in the unexpected outcome; and (3) are surprised[4] by this violation (Wang, Baillargeon, & Brueckner, 2004).

While data obtained from violation-of-expectancy experiments have been taken as evidence that infants possess a range of complex cognitive abilities, the ability to draw inferences about underlying (hidden) cognitive processes has been questioned (i.e., Haith, 1998). While the extent of infants' understanding in such violation-of-expectancy experiments remains unspecified (see Aslin, 2007 for a discussion), the inferences drawn from looking time data have been bolstered by findings using converging measures. For example, in a short-term longitudinal study of infants' understanding of intentional action (Olineck & Poulin-Dubois, 2009), infants' performance on a task of visual attention (i.e., violation-of-expectancy paradigm) at 10 months was predictive of their performance on a behavioral measure (i.e., imitation task) at 14 months. Such a finding suggests that, at the very least, the expectations measured by the violation-of-expectation paradigm can be viewed as precursors to infants' later cognitive abilities.

The experiments presented in this thesis will test samples between 8 and 24 infants per condition, in accordance with the sample size parameters of other violation-

[4] Here, the term 'surprise' is used to denote a state of heightened attention or interest caused by a violation of expectation.

of-expectancy studies in the literature (e.g., 7 infants per condition: Onishi & Baillargeon, 2005; 10 infants per condition: Kuhlmeier, Bloom, & Wynn, 2004; 12 infants per condition: Xu & Carey, 1996; 16 infants per condition: Woodward, 1998; 24 infants per condition: Spelke et al., 1992). By selecting a sample size range comparable to similar studies using the same paradigm, it is expected that the current experiments will possess sufficient statistical power to detect the effects under examination.

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Chapter 2. Domain Differences in Infants' Expectations of Object Labels[5]

2.1 Introduction

Do infants evidence a domain differences in their representations of labeled objects? That is, do they expect labels for objects in different domains to have different perceptual correlates and, moreover, are these expectations in place at the outset of language learning?

There is evidence to suggest that young children attend to different object-relevant properties depending on the apparent domain of the object in question. For preschoolers, both corpus analyses and word learning experiments suggest that labels for different domains of objects – animals, artifacts, and food objects – have different perceptual correlates (e.g., Jones & Smith, 2002). In such experimental tasks, children as young as 2 years of age have been found to attend to distinct object properties for different object domains—to the multiple similarities of animals, the shapes of artifacts, the material of substances, or the color of foods (e.g., Booth & Waxman, 2002; Imai & Gentner, 1997; Jones & Smith, 2002; Macario, 1991; Soja, Carey, & Spelke, 1991).

The majority of words young children know are nouns (Bloom, 2000; Colunga & Smith, 2005; Nelson, 1973). The categories these nouns refer to divide into two subgroups, solid things in shape-based categories and nonsolid things in material-based categories (Samuelson & Smith, 1999). Thus, the entities children encounter are roughly divided into objects for solid entities and materials for nonsolid entities. When shown a novel exemplar and told its name, 2- and 3-year-olds systematically generalize that name to new instances on the basis of shape for solids but on the basis of material for nonsolids

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(i.e., Imai & Gentner, 1997; Samuelson & Smith, 1999; Soja, 1992; Soja, et al, 1991; Subrahmanyam, Landau, & Gelman, 1999). However, solidity is not the only cue children use when interpreting a new word for a physical entity. Children have also been shown to take into account conceptual information about the domain of an object in interpreting the extension of a new word. For example, when objects were described as having conceptual properties typical of artifacts (e.g., is used to fix something), infants as young as 18 months of age extended novel labels for these objects on the basis of shape alone. However, when the very same objects were described as having conceptual properties typical of animate kinds (e.g., is very hungry), children extended novel labels for these objects on the basis of both shape and texture (Booth & Waxman, 2002; Booth, Waxman, & Huang, 2005).

When given information about an object's domain, children are able to abandon their reliance on shape for classification in favor of a more domain-appropriate property. For instance, Macario (1991) asked preschoolers to categorize solid entities and found that they did so on the basis of shared shape when they were told that the entities were toys. In contrast, when preschoolers were told that these same entities were food, they categorized on the basis on color. This same pattern of results has also been found in a linguistic context. Lavin and Hall (2002) presented 3-year-olds, and adults, with a novel neutral noun ("my X") for a solid entity described either as a toy or a food. They were then asked to extend the word to one of two other solid entities, one of which differed from the standard in an object relevant property (shape) and the other which differed in a substance relevant property (color, texture, smell). Both children and adults were more

likely to select the same-colored entity if the standard was described as a kind of food than if it was described as a toy.

How do children come to rely predominantly on object shape when generalizing to new instances in a linguistic context? Countless studies with young children provide evidence for a 'shape bias', i.e., the expectation that objects that share the same shape should also share a label (e.g., Imai & Gentner, 1997; Landau, Smith, & Jones, 1988; Samuelson & Smith, 2005; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002; Yoshida & Smith, 2001; among many others). Given a single exemplar of a novel object category, children extend the category label to similarly shaped objects, as opposed to objects that share the same size, texture, or color as the exemplar (e.g., Heibeck & Markman, 1987; Landau, Smith & Jones, 1988). It has been suggested that the shape bias develops over the course of early word learning, i.e., after children have learned many initial object labels (in and around their second birthdays). Once formed, this bias then allows for vastly more rapid learning of subsequent object labels (Samuelson, 2002; Smith, Jones, Landau, Gershkoff-Stowe and Samuelson, 2002). However, it could be that the shape bias is in place well-before children form their initial object labels. In order to examine whether the reliance on shape for artifact objects was present at the outset of word learning, Dewar and Xu (2007) conducted a study with young infants, 9-month-olds, who are just beginning the process of language learning.

Using a violation of expectancy looking time method, Dewar and Xu (2007) explored whether shape is central in determining linguistic reference for artifact objects. During familiarization, a box was opened to reveal two objects inside: either two identical objects or two different objects. Test trials followed the same procedure except,

before the box was opened, the contents were described using either two distinct labels ("I see a wug! I see a dak!"), or the same label twice ("I see a zav! I see a zav!"). Nine-month-olds hearing different labels looked longer at two identical objects versus two different objects. This pattern was reversed when infants heard a label repeated twice. When the objects differed only in shape (Exp. 2), results mirrored that of the first study: infants expected different-shaped artifacts to be marked by distinct labels. However, a third experiment found this expectation didn't hold for artifacts differing only in color. Thus, infants do not merely expect distinct words to refer to different objects: the way in which the objects differ is important. Nine-month-olds expect objects differing in an object relevant property (shape) to be marked by distinct labels, but they don't hold this expectation for objects differing in a property unrelated to artifact kind (color). Thus, sensitivity to shape appears to be present from the outset of word learning. However, these findings leave open the question of whether infants understand that shape is the relevant property for the artifact domain and, for domains other than artifacts, that other perceptual dimensions may be more important.

The question arises as to whether infants have a general expectation that distinct labels refer to distinct shaped objects, regardless of the domain of objects, or, whether infants, like preschoolers, expect labels for objects in different domains to have different perceptual correlates. In order to investigate this question, the current study, employing the same methodology as Dewar and Xu (2007), tests whether infants rely exclusively on shape in their expectations for the application of object labels. Here, instead of presenting infants with artifact objects, as in Dewar and Xu (2007), infants will be shown solid food objects. Findings with preschoolers have shown that when the labeled objects are

identified as kinds of food, children generalize to new instances on the basis of color, not shape (i.e., Lavin & Hall, 2002). The current study asks whether infants, like preschoolers, expect color to be the perceptual correlate for the application of labels for food objects. It is hypothesized that if the objects presented are food, infants will not expect objects marked by distinct labels to differ in shape. Instead, infants might expect food objects marked by distinct labels to differ in color.

The food domain was chosen because, in this domain, shape is not the primary perceptual correlate of kind membership. Thus, by presenting food objects, we are able to examine whether infants expect objects differing in the domain-relevant property (i.e., color) to be marked by distinct labels, or, whether they always expect objects that differ in shape to be marked by distinct labels, regardless of the domain of the labeled objects. However, it should be noted that, unlike the artifact domain, in the domain of food, the perceptual features that correspond to the different food kinds are more varied. For example, for many food objects, color is the relevant feature along which different basic-level food kinds vary (e.g., plums and apricots), however, many subordinate food categories also vary in color (e.g., red and green apples). In addition, the linguistic labels applied to food items include both count nouns and mass nouns, e.g., a piece of cake versus some cake. Because the perceptual feature and labeling information is more varied in the food domain, infants' expectations for labeled food objects may not be as strong as their expectations for labeled artifact objects. Therefore we tested both 9- and 12-month-old infants in the current study.

The results of the current study would speak directly to the issue of whether infants expect labels for objects in different domains to have different perceptual correlates. It

has previously been shown that, for artifact objects, infants expect objects marked by distinct labels to differ in shape. If, for food objects, infants do not expect objects marked by distinct labels to differ in shape, it would indicate that shape is not a privileged perceptual dimension for all object categories.

2.2 Experiment 1

2.2.1 Method

2.2.1.1 Participants

Participants were 48 full term infants, 24 male and 24 female. Half of the participants were 9-month-olds (mean age 9 months, 0 days; range 8 months, 15 days to 9 months, 15 days), while the other half were 12-month-olds (mean age 11 months, 25 days; range 10 months, 28 days to 12 months, 15 days)[6]. Infants were recruited from the Greater Vancouver area by mail and subsequent phone calls. Most infants came from a middle-class, white background with 2% of Hispanic and 12% of Asian infants. The infants received a token gift (a T-shirt with a university logo) after the study. English was the primary language spoken at home for all infants. An additional 11 infants were tested but were excluded due to experimenter error (1), fussiness (8), or parental interference (2).

2.2.1.2 Materials

Objects were presented in a 28 x 19 x 23 cm box constructed out of foam core. The top of the box had an opening that measured 18 x 10 cm and was covered by

[6] Experiment 1 was originally conducted as two separate experiments (the initial experiment was conducted with twenty-four 9-month-olds while a follow-up experiment was conducted with twenty-four 12-month-olds. The procedure was identical for both experiments. Because statistical analysis revealed no systematic differences between the performance of 9- and 12-month-olds in the current procedure, the data have been combined for analysis.

spandex. The front of the box swung open in a door-like movement. Four pairs of objects were used in this experiment: a purple ceramic plum (approximately 9 x 6 cm in size) and an orange ceramic apricot (approximately 9 x 6 cm in size); a bunch of green ceramic grapes (approximately 9 x 6 cm in size) and a bunch of purple ceramic grapes (approximately 9 x 6 cm in size); a slice of red watermelon (approximately 4 x 9 cm in size) and a slice of yellow cantaloupe (approximately 4 x 9 cm in size); a wedge of yellow lemon (approximately 9 x 6 cm in size) and a wedge of green lime (approximately 9 x 6 cm in size). The objects in each pair were identical in material, texture, and shape; thus, the objects in each pair only differed from one another in color. Each of the eight objects had a duplicate. Each object sat atop a square of white foam-core with a magnet on the bottom so that the objects could be spaced a uniform distance apart. See Figure 2.1 for an example of the identical and different-colored food object outcomes.

2.2.1.3 Apparatus

The events were presented on a stage with a display area that measured 94 cm in width and 55 cm in height. The infant sat in a high chair about 70 cm from the stage, with eye level about 8 cm above the floor of the stage. The parent sat next to the infant with his/her back toward the stage. A video camera, set up under the stage, focused on the infant's face and recorded the entire session. The video camera was connected to a 19-inch TV placed in one corner of the room. An observer watched the infant on the TV monitor and recorded the infant's looking times. The observer was not able to see what was presented on the stage nor were they aware of the order of the trials. A key on a laptop computer was pressed during infants' on-target looking. A computer program

written specifically for looking time studies (Hypercard, Version 2.4.1; Pinto, 2002) was used to record the looking times.

2.2.1.4 Design and procedure

The experimenter began by waving a set of keys at all corners of the stage in order to define the window of looking for the observer. During the experiment, the experimenter sat behind the stage in view of the infant at all times.

To begin, the experimenter looked into the top of the empty box, pulling apart the spandex covering in order to look inside. The front door of the box was opened to show the infant that the box was empty. In infant-directed speech, the experimenter said, "Look, it's empty! There's nothing in there!" The door of the box was then closed.

Modeling phase. Each infant was shown a modeling demonstration prior to the familiarization trials. One at a time, the experimenter pretended to eat four of the objects to be shown during the study. The experimenter brought each object to her mouth, pretended to take a bite out of the object and chew (as if a piece had been bitten off). One object from each of the four pairs was 'eaten'. The purpose of the modeling phase was to indicate to the infant that the test objects were plausible food items.

Familiarization trials. Each infant received 4 familiarization trials[7]. Two objects were placed inside the box out of view of the infant. The box was then turned to face the infant. The experimenter pulled apart the spandex on top of the box, so she was looking at the objects inside the box. While looking inside, the experimenter said, "I see something! There's something there! [Baby's name], look!" The front door of the box

[7] The 9-month-olds in the current experiment saw 8 familiarization trials. Familiarization trials 5-8 were a repetition of familiarization trials 1-4.

was then opened to reveal the objects inside. The experimenter lowered her head and eye gaze to ensure that she was not making eye contact with the infant while the box contents were visible. Infant looking times were recorded. When the infant turned away for two consecutive seconds, the trial ended. The door of the box was closed and the box was turned around so that new objects could be placed inside the box to begin the next trial. Objects from each of the four pairs (purple plum-orange apricot, green grapes-red grapes, red watermelon-orange cantaloupe, yellow lemon-green lime) were shown during the familiarization trials (either both objects of the pair were shown (different objects), or one object from the pair was shown with its duplicate (identical objects)). Infants saw one of four possible orders (identical (i), different (d), identical (i), different (d); didi, diid, iddi). Which objects were shown and which side of the box an object was positioned on were counterbalanced across infants.

Test trials. Each infant received four test trials. Test trials were identical to the familiarization trials with one critical difference: before opening the front of the box, the experimenter looked into the top of the box and labeled the objects inside with either the same label twice (i.e., "I see a zav! I see a zav! There's a zav! There's a zav! [Baby's name], a zav! [Baby's name], a zav!"), or with two different labels (i.e., "I see a wug! I see a dak! There's a wug! There's a dak! [Baby's name], a wug! [Baby's name], a dak!"). Each sentence was spoken in infant-directed speech as the experimenter looked into the box. Infants saw two unexpected and two expected trials. For an expected outcome, an infant either heard two different labels applied to the objects inside the box and two different objects were revealed when the box was opened or, conversely, an infant heard one repeated label applied to the objects inside the box and two identical objects were

revealed when the box is opened. For an unexpected outcome, an infant either heard two different labels applied to the objects inside the box and two identical objects were revealed when the box was opened or, conversely, an infant heard one repeated label applied to the objects inside the box and two different objects were revealed when the box was opened. The eight objects were labeled with nonsense words (fep, zav, wug, dak, toma, blicket, muba, and tupple), and a particular object was always labeled with the same nonsense word. The same objects shown during familiarization were shown on the test trials; however, the order of object-pair appearance differed. The test trials included two instances of expected and unexpected outcomes such that all four of the label-by-object pair outcomes were shown (repeated label-identical objects (expected), different labels-different objects (expected), repeated label-different objects (unexpected), different labels-identical objects (unexpected)). Infants were shown one of four possible outcome orders (expected (e), unexpected (u), expected (e), unexpected (u); ueue; euue, ueeu). Whether an identical or different object outcome was presented first and whether objects were first labeled with repeated or different labels were counterbalanced across infants. See Figure 2.2 for a schematic representation of the procedure.

2.2.2 Results

The results of Experiment 1 are shown in Figure 2.3. An alpha level of 0.05 was used in all statistical analyses. Preliminary analyses found no effect of gender or test trial order (whether the expected or unexpected trial was presented first). Subsequent analyses were collapsed over these variables. All infants were off-line observed by a second

observer who was completely blind to the order of object outcome. Interscorer reliability averaged 89%[8].

Familiarization trials. Averaging across all familiarization trials, it was found that infants had a marginal tendency to look slightly longer when two different-colored objects were revealed (M = 11.79s, SD = 5.02) than when two identical objects were revealed (M = 10.05s, SD = 3.51), $t(47) = 1.98$, $p = .06$.

Test trials. Infants' looking times to the test outcomes were compared by means of a 2 × 2 repeated measures analysis of variance (ANOVA), with number of labels (one vs. two) and object-pair outcome (identical vs. different) as within-subject factors. The analysis revealed a word × outcome interaction ($F(1,46) = 7.29$, p = .01; effect size (ηp^2) = .14). Planned comparisons were performed for each label number (one repeated label vs. two different labels) in order to determine whether infants looked longer to one of the two object outcomes (either identical food objects or different-colored food objects). When infants heard the box contents described using one label repeated twice, they looked significantly longer when two different-colored food objects were revealed (the unexpected outcome) (M = 8.90s, SD = 5.50) as when two identical food objects were revealed (the expected outcome) (M = 6.80s, SD = 3.67), $t(47) = -3.05$, $p < .01$; effect size (d) = .45. When infants heard the box contents described using two distinct labels, they looked slightly longer when two identical food objects were revealed (the unexpected outcome) (M = 8.66s, SD = 7.06) then when two different-colored food

[8] For each trial (familiarization and test), and for every infant, the percent agreement between the primary and secondary observers was calculated. The percent agreement was calculated as the percentage of total time (in tens of seconds) inspected, in which there was agreement between the two observers. Interscorer reliability was calculated as the mean, or average, percent agreement across all of the trials. In each of the subsequent experiments of this thesis, interscorer reliability will be calculated in this manner.

objects were revealed (M = 7.72s, SD = 4.66), although this different was not significant, $t(47) = 0.97$, $p = .34$; effect size (d) = .16. Examination of individual infants' pattern of looking, by means of non-parametric analyses, yielded similar results. When one repeated label was applied to the box contents, 31 of 48 infants looked significantly longer when two different objects were revealed (unexpected outcome) than when two identical objects were revealed (expected outcome), Wilcoxon Signed Ranks Test, $z = -2.83$, $p < .01$. Conversely, when two distinct labels were applied to the box contents, 28 of the 48 infants looked longer when two identical objects were revealed (unexpected outcome) then when two different objects were revealed (expected outcome), however, this pattern was not significant, Wilcoxon Signed Ranks Test, $z = -0.91$, $p = .36$.

2.2.3 Discussion

When the unseen contents of the box were described using one repeated label, 9- and 12-month-old infants expected to see identical food objects revealed inside the box and found it unexpected if two different-colored food objects were revealed. However, when the unseen contents of the box where referred to using two distinct labels, infants looked equivalently whether the box door opened to reveal two different-colored food objects or two identical food objects. A possible reason as to why infants did not appear surprised to see two identical food objects after hearing two distinct labels is that this looking pattern requires infants to overcome their marginal baseline preference for the different-colored food object outcome. Thus, in order for infants to look longer at the identical object pair (the unexpected outcome) after hearing two distinct labels, they would have to overcome this preference. It is not the case, however, that infants simply preferred to look longer at the different-colored food object outcome in general, because

there was no main effect of object outcome. This result is compelling because Exp. 3 of Dewar and Xu (2007), using an identical procedure, demonstrated that when the objects presented were either identical or different-colored artifacts, 9-month-olds did not expect one repeated label to refer to identical artifact objects. In fact, in Exp. 3, Dewar and Xu (2007) found a main effect of object outcome where, regardless of the number of type of labeling, infants preferred to look longer at two different-colored artifact objects. Hence, the findings from the current experiment offer evidence that infants respond differentially depending on whether the objects presented are artifacts or food objects. It should be noted that this pattern of results replicates the findings of Exp. 1 in Dewar and Xu (2007)'s artifact study where the objects presented were either identical or completely different artifact objects.

While the results of Exp. 1 indicate that infants are demonstrating some sensitivity to color when presented with food objects in a linguistic context, Exp. 2 explores whether infants are sensitive to shape when presented with food objects.

2.3 Experiment 2

2.3.1 Method

2.3.1.1 Participants

Participants were 48 full term infants, 24 male and 24 female. Half of the participants were 9-month-olds (mean age 9 months, 0 days; range 8 months, 11 days to 9 months, 15 days)), while the other half were 12-month-olds (mean age 12 months, 0 days; range 11 months, 16 days to 12 months, 16 days)[9]. All infants were recruited from

[9] Experiment 2 was originally conducted as two separate experiments (the initial experiment was conducted with twenty-four 9-month-olds while a follow-up experiment was conducted with twenty-four 12-month-olds. The procedure was identical for both

the same population as in Experiment 1, but none participated in the first experiment. Most infants came from a middle-class, non-Hispanic white background with about 13% of Asian infants. The infants received a token gift (a T-shirt with a university logo) after the study. English was the primary language spoken at home for all infants. An additional eight infants were tested but were excluded due to fussiness (7) or parental interference (1).

2.3.1.2 Materials and apparatus

All materials and apparatus were the same as were used in Experiment 1. Four pairs of objects were used in this study. Each object used in Experiment 1 was duplicated except that the shape of the original object was changed resulting in an identical pair that differed only in shape. The objects in each pair were identical in material, texture, and color; thus, the objects in each pair only differed from one another in shape. Every object had a duplicate (see Figure 2.1).

2.3.1.3 Design and procedure

Identical to that of Experiment 1.

2.3.2 Results

The results of Experiment 2 are shown in Figure 2.4. An alpha level of 0.05 was used in all statistical analyses. Preliminary analyses found no effect of gender or test trial order (whether the expected or unexpected trial was presented first). Subsequent analyses were collapsed over these variables. Half of the infants were randomly selected and off-

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experiments. Because statistical analysis revealed no systematic differences between the performance of 9- and 12-month-olds in the current procedure, the data have been combined for analysis.

line observed by a second observer who was completely blind to the order of object outcome. Interscorer reliability averaged 92%.

Familiarization trials. Averaging across all of the familiarizations trials, it was found that infants looked about equally whether two different-shaped objects were revealed (M = 10.33s, SD = 4.54) or when two identical objects were revealed (M = 10.27s, SD = 4.39), $t(47) = 0.08$, $p = .94$.

Test trials. Infants' looking times to the test outcomes were compared by means of a 2 × 2 repeated measures ANOVA, with number of labels (one vs. two) and object-pair outcome (identical vs. different) as with-in subject factors. The analysis revealed no main effects nor significant interactions ($F(1, 46) = 0.15$, $p = .70$; effect size (ηp^2) < .01). Planned comparisons were performed. When infants heard the box contents described using a single label repeated twice, they looked about equally when two different objects were revealed (the unexpected outcome) (M = 7.01s, SD = 5.00) and when two identical objects were revealed (the expected outcome) (M = 7.26s, SD = 5.40), $t(47) = 0.25$, p = .80; effect size (d) = .05. When infants heard the box contents described using two distinct labels, they looked about equally when two identical objects were revealed (the unexpected outcome) (M = 7.08s, SD = 5.53) than when two different objects were revealed (the expected outcome) (M = 7.35s, SD = 5.27), $t(47) = -0.30$, $p = .77$; effect size (d) = .05. Examination of individual infants' pattern of looking, by means of non-parametric analyses, yielded similar results. When one repeated label was applied to the box contents, 22 of 48 infants looked longer when two different objects were revealed (unexpected outcome) than when two identical objects were revealed (expected outcome), which was not a significant difference, Wilcoxon Signed Ranks Test, z = -

0.17, $p = .87$. Conversely, when two distinct labels were applied to the box contents, only 19 of the 48 infants looked longer when two identical objects were revealed (unexpected outcome) then when two different objects were revealed (expected outcome); again, this pattern was not significant, Wilcoxon Signed Ranks Test, $z = -1.11$, $p = .27$.

2.3.3 Discussion

Both 9- and 12-month-old infants did not expect two distinct labels to refer to two different-shaped food objects. When the unseen contents of the box where referred to using two distinct labels, infants did not look differentially when the box door opened to reveal either two different-shaped food objects or two identical food objects. Conversely, when the box contents were described using one repeated label, infants also did not look differentially when the door opened to reveal either two identical food objects or two different-shaped food objects.

The results of the current experiment are striking because Dewar and Xu (2007) demonstrated, using an identical procedure, that when the objects presented were artifacts, 9-month-olds expected two distinct labels to refer to different-shaped objects. Thus, the current result provides evidence that, for infants, distinct labels do not always refer to distinct shapes. The findings of Experiments 1 and 2 suggest that infants may respond differentially to a salient perceptual difference depending on the domain of the labeled objects.

2.4 General discussion

It has previously been established that 9-month-old infants expect artifact objects differing in a domain relevant property (shape) to be marked by distinct labels, but they do not hold this expectation for objects differing in a property unrelated to artifact kind

(color) (Dewar & Xu, 2007). The current study investigates whether infants expect labels for objects in different domains to have different perceptual correlates or whether shape has a privileged status for all object domains early on. We address this question by looking at a different object domain: food, a domain of objects in which shape is less indicative of kind. In the current study, we employed the same methodology as Dewar and Xu (2007), except that food objects were presented instead of artifact objects. We hypothesized that if the objects presented were food, infants would not expect objects marked by distinct labels to differ in shape; instead, they may expect objects marked by distinct labels to differ in color (because color is a domain relevant property for food objects).

In the current study with food objects, 9- and 12-month-olds did not demonstrate any evidence of shape sensitivity when provided with labeling information. In stark contrast to the results of Dewar and Xu (2007) with artifact objects, infants in the current study did not expect food objects differing in shape to be marked by distinct labels. These findings indicate that shape is not a privileged perceptual dimension for all object categories.

In addition, we found that both 9- and 12-month-old infants demonstrate some evidence of color sensitivity when provided with labeling information. Infants who heard the hidden contents of a box referred to with one repeated label expected identical food objects to be revealed when the box door opened and looked longer when the door opened to reveal different-colored food objects. However, infants did not expect distinct labels to refer to different-colored objects: having heard the box contents referred to using distinct labels, infants looked equally long when the door opened to reveal identical

objects and different-colored objects. These results indicate that the color difference did not produce a strong effect. However, even the weak color effect found in Exp. 2 is evidence of a domain difference. When compared to the results of Dewar & Xu (2007), where 9-month-olds demonstrated zero sensitivity to color when presented with artifact objects in an identical procedure, it is apparent that infants respond to the perceptual dimension of color differentially depending on whether they are presented with artifact or food objects.

Why are the results of the current experiments with food objects weaker than the previous results reported with artifact objects? The obtained pattern of results may reflect the reliability of the feature in question to predict kind membership for each domain of objects. It has been proposed that correlated linguistic cues help young children discover the regularities that characterize early noun categories (e.g., Yoshida & Smith, 2005). In the domain of artifacts, object kinds are simply structured and based primarily on shape. Thus, for artifacts, there is a very robust correlation between labels and shape: artifact objects differing in shape are marked by different basic-level count nouns. However, for the domain of food, object kinds are more richly structured and the perceptual features that correspond the different food kinds are more varied. Food kinds can be most readily distinguished by their taste: food objects differing in taste are marked by basic-level nouns. Since we do not have visual access to taste, this property is approximated by attending to features with which it is associated: color, texture, and smell. Thus, for many food objects, color can be used to distinguish basic-level food kinds. However, color is not always indicative of kind for food objects. Indeed, many subordinate food categories vary in color (e.g., red and green apples). Thus, food objects that differ in color

are usually, but not always, marked by different basic-level count nouns. Because the visual features associated with taste (i.e., color, texture, smell) are not perfectly correlated among different food kinds, infants may have a harder time learning the relevant feature-label correlations in the food domain as compared to the artifact domain. In addition, food kinds are sometimes identified as individuated objects (e.g., an apple or a banana) and sometimes identified as kinds of substances (e.g., apple sauce), making the linguistic input messier (pun intended!) therefore the correlational learning more difficult. It is also the case that infants in this age bracket (9 to 12 months), most likely, have significantly less experience interacting with solid food objects than they have interacting with artifact objects, giving them less opportunity to observe the feature regularities of objects in the food domain.

How are infants able to learn these domain differences? In order to evidence a domain difference between artifact and food objects, infants must be able to identify the object-relevant perceptual feature of each object domain. One way in which infants may be accomplishing this task is by keeping track of the correlations between feature variability and labeling (Smith et al. 2002). An examination of the feature-label co-occurrences for each object domain yields two distinct patterns. For artifacts, there is a very robust correlation between labels and shape: different labels mark objects that differ in shape. However, for the domain of food, the perceptual features that correspond the different food kinds are more varied, yielding less reliable relationship between labels and color: different labels usually, but not always, mark objects that differ in color. In certain cases, the features of texture, smell, and shape can also be kind-relevant for food

objects. However, unlike artifacts, shape is not the pre-dominant feature used to indicate kind for food objects.

Given that traditional word learning studies show very limited sensitivity to domain differences in domain relevant features before two years of age, why are infants able to demonstrate sensitivity to object-relevant features in a linguistic context in the current study? For a novice word learner, forging a link between a label and an object is quite a computationally demanding task (e.g., Fennell & Werker, 2003; Stager & Werker, 1997; Werker, Cohen, Lloyd, Casasola, & Stage, 1998). Young infants may have expectations about labels and their referents, but are not able to demonstrate these expectations in standard word learning tasks because of the processing requirements inherent in forming the initial word-object mappings. The benefit of the current design is that it allows us to test infants' expectations about the ways in which labels impact object representations, in general, as opposed to testing infants' expectations about particular word-object mappings (as in a word extension task).

The findings from the current study, as well as Dewar & Xu (2007), using the same method, provide converging results that infants appear to hold domain-relevant expectations about labeled objects. The results show that young infants do not privilege (or evidence a bias for) shape in all linguistic contexts: infants do not expect labels for different object domains to have the same perceptual correlate (i.e., shape). Presumably the domain differences found in the current study are learned, and one way by which this learning may be accomplished is by keeping track of the correlations between feature variability and labeling.

Figure 2.1 Examples of an identical and a different (different-shaped or different-colored) object outcome from Experiments 1 and 2.

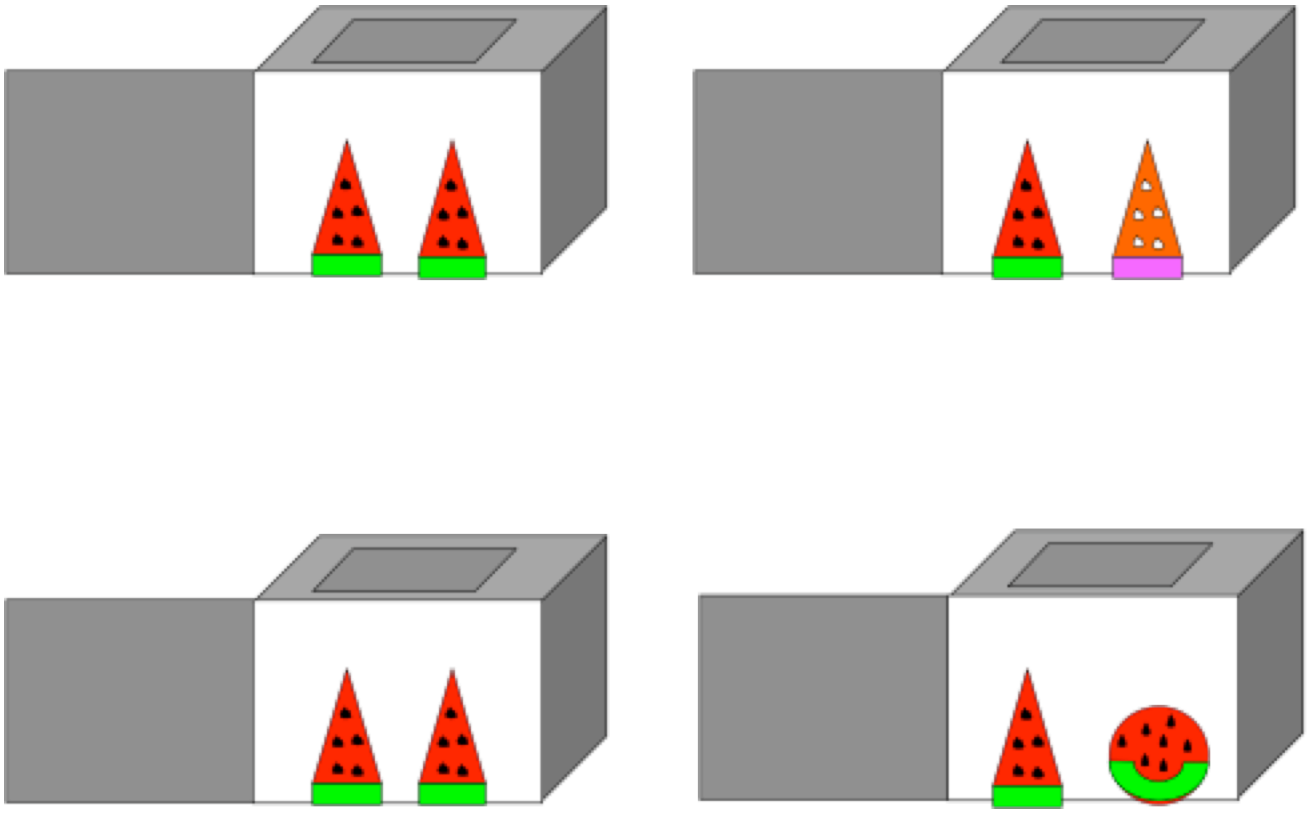


Figure 2.2 A schematic representation of the experimental procedure for the test trials for Experiment 1.

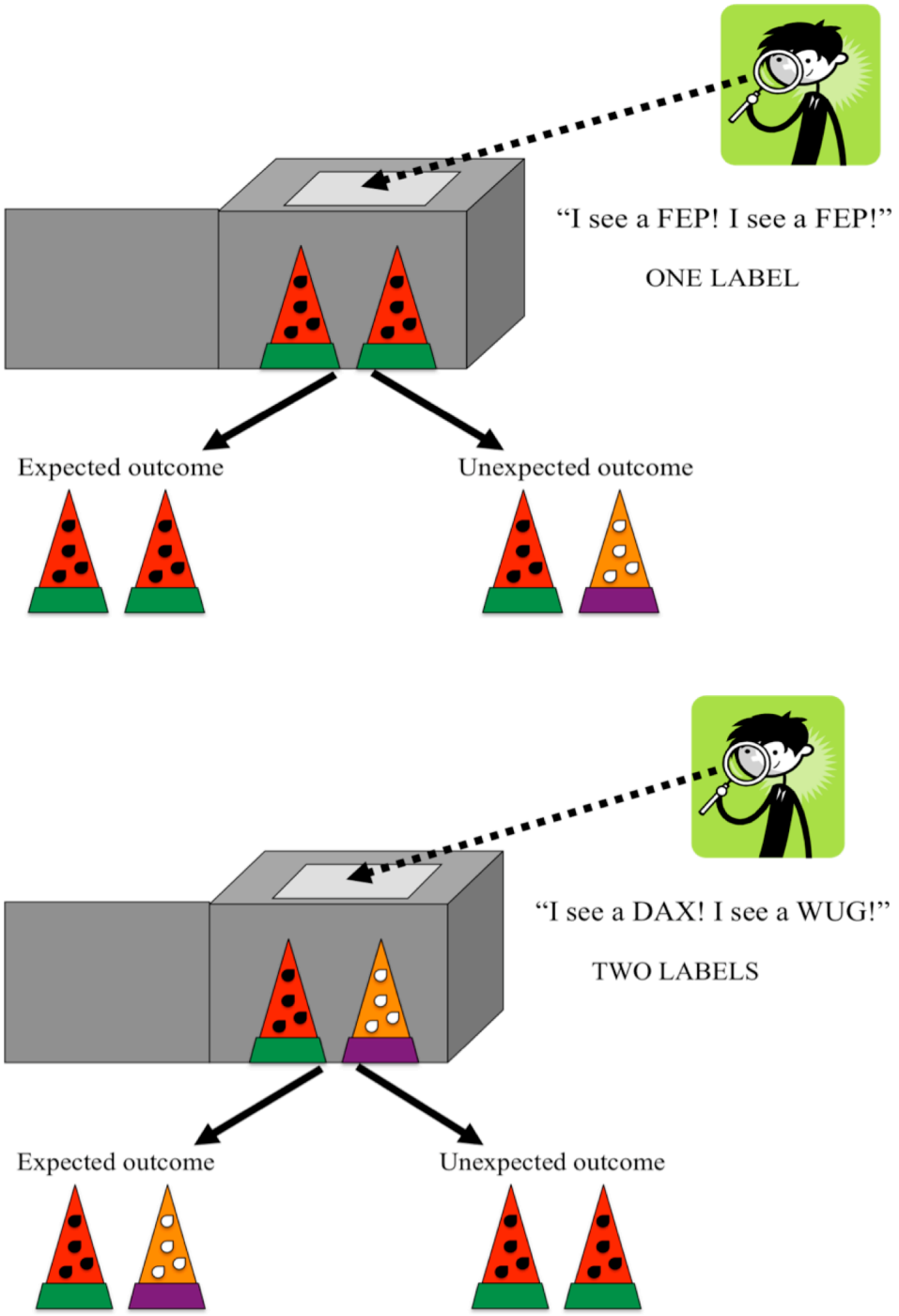


Figure 2.3 Mean looking time (s) as a function of the number of distinct labels heard and the revealed object pair outcome for Experiment 1.

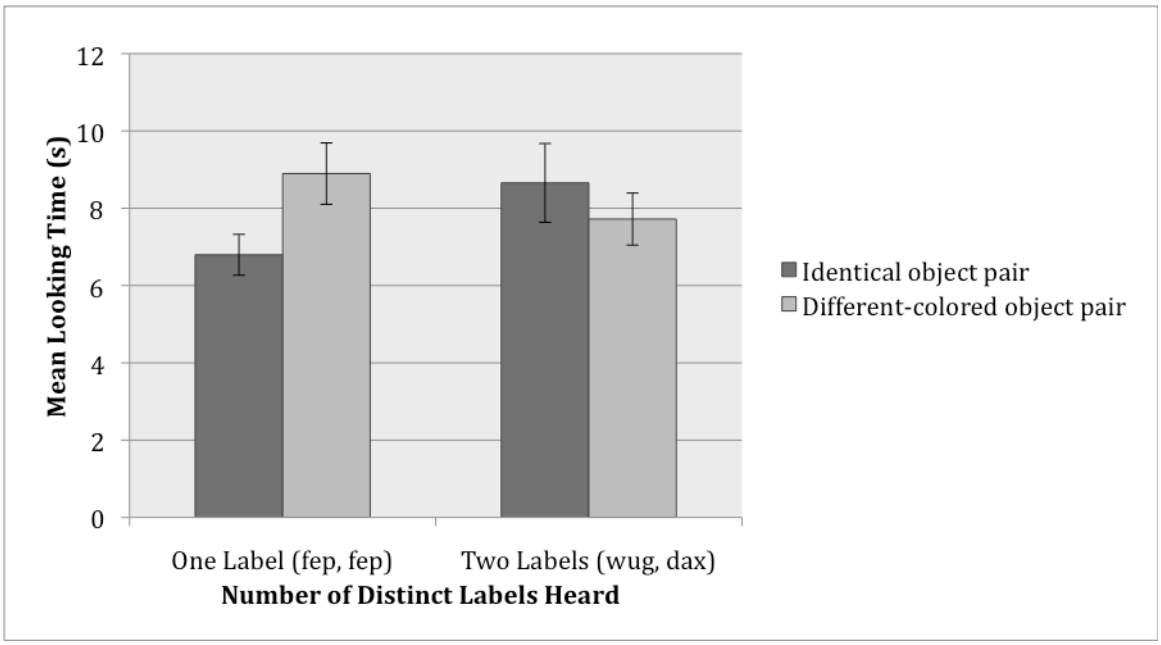
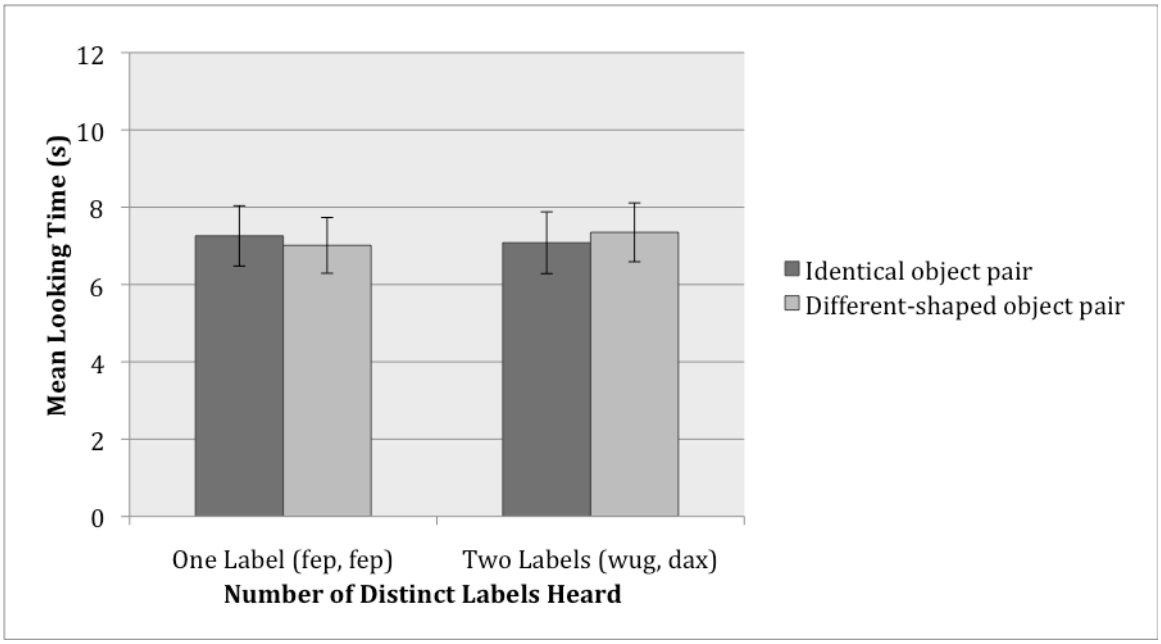


Figure 2.4 Mean looking time (s) as a function of the number of distinct labels heard and the revealed object pair outcome for Experiment 2.



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Chapter 3. Do Early Nouns Refer to Kinds or Distinct Shapes? Evidence from 10-Month-Old Infants[10]

3.1 Introduction

Do early words for objects refer to kinds or distinct shapes? This is a long-standing debate in the study of language development. Many studies with young children provide evidence for a 'shape bias', i.e., objects that share the same shape should also share a label (e.g., Landau, Smith, & Jones, 1988; Samuelson & Smith, 2005; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002; Imai & Gentner, 1997; Yoshida & Smith, 2001; among many others). The question arises as to whether early words map onto distinct shapes or whether early words refer to kinds and shape is a proxy for kind membership (Markson, Diesendruck, & Bloom, 2008; Samuelson & Bloom, 2008; Soja, Carey, & Spelke, 1991).

Representations of kinds specify categorization under concepts such as *dog*, *ball*, and *car*, categories of objects united by functional/causal features, as well as perceptual features. According to one analysis, namely psychological essentialism, members of the same kind share both internal, non-obvious as well as external, perceptual properties. The perceptual similarity reflects, and is caused by, shared deeper properties (Gelman, 2003, Medin & Ortony, 1989). In fact, it is possible to have objects that look different to be members of the same kind (e.g., a poodle and a Chihuahua, a telephone shaped like a banana and a telephone shaped like a stuffed dog) as well as to have objects that look very similar or the same to be members of different kinds (e.g., a baseball and an orange,

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[10] A version of this chapter has been published and is reprinted with permission from © 2009 Wiley-Blackwell. Dewar, K. M. and Xu, F. (2009). Do early nouns refer to kinds or distinct shapes? Evidence from 10-month-old infants. *Psychological Science, 20*, 252-257.

a rock and a fake rock made of foam).

There is evidence to suggest that older children rely on count noun labels to make inferences about internal object properties. For example, Gelman and Coley (1990) showed two-year-olds pictures of familiar, prototypical objects and reminded them of a familiar property of that object. Children were then tested on whether they generalized that property to another object that is similar in appearance or an object that was different in appearance but was labeled with the same count noun. When the object was not labeled, children generalized the property to a perceptually similar object. In the absence of labeling information children rely on perceptual cues (i.e., the shape of the object) for categorization. When a label was provided, two-year-olds inferred that objects that shared the same label would also share the same property. Thus, by two years of age, children who hear the same label applied to perceptually dissimilar objects, assume that the objects are members of the same category, or kind, and expect those objects to share non-obvious, internal properties (e.g., Davidson & Gelman, 1990; Gelman & Coley, 1990; Gelman & Markman, 1986; Kalish & Gelman, 1992). This ability has also been demonstrated in younger children (Graham & Kilbreath, 2007; Graham, Kilbreath, & Welder, 2004; Welder & Graham, 2001). For example, in a recent study by Graham and Kilbreath (2007), when objects were labeled with the same count noun, both 14- and 22-month-olds generalized non-obvious properties to objects that shared very minimal perceptual similarity. If early words refer to object kinds, and not just distinct shapes, infants should expect other kind-relevant, non-obvious properties to be predicted by labeling.

In the absence of labeling information, object shape is not the only cue used by

older children in service of object categorization. There is evidence suggesting that intention may override shape information in word learning. Gelman and Ebeling (1998) showed 2- and 3-year-old children line drawings roughly shaped like various namable objects. For half the participants, each line drawing was described as depicting a shape that was created intentionally (e.g. someone painted a picture). For the remaining participants, each drawing was described as depicting a shape that was created accidentally (e.g. someone spilled some paint). Participants were asked to name each picture. The findings suggest that subjects use shape as the basis of naming primarily when the shapes were intentional. These results suggest that, although shape does play an important role in children's early naming, other factors are also important, including the mental state of the picture's creator (see also Bloom & Markson, 1998). More recent studies provide additional evidence that 18-month-old infants take into account conceptual knowledge (e.g., describing the object as "happy") in labeling (Booth, Waxman, & Huang, 2005). Such findings imply that, for young children, labels for objects (and representations of those objects) are not wholly determined by shape similarity; shape may be being used as a proxy for kind membership.

Thus, by 14-18 months of age, children expect words for object categories to refer to kinds. However, it remains an open question whether infants, who are at the beginning of word learning, have the same expectation. It may be the case that infants expect words to refer to distinct shapes and, later in development; they realize that shape is correlated with kind membership.

A recent set of studies from our lab demonstrated that 9-month-old infants expect objects differing in a kind relevant property (shape) to be marked by distinct labels, but

they do not hold this expectation for objects differing in a property unrelated to kind (color) (Dewar & Xu, 2007). These findings, however, are ambiguous as to whether infants who are on the cusp of learning words understand that shape is a salient cue to kind membership, or if they have simply formed an association between labeling and shape, such that objects that are referred to by the same label share the same shape and objects that are marked by distinct labels have different shapes.

Because shape is highly correlated with kind membership, it is very difficult to tease these interpretations apart, especially with very young word learners. We investigate this issue by asking if infants expect internal properties of objects to be predicted by labeling.

The current study makes two novel contributions to the literature on how labeling influences infants' representations of object properties. First, we employ a more stringent test of the role of perceptual similarity and labeling. In previous studies by Graham and colleagues (Graham & Kilbreath, 2007: Graham, Kilbreath, & Welder, 2004; Welder & Graham, 2001), objects that were termed 'high-similarity' were similarly shaped and objects that were termed 'low-similarity' were differently shaped. Here, we use <u>identical</u> and <u>different-looking</u> objects (in shape, color, and texture) as our contrasting pairs. We test to see if labeling is such a powerful cue for non-obvious, internal object properties that it may, in fact, override perceptual similarity completely, both for identical and different-looking pairs of objects. Second, we develop a looking time method that has not been used before in these types of studies, and this method allows us to test younger infants who are just on the cusp of learning words for objects, namely, 10-month-olds. Previous studies, in contrast, used a manual manipulation task with older infants who

were between 13 and 24 months (Graham et al. 2004; Welder & Graham, 2001). Our study tests to see if younger infants might approach the task of predicting the non-obvious properties of objects differently from older, more expert word learners, given perceptual and linguistic information.

In the current study, infants were presented with pairs of objects that were demonstrated to make sounds. In this between-subjects design, half of the infants were shown only identical-looking object pairs, while the other half were shown only different-looking object pairs. During familiarization, each infant was familiarized with one object pair that made the same sound and a second object pair that made two different sounds. On the test trials, object pairs were labeled. Labeling also varied between subjects: for half the infants, object pairs were labeled with one repeated count noun label and, for the other half, object pairs were labeled with two distinct labels. The dependent measure was infant looking time. The question of interest was whether infants could use the linguistic information to predict whether a particular pair of objects should make the same sound or different sounds, regardless of the object pairs' perceptual similarity. If, for 10-month-olds, labels reference kind, they should expect the internal properties of the objects (properties determined by kind membership) to accord with the objects' label. Thus, regardless of the perceptual similarity of the object pair (whether identical- or different-looking), upon hearing the pair labeled with the same count noun, infants should expect the object pair to make identical sounds. Conversely, despite object pair appearance, upon hearing the pair labeled with two distinct count nouns, infants should expect the object pair to make different sounds. If, however, young infants merely expect that distinct labels mark distinct shapes, labeling should not lead to differential

predictions about the internal properties of the object pairs. Thus, regardless of the labeling information provided, infants should rely on the appearance of the object pair to drive their expectations regarding the properties of the object pairs -- identical pairs should make identical sounds and different-looking pairs should make different sounds.

3.2 Methods

3.2.1 Participants

Participants were 64 full term infants, 34 male and 30 female (mean age 10; 2 [months; days]; range 9; 15 to 10; 29). Each of four conditions included 16 infants. All infants were recruited from the Greater Vancouver area by mail and subsequent phone calls. Most infants came from a middle-class, non-Hispanic white background with 20% of Asian infants. The infants received a token gift (a T-shirt or bib with a university logo) after the study. English was the primary language spoken at home for all infants. An additional 13 infants were tested but were excluded due to experimenter error (2) fussiness (8) or parental interference (3).

3.2.2 Materials

Two pairs of objects were used in the study: a plush dog-like toy (approximately 13 x 11 cm in size) and a plush toy fish (approximately 10 x 14 cm in size); a cylinder covered with multicolored beads (approximately 14 x 6 cm in size) and a rectangle covered in foam flowers (approximately 12 x 7 cm in size). Each of the four objects produced a distinct sound when manipulated by the experimenter (the dog-like toy squeaked when it was compressed, the plush fish contained beads that rattled when shook, the cylinder contained jingle bells that jingled when moved, and the rectangle contained rocks which rattled when shook). Each of the four objects had two identical-

looking copies: one identical copy that made the same sound as the original object and one identical-looking copy that produced the sound made by the object's pair. A total of 12 objects were used in the experiment. The dog-like toy and the fish were only paired with each other and the rectangle and the cylinder were only paired with each other. Depending on assigned condition, an infant would either see all four objects or identical objects from each of the object pairs (i.e., identical fish and identical rectangles).

3.2.3 Apparatus

The events were presented on a stage with a display area that measured 94 cm in width and 55 cm in height. The infant sat in a high chair about 60 cm from the stage, with eye level slightly above the floor of the stage (about 8 cm). The parent sat next to the infant with his/her back toward the stage, and she/he was instructed not to look at the stage during the study. A video camera, set up under the stage, focused on the infant's face and recorded the entire session. The video camera was connected to a 19-inch TV placed in one corner of the room. An observer watched the infant on the TV monitor and recorded the infant's looking times. The observer was not able to see what was presented on the stage nor were they aware of the order of the trials. A key on a laptop computer was pressed during infants' on-target looking. A computer program written specifically for looking time studies (Xhab; Pinto, 2002) was used to record the looking times.

3.2.4 Design and procedure

Four conditions were created by crossing the two levels of each of the independent variables (object pair appearance [identical vs. different-looking] and number of distinct labels heard [one vs two]). Infants were randomly assigned to one of four conditions: an Identical Objects-Identical Labels Condition, an Identical Objects-

Different Labels Condition, a Different Objects-Identical Labels Condition, and a Different Objects-Different Labels Condition. Each infant received 4 familiarization trials and 4 test trials.

Familiarization trials. A pair of objects was placed on the stage in front of the infant. The objects in the pair were either identical or different-looking, depending on the assigned condition of the infant. Each infant, regardless of condition, was presented with one object pair that made identical sounds and one object pair that made different sounds.

For each object in the pair, the experimenter picked up the object and demonstrated the sound it made. After each object's sound was demonstrated twice, the experimenter left the object pair positioned at the front of the stage and in infant-directed speech, said, "Look, [Baby's name], look!" The experimenter lowered her head and eye gaze to ensure that she was not making eye contact with the infant. Infant's looking times were recorded. When the infant looked away for 2 consecutive seconds, the trial ended. The object pair was then removed from the stage. A new object pair was placed on the stage in order to begin the next trial.

Objects from both the object pairs (dog-fish, cylinder-rectangle) were shown during the familiarization trials. Familiarization trials 3 and 4 were a repetition of trials 1 and 2. Which side of the stage an object was positioned on and the order of object pair presentation was counterbalanced across infants.

Test trials. Test trials were identical to familiarization trials with one critical difference: before demonstrating the sounds made by the objects in the pair, the experimenter labeled the objects in the pair with either the same label twice (i.e., "There's a zav! There's a zav!"), or with two different labels (i.e., "There's a wug!

There's a dak!"), depending on the assigned condition of the infant. Each sentence was spoken in infant-directed speech as the experimenter picked up and looked at the object being labeled. See Figure 3.1 for a schematic representation of the test trials depicting the manipulation of the independent variables (object pair appearance and number of labels heard) in each of the four conditions.

The 4 objects were labeled with nonsense words (fep, zav, wug, dak). Throughout the study, a particular object was always labeled with the same nonsense word; thus, each object pair was always labeled with the same label pair. The same objects from each of the two pairs (dog-fish, cylinder-rectangle) that were shown during the familiarization trials were shown on the test trials. The four test trials included two instances of expected and unexpected outcomes such that each outcome was shown twice. The order of outcome (whether the infant saw an expected or unexpected trial first, whether the same sound or different sound object pair was presented first) was counterbalanced across infants.

Identical Objects-Identical Labels Condition. Infants in this condition saw only identical-looking object pairs. On the test trials, infants heard a given object pair labeled with one repeated label (i.e., "There's a zav! There's a zav!"). Hearing an identical-looking object pair being labeled with one repeated label should lead to the expectation that both objects in that pair should make the same sounds and, thus, it would be unexpected for the objects in the object pair to produce different sounds. In this condition, the same-sound object pair constituted the expected outcome, whereas the different-sound object pair constituted the unexpected outcome.

Identical Objects-Different Labels Condition. Infants in this condition saw only identical-looking object pairs. On the test trials, infants heard a given object pair labeled with two distinct labels (i.e., "There's a wug! There's a dak!"). Hearing an identical-looking object pair being labeled with two distinct labels should lead to the expectation that objects in that pair should make different sounds and, thus, it would be unexpected for both the objects in the object pair to produce the same sounds. In this condition, the different-sound object pair constituted the expected outcome, whereas the same-sound object pair constituted the unexpected outcome.

Different Objects-Identical Labels Condition. Infants in this condition saw only different-looking object pairs. On the test trials, infants heard a given object pair labeled with one repeated label (i.e., "There's a zav! There's a zav!"). Hearing a different-looking object pair being labeled with one repeated label should lead to the expectation that both objects in that pair should make the same sounds and, thus, it would be unexpected for the objects in the object pair to produce different sounds. In this condition, the same-sound object pair constituted the expected outcome, whereas the different-sound object pair constituted the unexpected outcome.

Different Objects-Different Labels Condition. Infants in this condition saw only different-looking object pairs. On the test trials, infants heard a given object pair labeled with two distinct labels (i.e., "There's a wug! There's a dak!"). Hearing a different-looking object pair being labeled with two distinct labels leads to the expectation that objects in that pair should make different sounds and, thus, it would be unexpected for both objects in the object pair to produce the same sounds. In this condition, the different-

sound object pair constituted the expected outcome, whereas the same-sound object pair constituted the unexpected outcome.

3.3 Results

An alpha level of 0.05 was used in all statistical analyses. Preliminary analyses found no effects of gender or object animacy. Subsequent analyses collapsed over these variables. All infants were off-line observed by a second observer who was completely blind to the order of the trials. Interscorer reliability averaged 98%.

Familiarization trials. Averaging across all 4 of the familiarizations trials, a 2 x 2 analysis of variance (ANOVA) with object-pair appearance (identical vs. different) and sound (same vs. different) as factors revealed a significant interaction, $F(1,32) = 5.59$, $p = .02$; effect size (ηp^2) = .08. Infants who saw only identical object pairs looked equivalently to the object pair that produced different sounds ($M = 12.23$ s, $SD = 7.61$) and to the object pair that produced the same sounds ($M = 11.28$ s, $SD = 6.50$), $t(31) = -.86$, $p > .05$; effect size (d) = .15. However, infants who saw only different-looking object pairs looked significantly longer to the object pair that produced identical sounds ($M = 14.77$ s, $SD = 6.99$) than to the object pair that produced different sounds ($M = 11.81$ s, $SD = 5.41$), $t(31) = 2.40$, $p = .02$, effect size (d) = .42.

Test trials. The mean looking times to the same-sound object pair and the different-sound object pair for each of the four conditions is presented Table 3.1. Infants' looking times to the test outcomes were analyzed by means of a 2 × 2 × 2 repeated measures ANOVA, with sound (same vs. different) as a within-subject factor and number of labels (one vs. two) and object-pair appearance (identical vs. different) as between-

subject factors. There was a statistically significant sound (same vs. different) by number of labels (one vs. two) interaction, $F(1, 60) = 8.46$, $p < .01$, effect size (ηp^2) = .12. Whether shown identical-looking object pairs or different-looking object pairs, when infants heard the object in the pair referred to with the same label, they looked significantly longer when the pair made two different sounds than when the pair made identical sounds, $t(31) = -2.11$, $p = .04$, effect size (d) = .37. Conversely, whether shown identical-looking object pairs or different-looking object pairs, when infants heard the object in the pair referred to with two distinct labels, they looked significantly longer when the pair made identical sounds than when the pair made different sounds, $t(31) = 2.09$, $p = .05$, effect size (d) = .37. There were no other main effects, two-way interactions, or a three-way interaction ($p > .1$). In other words, object appearance did not have a significant effect on how infants predicted internal properties of objects.

3.4 Discussion

In the current study, we found that 10-month-old infants used linguistic information (count noun labels) to predict whether a particular pair of objects should make the same sound or different sounds, regardless of the object pairs' perceptual similarity or dissimilarity. Infants who heard two distinct labels expected the object pair to make different sounds, whereas infants who heard one repeated label expected the object pair to make the same sound. Importantly, this effect was independent of the appearance of the objects. This was particularly remarkable given that, at least for different-looking objects, infants had expected them to make different sounds, as was shown in the familiarization trials. The provision of linguistic labels allowed the infants to override this initial expectation, suggesting a heavy reliance on linguistic information

in identifying object kinds during the first year of development (see also Waxman, 2004; Xu, 2002, 2007).

It should be made clear that there is no evidence that the 10-month-olds in the current study actually learned the labels for the objects, nor were they expected to. The events presented to the infants involved both novel objects and novel labels. These certainly aren't optimal conditions for word learning, especially for infants of this age. However, even in the absence of specific word-object mappings, infants as young as 10 months seem use the labels, and not object appearance, to guide their expectations about the objects' non-obvious internal properties.

Are the results of the current study specific to the property of sound or do they include non-obvious object properties, more generally? It may be theorized that the obtained results could be due to the fact that the chosen internal properties of the objects (i.e., sounds) were of the same modality as the count noun labels (i.e., both auditory). However, this seems unlikely given that the perceptual information (i.e., the appearance of the objects) was constantly available. It would have been easier for the infants to match object appearance and sound (available concurrently) than matching labeling with sound (both transient and temporally separated). There is reason to believe that these results should apply to non-obvious properties more broadly. Recent evidence examining inductive generalization shows that infants as young as 14 months of age expect objects (even perceptually dissimilar objects) that share a label to also share other non-obvious properties (both perceptual internal properties, i.e., same insides, and internal sound properties, i.e., squeaking when squeezed) (Graham & Kilbreath, 2007). Thus, children who are several months older than the 10-month-olds in the current study react to non-

obvious perceptual features (hidden insides) equivalently to non-obvious auditory features (squeaking when squeezed). It seems likely that 10-month-olds would also consider both hidden visual features and non-obvious sound properties as kind-relevant internal properties, and both should accord with the object's label.

We provide the first evidence that, at as young as 10 months of age, infants expect objects to have shared internal properties given shared object labels. This finding suggests that words for objects refer to kinds, not just shape, even at the beginning of word learning.

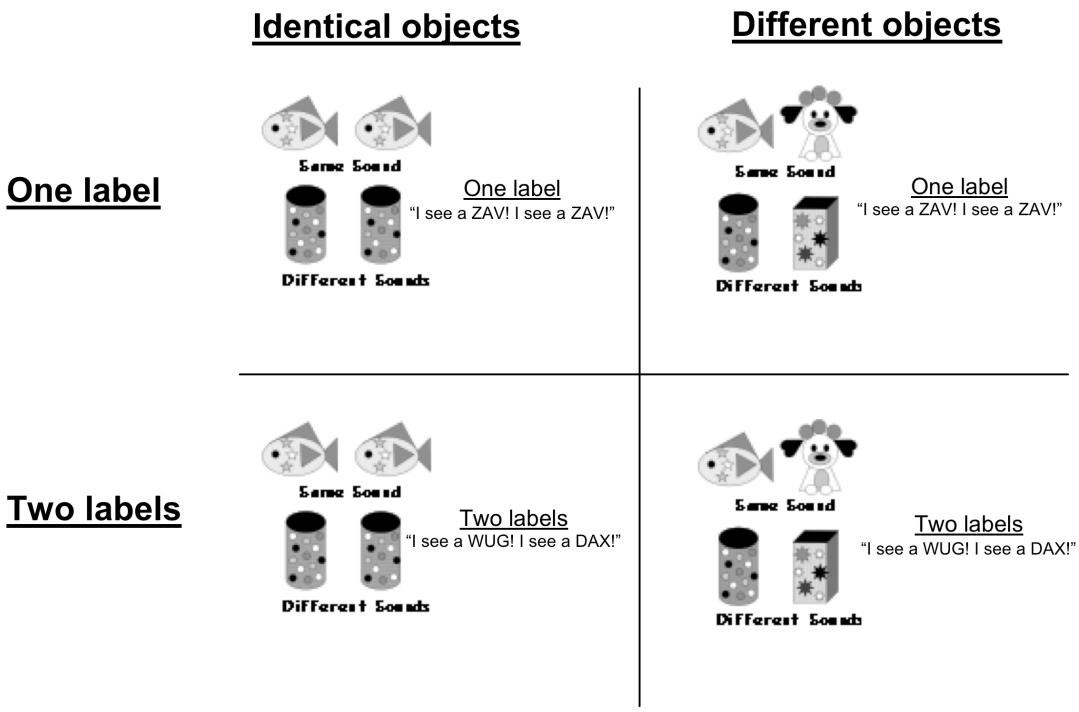
Table 3.1

Mean Looking Times on the Test Trials to the Same-Sound and Different-Sound Producing Object Pairs by Condition

	Same Sounds		Different Sounds	
	M	*SD*	*M*	*SD*
Condition[a]				
Identical objects-identical labels	7.45	4.62	8.76	6.17
Identical objects-different labels	7.89	3.31	6.77	4.14
Different objects-identical labels	8.47	6.95	9.84	6.77
Different objects-different labels	10.75	4.42	8.01	3.42

Note. [a]n = 16 for each condition.

Figure 3.1 Schematic representation of the test trials in each of the four conditions. The manipulated variables were object-pair appearance (identical vs. different looking) and number of labels heard (one vs. two).



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Chapter 4. Induction, Overhypothesis, and the Origin of Abstract Knowledge: Evidence from 9-Month-Old Infants[11]

4.1 Introduction

One of the greatest puzzles of human learning is the question how our experience leads to the formation of abstract knowledge. The 'problem of induction' (Hume, 1748) concerns our ability to infer a general law or principle based on the observation of particular instances. Inductive inferences go beyond the available data in order to arrive at conclusions that are likely, but not certain, given the available evidence (Goodman, 1955; Hume, 1739/1978; Quine, 1960). Since the vast majority of our everyday beliefs about how the world works, including our scientific reasoning; is based upon induction, it is important to understand how inductive generalizations are able to lead to the formation of abstract knowledge.

Human cognition centers on our unique capacity for extracting generalizable knowledge from sparse data. Consider that a single labeled exemplar is enough for children to learn the meaning of some words (Carey & Bartlett, 1978), and children develop grammatical constructions that are rarely found in the sentences they hear (Chomsky, 1980). These inductive leaps appear even more impressive when one considers the countless interpretations of the data that are logically possible but never entertained (Goodman, 1955; Quine, 1960). The ability to generalize from a few specific examples is essential, not only in language learning, but also in learning about cause-effect relations (i.e., Gopnik & Sobel, 2000; Kemp, 2008; Kelley, 1972), the properties of

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objects (i.e, Madole & Cohen, 1995), social rules (i.e., Jones, 2003), and many other knowledge domains.

In order to circumvent the problem of induction, Goodman (1955) proposed that multiple levels of generalization are required in order to form a hypothesis or principle, which would subsequently be able to be applied to novel instances. Goodman introduced the term 'overhypothesis' to embody this inferential ability and used the following example to illustrate the idea. Suppose you are shown a selection of identical bags. A few white marbles are drawn from the first bag. A handful of red marbles are pulled out of the second bag. Some green marbles are pulled from the third bag. If you saw a single blue marble being sampled from a new bag, what do you think the color of the next marble drawn would be? Your answer would probably be blue. The learner is making both a first- and second-order generalization. The first-order generalization concerns the contents of each individual bag. Only white marbles have been drawn from the first bag, so the next marble drawn should also be white. The learner has also formed a second-order generalization, or overhypothesis, that "bagfuls of marbles are uniform in color," and it allows the learner to make predictions about a brand new bag containing novel-colored marbles.

The ability to form overhypotheses enables a learner to make inferences that take them beyond the limits of their direct experience. Consider a child learning about animal species. They might learn that cows eat grass, rabbits eat carrots, and monkeys eat bananas. From these data, they may form the overhypothesis that animal kinds have characteristic diets. Once this second-order generalization is formed and if, for example, a novel animal, such as aardvark, is identified, then the learner will believe that aardvarks

have a characteristic diet, even though they know nothing about the specific diet of any individual aardvark. Then, the learner will quickly induce the characteristic diet of aardvarks, namely termites, from observation of only a few aardvarks eating termites. The ability to form overhypotheses allows the learner to go beyond the specific categories and properties they have learned (i.e., dogs bark) in order to make a principled generalization about all categories and properties of that type (i.e., all animals of the same kind make the same sound). Thus, this learning mechanism is able to make meaningful and principled generalizations about an entire class of entities based on a limited amount of data. The main advantage of such an inferential mechanism is that once abstract knowledge has been formed, this knowledge can be applied to new exemplars and new categories of objects.

An early capacity to form overhypotheses may account for the development of several key cognitive learning biases. Recent computational findings, using a hierarchical Bayesian model of overhypothesis formation (Kemp, Perfors, & Tenenbaum, 2007), suggest that certain cognitive biases (i.e., the shape bias in word learning, the ability to group categories into ontological kinds, learning causal schemata) can be acquired via this inductive mechanism. The computational work provides a plausible analysis and instantiation for overhypothesis formation as a way of acquiring inductive biases, but to date empirical evidence is lacking in human infants.

If this inductive mechanism is responsible for the formation of early-developing learning biases, then it holds that even young infants should be able to demonstrate this ability. To date the empirical evidence is lacking. Our experiments ask whether young infants, 9-month-olds, are able to form overhypotheses about feature variability. We

investigate whether, when provided with partial evidence about a few objects in a category, infants will be able to form a second-order generalization about a novel member of that class. In three experiments, we tested if infants were able to form overhypotheses, using the violation-of-expectancy looking time methodology (Onishi & Baillargeon, 2005; Spelke, Breinlinger, Macomber, & Jacobson, 1992).

4.2 Experiment 1

The first experiment asked whether 9-month-old infants are able to form a second-order generalization about a novel member of a category, when given only partial evidence about a few objects in a category.

4.2.1 Method

4.2.1.1 Participants

Participants were 48 full-term infants, 24 male and 24 female (mean age = 9 months, 0 days; range = 7 months, 15 days to 10 months, 15 days. Equal numbers of infants (24) were randomly assigned to each of two conditions: the Experimental condition (mean age = 9 months, 0 days) and the Control condition (mean age = 9 months, 0 days). All infants were recruited from the Greater Vancouver area by mail and subsequent phone calls. An additional eleven infants were tested but were excluded due to experimenter error (4) or fussiness (7).

4.2.1.2 Materials

Objects were sampled out of four identical boxes. The tops of the boxes were not covered and were; thus, open, however, the boxes were tall enough that the infants were not able to see into the top of the boxes. A small transparent container was attached to the front of each box. Five types of objects were sampled from the boxes: spheres, cubes,

stars, triangles, and thimbles. Each of the sampled objects was painted in one of five potential colors (blue, green, pink, purple, and yellow). Sampled objects were placed into the transparent containers attached to the boxes from which they were sampled and remained visible to the infants throughout a test trial.

4.2.1.3 Apparatus

All infants watched the events unfold on a puppet stage while sitting in a high chair. The parents sat next to the infants and faced away from the stage. They were instructed not to look at the displays during the study. An experimenter sat behind the stage. The stage was lit and the rest of the room was dark. Each infant was shown a set of four test trials. Infants' looking times were recorded. Each trial ended when the infant looked away for 2 consecutive seconds. A video camera below the stage focused on the infant's face and recorded the entire session. An observer sat in a corner of the testing room, watched the infant on a TV monitor, and recorded the looking times by depressing a computer key. A computer program was used to record the looking times. The observer had no knowledge of the order of the trials. A second observer coded the data from the video and inter-observer reliability averaged 88%.

4.2.1.4 Procedure

In Experiment 1, 9-month-old infants were randomly assigned to one of two conditions: the Experimental condition and the Control condition. At the beginning of each test trial, four identical boxes, with small transparent containers attached to the front of each box, were placed across the front of the stage (see Figure 4.1). Beginning with the leftmost box (box 1), the experimenter closed her eyes and obverted her gaze and reached into the top of the box and pulled out a shape (i.e., a sphere) from inside the box. The

experimenter held up the shape and placed it into the transparent container in front of the box. This sampling procedure was repeated until box 1's container was filled with four different-colored objects of uniform shape (i.e., spheres). The experimenter then moved on to repeat this procedure with boxes 2 and 3. Each of the first three boxes produced a different-shaped sample (i.e., box 1 produced multi-colored spheres, box 2 produced a multi-colored squares, and box 3 produced multi-colored triangles). With the three boxes and their samples in plain view of the infant, the experimenter turned her attention to the final box: the test box. The experimenter sampled a novel-shaped object (i.e., a pink star) from the test box at random and placed it in the test box's container.

In the Experimental condition, during an expected trial, the second object sampled from the test box matched the first object in shape (i.e., a blue star). Thus, in an expected trial, the test sample consisted of two same-shaped objects (i.e., stars): one familiar-colored object (i.e., pink) and one novel-colored object (i.e., blue). During an unexpected test trial, the second object sampled from the test box did not match the first object in shape (i.e., a blue sphere). Thus, in an unexpected trial, the test sample consisted of two different-shaped objects (i.e., a star and a sphere): one familiar-colored object in a novel shape (i.e., a pink star) and one familiar-shaped object in a novel color (i.e., a blue sphere).

The sampling of objects from boxes 1-3 supports the formation of the overhypothesis that, "each box contains uniformly-shaped objects". Thus, if infants have formed this overhypothesis, the sampling of a second same-shaped object from the test box would be expected, as it is consistent with this overhypothesis. However, it would be surprising, or unexpected, if the second object sampled from the test box did not match

the first object in shape, as this would violate the overhypothesis that “boxes contain same-shaped objects”.

In the experimental condition, infants’ looking pattern to the test events are hypothesized to be driven by their expectation that “boxes contain same-shaped objects” (the expected outcome is consistent with this hypothesis, the unexpected outcome violates this hypothesis). However, infants’ looking pattern to the test events might instead be driven by an inherent preference to look longer at two different-shaped objects (i.e., the unexpected outcome) than at two same-shaped objects (i.e., the expected outcome). A Control condition, which presented identical test displays to that of the Experimental condition, was included in order to ensure infants’ looking pattern to the test outcomes was not being driven by an inherent preference for different- over same-shaped test objects.

Each test trial in the Control condition was identical to that of the Experimental condition, except, for the sampling of the second test object in the unexpected outcome (see Fig. 4.1). In the ‘unexpected’ outcome of the Control condition, the second test object was not sampled from the test box, but was sampled from the first box (whose contents match the sampled object in shape). Thus, the object displays for the unexpected outcomes of both the Experimental and Control conditions were identical, however, the location the second different-shaped object was drawn from differs (in the Experimental condition, the object is drawn from the test box, while in the Control condition, the object is drawn from box 1).

In the Control condition, like in the Experimental condition, sampling from boxes 1-3 supports the overhypothesis that “boxes contain objects that are uniform in shape”

and sampling same-shaped objects from the test box (the expected outcome) is consistent with this overhypothesis. However, in the 'unexpected' outcome of the Control condition, sampling the second different-shaped test object from its own same-shaped box should not be surprising as it does not violate the overhypothesis.

In both conditions, on each test trial, once the second object was placed in the test box's container, the experimenter, in infant-directed speech, said, "Look, [Baby's name], look!" The experimenter then lowered her head and eye gaze to ensure that she was not making eye contact with the infant. Infant's looking times were recorded. The experimenter then removed all boxes, and their samples, from the stage and began the next test trail until a total of four test trials had been completed. Each infant saw two expected trials and two unexpected trials.

4.2.2 Results

Infants in the Experimental condition looked reliably longer to the unexpected outcome (M = 14.28 s, SD = 8.83) than the expected outcome (M = 11.32 s, SD = 6.24), $t(23) = -2.40$, $p = .03$; effect size (d) = .39. In contrast, infants in the Control condition looked equivalently to both the unexpected outcome (M = 10.29 s, SD = 6.54) and the expected outcome (M = 11.06 s, SD = 5.70), $t(23) = 0.62$, $p = .54$; effect size (d) .13, Fig. 4.2. It appears that 9-month-olds were able to form an overhypothesis across a relevant perceptual dimension while ignoring an equally salient perceptual feature (e.g., shape varies across boxes; color varies within boxes, thus, the overhypothesis was formed across shape but not color).

4.2.3 Discussion

In Exp. 1, infants formed the requisite overhypothesis over the dimension of shape, ignoring color. In Experiment 2, we will investigate whether 9-month-olds are equally adept at forming the relevant overhypothesis when these features are reversed (i.e., color will vary across boxes, while shape will vary within boxes, thus, the overhypothesis should be formed across color, not shape). There may be reason to believe that infants may be more acutely attuned to the dimension of shape than other perceptual dimensions. Shape has been argued to be a salient perceptual dimension for several cognitive domains early in development (e.g., generalizaing new properties, Diesendruck & Bloom, 2003; acquiring new words for object categories, Dewar & Xu, 2007; Landau, Smith, & Jones, 1988; reaching for objects in the dark, Robin, Berthier, & Clifton, 1996). If overhypothesis formation is a bottom-up inductive learning mechanism, we will expect that young infants be able to form overhypotheses across all perceptual dimensions, even those less salient and predictive perceptual dimensions, e.g., color.

4.3 Experiment 2

4.3.1 Method

4.3.1.1 Participants

Participants were 40 full term infants, 20 male and 20 female (mean age = 9 months, 2 days; range = 7 months, 17 days to 10 months, 13 days). Equal numbers of infants (20) were randomly assigned to each of two conditions: the Experimental condition (mean age = 9 months, 0 days), the Control condition (mean age = 9 months, 4 days). All infants were recruited from the same population as in Experiment 1, but none

participated in the first experiment. An additional seven infants were tested but were excluded due to experimenter error (1) or fussiness (6).

4.3.1.2 Materials and apparatus

Identical to Exp. 1.

4.3.1.3 Procedure

The experimental procedure was the same as Exp.1, except the perceptual dimensions of the test objects were switched: boxes contained different-shaped objects (i.e., cubes, spheres, stars, thimbles, triangles) of the same color (i.e., box 1 contains blue shapes, box 2 contains yellow shapes, box 3 contains green shapes). In the Experimental condition, on an expected outcome, the test sample consisted of two same-colored objects (of different shape), while, on an unexpected outcome, the test sample consisted of two different-colored objects (of the same color). In the Control condition, the expected and unexpected outcomes were identical to that of the Experimental condition, except that in an unexpected outcome, the second test object was drawn from box 1 (whose contents match the sampled object in color) instead of the test box (See Fig. 4.3).

4.3.2 Results

Infants in the Experimental condition looked reliably longer to the unexpected outcome (M = 11.35 s, SD = 5.79) than the expected outcome (M = 8.74 s, SD = 5.18), $t(19) = -2.91$, $p = .01$; effect size (d) = .48. In contrast, infants in the Control condition looked equivalently to both the ‘unexpected’ outcome (M = 9.57 s, SD = 5.90) and the expected outcome (M = 10.06 s, SD = 4.48), $t(19) = 0.47$, $p = .65$; effect size (d) = .09, Fig. 4.4. The results mirror those of Exp. 1. Thus, it appears that 9-month-olds have a general ability to form overhypotheses: they are equally adept at forming overhypotheses

across various perceptual dimensions (i.e., in Exp. 1 the overhypothesis was formed over shape, ignoring color, here, the overhypothesis was formed over color, ignoring shape).

4.3.3 Discussion

An alternative interpretation of the results of Exp. 1 and 2 is that infants' looking pattern was not being driven by a second-order generalization formed over the sampled contents of Boxes 1-3, but by a first-order generalization formed over the first object sampled from the test box. Even if infants weren't given any evidence about the contents of the first three boxes, they may expect the second object drawn from the test box to match the first sampled test object along at least one property dimension and, conversely, they might be surprised if it doesn't match. In order to ensure that the results of Exp. 1 and 2 were not being driven by a first-order generalization performed on the objects drawn from the test box alone, we conducted a control study in which infants saw objects being sampled from the test box only (i.e., they saw no sampling from boxes 1-3).

4.4 Experiment 3

4.4.1 Method

4.4.1.1 Participants

Participants were 16 full term infants, 8 male and 8 female (mean age = 9 months, 1 day; range = 7 months, 16 days to 10 months, 11 days). Equal numbers of infants (8) were randomly assigned to each of two conditions: the Shape condition (mean age = 8 months, 29 days) and the Color condition (mean age = 9 months, 3 days). All infants were recruited from the same population as in Exp. 1 and 2, but none participated in the first two experiments. An additional three infants were tested but were excluded due to experimenter error (2) or fussiness (1).

4.4.1.2 Materials and apparatus

Identical to Experiment 1 and 2.

4.4.1.3 Procedure

Infants were randomly assigned to one of two conditions: the shape condition (which served as a control for Exp.1) and the color condition (which served as a control for Exp. 2). The experimental procedure of the Shape condition was identical to the Experimental condition of Exp. 1, except that there was no sampling from boxes 1-3, only sampling from test box. Likewise, the experimental procedure of the Color condition was identical to the Experimental condition of Exp. 2, except that, again, there was no sampling from boxes 1-3 (See Fig. 4.5). Infants received 8 test trials: four expected trials and 4 unexpected trials.

If the results of the previous two experiments were driven by an overhypothesis being formed across the sampling pattern of boxes 1-3, then infants in the control study should not look longer to the unexpected outcome relative to the expected outcome as they received no sampling information from the first three boxes.

4.4.2 Results

Infants in the Shape condition looked equally upon seeing two different-shaped objects (M = 6.83 s, SD = 3.53; unexpected outcome) and two same-shaped objects (M = 7.18 s, SD = 4.25; expected outcome) drawn from the test box, $t(7) = 0.19$, $p = .87$; effect size (d) = .09. Similarly, infants in the Color condition looked equally upon seeing two different-colored objects (M = 6.41 s, SD = 3.44; unexpected outcome) and two same-colored objects (M = 8.33 s, SD = 4.52; expected outcome) drawn from the test box, $t(7) = 1.01$, $p = .35$; effect size (d) = .48, Fig. 4.6.

4.4.3 Discussion

These findings indicate that the results found in Exp. 1 and 2 were not driven by a first-order generalization formed over the outcomes of the test box alone, as infants in the control experiment were presented with identical test events to that of Exp. 1 and 2. Thus, these results provide evidence that the results of Exp. 1 and 2 are due to infants' ability to form the relevant overhypotheses based on the pattern of objects sampled from boxes 1-3.

It is possible that the null result found for both conditions in Exp. 3 resulted, not from infants' inability to form a first-order generalization over the objects drawn from the test box, but from a lack of sufficient statistical power to detect the effect due to the small sample size in each condition. In this experiment, eight infants were tested in both the Shape condition and the Color condition, compared to the twenty-four and twenty infants that were tested in each of the Experimental and Control conditions of Exp. 1 and 2, respectively. However, in both the Shape and Color conditions of Exp. 3, infants tended to look slightly longer at the expected outcome relative to the unexpected outcome (a reversal of the looking pattern found in the Experimental conditions of Exp. 1 and 2). Moreover, this same pattern of looking (increased looking time to the expected relative to the unexpected outcome) was found in both the Control conditions of Exp. 1 and 2, suggesting that an increase in the sample size of Exp. 3 would, most likely, result in the maintenance of this looking pattern. While infants' looking patterns in both conditions of Exp. 3 were considered separately, these conditions could be combined into a single group of 16 infants, since there is no reason to suspect that infants will display different patterns of looking whether shown either identical objects versus different-shaped objects (Shape control) or identical objects versus different-colored objects (Color control). If

these conditions are combined, we see the same pattern of results as was found in both the original conditions: infants look equivalently whether shown identical objects (M = 7.19 s, SD = 4.28) or different-shaped/colored objects (M = 6.62 s, SD = 3.37) drawn from the test box, $t(15) = 0.88$, $p = .39$.

4.5 General discussion

Infants in the current study were able to make a principled generalization about a class of entities (in this case, boxes and the nature of the objects they contain) based on scant data. After being given limited evidence about the contents of the first three boxes (i.e., a random sample of four objects from each box), 9-month-old infants expected the contents of a new box, with novel objects, to accord with an abstract pattern. Infants' performance is impressive considering, in order to succeed on these tasks, they were required to make both a first-order generalization regarding the contents of individual boxes (i.e., box 1 contains sphere-shaped objects) and a second-order generalization, or overhypothesis, about the contents of these kinds of boxes, in general (i.e., boxes contain uniformly-shaped objects). It is even more impressive that infants were able to succeed in the first two experiments considering that the objects presented differed along two perceptual dimensions (shape and color). Thus, infants were required to form the requisite overhypothesis across the relevant perceptual dimension while ignoring an equally salient perceptual feature (e.g., color varies across boxes; shape varies within boxes, thus, the overhypothesis should be formed across color but not shape).

Previous inferential learning studies with infants have mainly focused on how infants employ 'intuitive statistics' to make use of a small amount of data in order to make inductive inferences about larger populations, and conversely, to make inferences

from populations to samples (Teglas, Girotto, Gonzalez, and Bonatti, 2007; Xu & Garcia, 2008). Studies such as Teglas et al. (2007) and Xu and Garcia (2008) examine infants' ability to form first-order generalizations about the expected composition of a population based on a small sample drawn from that population. Our experiments focus on how infants are able to go beyond these first-order generalizations in order to make a second-order generalization, or overhypothesis, about the composition of all populations of like kind. Thus, after seeing samples drawn from several boxes, infants are able to make an inductive inference about the expected composition of a brand new box based on the sampling of a single (novel) object.

Several researchers have applied the general idea of overhypothesis formation to account for children's acquisition of several cognitive constraints (e.g., Kemp, 2007; Kemp, Perfors, and Tenenbaum, 2007; Samuelson, 2002; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002). For example, in order to account for the acquisition of a shape bias in word learning, i.e., children's propensity to think that shape tends to be homogeneous within object categories (e.g., Heibeck & Markman, 1987; Landau, Smith & Jones, 1988), Smith et al. (2002) hypothesized that children initially acquire several words that refer to object categories, e.g., "cat" refers to cats; "chair" refers to chairs. Then, they form a first-order generalization across those words and objects categories, e.g., the word "cat" refers to objects that are cat-shaped; the word "chair" refers to objects that are chair-shaped. Once a number of individual words and categories are learned, the child forms a second-order generalization, or overhypothesis; that "Noun X refers to objects that are X-shaped." By making this second-order generalization, the child can now apply the shape bias to all new count nouns that he/she

might learn in the future. Here, the mechanism of overhypothesis formation provides a powerful tool for future learning: the child is able to go beyond the specific words and categories they have learned in order to make a principled generalization about all count nouns that refer to object categories. It should be noted that learning the shape bias is only one instance of the more general problem of learning about feature variability and research has shown that children (Macario, Shipley & Billman, 1990), adults (Nisbett, Krantz, Jepson & Kunda, 1983) and computational models (Kemp, Perfors, & Tenenbaum, 2007) demonstrate the ability to form overhypotheses about feature variability, more generally.

This general mechanism can be applied to the acquisition of several other cognitive constraints. For instance, before the age of 3, children demonstrate knowledge that object categories are grouped into ontological kinds, with different patterns of feature variability within each kind—they know that shape tends to be homogeneous within object categories but heterogeneous within substance categories (Imai, Gentner & Uchida, 1994; Samuelson & Smith, 1999; Soja, Carey & Spelke, 1991), that color tends to be homogeneous within substance categories but heterogeneous within object categories (Landau et al., 1988; Soja et al., 1991), and that both shape and texture tend to be homogeneous within animate categories (Jones, Smith & Landau, 1991). Computational work, using a hierarchical Bayesian model of overhypothesis formation, is able to account for children's acquisition of ontological knowledge (Kemp, 2007; Kemp, Perfors, & Tenenbaum, 2007). This same mechanism has also been used to explain the acquisition of causal knowledge in both adults and children (Kemp, 2007). Causal learning is rapid: children tend to make confident causal inferences given very sparse

data (e.g., Gopnik & Sobel, 2000). By tracking the characteristic features of causal types (via first-order generalizations formed over specific cause-effect relations), learners can often make strong predictions about a novel object before it is observed to participate in any causal interactions. Such findings indicate that overhypothesis formation is able to explain the development of many inductive biases over various domains of knowledge.

Research to date has only examined the mechanism of overhypothesis formation in adults and preschoolers (Macario, Shipley & Billman, 1990; Nisbett, Krantz, Jepson & Kunda, 1983). The current studies examine this ability in an infant sample using a novel method in order to outline the developmental origins of this learning mechanism. This ability appears both general and flexible since our findings show that infants are able to form overhypotheses across various perceptual features (i.e., across both shape and color).

The present studies provide evidence that early in development, infants are able to employ a powerful mechanism for inductive learning. Based on evidence from a few members of a category, infants are able to make 'meta-generalizations' allowing them to make predictions about new members of a category based on extremely scant data. This ability to form overhypotheses develops early and in the absence of schooling or explicit teaching. It may be the mechanism responsible for the acquisition of many, presumed innate, inductive biases. This inference mechanism is likely to be present in many knowledge domains, as it allows human learners to acquire abstract knowledge rapidly and accurately. It remains to be seen how general this inductive learning ability is and whether we share it with non-human animals.

Figure 4.1 Example of an expected and unexpected test outcome in Experiment 1.

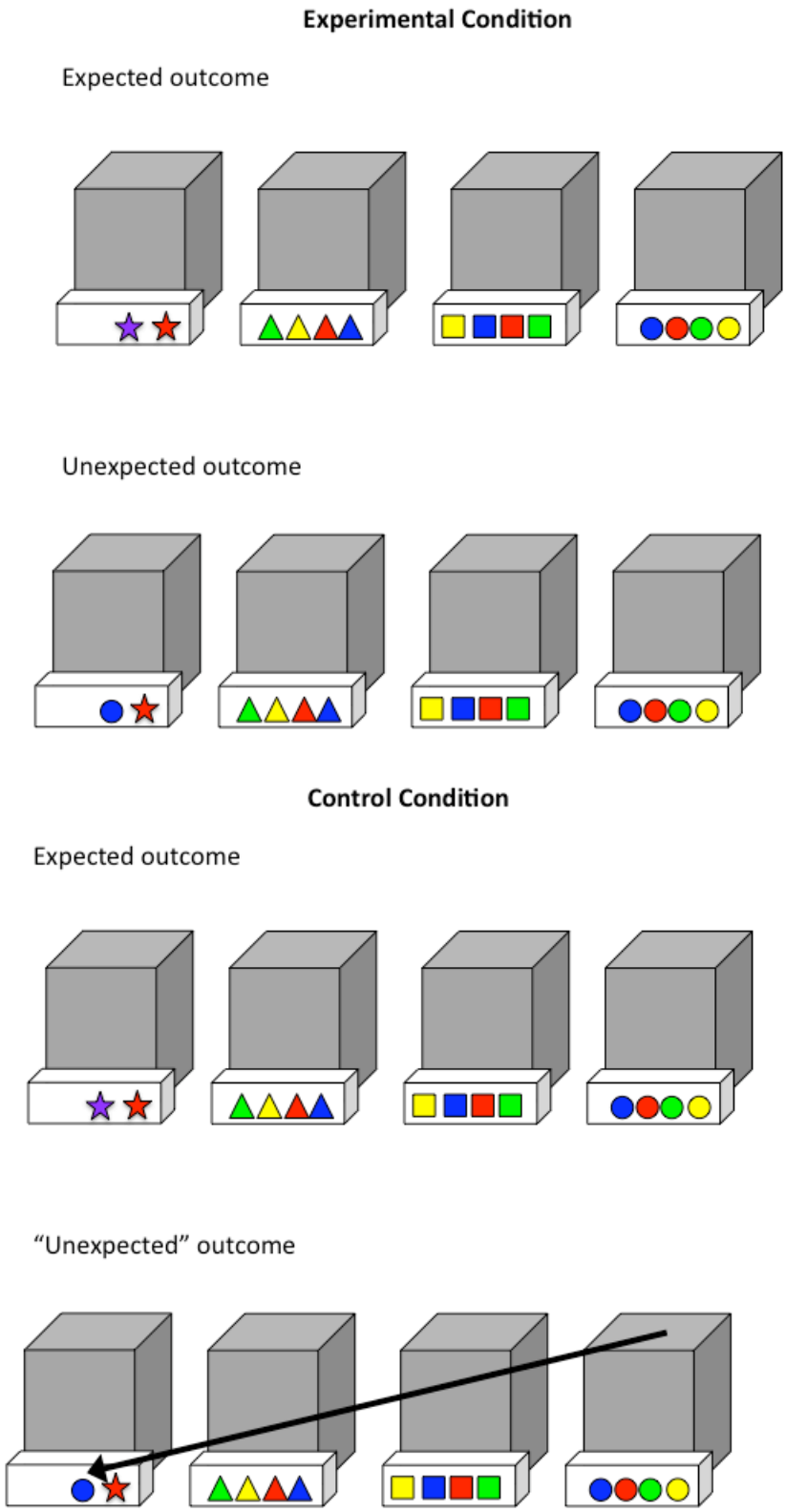


Figure 4.2 Mean looking times for Experiment 1 with standard error.

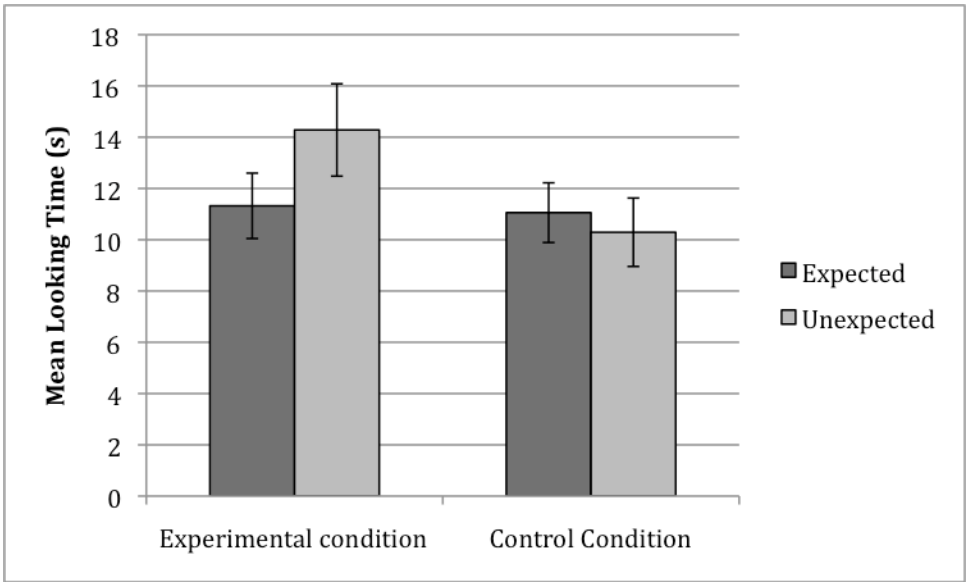


Figure 4.3 Example of an expected and unexpected test outcome in Experiment 2.

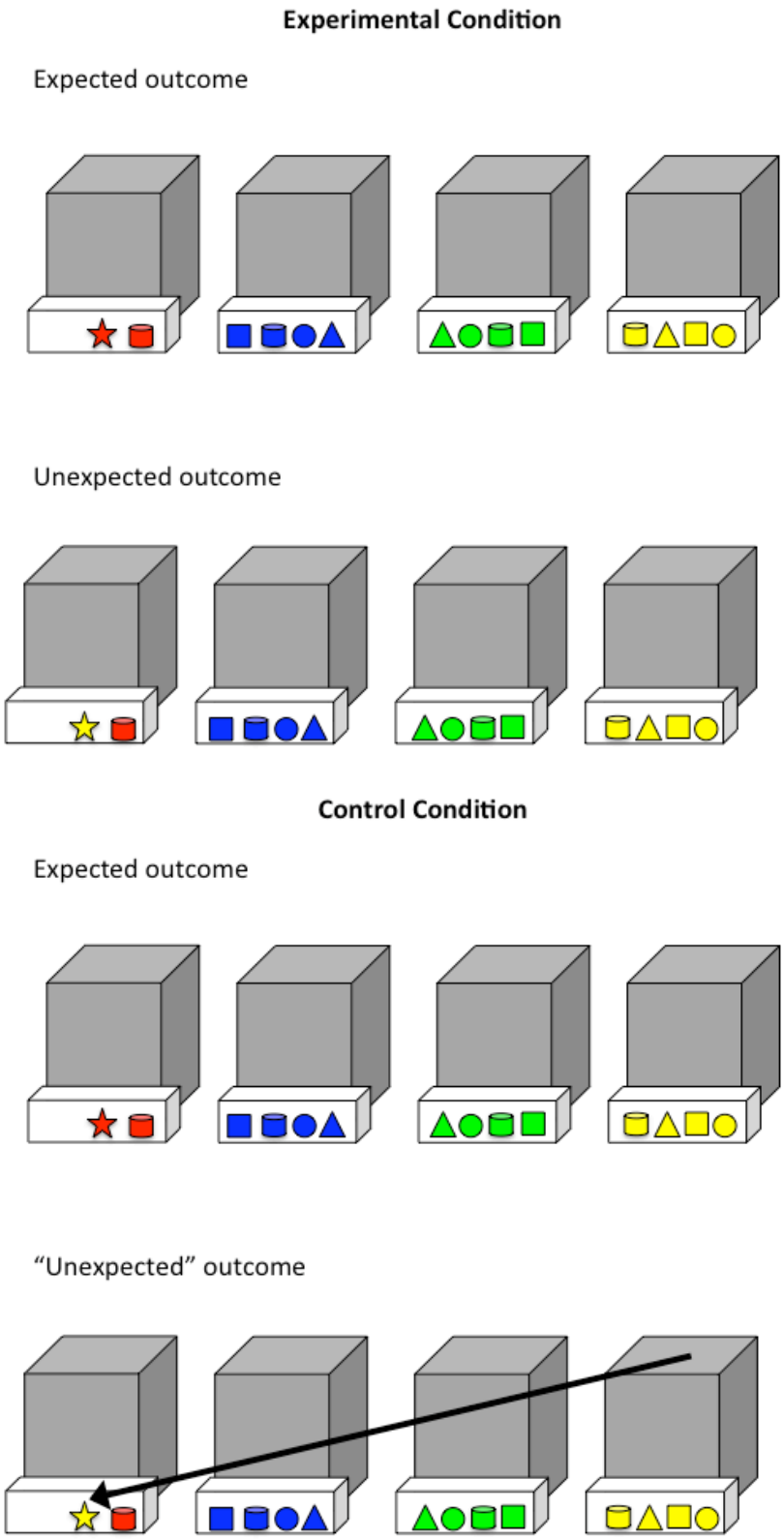


Figure 4.4 Mean looking times for Experiment 2 with standard error.

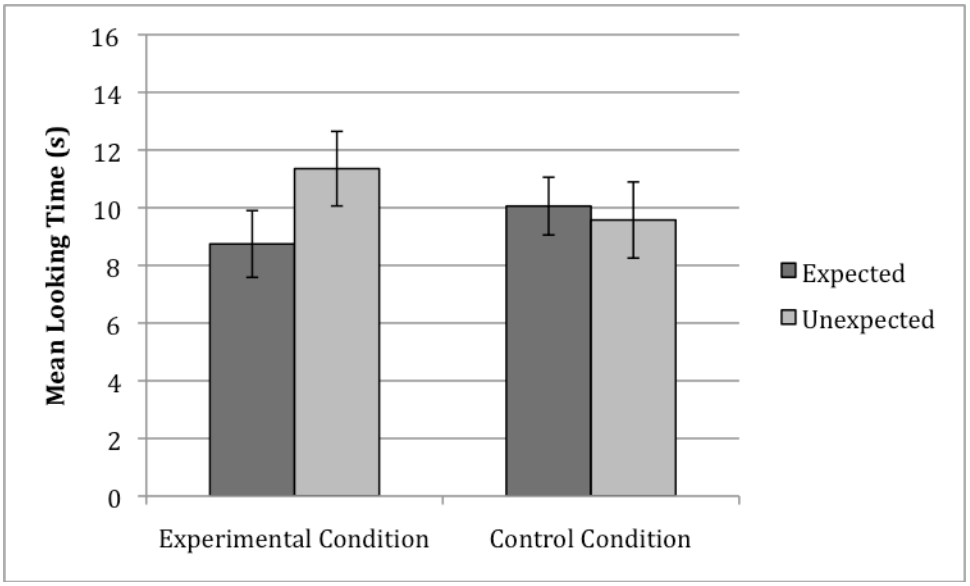


Figure 4.5 Example of an expected and 'unexpected' test outcome in Experiment 3.

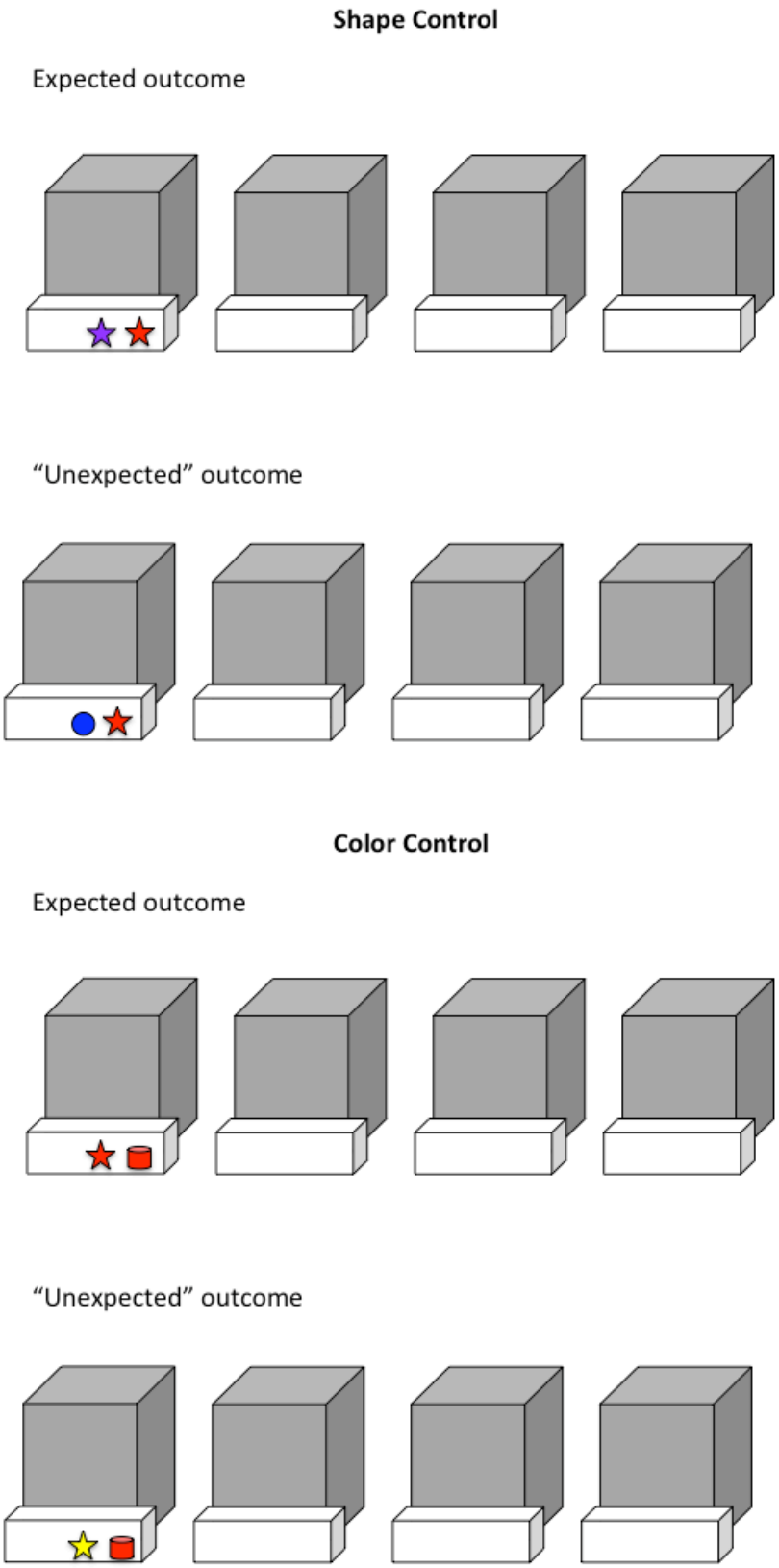
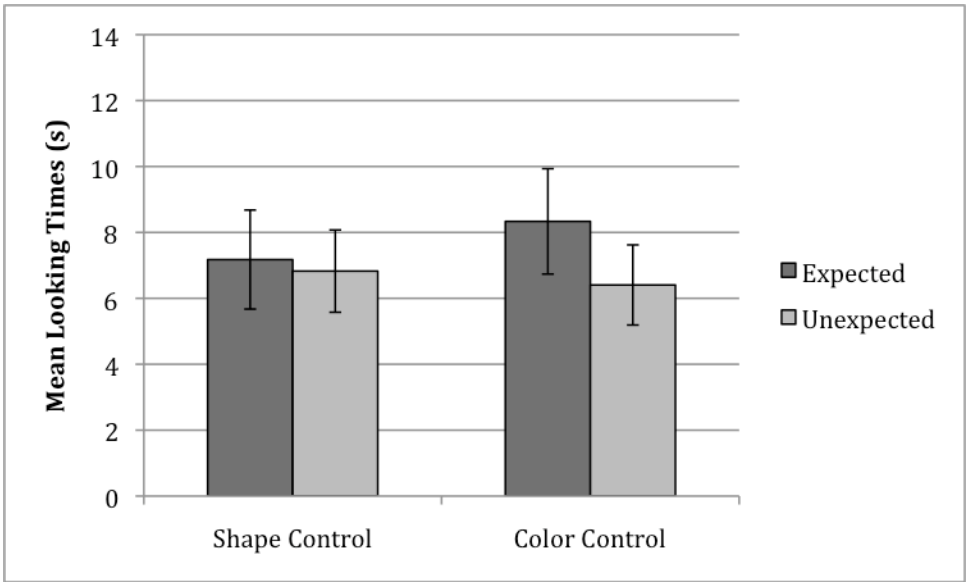


Figure 4.6 Mean looking times for Experiment 3 with standard error.



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Chapter 5. General Discussion

This thesis provides evidence addressing two central issues that had been left unresolved in the developmental literature. The first issue concerns a longstanding debate in the study of language development centering on the question of whether infants' earliest object labels map onto distinct shapes or whether these early labels refer to kinds and shape is a proxy for kind membership. Because shape is highly correlated with kind membership, it is very difficult to tease these interpretations apart, especially with very young word learners. In order to determine whether infants interpret labels as referring to kinds or distinct shapes, the perceptual dimension of shape must be decoupled from object kind. There are two potential ways in which kind can be disentangled from shape: (1) examine infants' expectations about the external properties of labeled objects in an object domain where shape is not indicative of kind membership, and (2) examine infants' expectations about the internal (nonobvious) properties of labeled objects.

The first alternative for decoupling shape from object kind was investigated in Study One, which examined infants' expectations about the external object properties of labeled objects in the domain of food (an object domain in which shape is not the primary perceptual correlate of kind membership). It has previously been established that 9-month-olds expect artifact objects differing in shape to be marked by distinct labels, but they do not hold this expectation for artifact objects differing color (Dewar & Xu, 2007). In contrast, the findings from Study One indicate that when the labeled objects are food items, both 9- and 12-month-olds demonstrate some evidence of color sensitivity when provided with labeling information and, more importantly, infants in this study did not expect food objects differing in shape to be marked by distinct labels. These findings

provide evidence that, for infants, distinct labels do not solely correspond to distinct shapes.

The second alternative for decoupling shape from object kind was investigated in Study Two, which examined 10-month-olds' expectations about internal object properties (as opposed to external object properties, such as, shape). Findings from the second study indicate that 10-month-olds are able to use linguistic information (the number of distinct object labels applied to an object pair) in order to predict whether a particular pair of objects should make the same sound or different sounds, regardless of the object pairs' perceptual similarity or dissimilarity. Strikingly, this effect was found to be independent of the appearance of the objects. These findings suggest that infants hold kind-relevant expectations about labeled objects: they expect objects that share an object label to have similar internal (unapparent) properties and, conversely, they expect objects marked by distinct object labels to have different internal properties.

The second issue addressed in this thesis concerns the question of the origin of infants' early linguistic sensitivity to shape (for artifact objects); that is, identifying a potential mechanism through which a 'shape bias' may be learned. The inductive mechanism of overhypothesis formation has been proposed to account for older children's acquisition of the shape bias (e.g., Kemp, Perfors, and Tenenbaum, 2007; Samuelson, 2002; Smith, et al., 2002). Study Three examined whether 9-month-old infants (the youngest age group to demonstrate a shape sensitivity in their linguistic expectations; Dewar and Xu, 2007) were capable of forming overhypotheses across feature variability (i.e., across shape, ignoring color and across color, ignoring shape). Findings from the third study indicate that 9-month-olds are, in fact, able to generate an

appropriate overhypothesis and, moreover, that they use this induction to guide their expectations about the properties of a novel category member. Given that 9-month-olds are able to form overhypotheses flexibly, over multiple property dimensions, it follows that infants of this age are, in theory, capable of forming a second-order generalization of the kind required to support a shape bias (i.e., object label X refers to objects that are X-shaped) by making a relatively limited number of first-order generalizations. The results of Study Three suggest that infants have at their disposal a powerful learning mechanism capable of supporting the formation of strong inductive inferences.

The provision of linguistic information is proposed to be vital to infants' identification of object kinds during the first year of development (Waxman, 2004; Xu, 2002, 2007). Under this interpretation, labels serve as invitations to form object categories: naming (the act of labeling objects) advances infants beyond observable commonalities and points them toward the deeper commonalities that characterize object concepts (Brown, 1958; Macnamara, 1982; Waxman & Braun, 2005). A closely related view suggests that labels for object categories, or kinds, serve as "essence placeholders" (Gelman, 2003; Medin & Ortony, 1989; Xu, 2005). Thus, the fact that one object is called "a duck" and another object is called "a ball" is sufficient evidence for infants to infer two distinct kinds or essences. Simply hearing and, subsequently, learning labels for object kinds would not confer upon the infant the concepts *duck* and *ball*, but labels such as "duck" and "ball" may direct the infant to establish "placeholders" for the relevant concepts and through subsequent interactions with the world, these concepts are developed and beliefs about these concepts are expanded. Under such 'content rich' views of naming, the application of labels to referent objects presumes the possession of

certain expectations on the part of the infant; namely, that objects that share the same label should also be expected to share many other similarities, most vitally, these 'deeper' commonalities.

The findings from three separate studies (Dewar & Xu, 2007; Study 1 and 2), using similar methods, provide converging results that young infants appear to hold kind-relevant expectations about both the external and internal properties of labeled objects. If infants' early object labels do, indeed, reference kinds, it remains an open question as to (1) how these specific expectations are acquired, if they are acquired, and (2) whether infants' representation of 'kind' is as conceptually rich as that of older children and adults.

Young infants' sensitivity to shape (for artifacts) in the context of labeling may be taken as evidence of a general, potentially innate, tendency for infants to privilege the dimension of shape as an object feature in a linguistic framework. However, the results of Study One demonstrate that, by 9 months of age, infants do not privilege object shape in all labeling contexts. Indeed, these findings suggest that infants may, in fact, be sensitive to other, more category-relevant, object features, like color, under appropriate conditions, i.e., when the labeled objects are food items. One possible developmental account of this evidence is that shape sensitivity may initially exist across domains and, in and around 9 months of age, domain knowledge for food object leads infants to identify the appropriate category-relevant feature in this particular object domain. An alternate developmental account would be that infants learn that the feature of shape is privileged for artifact kinds while the feature of color is privileged for food kinds, with no strong prior bias for either feature. This account posits that shape isn't 'special' in a linguistic context and that

sensitivity to the category-relevant features for each object domain may be learned. Indeed, in our evolutionary past, the environment had very few artifact kinds, making the existence of a dedicated shape bias in the context of artifact kinds somewhat implausible.

There is reason to believe that the kind-relevant expectations evidenced by infants in a labeling context may be learned, or at least, that the learning of these conceptual biases is, in theory, possible. Take, for example, the domain difference demonstrated by 9- and 12-month-olds in their expectations regarding the perceptual object properties relevant for labeling for food objects versus artifact objects (Study 1). In order to display this domain difference, infants must be able to identify the category-relevant perceptual feature for each object domain. One way in which infants may be accomplishing this task is by keeping track of the correlations between feature variability and labeling (Smith et al. 2002). Once a requisite number of feature-label co-occurrences have been established, an overhypothesis about feature relevance and labeling can be formed in each object domain, i.e., "for artifact objects, object label X corresponds to objects that are X-shaped" and "for food objects, object label X corresponds to objects that have X color/taste".

This pattern of learning would explain the differential strength of the relationship between object feature and labeling in each object domain: infants demonstrate a strong sensitivity to shape in the artifact domain; yet, they demonstrate a weak sensitivity to color in the food domain. The relative strength of the correlations between object labels and category-relevant properties directly affects the speed at which a label-feature bias would be formed. Indeed, an examination of the feature-label co-occurrences for each object domain yields two distinct patterns. For artifacts, there is a very robust correlation

between object labels and shape: distinct labels mark different-shaped objects (e.g., Jones & Smith, 2002; Yoshida & Smith, 2005). An overhypothesis regarding artifact labels and object shape would be formed relatively quickly and would become deeply entrenched due to the consistency of the relationship between labeling and shape. However, in the domain of food, the perceptual features that correspond to the different food kinds are more varied, yielding a far less reliable relationship between object labels and color: distinct labels usually, but not always, mark objects that differ in color (e.g., Jones & Smith, 2002; Yoshida & Smith, 2005). Indeed, the properties of texture, smell, and shape can also be kind-relevant for food objects. An overhypothesis regarding food labels and object color would, presumably, form much more slowly and entrenchment would be hampered by the label-feature variability inherent in the domain of food.

An alternate explanation for infants' seemingly biased sensitivity to object shape in a linguistic context can be found in infants' differential attention to the object features themselves. In comparison to infants' relatively strong sensitivity to shape in the domain of artifacts, infants' weak sensitivity to color in the food domain may be interpreted as evidence that color, as an object feature, is not particularly prominent for infants. However, the findings of Study Three make this interpretation unlikely: 9-month-olds were equally likely to form overhypotheses over both color and shape depending on which particular property supported the appropriate induction, given the evidence. Given that the objects presented in Study Three varied along both property dimensions simultaneously, infants' ability to form separate overhypotheses over color and shape, suggests that both object features are salient to young infants. Because infants are capable of forming inductions over both object shape and object color, it begs the question as to

why, in a linguistic context, infants display a differential sensitivity to each of these object properties. The learning account detailed above provides an explanation as to why infants demonstrate a bias towards shape in a labeling context (for artifacts) before they demonstrate sensitivity to other category-relevant features in other object domains.

Does evidence of young infants' ability to form kind-relevant expectations about both the external and internal properties of labeled objects (Dewar & Xu, 2007; Study 1 and 2) reflect a conceptually mature representation of kind? A conceptually rich notion of kind embodies the understanding that the perceptual similarity shared by members of the same kind reflects, and is caused by, shared deeper causal/functional properties. Thus, under this representation of kind, perceptual features may vary amongst kind members, as long as their causal/functional similarities are preserved. Older children demonstrate this 'rich' kind interpretation: Preschoolers extend the label of a novel artifact to other artifacts that share the same salient function (e.g., Kemler Nelson, Russell, Duke, & Jones, 2000) or causal property (Gopnik & Sobel, 2000), even when perceptual similarity is in conflict with these functional or causal properties. And, indeed, previous findings indicate that infants as young as 14 months expect objects that share a label, but are dissimilar in appearance, to share a nonobvious property (at 14 and 20 months: Graham & Kilbreath, 2007; at 16 and 21 months: Welder & Graham, 2001). The results of Study Two seem to reinforce this developmental trajectory: 10-month-olds expected object pairs referred to using the same object label to make identical sounds and they expected pairs of objects referred to using distinct object labels to make different sounds, regardless of object appearance. Thus, even when a pair of objects looked entirely dissimilar, when identical labels were used to mark the objects, infants expected both

objects to share the same internal property. And, conversely, even when pairs of objects looked identical, when distinct labels were used to mark the objects, infants expected the objects to display different internal properties.

However, the question arises as to whether all internal object properties are created equal; that is, should expectations regarding objects' internal perceptual properties (i.e., sound) be regarded in a similar fashion to expectations about the functional and causal properties of objects? It might be the case that infants, like older children, have equivalent expectations for all internal object properties, i.e., that those properties are predicted by an object's label (be they perceptual, causal, or functional internal properties). However, it might also be the case that infants' expectations regarding the nonobvious sound properties of objects reflects a less conceptually complex understanding of 'internal property' than is demonstrated by older children's expectations about the functional and causal properties of objects. The internally generated sounds produced by an object can be conservatively viewed as a perceptual feature of that object, much like the visible perceptual features of object shape and color. However, unlike visible object properties, the sound properties of objects are temporal, i.e., not consistently present. Ten-month-olds' performance in Study Two may reflect their understanding that object labels reference categories of objects united by various perceptual object properties (both internal and external), as opposed to, an understanding that object labels reference categories of objects united by both perceptual and causal/functional properties. It is possible that a conceptually rich notion of kind (i.e., an understanding of the shared causal/functional features between categories members) emerges later in development.

Future research should address the nature of infants' understanding of internal object properties by determining whether 10-month-olds' performance in Study Two was driven by their construal of the sound properties as internal 'perceptual' features or as 'deep' internal properties, akin to causal/functional properties. One potential way of parsing these separate internal property construals would be to conduct another version of Study Two where, instead of demonstrating the sounds of each object, objects in a pair would be shown to fulfill either the same function or two distinct functions (e.g., used to brush the experimenter's hair, used by the experimenter to drink out of). Similarly, a version of Study Two could be conducted using internal causal properties: where objects in a pair would be shown to fulfill either the same cause or two distinct causes (e.g., used to activate a toy, used as a key to open a locked box). If 10-month-olds evidence the same pattern of results in the functional/causal experiments as they did in the original version, it would suggest that infants' expectations about internal object properties reflect a conceptually mature notion of kind.

The findings from Dewar and Xu, 2007, Study One, and Study Two provide converging evidence that young infants hold specific expectations about both the external and internal properties of labeled objects. However, such results do not speak to the developmental origins of these expectations. The findings from Study Three offer a candidate learning mechanism through which these specific expectations may be derived: overhypothesis formation. After being given limited evidence about the contents of the first three boxes (i.e., a random sample of four objects from each box), 9-month-old infants expected the contents of a new box, with novel objects, to accord with an abstract pattern. Infants' performance is striking considering, in order to succeed on this task,

infants were required to make both a first-order generalization regarding the contents of individual boxes and a second-order generalization, or overhypothesis, about the contents of these kinds of boxes, in general. It is impressive that infants were able to succeed in the first two experiments given that the objects presented differed along two perceptual dimensions (shape and color). Thus, infants were required to form the requisite overhypothesis across the relevant perceptual dimension while ignoring an equally salient perceptual feature (e.g., color varies across boxes; shape varies within boxes, thus, the overhypothesis should be formed across color but not shape).

The evidence infants used to form these overhypotheses was limited: only four objects were drawn from each of three boxes. Given this data, 9-month-olds were able to form an appropriate second-order generalization, and apply that induction to the contents of a new box. However, the amount of data infants require in order to make such an induction has yet to be specified. For instance, would a smaller amount of data (i.e., two objects) drawn from an increased number of category members (i.e., five boxes) be an equally likely to result in the formation of a second-order generalization, or, would a larger amount of data drawn from a decreased number of category members be sufficient? Further research is required in order to outline the parameters of this learning mechanism.

The demonstration that 9-month-olds are able to form overhypotheses flexibly, over multiple property dimensions, suggests that infants of this age are, in theory, capable of forming a second-order generalization of the kind required in order to facilitate the creation of a shape bias. Yet, while the results of Study Three may indicate that infants have at their disposal a powerful learning mechanism capable of supporting the formation

of cognitive biases (Kemp, 2007; Kemp et al., 2007), it is unclear whether overhypothesis formation plays a role in the actual development of these early biases.

Further research is required to ascertain whether overhypothesis formation is the learning mechanism responsible for the development of infants' expectations regarding the internal and external properties of labeled objects. One potential way in which this inductive mechanism's participation in the creation of cognitive expectations could be examined is by investigating the inductive capabilities of younger infants. If infants acquire the shape bias via the mechanism of overhypothesis formation, then it stands to reason that the ability to form overhypotheses should predate infants' linguistic sensitivity to shape. If it were to be demonstrated that a younger group of infants (i.e., 6- or 7-month-olds) were not able to evidence sensitivity to shape in a labeling context (i.e., they 'fail' the shape experiment of Dewar & Xu, 2007) but were able to evidence the ability to form overhypotheses (i.e., they succeed at the shape experiment of Study 3), it would indicate that the mechanism is a precursor to this particular linguistic bias. While such a demonstration would not provide confirmation that infants' expectations about labeled objects are derived via the mechanism of overhypothesis formation, it would provide an indication that this developmental explanation was, in theory, plausible.

The findings of this thesis address the relation between language and conceptual organization. Developmental research has focused considerable attention on examining the influence of labeling on infants' and young children's representation of individual objects and object categories. A central finding derived from these empirical efforts is that object naming facilitates the formation of stable object categories (Balaban & Waxman, 1997; Braun & Waxman, 2005; Fulkerson & Haaf, 1998; Fulkerson &

Waxman, 2007; Waxman & Booth, 2003; Welder & Graham, 2001). The current findings further elucidate the nature of these early object categories by examining infants' expectations regarding the labeled objects themselves. Infants were found to hold specific, kind-relevant, expectations regarding both the external and internal properties of that labeled object (and, presumably, its category). Furthermore, this thesis addresses the developmental origins of such expectations. A candidate learning mechanism is identified which may account for the acquisition of many early cognitive and linguistic biases.

This thesis presents a case study of a specific aspect of cognitive development: the impact of labeling on young infants' object representations and, in particular, the nature of a 'shape bias' constraining infants' early linguistic understanding. The findings presented here speak directly to the nature of conceptual development. Specifically, we present evidence that infants' representations of labeled objects can best be described as following a continuous developmental trajectory; in that, at every age tested, using a variety of measures, infants appear to expect object labels to refer to kinds (i.e., at 9 months: Study 1; at 10 months: Study 2; at 14 and 20 months: Graham & Kilbreath, 2007; at 16 and 21 months: Welder & Graham, 2001; at 18 months: Booth, Waxman, & Huang, 2005). Like older children and adults, infants in Studies One and Two were found to hold kind-relevant expectations regarding the both the internal and external properties of labeled objects: they expected objects marked by the same label to share both category-relevant perceptual features (which differed according to the domain of the labeled objects) and internal object properties. The finding that infants expect even dissimilar-looking objects referred to by the same label to share the same internal property is especially compelling, as it reflects a conceptually rich notion of kind, that is,

that the perceptual similarity shared by members of the same kind reflects, and is caused by, shared deeper internal properties.

According to a discontinuous account, infants' object labels are initially perceptually based, picking out same-shaped things regardless of the taxonomic categories to which these things belong and, only after becoming familiar with the labeled objects are infants able to learn about the specific properties relevant to those categories (e.g., Imai, Gentner, & Uchida, 1994; Landau, Smith, & Jones, 1988). In contrast, the results of Study One and Two suggest that, for infants, object labels do not exclusively pick out distinct-shaped things. Instead, infants expect labels to refer to objects that share kind-relevant features: they hold these expectations from the outset of word learning without having to form specific word-object pairings and independent of experience with the objects themselves.

We also offer evidence that infants have access to an inductive learning mechanism capable of supporting the acquisition of infants' kind-relevant expectations of labeled objects. The results from Study One suggest that infants expect labels for objects in different domains to have different perceptual correlates. The finding that shape is not a privileged perceptual dimension for all object domains suggests that sensitivity to the category-relevant perceptual dimensions in each object domain may be learned.

For development to be continuous, infants must possess the conceptual resources to represent their world in an adult-like fashion. We present a candidate learning mechanism, which is available early in development, through which infants' kind-relevant expectations of labeled objects may be acquired. The results of Study Three indicate that infants possess a powerful mechanism for inductive learning, and this

mechanism may be applied to many domains, and can account for the development of many inductive biases (Kemp, 2007; Kemp et al., 2007; Marcario, Shipley, & Billman, 1990; Nisbett, Krantz, Jepson, & Kunda, 1983). Using the mechanism of overhypothesis formation, by making a relatively limited number of label-feature (both external and internal feature) correlations, it is theoretically possible that infants may be able to form the requisite second-order generalizations required to support the formation of kind-relevant expectations about labeled objects.

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Appendix A

The University of British Columbia
Office of Research Services and Administration
Behavioural Research Ethics Board

Certificate of Approval

PRINCIPAL INVESTIGATOR	DEPARTMENT	NUMBER
Xu, F.	Psychology	**B03-0657**

INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT

UBC Campus ,

CO-INVESTIGATORS:

Atwal, Pritpal, Psychology; Denison, Stephanie, ; Dewar, Kathryn, Psychology; Garcia, Vashti, Psychology; Joshi, Anjula, Psychology; Konopczynski, Katie, Psychology; Narayan, Jane, Psychology; Omaid, Tara, Psychology; Talbot, Alena, Psychology; Yeung, Henny, Psychology; Zysk, Eva, Psychology

SPONSORING AGENCIES

Natural Science Engineering Research Council

TITLE :

Language and Cognition in Infants and Children

APPROVAL RENEWED DATE	TERM (YEARS)	AMENDMENT:	AMENDMENT APPROVED:
MAR 13 2006	1	Mar. 8, 2006, Co-PIs	MAR 13 2006

CERTIFICATION:

The request for continuing review and amendment of the above-named project has been reviewed and the procedures were found to be acceptable on ethical grounds for research involving human subjects.

Approved on behalf of the Behavioural Research Ethics Board
by one of the following:
Dr. Peter Suedfeld, Chair,
Dr. Susan Rowley, Associate Chair
Dr. Jim Rupert, Associate Chair
Dr. Arminee Kazanjian, Associate Chair

This Certificate of Approval is valid for the above term provided there is no change in the experimental procedures