Developmental and Evolutionary Origins of Language: Insights from the Study of Pointing and Gaze in Infants, Bonobos, and Chimpanzees

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Brian Hare

Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Psychology & Neuroscience in the Graduate School of Duke University

2017
ABSTRACT

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Abstract

The uniquely human ability to acquire language has led to two important and enduring questions: how did humans evolve the ability to communicate through language, and how do human infants acquire this ability so adeptly? Here, I aim to provide new insights into these long-standing questions by exploring how human infants and nonhuman primates use and develop nonverbal communicative behaviors.

Chapter 1 introduces the significance of the empirical studies by outlining the role of nonverbal behaviors in shaping uniquely human communicative skills, along both evolutionary and developmental timelines. In Chapter 2, I take a developmental approach and investigate the role of one particularly important nonverbal behavior, infants’ pointing gestures, in facilitating early language development. I found that pointing has a direct and immediate impact on word learning: in the moment an infant points toward an object, they have a heightened readiness to learn that object’s label. In Chapter 3, I test how pointing relates to learning in a variety of domains, and explores potential motives driving infants’ production of pointing. Results demonstrated that pointing reflects a heightened readiness to learn both labels and functions, and are potentially motivated by requests for objects’ labels. In Chapter 4, I take an evolutionary approach and describe a study assessing another important form of nonverbal communication, gaze alternations, in bonobos and chimpanzees. Like humans, bonobos and chimpanzees gaze alternated more when interacting with an attentive, as opposed to inattentive, communicative partner. However, unlike
humans, individuals produced few gaze alternations (bonobos) or only frequently gaze alternated after reaching adulthood (chimpanzees).

Chapter 5 provides an overview and synthesis of the empirical findings, as well as important future directions. Together, the studies presented here confirm that nonverbal behaviors are a critical feature of the communication systems of both nonhuman apes and human infants. By demonstrating how human infants and nonhuman apes use nonverbal behaviors to communicate and learn, the current findings provide unique insights into the origins and development of language.
Dedication

In memory of my father—

whose influence on my development was, and continues to be, immense.
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Acknowledgements

There is a well-known saying that you should never work with children or animals. In this dissertation I took on both. Fortunately, I was not alone.

I would first like to thank my advisor, Dr. Makeba Parramore Wilbourn. This research would not have been possible (and definitely not as much fun) without your unwavering encouragement and generous guidance. It’s hard to imagine that there are more supportive, thoughtful, and caring mentors out there. Thank you for always believing in me, for creating a home for me in the WILD, and for scaffolding my development in ways that have brought me to new levels of thinking and creativity.

I would also like to thank my committee members, Drs. Beth Marsh, Michael Tomasello, Elika Bergelson, and Brian Hare, for dedicating their time and for their helpful feedback and support at various stages of this project’s development. I would particularly like to thank Brian and Elika, who offered much needed critical insights to the development of these studies and to drafts of this dissertation.

I owe a huge debt of gratitude to the many incredible research assistants, lab managers, and summer interns of the WILD. This dissertation would have taken a lot longer, and would have been a lot less fun, without all of you around. I am especially indebted to KC Young, Natalie Quan, Adrienne Castro, Camille Hayward, Catherine Yang, Devin Jones, Primula Lane, and the wonderful women (and Stephen!) of the WILD writing group. I am also grateful to Evan MacLean, who very generously allowed me to use the data he collected from
bonobos and chimpanzees in my own research, and who offered invaluable insights on drafts of this dissertation. And to the many babies and families who took the time to participate in my studies, this project would have never seen the light of day without their generosity.

This dissertation, without a doubt, is a product of the constant enthusiasm and tireless support of my family and friends. Thank you to Emily and Niki, for just about everything. To the women of P&N, who have inspired me in countless ways and very quickly became life-long friends, making it all so much more fun: Jess, Alison, Charlotte (honorary member), Emma, and Anika. To the Synder-Mackler clan, especially Lynn. And to my family, especially my pioneering grandmothers, Rosemary and Regina, both of whom passed away while I was writing this dissertation. I could not have done this without you.

To my brother Jason, whose ability to fearlessly navigate a hearing world without being able to hear inspired my life-long obsession with language. And to my mom, whose love, boundless encouragement, and sacrifices made this all possible.

Finally, I would like to thank my outrageously supportive, kind, brilliant, and loving partner, Noah, who (very patiently) stood with me along every step of this adventure.
Chapter 1. Introduction

To communicate, honeybees dance in circles that direct others to the location of food (von Frisch, 1967). Whales emit song-like calls to spread their message around the world (Zimmer, 2011). There is simply no denying that nonhuman animals are capable of communicating in fascinating and complex ways. Yet, despite these abilities, the communication of other species does not match the complexity of human language. Only humans possess the ability to communicate with abstract, conventionalized symbols, and are able to combine such symbols in infinite and recursive ways to convey ideas about the past, present, and future. This representational system of communication is made possible by a set of early emerging, uniquely human social-cognitive skills. There are simply no analogs of human language in the nonhuman animal world.

The complexity and uniqueness of human language has posed two fundamental questions for researchers: (1) how did language evolve, and (2) how do human infants acquire language so proficiently? For decades, researchers have argued that nonverbal behaviors, and gestures in particular, are the “royal road to language”, both developmentally and evolutionarily (Butterworth, 2003; Corballis, 2003; Goldin-Meadow, 2007; Liebal & Call, 2012; Tomasello, Carpenter, & Liszkowski, 2007). The empirical studies presented in the current dissertation build on this hypothesis by investigating how human infants and nonhuman primates use and develop nonverbal communicative behaviors.
In this first Chapter, I introduce the literature motivating each of these empirical studies. First, I review research on language evolution and nonhuman primates’ nonverbal communication. In this section, I highlight important open questions and describe how answering these questions can provide new insights into the evolution of language. Next, I turn to the developmental literature and synthesize what is known about the role of nonverbal behaviors in shaping human language acquisition. Here, I point out gaps in our understanding of nonverbal communication, and explain why filling these gaps is critical for advancing our understanding of language development. I end by briefly summarizing the overarching objective of the current dissertation: to provide new insights into the development and evolution of language by studying the nonverbal behaviors of infants, bonobos, and chimpanzees.

**Nonverbal Behaviors and the Evolution of Language**

The evolution of language has famously been referred to as the “hardest problem in science” (Christiansen & Kirby, 2003). Discussion of the topic was banned by the Paris Society of Linguistics in 1866, and remained largely marginalized by researchers until recently (Fitch, 2002). Without fossil records to draw from, theories of the evolution of language were, for a long time, largely speculative. Initially, researchers argued that language was a result of a random genetic mutation, or a byproduct of selection pressures for a larger, more powerful brain (Chomsky, 1972; Enard et al., 2002; Gould, 1987). However, years of research into the design and use of language have shifted this perspective. The
complexity of language, in both its structure and pragmatics, has led researchers to conclude that language itself is a result of Darwinian natural selection (Pinker & Bloom, 1990).

If language did evolve via a process of natural selection, then there must be homologies of human language in our nonhuman primate relatives. Thus, some of the most informative hypotheses about the evolution of language come from studies that compare the communicative and social-cognitive abilities among nonhuman primates (Harvey & Pagel, 1991; Mayr, 1982). Comparative studies of bonobos and chimpanzees, as opposed to other nonhuman primates, are the most explanatory because they are humans’ closest living relatives and provide the best representation of our last common ancestor. Bonobos and chimpanzees diverged from the human lineage approximately 6 million years ago and we share approximately 99 percent of our genome with them (Won & Hey, 2005). By identifying aspects of cognition and communication that are shared with our nonhuman primate relatives, we can formulate hypotheses about which components of or precursors to human language are deeply rooted in our evolutionary history (i.e., traits that have been conserved from our last common ancestor with bonobos and chimpanzees, or earlier). Alternatively, by identifying aspects of cognition and communication that are uniquely human, researchers are able conclude that these abilities are likely a result of more recent selection pressures that are unique to the human lineage.

Nonhuman Primate Vocal Communication

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Historically, research on nonhuman primate communication has primarily focused on vocalizations (Seyfarth, Cheney, & Marler, 1980; Seyfarth & Cheney, 2003; Todt, Goedeking, & Symmes, 1988). Research in this domain has uncovered that nonhuman primate vocal communication shares many features with human language. For instance, Seyfarth and colleagues (1980) demonstrated that nonhuman primate vocalizations are referential in nature: specific alarm calls are produced in the presence of specific predators and, in response to certain calls, conspecifics react in predictable ways. For example, if one individual gives an “eagle call”, other members of the group will reliably respond by looking up and scanning for eagles. Researchers have taken this as evidence of some form of semantics because distinct calls have distinct meanings.

More recently, researchers have expanded on these findings by demonstrating that monkeys not only produce individual calls with meaning, but they also combine these calls to construct new meanings – an ability that many researchers have argued to be akin to syntax (Arnold & Zuberbühler, 2008; Arnold & Zuberbühler, 2006). While these findings are compelling, there are several reasons to reject the hypothesis that these calls fit the criteria for human language (Fischer, 2017). For instance, these vocalizations are mainly driven by emotional states and are almost always tied to certain behavioral contexts (Goodall, 1986). Moreover, these vocalizations are typically associated with urgent functions (e.g., escaping predators) and are likely genetically fixed, as
nonhuman primates rarely modify their vocal repertoires by adding new calls (Cheney & Seyfarth, 2003).

**Nonhuman Primate Gestural Communication**

Studies searching for homologs of human language in nonhuman primate communication have been much more fruitful when they have focused on gestural communication, rather than vocal communication (Moore, 2014). For instance, compared to vocalizations, great apes use gestures flexibly and in a goal-directed manner (Pollick & de Waal, 2007; Tomasello & Call, 2007). This is evidenced by findings that great apes modify their gestural signaling according to recipient familiarity and attentional state (i.e., they will take into account any shared history or whether the recipient is attentive or not; Genty, Neumann, & Zuberbühler, 2015; Liebal, Pika, Call, & Tomasello, 2004). Moreover, great apes gestures fit an important criterion for intentional communication: they continue to gesture until they achieve a preferred outcome from a communicative partner (Cartmill & Byrne, 2007; Liebal, Call, & Tomasello, 2004).

Great apes also have larger repertoires of gestural signals than vocal signals, and appear to combine them in more sophisticated and elaborate ways (Hobaiter & Byrne, 2011b, 2014). What’s more, these gestures, unlike vocalizations, do not appear to be genetically fixed and are instead used in different ways across contexts and settings (Halina, Rossano, & Tomasello, 2013). Finally, recent evidence has documented that chimpanzees will engage in cooperative “turn-taking” while gesturing (i.e., they will wait for a
communicative partner’s response after producing an initial communicative signal, and before producing a second signal; Fröhlich et al., 2016).

Further insights into the flexible use of great apes’ communicative abilities comes from language training studies. While great apes have never successfully acquired full-blown language, attempts made in the visual modality (e.g., gestures to refer to objects) have been much more successful than those made in the auditory modality (e.g., vocalizations to refer to objects; Furness, 1916; Gardner & Gardner, 1969; Hayes, 1951; Savage-Rumbaugh, 1986; Terrace, Pettito, Sanders, & Bever, 1979). In these studies, apes were taught American Sign Language (ASL) signs or pictograms to refer to objects. Subjects acquired a “vocabulary” of up to 256 signals, and were also able to learn basic combinations of these signals (Savage-Rumbaugh, McDonald, Sevcik, Hopkins, & Rubert, 1986).

**The Transition to Human Language – What Changed?**

If great apes are capable of learning, processing, and recalling signs, then what constrains their ability to acquire language? In other words, what specific abilities do humans possess that enable them, but not other animals, to acquire language? One clear discontinuity between human and ape language learning is the ways in which symbols are combined. Although great apes can learn basic combinations of symbols, these combinations fail to reach the syntactic complexity of young children’s (Yang, 2013). The process of acquiring these combinations is also fundamentally different that of than children’s. An analysis
conducted by Yang (2013) revealed that nonhuman primates acquire combinations of symbols by rote imitation, whereas young children’s acquisition of grammar is “systematically productive” – it happens rapidly and spontaneously, without explicit instruction.

Another clear limitation on great ape language learning is in the way language is used (i.e., the social and pragmatic usage of language; Bruner, 1983; Tomasello, 2008). The bonobo Kanzi, one of the most successful examples of great ape language training, exemplifies this limitation most clearly. Although Kanzi was able to learn many signs, over 95% of those signs were imperatives, or requests for objects (Greenfield & Savage-Rumbaugh, 1990). Kanzi did not produce signs for declarative reasons, or to purely share his attention around objects. This is in stark contrast to humans, who begin communicating in declarative ways before even producing words (e.g., by pointing to objects to share attention another individual; Tomasello et al., 2007).

A Gestural Origins of Human Language

Although nonhuman primates never fully acquire language, studying which features of their communication system are shared with human language provides insights into what the earliest form of human language may have looked like. The findings that nonhuman primates communicate most flexibly in the nonverbal modality has led many scholars to propose a gestural origin for

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1 Tomasello (2008) argues that these skills, together with other social-cognitive abilities, such as following communicative cues to locate a hidden reward or understanding other’s intentions, are part of a broader adaptation for cooperative and collaborative activities (see also Herrmann, Call, Hernandez-Lloreda, Hare, & Tomasello, 2007).
human language (Arbib, Liebal, & Pika, 2008; Armstrong & Wilcox, 2007; Armstrong, Stokoe, & Wilcox, 1995; Cartmill, Beilock, & Goldin-Meadow, 2012; Corballis, 2002; Hewes, 1973; Pollick & de Waal, 2007; Tomasello, 2008; Wundt, 1973). This theory posits that the first form of human language was in the form of gestures. To date, the gestural origins theory continues to have broad and robust support².

The gestural origins theory maintains that before humans became bipedal (approximately 4 million years ago), they spent millions of years adapting to life in the trees (Aiello & Dean, 1990; Ward, 2002). This lifestyle provided our ancestors with precise and intentional control over the arms and hands. However, the emergence of bipedalism (i.e., walking upright), a feat unique to the hominin lineage, freed the arms and hands, which allowed for more complex and effective communication via manual gestures. As a result, proponents of the gestural origins theory contend that gesture was the first form of uniquely human communication, co-occurring with the advent of bipedalism in our hominin ancestors (Corballis, 2002).

While gestures may have laid the foundation for an advanced system of communication, somewhere along the path to modern human language, oral speech took over. Lieberman (2006) contends that bipedalism may have led to the dropping of the vocal cords, allowing for human-like speech articulation. However, the dropping of the vocal cords was also costly. The shape of the

²Although, for debate see Kendon (2016) and Seyfarth (2005).
human vocal tract is configured in such a way that, compared to other species, the likelihood of choking while eating is much higher (Darwin, 1859; Fitch, 2000). To compensate for this cost, spoken communication must have conferred several advantages over relying on gestural communication alone (Lieberman, 2006). For instance, speech may have been able to fill in several gaps when gestures fell short. Speech, but not gestures, would have allowed our ancestors to communicate when their hands were occupied or with individuals who were not directly visible. Although there is no strong consensus on to the exact path to human language, the research reviewed here suggests that to better understand the evolution of human language, it is advantageous to study nonverbal communication in nonhuman primates.

**Nonhuman Primate Communication – Open Questions**

While our knowledge of nonhuman primates’ nonverbal communication has greatly advanced in the past several decades, important questions surrounding the full extent and nature of nonhuman primates’ nonverbal communication remain. Broadly, these questions concern how their nonverbal communication (1) develops and changes over time, (2) differs across great ape species, (3) and is used flexibly. These questions remain unanswered because the extant research has relied on a model/single species and overlooked various, less salient, forms of nonverbal communication.

**Reliance on a model/single species.** Historically, the majority of studies on nonhuman primate communication have included only a single species (de
Waal & Lanting, 1997). Although bonobos and chimpanzees are equally related to humans, sharing 99% of their genome with humans, bonobos continue to be severely unstudied compared to chimpanzees (Hare, 2007; Hare & Yamamoto, 2015). Relying on a single species to formulate hypotheses regarding the origins of communication is problematic because it limits our ability to determine which traits are derived, and which are new (and unique) to the human lineage. If certain traits are uniquely human, then the most parsimonious prediction is that they would be absent in both bonobos and chimpanzees. Although bonobos and chimpanzees diverged from each other only 2 million years ago, there are a number of important differences between these species. For example, bonobos often exhibit developmental delays relative to chimpanzees in skills relating to foraging, such as spatial navigation (Hare, Wobber, & Wrangham, 2012; Rosati & Hare, 2012; Wobber, Wrangham, & Hare, 2010). Thus, to answer questions related to human cognitive evolution, researchers must make within-great ape comparisons, and study both bonobos and chimpanzees (MacLean, 2016).

**Understudied forms of nonverbal communication.** The majority of studies on nonhuman primates’ nonverbal behaviors have focused on manual and/or facial gestures (Slocombe, Waller, & Liebal, 2011). It is possible that, similar to human infants, nonhuman primates also communicate with their eyes. Indeed, from the first year of life, infants communicate with their gaze. For example, infants frequently produce gaze alternations, in which they alternate their gaze between an object of interest and another individual also attending to
that object (Bates, Camaioni, & Volterra, 1975; Bruner, 1982; Tomasello, 1995). Gaze alternations in human infants are consistently used as a key feature of joint attention, and have been argued to provide the foundation for more complex social-cognitive skills, such as theory of mind and language (Akhtar & Gernsbacher, 2007; Bruner, 1983; Tomasello, Carpenter, & Liszkowski, 2007).

Although some research has focused on gaze alternations in nonhuman primates, the extent to which and flexibility with which nonhuman primates use gaze alternations remains unanswered (Anderson et al., 2007; Bourjade, Meguerditchian, Maille, Gaunet, & Vauclair, 2014; Leavens & Hopkins, 1998; Plooij, 1978; Tomasello et al., 1994; Tomasello, George, Kruger, Farrar, & Evans, 1985). The lack of research in this area is not surprising, given that nonhuman primates’ eyes have less salient white sclera (i.e., white outer layer of the eyeball) compared to humans (Kobayashi & Kohshima, 2001). Indeed, one quantitative comparison found that humans’ white sclera is three times more visible than that of other great apes (Kaplan & Rogers, 2002). The lack of salient white sclera in nonhuman primates not only makes it difficult to capture and study their eye movements, it may also limit the likelihood that they use gaze alternations in ways similar to humans. However, given the critical importance of gaze alternations in human communicative development, this remains an important area of research.

The research presented in Chapter 4 of this dissertation aims to answer these questions by examining the flexibility and use of gaze alternations in a
large, developmental sample of both bonobos and chimpanzees.

**Nonverbal Behaviors and the Acquisition of Language**

*Gesture is not a behavioral fossil that was superseded by language but an indispensable part of language*

McNeil, 2004, p. 1317

When we think of communication, we typically think of spoken language first. However, nonverbal behaviors, and gestures in particular, are an integral part of how we communicate (Goldin-Meadow, 1999; Kendon, 2004; McNeil, 2000). Humans gesture routinely when they speak, and asking them *not* to gesture disrupts their ability to communicate effectively (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Gestures are so closely integrated with communication that even blind speakers, who have never seen gestures, will gesture when they are knowingly communicating with blind listeners (Iverson & Goldin-Meadow, 1998). This gesture-communication link is present from very early in development: one of the very first ways that infants communicate is through their gestures. Thus, not surprisingly, researchers have long been interested in what infants do with their hands.

In 1877, Darwin made the first systematic observations of an infant’s gestures. In his well-known *Biographical Sketch of an Infant*, Darwin outlined how the development of infants’ hands far out-paces the development of other parts of the body. Darwin argued that because infants’ first “rational actions” are in the form of gestures, they can serve as a window into infants’ interests and thoughts. Infants produce a wide variety of communicative gestures, such as
attention-getters, reaching arms out to be picked up, “bye-bye”, holding out hands to show an object. However, the pointing gesture is consistently argued to be of particular importance to language development (Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Bruner, 1975; Colonnesi, Stams, Koster, & Noom, 2010; Dobrich & Scarborough, 1984; Goldin-Meadow, 2007; Leung & Rheingold, 1981; Masur, 1983; Murphy & Messer, 1977; Tomasello, 2008; Werner & Kaplan, 1963). Some researchers have gone as far as to say that pointing “paves the way” for language development (Iverson & Goldin-Meadow, 2005).

Several lines of evidence provide support for this claim. First, infants all around the world point with an index-finger, despite the fact that index-finger pointing during adulthood is not universal (Blake, Osborne, Cabral, & Gluck, 2003; Callaghan et al., 2011; Cooperrider, Núñez, & Slotta, 2014; Liszkowski, Brown, Callaghan, Takada, & de Vos, 2012; Salomo & Liszkowski, 2013). Second, pointing appears to be uniquely human (Tomasello, 2006). Although nonhuman primates can be trained to produce point-like gestures in captivity (Leavens & Hopkins, 1998; Savage-Rumbaugh, 1990), there is currently no evidence that they point in the wild or in the same way that human infants do (i.e., declaratively, to share their attention around objects; Liszkowski, Schäfer, Carpenter, & Tomasello, 2009; van der Goot, Tomasello, & Liszkowski, 2014). Finally, infants’ pointing gestures have strong ties to early language development: infants’ pointing gestures are one of the strongest predictors of their early vocabulary size (Bates et al., 1979; Brooks & Meltzoff, 2005; Colonnesi et al., 2010; Dobrich &
How does Pointing Develop?

Infants begin to point around 9 months, with an average age of onset of 12 months (Bates et al., 1975; Butterworth & Grover, 1988; Carpenter, Nagell, & Tomasello, 1998; Dobrich & Scarborough, 1984; Gredebäck & Melinder, 2010; Leung & Rheingold, 1981). While there is a general agreement on the developmental timeline of infants’ pointing gestures, researchers have long disagreed about how pointing develops. Cross-cultural research, documenting variation in the timing of infants’ first pointing gestures, has ruled out the possibility that pointing is the result of purely maturational processes that unfold on a genetically determined timeline (Callaghan et al., 2011; Salomo & Liszkowski, 2013). For instance, on average, Chinese infants begin to point earlier, and with higher frequency, than Mexican or Dutch infants (Salomo & Liszkowski, 2013). Thus, the development of pointing gestures is socially mediated. However, the precise nature of the social experiences that shape the development of pointing has been, and continues to be, widely debated.

Some of the earliest theories on the developmental origins of pointing emerged during the 20th century from the work of two pioneering psychologists, working independently. Wilhelm Wundt (1973) and Lev Vygotsky (1978) proposed that pointing is a fundamentally simple and egocentric act – nothing more than an abbreviated grasping movement (see also Leung & Rheingold,
1981; Murphy & Messer, 1977). They argued that several months before infants produce index-finger points, they frequently stretch their arms out to acquire out-of-reach objects. As a result, adults notice this behavior and respond by obtaining out-of-reach objects for the infant. As this cycle of failed reaches driving adult responses repeats, the infant comes to anticipate the adult’s response and abbreviates their movement from a full reaching gesture to a pointing gesture. In other words, an initially non-communicative behavior becomes ritualized into a communicative behavior because of a communicative partner’s reaction to it and an infant’s anticipation of that reaction (i.e., “ontogenetic ritualization”; Tomasello & Call, 1997).

Other researchers have similarly noted that pointing may originate out of non-communicative acts. Before infants start pointing, they use their index finger to manually explore objects (Mead, 1934; Shinn, 1900; Zinober & Martlew, 1985). As infants gain motor control over their fingers and arms, they may expand their index finger explorations into full pointing gestures. Pointing gestures would then allow infants to visually explore and orient themselves toward out-of-reach objects (Bates et al., 1979; Carpendale & Carpendale, 2010; Lock, Young, Service, & Chandler, 1990; Mead, 1934; Werner & Kaplan, 1963). Evidence for this hypothesis comes from the finding that infants point in non-social ways (i.e., in the absence of any potential communicative partners; Delgado, Gómez, & Sarriá, 2009). Together, these proposals argue that infants’ early pointing gestures are purely egocentric and are reflections of their attention, interests and desires.
Another possible explanation for the development of pointing is imitation. On the lowest level, infants may see adults point and mimic that behavior without an understanding of why that gesture was used (Cochet & Vauclair, 2010; Heimann, Strid, & Smith, 2006). Alternatively, infants may observe an adult point and understand that they are pointing to accomplish a specific goal. Then, when infants have that same goal, they may reproduce that gesture. Tomasello and colleagues (1993; 2016) have labeled this process “cultural learning” and have used it to explain other key developmental milestones, such as conforming to cultural norms. According to this theory, infants learn to point through taking another individual’s perspective on a situation, and then reapplying that behavior when they are in a similar situation.

There is currently no research that can directly disentangle hypotheses about the origins of pointing. Answers about exactly how pointing develops would need to come from studies that longitudinally track the development of pointing and evaluate the contexts in which it occurs. For instance, it would be informative to understand the referents that infants point to and the types of things caregivers do and say before and after the gesture is produced. This would help pinpoint the specific socialization experiences that contribute to the development of pointing. However, longitudinally tracking the moment-to-
moment ontogeny of pointing is very time consuming, both in terms of data collection and coding. Thus, very few studies have taken this approach. Those that have typically focus on very few infants (e.g., 2-10), making any generalizations difficult (Carpendale & Carpendale, 2010; Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007).

**Infants Point their Way to Language**

Although there is little agreement on how infants’ pointing first develops, there is strong evidence that pointing gestures are closely linked with other communicative abilities. The earliest signs of pointing emerge between 3 and 6 months\(^3\), when infants first begin to extend their index finger (Masataka, 1995; Trevarthen, 1977). These early “point-like” gestures are already linked with communicative development: infants are more likely to produce these types of index-finger extensions when they are engaged in face-to-face interactions with their caregivers (Fogel & Hannan, 1985). These early gestures are also reliably produced in combination with speech-like vocalizations (i.e., vocalizations that are syllabic with more oral resonance and pitch contours; Bloom, 1988; Masataka, 1995). Importantly, this gesture-speech coupling continues throughout development. As infants gain more strength and control of their upper body at around 6 months, they begin to produce manual arm movements that are consistently produced alongside speech-like vocalizations (Blake, O’Rourke, & Borzellino, 1994; Franco & Butterworth, 1996; Iverson & Fagan, 2004). By 9

\(^{3}\) Though there is some evidence that the first precursors of pointing may actually be present in neonates (Nagy et al., 2005).
months, the first signs of “true” index-finger pointing begin to appear (i.e., an index finger protruded from the other fingers with the arm fully extended; Dobrich & Scarborough, 1984; Gredebäck & Melinder, 2010; Leung & Rheingold, 1981), with an average age of onset of about 12 months (Carpenter et al., 1998). These fully-formed pointing gestures continue to be produced together with speech-like vocalizations (Esteve-Gibert & Prieto, 2014; Grünloh & Liszkowski, 2015).

Infants’ pointing gestures emerge at a critical time in their development. Between 9 and 12 months, infants enter the “social-cognitive revolution” (Tomasello, 1995). During this time, infants are rapidly acquiring a broad set of social-cognitive skills that prepare them to effectively communicate with others. For instance, infants acquire the understanding that others are intentional agents. Infants comprehend that the actions of others are goal-directed4 (Behne & Carpenter, 2005; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Falck-Ytter, Gredebäck, & von Hofsten, 2006) and are able to reliably follow the gaze of others in complex situations (e.g., to determine what is behind a barrier; Brooks & Meltzoff, 2005; Caron et al., 2002; Moll & Tomasello, 2004). Infants are also beginning to form representations of the basic mental states of others: they know what others have and have not seen (Tomasello & Haberl, 2003). Finally, at this age, infants are also frequently engaging in triadic interactions (i.e., interactions in which infants and adults jointly attend to an object of shared attention;

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4 Although see Woodward (1998) for evidence that components of this ability may develop earlier.
Bakeman & Adamson, 1984; Ratner & Bruner, 1978; Ross & Lollis, 1987). That infants have the requisite skills for effective communication when they start pointing suggests that this gesture is strongly linked to language development.

Further evidence for an intricate link between pointing and language development comes from the way in which infants’ pointing gestures are used. For instance, infants’ pointing gestures are consistently produced with gaze alternations (Bates et al., 1975; Franco & Butterworth, 1996). In other words, when infants point they will also frequently alternate their gaze between the referent of their point and an adult who is also attending to that referent. Gaze alternations are consistently used as a key operational feature of joint attention because it signals that the infant is coordinating their attention to a referent and an adult who is simultaneously coordinating his or her own attention to that referent and the infant (Tomasello, 1995). These gaze alternations suggest that infants are aware that they have a shared focus of attention with adults. Gaze alternations are also used as an indicator of early intentionality because they suggest that infants understand the influence their pointing gesture has on others (i.e., they understand that their pointing gestures produce a specific, desired outcome; Akhtar & Gernsbacher, 2007; Bates et al., 1975; Bruner, 1983; Franco & Butterworth, 1996; Tomasello, Carpenter, & Liszkowski, 2007).

While the literature reviewed above suggests a strong link between pointing and language development, some of the strongest evidence for this connection comes from the finding that infants’ pointing gestures are one of the
strongest predictors of their vocabulary development. For instance, the timing of infants’ first pointing gestures predicts the age at which they will comprehend and produce their first words (Carpenter et al., 1998; Harris, Barlow-Brown, & Chasin, 1995). By observing when infants first begin to point, as well as the rate at which they point at 12 months, researchers can reliably predict how many different gestures and words these infants will comprehend at 14 months (Fenson et al., 1994), along with their speech production rates at 24 months (Camaioni, Castelli, Longobardi, & Volterra, 1991). Importantly, these relations are also predictive from infancy to the preschool years: infants’ rate of pointing at 14 months also predicts their vocabulary size at 42 months (Rowe et al., 2008). Taken together, there is overwhelming evidence to suggest that infants’ early pointing gestures are robust predictors of their vocabulary development (Carpenter et al., 1998; Colonnesi et al., 2010; Fenson et al., 1994; Harris et al., 1995; Iverson & Goldin-Meadow, 2005).

More recently, it has been suggested that the relation between pointing and language development is not just correlational, but also potentially causal in nature. This evidence comes from a study conducted by Lebarton and colleagues (2015), in which infants were trained by an experimenter to increase their use of pointing gestures. Results revealed that infants trained to increase their rate of pointing, compared to a control group of infants exposed to music training, had
significantly larger vocabulary sizes eight weeks later\(^5\) (Lebarton, Goldin-Meadow, & Raudenbush, 2013).

**Why Do Infants Point?**

Given that infants’ pointing gestures do not just *reflect* their language development, but may also *drive* it\(^6\), it is imperative to understand why infants point. Since it is impossible to ask infants why they point, researchers formulate hypotheses about the motives of pointing by observing naturally occurring pointing gestures or designing experiments that elicit pointing gestures. Not surprisingly, this has led to much debate (D’Entremont & Seamans, 2007; Gómez, 2007; Southgate, van Maanen, & Csibra, 2007; Tomasello et al., 2007).

Some of the first speculations on infants’ motivations for pointing came from Wundt (1973) and Vygotsky (1962) who contended that infants’ pointing gestures are failed reaching attempts. According to their perspective, infants point with the objective of touching, holding, or acting on that object in some way. Later, during the 1960’s and 70’s, a slightly more nuanced perspective emerged. Werner and Kaplan (1963) argued that infants point toward an object to individuate that object amongst others. Bates and her colleagues (1975; 1979; 1983; 1987).

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\(^5\)When researchers attempted pointing-training interventions with younger infants (9 months), and had parents (as opposed to experimenters) administer the intervention, they were not as successful (Matthews et al., 2012).

\(^6\) It is important to point out that the process of language learning begins long before infants produce some nonverbal behaviors. Infants discriminate and perceive speech sounds as early as in utero (DeCasper & Spence, 1986; Mehler et al., 1988), and comprehend their first words by 6 months (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999). Here, when I state that language is driven by nonverbal behaviors, I am only referring to certain language abilities that are only present *after* infants communicate nonverbally. Nonverbal behaviors contribute to the growth of language development, but are not necessary as children who can’t gesture acquire language.
1987) subsequently built on this proposal and famously dubbed infants’ pointing gestures the “quintessential act of reference”. According to these researchers, infants’ use of their pointing gestures to refer to objects directly facilitates their ability to contemplate those objects. When an infant contemplates an object, they carefully and thoughtfully consider, think about, and reflect upon that object. Thus, there are qualitative differences in the acts of grasping, reaching, and pointing. While reaching and grasping gestures are “tied up with pragmatic things-of-action”, pointing gestures are uniquely linked to a world of “contemplated objects” (Werner & Kaplan, 1963, p. 79).

Infants’ use of their pointing gestures to contemplate objects may strengthen abilities that underlie word learning. Werner and Kaplan (1963) argued that one way infants formulate linguistic representations is by distancing themselves from the objects they are representing. Infants’ pointing gestures, in that they facilitate infants’ ability to contemplate objects, helps them begin to differentiate external objects from themselves. This contemplation of objects that are immediately present facilitates infants’ emerging ability to contemplate objects that are not immediately present. This ability may in turn facilitate infants’ ability to refer to objects that are not immediately present (i.e., displacement). Displacement is one of language’s key, incomparable properties (Brown, 1973; Hockett, 1960).

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7 This theoretical distinction between reaching and pointing was later supported by observational research revealing that infants rarely use reaching and pointing gestures interchangeably (Franco & Butterworth, 1991).
The historical perspectives on infants’ pointing gestures help explain how infants acquire certain properties of language, however, they don’t offer a full picture of how pointing may contribute to language development. In sum, these perspectives viewed infants’ pointing gestures as being purely egocentric and simple manifestations of their attentional states (e.g., “I’m looking at that”; Werner & Kaplan, 1963) or imperative and reflective of their desires to obtain objects (e.g., “I want that” Bates et al., 1975; Vygotsky, 1962). However, research conducted over the past 20 years has significantly altered this perspective. Currently, there is an agreement that infants point for a variety of reasons, some of which may be deeply social in nature (Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004). These newly uncovered functions of pointing offer novel insights into how pointing may relate to, and potentially contribute to, early language development.

In a series of different studies using experimental techniques, researchers have provided compelling evidence that infants’ points are guided by several potentially complimentary motivations to (1) share interest in some object or event (e.g., “look at that”; Liszkowski et al., 2004), (2) help others by sharing relevant or useful information with others (e.g., “there it is!”; Liszkowski, Carpenter, & Striano, 2006), or (3) request information (e.g., “what is that?”; Begus, Gliga, & Southgate, 2014). These first two motives have been studied extensively, and have a well-documented importance for early development (e.g., they support the development of uniquely human skills for cooperation
and shared intentionality; Bates et al., 1975; Tomasello et al., 2007). In comparison, research on this third motive, the information-requesting motive, is underdeveloped.

**Infants Point to Acquire Information**

Begus and Southgate (2012) provided the first direct evidence for an information-requesting motive of pointing. In this study, researchers found that infants were more likely to point for individuals they knew to be knowledgeable, rather than ignorant. Kovács and colleagues (2014) built on this research by demonstrating that infants are more satisfied when an experimenter responds to their pointing gestures with information, compared to when an experimenter responds to their pointing gestures by acknowledging their interest, but not providing any information.

Although an information-requesting motive is much more selfish than more declarative (i.e., attention sharing) motives of pointing, it may be this type of utilitarian function of pointing that makes it such a powerful, driving force for early learning and development. If infants’ pointing gestures provide them with access to new information, it would directly fulfill their need to successfully learn about the world around them (Southgate et al., 2007).

**Pointing and Language Development – Open Questions**

The research presented in Chapter 2 builds on this idea, that pointing gestures are related to learning, by testing whether infants’ pointing gestures signal a heightened readiness to learn new information. Infants’ pointing
gestures may represent a heightened readiness to learn because pointing allows infants to receive information when they are most receptive to it (i.e., when they are explicitly requesting it). To test developmental differences in the link between pointing and learning, infants were tested at key milestones: (1) 12 months, when infants first begin to point, and (2) 18 months when infants are entering the “vocabulary burst” and have had several months of experience pointing (Bloom, 1973).

Chapter 3 builds on the research from Chapter 2 by exploring the specificity of infants’ information-requesting via pointing. In other words, when infants point toward an object, do they want to receive a certain type of information about that object (i.e., its function or label), or are they satisfied with receiving any type of information in response to their pointing gestures? Relatedly, does pointing lend itself to learning certain types of information (i.e., functions vs. labels) more readily than others, or does pointing reflect a readiness to learn any type of information? To investigate the unique function of infants’ pointing gestures as an information-requesting behavior, I also examined how infants’ learning and satisfaction with information for objects varies if they don’t point towards those objects before receiving information for them (e.g., they reach out to grab the objects).

In sum, the studies presented in Chapters 2 and 3 test (1) whether infants’ pointing gestures uniquely reflects a heightened state for learning, (2) if pointing is produced to obtain a specific type of information, and (3) how the link
between pointing learning differs across development and different domains of information. In answering these questions, these studies aim to provide new insights into the role of pointing gestures as a cultural learning mechanism that facilitates the acquisition of new information. This information, in turn, will be critical for understanding why infants’ pointing gestures are of “cosmic importance” to language development (Bates et al., 1979).

**The Current Dissertation**

*<i>A full understanding of how human beings have come to be as they are requires an understanding of both human evolution and human ontogeny.</i>*

Tomasello & Gonzales-Cabrera, 2016, p. 16

The literature reviewed above demonstrates that nonverbal behaviors can serve as a unique window into cognition and communicative abilities when verbal behaviors have yet to develop (e.g., during infancy), or are non-existent (e.g., in nonhuman primates). The studies presented in this dissertation build on this proposal by experimentally investigating the use and development of nonverbal behaviors in both human infants and nonhuman primates. In doing so, the current dissertation has the potential to provide unique insights into (1) the mechanisms by which infants’ early nonverbal communicative behaviors facilitate early language acquisition and (2) which aspects of human nonverbal communication are shared with our nonhuman primate relatives. By integrating experimental evidence from both humans and nonhuman primates, the studies presented in the current dissertation drive home the importance of nonverbal
behaviors in the key transition from nonverbal to verbal communication – on both developmental and evolutionary timelines.
Chapter 2. Communicating to Learn: Infants’ Pointing Gestures Result in Optimal Learning

Introduction

Months before infants produce their first words, they begin to initiate communicative interactions with their gestures. Researchers have long argued that these early gestures lay the foundation for later language development (Bates, Camaioni, & Volterra, 1975; Goldin-Meadow, 2007). Pointing gestures specifically, because of their universality and ability to consistently predict infants’ later vocabulary size, are considered to be of special importance to language development – particularly in the domain of early word learning (Colonnesi et al., 2010). For instance, the age at which infants first begin to point and the rate at which they point at age 12 months reliably predicts their vocabulary knowledge at 14 months (Fenson et al., 1994), and speech production at 24 months (Camaioni et al., 1991). Importantly, the robust relation between early pointing and vocabulary size persists throughout development; pointing at 14 months predicts subsequent vocabulary size at 42 months (Rowe et al., 2008). While it is clear that pointing plays a fundamental role in early vocabulary development (Iverson & Goldin-Meadow, 2005), important questions remain as to how and in what contexts pointing influences early word learning. The goal of the current studies is to investigate these questions.

1 This chapter is published in Child Development (Lucca & Wilbourn, 2016).
One way that infants’ early pointing may influence word learning is by providing infants with increased exposure to language. Through pointing, infants signal to their caregivers a referent of interest. In turn, these signals provide caregivers opportunities to offer labels, translations, or commentary tailored to their infants’ interests, desires, or goals (Golinkoff, 1986). This type of tailored linguistic input is particularly advantageous for early word learning. Indeed, infants learn word-object relations more readily when they are attending to an object being labeled than when their attention is redirected to a new object (Baldwin, 1991; Goldstein, Schwade, Briesch, & Syal, 2010; Tomasello & Farrar, 1986). Consequently, the more infants point towards objects, the more likely it is that the labels or words for those objects will enter their vocabularies (Goldin-Meadow, Goodrich, Sauer, & Iverson, 2007). Together, these findings suggest that by guiding their language input, infants’ pointing gestures facilitate language acquisition (Butterworth, 2003).

**Infants as Information-Seekers**

Infants do not passively absorb the input they receive in response to their pointing gestures. In fact, it is likely that infants play a constructive role in their learning by actively seeking out that information (Csibra & Gergely, 2006; Piaget, 1954). Indeed, from early on in development, infants display perceptual biases and attentional patterns that strongly suggest a motive to acquire information (Xu & Kushnir, 2013). For instance, in a series of studies, Kidd and colleagues (2012, 2014) found that 8-month-old infants selectively attend to patterns of
stimuli that are of intermediate complexity, compared to patterns of stimuli that are too simple (overly predictable) or too complex (overly unpredictable). Patterns of stimuli with this particular level of intermediate complexity are likely ideally suited for infants to learn from because they are: (1) not overly simple such that infants could quickly understand them, and (2) not overly taxing such that they exceed infants’ information-processing capacity, making them too difficult to learn from. Thus, Kidd and colleagues conclude that by 8 months, infants prefer to examine stimuli that have the potential for the most information gain (Kidd, Piantadosi, & Aslin, 2012; 2014).

Additional support for infants as active contributors to their development comes from research demonstrating that even newborns have been shown to differentially allocate their attention depending on the complexity of the stimuli. For instance, Morton and Johnson (1991) found that from the first few days of life, infants selectively attend to human faces, compared to other salient stimuli (e.g., a face with scrambled features). Likewise, young infants tend to selectively listen to human voices, as opposed to other dynamic sounds (Vouloumanos & Werker, 2004). Since faces and voices are important sources of information (Csibra & Gergely, 2006), these biases strongly suggest that infants allocate their attention in ways that maximize their potential for information gain. Infants’ early manual exploration also supports this claim in that infants, by around 12 months, spend more time exploring objects that may potentially provide new information (i.e., objects that have previously violated their expectation; Stahl &
There is compelling evidence to suggest that infants understand that their caregivers are particularly important sources of information, and are highly motivated to access that information (Gergely, Egyed, & Kiraly, 2007; Homer & Tamis-Lemonda, 2013; Vaish, Demir, & Baldwin, 2011). For instance, in ambiguous learning situations (e.g., when a referent of a spoken label is unclear), infants will consult an adult’s gaze direction to assist them in locating the correct object (Baldwin, 1991; Vaish et al., 2011).

Infants do not only attend to and prefer stimuli that are highly informative, they will also explicitly *request* information. One potent way for infants to request information is through pointing. Pointing gestures, because of their salient nature, afford infants with a particularly powerful means of eliciting information (Southgate, van Maanen, & Csibra, 2007). Recent experimental studies have provided compelling support for the hypothesis. For instance, 16-month-old infants are significantly more likely to point for knowledgeable recipients (i.e., someone they had seen correctly label a familiar object) than for ignorant recipients (i.e., someone they had seen incorrectly label a familiar object; Begus & Southgate, 2012). Infants are also more likely to point for recipients that respond with informing behavior (i.e., providing valence information about an object) rather than with non-informing behavior (i.e., sharing attention around objects; Kovács et al., 2014). Not surprisingly, this is an effective communicative strategy: observational research has demonstrated that caregivers respond to
infants’ pointing gestures with information for what was pointed to (Kishimoto et al., 2007). Together, this work has led researchers to suggest that infants use their pointing gestures as a way to obtain information from others.

While research has suggested that infants will point to request information (i.e., interrogatively; Begus & Southgate, 2012; Kovács et al., 2014), it is certainly not the only way that infants’ pointing has been interpreted. For decades, researchers have provided compelling evidence to suggest that infants will point imperatively, to establish their preference and request objects (Bates et al., 1975), as well as declaratively, to engage in joint attention with others (Liszkowski et al., 2004). Thus, infants’ early pointing gestures (interrogative, imperative, and declarative) appear to both overlap with and be distinct from other ways in which infants express preference for objects (e.g., reaching or looking; Thelen et al., 1993) and engage in joint attention (e.g., gaze alternation; Carpenter, Nagell, & Tomasello, 1998). For instance, infants’ pointing for imperative reasons may also be accomplished through reaching or looking behaviors. Moreover, infants’ pointing for declarative reasons may also be accomplished through gaze alternating behaviors. Thus, while infants’ pointing gestures appear to be similar to other early communicative behaviors in their imperative (e.g., “I want that!”) and declarative (e.g., “Look at that!”) functions, pointing appears to be unique in that it is also a tool for requesting information from adults (e.g., “What is that?”).

**Pointing as Information Seeking may Enhance Learning**
Why might infants use their pointing gestures, but not other communicative behaviors, to obtain information from adults? Observational research on parent-child interactions has demonstrated that caregivers are significantly more likely respond to infants’ pointing gestures, compared to other communicative behaviors (e.g., reaching), with information about what the infant referenced (Kishimoto et al., 2007; Leung & Rheingold, 1981). Extending this work to word learning, Wu and Gros-Louis (2014) found that caregivers provide more labels in response to infants’ pointing gestures than to other communicative behaviors. Together, this research suggests that infants’ pointing gestures are unique in their ability to reliably elicit information from adults. Thus, it would not be surprising if infants selectively utilize pointing gestures as a tool to obtain information from adults (Csibra & Gergely, 2006).

This interest in obtaining information may directly support memory of that information. Research has demonstrated that when individuals are curious about (i.e., specifically interested) or motivated to obtain certain types of information, they are better able to remember that information (Adcock, Thangavel, Whitfield-Gabrieli, Knutson, & Gabrieli, 2006; Gruber & Otten, 2010; Kang et al., 2009; Loewenstein, 1994). For instance, Kang and colleagues (2009) discovered that when subjects reported interest in obtaining information they were more likely to retain that information, compared to when they did not report a specific interest in receiving that information. The researchers measured participants’ electrical brain activity and found that an increased desire to obtain
information was associated with increased activity in memory areas of the brain, which may have promoted subsequent memory formation. Thus, pointing may not only drive infants’ learning by increasing their exposure to language. Because research has provided compelling evidence that infants use their pointing gestures as a way to seek out information, these gestures may also signal that infants are in an optimal state to learn new information.

To explore this possibility, Begus, Gliga, and Southgate (2014) tested infants’ ability to learn about objects immediately after they had pointed towards those objects. When the function of an object was presented immediately after infants pointed towards that object, they were significantly more likely to learn that object’s function than when this information was provided for an object that infants had not pointed towards. This finding is consistent with the interpretation that infants use their pointing gestures as a way to actively seek out information and are therefore in an optimal state to assimilate it (Begus et al., 2014).

**The Current Study**

The purpose of the current study was to explore developmental changes in the relation between infants’ pointing and early word learning. While Begus and colleagues’ (2014) findings demonstrate that infants learn best when information is provided in response to their pointing gestures, it remains unknown as to whether this effect generalizes to early word learning. Moreover, it is unclear whether and how the relation between pointing and learning differs
across development. In addition, research has yet to pinpoint the mechanism driving the relation between pointing and learning.

Testing whether infants’ pointing gestures *uniquely* reflect an optimal state for learning may shed light on and isolate a potential mechanism influencing this relation. Since infants’ pointing gestures have also been interpreted as a way for infants to express their preference for objects (Bates et al., 1975), and desire to engage in joint attention with others around objects (Liszkowski et al., 2004), it is important to pit infants’ ability to learn in response to their pointing gestures against their ability to learn in response to other communicative behaviors known to reflect preference (e.g., reaching) and a desire to engage in joint attention (e.g., gaze alternation). For instance, if infants’ pointing gestures reflect an optimal state for learning, above and beyond other ways of expressing their preference for objects (reaching, looking) or desire to engage in joint attention (gaze alternating) around objects, it would suggest that infants’ heightened attention when seeking information about objects (as opposed to heightened attention associated with preference for objects or engaging in joint attention around objects) may play a role in the relation between pointing and learning.

Infants express their preference for objects in numerous ways. For instance, infants may produce reaching gestures (Carpenter et al., 1998; Thelen et al., 1993), looking behaviors (Fantz & Nevis, 1967), or pointing gestures (Bates et al., 1975). Similarly, there are multiple ways for infants to express their desire to engage in joint attention around objects. In addition to pointing, infants’ gaze
alternations (i.e., alternation of gaze between an object of interest and another individual who is jointly attending to that object) also provide a means for them to engage in joint attention with others around objects (Carpenter et al., 1998). Indeed, infants’ gaze alternations are often regarded as the “hallmark” of joint attention because they demonstrate infants’ desire to share attention with a partner (Bruner, 1983; Tomasello, 1995). While there is compelling evidence that infants’ pointing gestures, reaching, looking and gaze alternating behaviors may all reflect their preference for and desire to engage in joint attention around objects, pointing gestures may be unique in that they may also reflect infants’ desire to obtain information about objects. Infants’ pointing gestures may be unique in this way because they are the only known pre-verbal behavior that reliably elicits information from caregivers (Kishimoto et al., 2007; Wu & Gros-Louis, 2014). If infants have ascertained that information is most often provided in response to their pointing gestures, but not in response to other behaviors (e.g., reaching, looking, gaze alternating), then pointing gestures, but not other behaviors, should reflect a readiness or expectation to obtain information. As a result, if infants point to receive information about objects this should then heighten their attention to the information provided in response, which should in turn scaffold their encoding of that information (Gruber & Otten, 2010; Kang et al., 2009). Support for this hypothesis comes from research demonstrating that while infants’ early pointing is highly predictive of their vocabulary development, other expressions of preference and engagement in joint attention
are not related to infants’ overall vocabulary growth (Blake, Osborne, Cabral, & Gluck, 2003). While we cannot directly pinpoint why an infant points, we can assess the degree to which learning is enhanced when they produce a point, compared to when they produce other behaviors. We reasoned that, if different behaviors (e.g., pointing vs. reaching or looking) reflect different learning outcomes (e.g., successful vs. unsuccessful fast mapping), then it is possible that (1) infants produce these behaviors for different reasons or (2) these behaviors differentially influence infants’ ability to learn. To explore these possibilities, the current studies examined 12 and 18-month-old infants’ fast mapping of labels onto objects in direct response to their pointing gestures, compared to other expressions of preference (i.e., reaching, looking) and joint attention (i.e., gaze alternating), towards objects.

**Study 1**

Infants were tested in a novel experimental paradigm designed to elicit communicative behaviors. Infants’ spontaneous communicative behavior towards different objects was observed and then categorized twice, along two different dimensions: expressions of preference or engagement in joint attention. Expressions of preference were operationalized as points, reaches, or looks, whereas engagement in joint attention was operationalized as pointing gestures or gaze alternations produced without gesturing. Since fast mapping is an essential precursory skill that underlies more sophisticated and symbolic word learning (Carey & Bartlett, 1978), this study represents a first step towards
understanding the immediate effects of pointing on word learning. To emulate fast mapping “in the wild”, and maximize infants’ ability to map labels onto objects, we had an interactive human experimenter teach infants labels (Koenig & Echols, 2003). In this study, an experimenter labeled the object infants referred to (by pointing, reaching, or looking) and then tested infants’ ability to form the label-object association. This procedure was repeated three times with each infant. Across trials, infants spontaneously altered how they referred to the novel object (e.g., Trial 1 = point, Trial 2 = reach, Trial 3 = point), allowing us to directly assess infants’ fast-mapping as a function of the behavior exhibited within a given trial. Infants’ pre-existing vocabulary size was also measured using the MacArthur Communicative Development Inventory (MCDI; Fenson et al., 1994). This allowed us to ensure that it was infants’ behavior during the experiment, as opposed to the linguistic abilities that infants came to the experiment with, that was driving fast mapping success.

We assessed infants at two strategic time points: (1) at 12 months, as infants are beginning to produce their first words and pointing gestures (Bates et al., 1975) and (2) at 18 months, after infants have acquired many new words, and have had months of experience pointing and receiving information in response (Kishimoto et al., 2007). Since 12-month-olds are just beginning to produce pointing gestures, they may not have had sufficient experience pointing and receiving information from caregivers in response to understand the information-eliciting function of their points. Thus, we predicted that 12-month-
olds would use pointing in the same way as other expressions of preference (i.e., reaching, looking) and joint attention (i.e., gaze alternating) and as a result, their pointing gestures towards objects would not lead to superior fast mapping. However, because 18-month-olds have had several more months of experience pointing and receiving information from caregivers in response (Kishimoto et al., 2007), we hypothesized that by 18 months infants have acquired an understanding that their pointing gestures, but not other ways of expressing preference and joint attention, reliably elicit information from adults. Moreover, since the relation between infants’ pointing gestures and vocabulary development is most robust at 18 months (Colonnesi et al., 2010), we predicted that 18-month-olds’ pointing gestures towards objects, compared to other expressions of preference and joint attention, would reflect an optimal state to map labels onto those objects.

Methods

Participants

Participants were recruited from birth records from three counties in the southeastern part of the United States. Once infants reached the selected age range, caregivers were notified and invited to participate. The final sample included 72 infants: 36 full-term, healthy 18-month-olds (18 females, $M = 18.0$ months, $SD = .62$, range = 16.2-18.8 months) and 36 full-term, healthy 12-month-olds (18 females, $M = 12.2$ months, $SD = .92$, range = 10.1-13.5 months). The sample was comprised of monolingual, English-speaking infants from
predominantly middle-class households (80% Caucasian, 8% African American, 7% other, 3% Asian, 1% American Indian, 1% did not report). Data from six additional infants were excluded due to fussiness (n = 5; three 18-month-olds, two 12-month-olds) or parental interference (n = 1).

**Stimuli and Apparatus**

Caregivers completed consent, the MCDI, an early gesture and demographic survey. After completing these forms, participants and their caregivers were taken into a 3.7 by 2.6 m testing room. Infants were seated on their parent’s lap in front of a 76 by 50 cm table across from the experimenter (Figure 1A). Infants were presented with three pairs of novel toys (rated for equal attractiveness), one pair at a time (Figure 1B). The toys were given the nonsense labels “Blicket”, “Modi”, or “Dax”, selected based on their phonotactic similarity to English words and frequent use in previous word learning studies. The presentation order of labels and toys was counterbalanced.
Procedure

In the testing room, parents were instructed to remain completely neutral and to not interfere with their infants’ behavior in any way. The experimental session was divided into four phases: Familiarization, Choice, Labeling, and Testing (Figure 1C).

**Familiarization Phase.** Infants were presented with two novel objects, one at a time, and allowed to play with each toy for approximately 30 seconds. This ensured that infants both visually and physically explored each object before choosing one of them.

**Choice Phase.** The experimenter reintroduced both objects, on opposite sides of the table, just out of infants’ reach (Figure 1A). To encourage infants to choose one of the objects, the experimenter prompted, “Wow! See these! Point to one of these! Which one? Point to the one you want!” Once infants clearly chose an
object, by pointing, reaching, or looking towards one of the objects, the experimenter initiated the Labeling Phase with that object (i.e., target object). All videos were recoded off-line to establish inter-rater reliability on infants’ choice of object. Any trial in which there was disagreement about the object of infants’ choice of object (i.e., the experimenter misinterpreted the infants’ choice of object during the task, the infant did not clearly establish interest in one of the two objects, or the infant was fussy) was excluded from the analyses ($n = 2$ of 216). It took infants an average of seven seconds to choose an object.

**Labeling Phase.** During the Labeling Phase (12 seconds), the experimenter brought the target object close to infants and labeled it four times, engaging in joint attention and using enthusiastic, child-directed speech (e.g., “This is a Modi! See the Modi! Wow, it’s a Modi! Look at the Modi!”). This was designed to be highly engaging to ensure that regardless of how infants initially referenced the target object (i.e., by pointing or not), they were equally attentive to it while it was labeled. The experimenter only initiated Labeling when it was clear that infants were fully attentive to both the experimenter and target object. Throughout the Labeling Phase, the non-target object remained on the table in the infants’ view. After this phase, the experimenter removed the toys and presented a six second distraction by bouncing a stuffed rabbit across the table.

**Test Phase.** Following the rabbit distractor, the experimenter initiated the six second Test Phase by placing the target and non-target object back on the table while prompting, “Where is the Modi? Find the Modi! See the Modi?”. The
label was presented 2,400 ms after the objects appeared on the table. The Test Phase was divided into two parts: a period of 2,400 ms before the onset of the target label (i.e., Pre-Word Test Phase) and a period of 3,600 ms following the onset of the target label (i.e., Post-Word Test Phase). This allowed us to establish infants’ baseline preferences for the objects, when they could freely look at them without verbal instruction, in addition to infants’ fast mapping of labels, when they could look at the target and distractor objects immediately after hearing the target label. In doing so, we were able to quantify fast mapping success (i.e., looking toward the target object as a direct function of hearing the target’s label), as opposed to increased looking times due to initial salience of either object.

These phases were repeated with two additional sets of toys. In total, infants saw three sets of novel toys and labels. Thus, each infant had the potential to provide fast mapping data across three trials. The entire experiment lasted approximately five minutes per participant.

Coding

Infants’ behavior was coded based on: (1) Choice Phase Communicative Behavior, the key independent variable, and (2) Test Phase visual fixation, the key dependent variable.

**Choice Phase: Communicative Behaviors.** Criteria used to code infants’ communicative behaviors are presented in Table 1 (based on Matthews, Behne, Lieven, & Tomasello, 2012). Infants’ Communicative Behaviors during the Choice Phase (i.e., in response to, “Point to one of these!”) were categorized
twice, along two different dimensions. First, behaviors were coded as an “Expressions of Preference” (i.e., point, reach, look). Infants’ behavior was then re-coded as an “Engagement in Joint Attention” (i.e., point, gaze alternation without any gesture, no joint attention). While all videos were recoded off-line to establish inter-rater reliability on infants’ choice of object (i.e., whether the experimenter chose the object the infant desired), only 20% of the videos were recoded to establish inter-rater reliability on the specific type of communicative behavior produced (Cohen’s Kappas for Expression of Preference = .89; Engagement in Joint Attention = .71; Fleiss, 1981).

Table 1: Coding of Infants’ Communicative Behavior during the Choice Phase.

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Description</th>
<th>Behavior</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td>Infant extended their arm and finger towards an object of interest while maintaining an upright posture (i.e. the infant did not lean towards the object).</td>
<td>Point</td>
<td>Infant extended their arm and finger towards an object of interest while maintaining an upright posture (i.e. did not lean towards the object).</td>
</tr>
<tr>
<td>Reach</td>
<td>Infant extended their arms and fingers towards an object of interest while leaning their entire body forward, as if attempting to grab the object, often accompanied by a grasping motion of the hand.</td>
<td>Gaze Alternation without a Gesture</td>
<td>Infant alternated their gaze between the target object and the experimenter, but did not produce a gesture.</td>
</tr>
<tr>
<td>Look</td>
<td>Infant did not produce a manual gesture towards an object of interest. Infants’ interest in an object was defined as the object they looked at longer during the Preference Phase. If the infant did not clearly fixate their attention on one of the two objects, the experimenter labeled the object that the infant looked at first.</td>
<td>No Joint Attention</td>
<td>Infant did not engage in one of the above behaviors: infant either fixated their attention solely on an object or did not point.</td>
</tr>
</tbody>
</table>

1The key distinction made between a “Point” and “Reach” was based on the posture of the infant: infants’ attempts to act on the object (by reaching forward to obtain the object) were classified as a reach, whereas infants’ clear, intentional communication about the object (by manually indicating what they were interested in) was classified as a point.

Test Phase: visual fixation to objects. To establish infants’ baseline preferences for the target objects and calculate fast mapping performance, infants’ visual fixation during the Test Phase was coded offline using DataVyu
At each 33-ms block of time, coders identified whether infants were fixated on the target object, non-target object, experimenter, or away. Inter-rater reliability was excellent (ICC = .98). Any block of time in which infants were not attending one of the two novel objects was excluded from the analyses.

**Baseline preferences.** We operationalized infants’ baseline looking preferences as the proportion of time infants looked towards the target object, compared to the non-target, during the Pre-Word Test Phase. This ensured that infants’ looking towards the target during the Post-Word Test Phase was not a result of selective interest in the target object, but due to true fast mapping (Reznick & Goldfield, 1992). These analyses are reported in the Supplemental Results.

**Fast mapping.** Consistent with prior research (e.g., Bergelson & Swingley, 2012) fast mapping was operationalized as the proportion of time infants spent looking towards the target object, compared to the non-target, during the Post-Word Test Phase. If infants successfully fast mapped, they should look at the target object at rates significantly above chance during the Post-Word Test Phase, but not during the Pre-Word Test Phase.

**Results**

We tested whether infants’ Communicative Behavior during the Choice Phase varied across the three trials of the experiment and predicted subsequent fast mapping success in the corresponding Test Phase of that trial. Infants’
productive vocabulary size on the MCDI was included as a covariate because it was more strongly correlated with infants’ overall fast mapping success (12-month-olds: $r = -.19$, $p = .26$; 18-month-olds: $r = .20$, $p = .29$) than infants’ receptive vocabulary size on the MCDI (12-month-olds: $r = .16$, $p = .35$; 18-month-olds: $r = -.06$, $p = .74$). Analyses were performed in R using the function glmer of the package lme4, cor.test, and wilcox.test (Bates & Maechler, 2010).

**Communicative Behaviors Across Trials**

The number of Choice Phases in which infants produced each Expression of: Preference (i.e., points, reaches, or looks) and Engagement in Joint Attention (i.e., points, gaze alternation without a gesture, or no joint attention) was calculated, in addition to the frequency with which infants varied their use of Communicative Behaviors across Choice Phases (Table 2). Forty-seven percent of 12-month-olds and 55% of 18-month-olds varied how they expressed their preference across the three trials (e.g., switched from reaching to pointing). Fifty-five percent of 12-month-olds and 75% of 18-month-olds varied how they engaged in joint attention across the three trials. Infants who pointed during the Choice Phases did not always point across all three trials. Only 29% of pointing 12-month-olds pointed across all three trials and 28% of pointing 18-month-olds pointed across all three trials – suggesting that any “pointing advantage” is due to the act of pointing itself, and not a result of infants who point more generating higher fast mapping success, since only very few infants always pointed.
Table 2: Proportion of Communicative Behaviors used in Choice Phases in Study 1.

<table>
<thead>
<tr>
<th>Expression of Preference</th>
<th>% Trials 12-month-olds / 18-month-olds</th>
<th>Expression of Joint Attention</th>
<th>% Trials 12-month-olds / 18-month-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td>24% / 32%</td>
<td>Point</td>
<td>24% / 32%</td>
</tr>
<tr>
<td>Reach</td>
<td>37% / 20%</td>
<td>Gaze Alternation + No Gesture</td>
<td>23% / 31%</td>
</tr>
<tr>
<td>Look</td>
<td>39% / 48%</td>
<td>No Joint Attention</td>
<td>53% / 37%</td>
</tr>
</tbody>
</table>

Communicative Behaviors and Fast Mapping Success Within Trials

Generalized linear mixed models (GLMM; Baayen, Davidson, & Bates, 2008) were used to test the influence of infants’ pointing gestures in the Choice Phase against that of other communicative behaviors on their subsequent fast mapping performance in the Test Phase of that trial. Consistent with prior research, the dependent variable in this logistic regression was whether infants looked at the target, compared to the non-target object, (i.e., yes or no) at each 200 ms block of time in the Post-Word Test Phase (i.e., Bergelson & Swingley, 2012). Fixed-effect predictors included infants’ Communicative Behavior during the Choice Phase (point vs. reach vs. look), Toy-Type (set 1 vs. 2 vs. 3; Figure 1B), Age (12- vs. 18-month-olds), and Sex. The interaction of Communicative Behavior and Age was included to determine whether infants’ Communicative Behavior differentially impacted fast mapping as a function of age. MCDI and Trial Number were set as covariates to control for infants’ pre-existing vocabulary levels and fatigue in later trials. Three repeated observations per infant were taken into consideration by including the infants’ ID in the model as a random effect. Likelihood ratio tests were used (Dobson, 2002) to compare the
fit of the full model \( \text{TARGET\_LOOK} \sim \text{TOY\_TYPE} + \text{MCDI} + \text{TRIAL\_NUMBER} + \text{SEX} + \text{COMMUNICATIVE\_BEHAVIOR} + \text{AGE\_GROUP} + \text{AGE\_GROUP*COMMUNICATIVE\_BEHAVIOR} + \text{random effect (INFANT\_ID)} \) to the null model \( \text{TARGET\_LOOK} \sim \text{random effect (INFANT\_ID)} \).

No main effects of Toy Type, Sex, or Age emerged (all \( p's > .05 \)). There was a main effect of pointing: infants were significantly more likely to look at the target object during Test if they had first pointed towards it during the Choice Phase \( \text{(Mean Proportion of Looking Time to Target} = .63, \text{SE} = .06) \), compared to if they had first looked at it \( (M = .54, \text{SE} = .05) \); look vs. point: \( Z = 2.55, p = .01 \). There was a marginal difference between pointing and reaching, such that infants were more likely to look at the target object during Test if they had first pointed towards it during the Choice Phase, compared to if they had first reached towards it \( (M = .50, \text{SE} = .06) \); point vs. reach: \( Z = -1.71, p = .08 \). However, a significant Age x Communicative Behavior interaction \( (Z = -2.10, p = .03) \) subsumed this main effect. The model including the interaction of Age and Communicative Behavior as a predictor fit substantially better than the model without the interaction term (Likelihood Ratio Tests, \( \chi^2 = 20.84, df = 7, p = .004 \)). The model did not improve in fit when Sex and Toy Type were included (Likelihood Ratio Tests, \( \chi^2 = 4.91, df = 3, p = .17 \)). As a result, these predictors were removed from subsequent analyses.

To determine how the influence of Communicative Behaviors on subsequent fast mapping success varied as a function of age, the following two
GLMMs were conducted within each age group (for a total of four models): (i) “Expression of Preference Model” – which tested the influence of infants’ pointing gestures on subsequent fast mapping success compared to other Expressions of Preference (i.e., reaching, looking); and (ii) “Engagement in Joint Attention Model” – which tested the influence of infants’ pointing gestures on subsequent fast mapping success compared to other ways of Engaging in Joint Attention (i.e., gaze alternations without a gesture, no joint attention). We ruled out the possibility that infants’ looking time during the Test Phase was a result of initial preference for the target or non-target objects, as opposed to true fast mapping success, by modeling infants’ looking time during the Pre-Word Test Phase. During the Pre-Word Test Phase, infants’ looking time towards the target never significantly differed from chance (all p’s > .05), suggesting that any increase in looking time during the Post-Word Test Phase is a result of true fast mapping success, as opposed to initial preference for the target object (see Supplemental Materials).

12-month-olds

Expressions of Preference Model. Infants’ vocabulary size was not a significant predictor of fast mapping success (Z = -.02, p = .98; Table 3). Infants were not more likely to look at the target object during Test when they had first pointed towards the target object during the Choice Phase (M = .55, SE = .10, 95% CI = .34 - .74), compared to when they had first reached (M = .47, SE = .08, 95% CI = .31 - .64, point vs. reach: Z = -1.83, p = .07) or looked (M = .57, SE= .08, 95% CI = .48 - .66, point vs. look: Z = 1.74, p = .08).
CI = .41 - .72, look vs. point: $Z = -.54, p = .59$) towards the target object (Table 3, Figure 2A). Infants had a greater proportion of looking time towards the target object during Test if they had first looked towards the target during the Choice Phase, compared to if they had first reached towards it (look vs. reach: $Z = -2.70, p = .007$). However, none of these behaviors led to looking times significantly different than chance (i.e., 50% looking time to target; point: $Z = .51, p = .61$; reach: $Z = .38, p = .71$; look: $Z = .91, p = .36$).

**Engagement in Joint Attention Model.** Infants’ vocabulary size was not a significant predictor of fast mapping success ($Z = -.37, p = .71$; Table 3). Infants were not more likely to map a label onto an object when they first pointed towards that object ($M = .55, SE = .10, 95\% CI = .34 - .74$), compared to when they had gaze alternated without gesturing ($M = .57, SE = .10, 95\% CI = .35 - .77$), gaze alternation without a gesture vs. point: $Z = -.18, p = .86$), or did not engage in joint attention ($M = .50, SE = .07$; point vs. no joint attention: $Z = -1.25, p = .21$; Table 3; Figure 2B). Infants were also not more likely to map a label onto the target object when they had first gaze alternated without gesturing, compared to when they did not engage in joint attention (gaze alternation without a gesture vs. no joint attention: $Z = -1.49, p = .14$). None of these behaviors led to looking times significantly different than chance (point: $Z = .51, p = .61$; gaze alternate without a gesture: $Z = .69, p = .49$; no joint attention: $Z = .00, p = 1.00$).
Infants’ point data is represented twice for each Study (as an Expression of Preference and Joint Attention). * $p < .05$

18-month-olds

**Expressions of Preference Model.** Infants’ vocabulary size was not a significant predictor of fast mapping success ($Z = -1.17, p = .86$; Table 3). Infants’ Expression of Preference during the Choice Phase was a significant predictor of fast mapping success. Infants were significantly more likely to look at the target object during the Test Phase when they had first pointed towards it ($M = .70, SE = .08, 95\% CI = .52 - .84$), compared to when they had first reached ($M = .57, SE = .11, 95\% CI = .34 - .78$, point vs. reach: $Z = -2.63, p = .008$) or looked ($M = .52, SE = .07, 95\% CI = .38 - .66$, point vs. look: $Z = -2.51, p = .01$) towards it during the Choice Phase (Table 3; Figure 2C). Infants looking towards the target object did not vary as a function of whether infants had first reached or looked towards it.
(reach vs. look: $Z = -.45, p = .65$). Infants’ looking time towards the target object during Test only differed from chance when infants had first pointed towards the target object, but not when they first reached or looked towards it (point: $Z = 2.33, p = .01$; reach: $Z = .66, p = .51$; look: $Z = .29, p = .78$).

**Engagement in Joint Attention Model.** Infants’ fast mapping success was not predicted by infants’ pre-existing vocabulary size ($Z = -.16, p = .88$; Table 3). Infants looked significantly longer at the target object during Test when they had first pointed towards it during the Choice Phase ($M = .70, SE = .08, 95\% CI = .52 - .84$), compared to when they had gaze alternated without gesturing ($M = .52, SE = .09, 95\% CI = .34 - .70$, point vs. gaze alternation without a gesture: $Z = -2.08, p = .03$), or did not engage in joint attention at all ($M = .54, SE = .08, 95\% CI = .38 - .70$, point vs. no joint attention: $Z = -2.10, p = .002$; Table 3; Figure 2D). Infants did not differ in their likelihood of looking towards the target object during the Test Phase if they had first gaze alternated without gesturing, compared to if they did not engage in joint attention (no joint attention vs. gaze alternation without a gesture: $Z = -.80, p = .42$). Infants’ looking times towards the target object during Test only differed from chance when infants had first pointed towards the target object during the Choice Phase, but not when they had gaze alternated without gesturing or did not engage in joint attention (point: $Z = 2.33, p = .01$; gaze alternate without a gesture: $Z = .23, p = .82$; no joint attention: $Z = .51, p = .61$).
Table 3: Study 1 Results of the Best-Fit Generalized Linear Mixed Models
Relations among Communicative Behavior during Choice Phases, MCDI scores, and fast mapping within trials.

<table>
<thead>
<tr>
<th>12-month-olds</th>
<th>18-month-olds</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expression of Interest Model</strong></td>
<td><strong>Expression of Joint Attention Model</strong></td>
</tr>
<tr>
<td><strong>Fixed Effects</strong></td>
<td><strong>Fixed Effects</strong></td>
</tr>
<tr>
<td>Point vs. Reach</td>
<td>Point vs. Gaze Alternation without a Gesture</td>
</tr>
<tr>
<td>Point vs. Look</td>
<td>Point vs. No Joint Attention</td>
</tr>
<tr>
<td>Look vs. Reach</td>
<td>Gaze Alternation without a Gesture vs. No Joint Attention</td>
</tr>
<tr>
<td>MCDI score</td>
<td>MCDI score</td>
</tr>
</tbody>
</table>

**Pointing vs. Non-Pointing Infants**

One possible explanation for these findings is that infants who pointed at least once during our task (i.e., “pointing infants”, n = 18) were more linguistically advanced, and therefore better fast mappers, than infants who did not point during our task (i.e., “non-pointing infants”, n = 18). If this were the case, then we would predict that the average fast mapping success of pointing infants, even on trials in which they did not produce a pointing gesture (number of trials = 20), would be higher than the average fast mapping success of non-pointing infants (number of trials = 53). This was not the case. The average fast mapping success of pointing infants in trials in which they did not produce a pointing gesture during the Choice Phase (M = .58, SE = .08) was not significantly different than the average fast mapping success of non-pointing
infants ($M = .49, SE = .08$, pointing infants vs. non-pointing infants: Wilcoxon $W = 434.5, p = .32$). Wilcoxon tests, as opposed to GLMMs, were used for this analysis so that we could compare fast mapping success across infants, as opposed to fast mapping success within infants. The average fast mapping success of these groups did not differ from chance (pointing infants in no-point trials: $Z = .72, p = .47$; non-pointing infants: $Z = .15, p = .88$), indicating that the communicative behavior produced within each trial (as opposed to across trials) is the strongest predictor fast mapping success.

**Discussion**

Study 1 assessed 12- and 18-month-olds’ ability to map labels onto objects in response to various communicative behaviors (i.e., Expressions of Preference or Engagement in Joint Attention) towards desired objects. Eighteen-month-olds, but not 12-month-olds, were significantly more likely to map a label to an object if they had first pointed to that object than if they had not pointed. More specifically, 18-month-olds’ pointing toward an object was related to enhanced learning about that object relative to all other expressions of preference (i.e., reaching or looking) and other ways of engaging in joint attention (i.e., gaze alternating without pointing) around that object. While previous research has demonstrated that infants who point more often have larger vocabulary sizes than infants who do not point as often (Colonnesi et al., 2010), the current findings are the first we know of to demonstrate that *in the moment* infants produce a pointing gesture, they are in an optimal state to fast map labels onto
objects – a skill that represents a critical step in early word learning (Carey & Bartlett, 1978).

**A Pointing Advantage?**

The current findings demonstrate that despite always receiving labels in the same way, and despite being equally attentive while the target object was labeled, fast mapping was only facilitated when infants pointed toward an object, but not when they reached, looked, or gaze alternated toward an object. Importantly, this was true within the same infant. Thus, it is possible that infants’ differential learning was the result of what drove them to use different communicative behaviors in the first place.

If infants’ sole motive for pointing was to express their preference for an object, and this heightened state of attention translates into enhanced learning, then infants should have been equally adept at mapping labels onto objects when this heightened attention was expressed by reaching or looking, two behaviors known to be driven by infants’ preferences for objects (Fantz & Nevis, 1967; Thelen et al., 1993). However, in the current study, this was not the case. Eighteen-month-olds were more likely to map labels onto objects when they had first pointed towards them than when they had first reached or looked towards them, suggesting that infants’ pointing gestures may do more than just serve as a means for expressing preference for objects.

Likewise, if infants’ sole purpose for pointing was to engage in joint attention with the experimenter, and this type of infant-initiated joint attention
translates into enhanced learning, then infants should have been equally adept at mapping labels onto objects when they engaged in joint attention via gaze alternation, either with or without producing a pointing gesture. However, this was not the case. Eighteen-month-olds were more likely to map labels onto objects when they had first pointed towards those objects, compared to when they had first gaze alternated between the object and the experimenter without pointing. Thus, infants’ pointing gestures may do more than just serve as a means for engaging in joint attention with others around objects.

Taken together, the current findings build on prior research and suggest that an alternate function may contribute to infants’ use of pointing (Southgate et al., 2007). In addition to reflecting infants’ preference for objects, and desire to engage in joint attention around objects, it is possible that pointing gestures may also reflect infants’ desire to learn about objects. If infants point because they want and expect to receive information in response, it follows that they would be in an optimal state to learn that new information when it is provided. While our findings provide preliminary support this theory, the design of the current could not directly measure infants’ motives in the moment they produced a pointing gesture. Thus, we propose other potential explanations for the relation between pointing and learning in the general discussion.

**Developmental Differences in the Relation Between Pointing and Learning**

Why might pointing have reflected an optimal state for learning in 18-month-olds, but not in 12-month-olds? Research has shown that parents
consistently respond to infants’ pointing towards objects by providing information about those objects (Kishimoto et al., 2007; Wu & Gros-Louis, 2014). However, infants only begin producing pointing gestures around 12 months (Bates et al., 1975). Thus, it is not surprising that by 18 months, infants have accumulated enough communicative experiences (e.g., pointing and receiving information in response) that they now come to expect information to be provided in response to their pointing. While 12-month-olds seem to prefer producing pointing gestures for recipients that respond with informing behavior, compared to other behaviors (e.g., sharing attention; Kovács et al., 2014), there is currently no empirical evidence demonstrating that 12-month-olds have formed an expectation that their pointing gestures will elicit information from others. Since 12-month-olds have just begun to produce pointing gestures, it might be the case that, at this early age, infants have not had sufficient experience pointing and receiving information in response to acquire the expectation that their pointing gestures reliably elicit information from others (Bates et al., 1975). Again, the current findings can only provide preliminary support for this proposal, since the design could not directly measure the infants’ motives or goals in the moment they produced a pointing gesture. Additional explanations for the observed developmental difference in the relation between pointing and learning are considered in the general discussion.

Study 2
The findings from Study 1 suggest that the ideal time to teach infants new information is in the moment they produce a pointing gesture. However, an open question remains as to how these findings might be used in real-life learning contexts. Namely, when a caregiver notices their infant producing a pointing gesture, will they be successful in teaching their infant any information, or is learning only facilitated when information is tailored to the specific object infants point to? In other words, do infants’ pointing gestures reflect a broad, heightened state of attention for learning, or is the relation between pointing and learning specifically tailored to the pointed-to-object? Study 1 was unable to disentangle these hypotheses because labels were always provided for the object that infants pointed towards. Thus, Study 2 tests this question.

While research has shown that infants have difficulty learning when their attention is re-directed (i.e., when they are taught about an object they are not engaged with; Baldwin, 1991), it remains to be seen whether the act of pointing can aid in overriding the effect of having their attention re-directed, enabling them to learn any new information when they produce a pointing gesture – even if it was not the focus of their point. If infants’ pointing gestures simply reflect a general heightened state of attention for learning more broadly, then infants should be in an optimal state to learn any information presented when they produce a pointing gesture, regardless of whether it is related to the specific object pointed towards, so long as this information was provided when an infant pointed. Alternatively, if infants’ pointing gestures reflect a readiness to learn
about pointed-to-objects, then infants’ pointing gestures should only reflect an optimal state for learning when information is tied to the specific objects pointed to (Begus et al., 2014).

Based on the findings from Study 1 demonstrating that pointing reflects a readiness to learn in 18-month-olds, but not 12-month-olds, we focused exclusively on 18-month-olds. In Study 2, we tested 18-month-olds in the same paradigm from Study 1, except that in response to infants’ communicative behavior towards a desired object, the experimenter instead labeled an alternate, undesired object (i.e., one that infants did not point, reach, or look towards; Begus et al., 2014).

Methods

Participants

Participants were recruited in an identical manner to Study 1. The final sample included 36 full-term, healthy 18-month-old infants (16 females, $M = 17.85$ months, $SD = .82$, range = 16.50 – 18.91 months). The sample was comprised of monolingual, English-speaking infants from predominantly middle-class households (74% Caucasian, 14% African American, 3% Asian, 3% American Indian, 3% did not report). Data from 3 additional infants were excluded from the final analyses due to fussiness ($n = 2$) or experimenter error ($n = 1$).

Stimuli, Apparatus, and Procedure
The stimuli, apparatus, procedure, and coding were the same as those used in Study 1, except that the experimenter labeled the object that infants did not point, reach, or look towards during the Choice Phase. Thus, in Study 2, the “target object” (i.e., the labeled object) is the object that the infant did not point, reach, or look towards. Any trial in which an offline coder disagreed with the experimenter’s choice of object \((n = 3)\) or in which the infant was inattentive during the Labeling Phase \((n = 2)\) was excluded from all analyses. Inter-rater reliability was calculated for Expressions of Preference during the Choice Phase (Cohen’s Kappa = .77), Engagement in Joint Attention during the Choice Phase (Cohen’s Kappa = .89), and looking time during the Test Phase (ICC= .96).

**Results**

**Communicative Behaviors across Trials**

Infants varied how they expressed their preference and engaged in joint attention around objects during the Choice Phases (Table 4). Infants did not always express their preference or engage in joint attention in the same way across the three Choice Phases. Fifty-three percent of infants varied how they expressed their preference across the three trials. Fifty-six percent of infants varied how they engaged in joint attention across the three trials. Infants who pointed in at least one Choice Phase (i.e., “pointing infants”) did not always point across all Choice Phases. Only 26% of pointing infants pointed across all three trials.
Table 4: Proportion of Communicative Behaviors used in Choice Phases in Study 2.

<table>
<thead>
<tr>
<th>Choice Phase Behavior</th>
<th>% Trials</th>
<th>Choice Phase Behavior</th>
<th>% Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Expression of Preference</strong></td>
<td></td>
<td><strong>Expression of Joint Attention</strong></td>
<td></td>
</tr>
<tr>
<td>Point</td>
<td>39%</td>
<td>Point</td>
<td>39%</td>
</tr>
<tr>
<td>Reach</td>
<td>23%</td>
<td>Gaze Alternation + No Gesture</td>
<td>32%</td>
</tr>
<tr>
<td>Look</td>
<td>38%</td>
<td>No Joint Attention</td>
<td>29%</td>
</tr>
</tbody>
</table>

Communicative Behaviors and Fast Mapping Success Within Trials

As in Study 1, a GLMM tested the influence of infants’ Communicative Behavior during the Choice Phase on subsequent fast mapping performance during the corresponding Test Phase of that trial. Infants’ Communicative Behavior (Expression of Preference or Engagement in Joint Attention) was set as a fixed effect; infants’ ID was set as a random effect. Pre-existing vocabulary size, as measured by productive vocabulary size on the MCDI, and trial number were set as covariates. Our dependent variable was whether infants looked at the target object (i.e., the object labeled during the Labeling Phase), compared to the non-target, at each 200 ms block of time in the Post-Word Test Phase. Analyses on infants’ baseline looking preferences (i.e., looking time during the Pre-Word Test Phase) are reported in the Supplemental Results.

**Expressions of Preference Model.** Infants’ vocabulary size was not a significant predictor of fast mapping success \(Z = .31, p = .76\). Infants did not display a greater proportion of looking time to the target object during Test if they had first pointed \(M = .53, SE = .08, 95\% CI = .37 - .69\), compared to if they had first reached \(M = .55, SE = .10, 95\% CI = .34 - .75\), reach vs. point: \(Z = -.44, p = .66\), or looked \(M = .58, SE = .08, 95\% CI = .41 - .74\), point vs. look: \(Z = .70, p = .61\).
.48) towards a different (i.e., non-target) object during the Choice Phase (Figure 3A). Infants were not more likely to look at the target object during Test if they had first looked towards the non-target object during the Choice Phase, compared to if they had first reached for it during the Choice Phase (look vs. reach: $Z = -1.01$, $p = .31$). See Table 5. None of these behaviors led to looking times different than chance (point: $Z = .38$, $p = .70$; reach: $Z = .49$, $p = .62$; look: $Z = .99$, $p = .32$).

![Figure 3: Proportion of Looks to Target during Test based on Communicative Behavior (Expression of Preference or Expression or Joint Attention) during the Choice Phase in Study 2.](image)

**Engagement in Joint Attention Model.** Infants’ vocabulary size was not a significant predictor of fast mapping success ($Z = .35$, $p = .72$). Infants were not
more likely to map a label onto an object if they had first pointed ($M = .53, SE = .08, 95\% CI = .37 - .69$), compared to if they had gaze alternated without gesturing ($M = .54, SE = .09, 95\% CI = .36 - .71$), gaze alternation without a gesture vs. point: $Z = -1.80, p = .07$), or did not engage in joint attention ($M = .59, SE = .09, 95\% CI = .40 - .77$, point vs. no joint attention: $Z = 2.00, p = .05$; Figure 3B) around the non-target object during the Choice Phase. Infants were more likely to map a label onto the target object if they first did not engage in joint attention around the non-target object, compared to if they had first gaze alternated without gesturing around the non-target object, (gaze alternation without a gesture vs. no joint attention: $Z = 3.27, p = .001$). See Table 5. Importantly, however, none of these behaviors led to looking times different than chance (point: $Z = .38, p = .70$; gaze alternate without gesturing: $Z = .46, p = .65$; no joint attention: $Z = .99, p = .32$).

Table 5: Study 2 Results of the Best-Fit Generalized Linear Mixed Models.

<table>
<thead>
<tr>
<th>Expression of Interest Model</th>
<th>$Z$</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed Effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point vs. Reach</td>
<td>-44</td>
<td>.66</td>
</tr>
<tr>
<td>Point vs. Look</td>
<td>.70</td>
<td>.48</td>
</tr>
<tr>
<td>Look vs. Reach</td>
<td>-1.01</td>
<td>.31</td>
</tr>
<tr>
<td>MCDI score</td>
<td>.31</td>
<td>.76</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expression of Joint Attention Model</th>
<th>$Z$</th>
<th>$p$-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed Effects</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Point vs. Gaze Alternation without a Gesture</td>
<td>-1.80</td>
<td>.07</td>
</tr>
<tr>
<td>Point vs. No Joint Attention</td>
<td>2.00</td>
<td>.05</td>
</tr>
<tr>
<td>Gaze Alternation without a Gesture vs. No Joint Attention</td>
<td>3.27</td>
<td>.001</td>
</tr>
<tr>
<td>MCDI score</td>
<td>.35</td>
<td>.72</td>
</tr>
</tbody>
</table>
Discussion

The purpose of Study 2 was to determine whether infants’ pointing gestures reflect an optimal state for learning when information is provided about objects that are not pointed towards. Study 2 was identical to Study 1, with one key difference: labels were provided for objects the infant did not point, reach, or look towards. The results revealed that, in this context, infants did not successfully map labels onto objects, regardless of whether they first pointed, reached, gaze alternated without a gesture, or just looked at a different object before receiving a label. These findings suggest that infants’ pointing gestures do not reflect a broad, heightened state of attention for learning. Rather, the relation between pointing and learning is specifically tailored to the pointed-to-object.

The findings from Study 2 have important practical implications for how to most effectively teach infants new information. If infants’ pointing gestures signal that they are in a general, heightened state of attention for learning, then infants could be taught information about any object in the moment they produce a pointing gesture, and this would result in successful assimilation of that information. However, these findings suggest that pointing gestures do not signal that infants are in an optimal state to learn more generally. Rather, infants’ pointing gestures signal that they are only in an optimal state to learn about the specific, pointed-to-objects. Thus, to transform moments in which infants produce a pointing gesture into learning opportunities, infants should be given information about the specific objects they point towards.
Why is Learning Yoked to the Referent of a Pointing Gesture?

If infants point to obtain information about specific objects, and this desire to obtain information translates into a readiness to learn that information, then this may help explain why infants were able to learn information about pointed-to-objects (Study 1), but not information about not pointed-to-objects (Study 2). Alternatively, it may be the case that infants’ pointing gestures do reflect a general heightened state for learning, but the design of the current study did not reveal this. Rather, in the current study it may have been too difficult for infants to switch their attention and learn about an object they were not interested in. If the task had been easier (e.g., included a more extensive labeling phase), it is possible that a relation between pointing and learning of information about not pointed-to objects would have been detected. Future research is needed to disentangle these possibilities.

General Discussion

The current studies assessed 12- and 18-month-olds’ ability to fast map labels onto objects when given labels in response to various types of communicative behaviors towards objects. In Study 1, 18-month-olds, but not 12-month-olds, were significantly more likely to map a label onto an object if they had first pointed towards that object, as opposed to if they had expressed their preference in other ways (i.e., reached or looked towards that object) or had engaged in another form of joint attention (i.e., alternated their gaze between that object and an experimenter). Conversely, in Study 2, when an experimenter
provided a label for the object that infants did *not* point, reach, or look towards, 18-month-olds did not display successful label-object mapping, regardless of whether they had first pointed before receiving that label. These findings suggest that pointing does not reflect a general state of heightened preparedness to learn, but that it is specific and limited to learning about the referent of the point.

By demonstrating that infants are in an optimal state to fast map a label to an object in the moment they produce a pointing gesture towards that object, the current findings build on decades of research demonstrating a link between early pointing and vocabulary development (Colonnesi et al., 2010). More specifically, the current findings demonstrate that infants’ pointing gestures do not only influence their early vocabulary development by increasing their exposure to language (e.g., increased frequency), as previously proposed (Wu & Gros-Louis, 2014). Here, we ruled out the possibility that increased exposure is the *sole* mechanism driving the relation between pointing and vocabulary growth because respective labels were provided in response to all of the infants’ behaviors. If exposure is sufficient to enhance learning, then infants in the current study should have been *equally* as likely to map labels onto objects regardless of which behavior they exhibited towards the objects or whether they pointed to the object being labeled or not (Study 2), because respective labels were always provided.

**Possible Explanations for a Pointing Advantage**
It is possible that infants’ pointing reflected a readiness to learn because they were simply more attentive and engaged in the task when they pointed. In both studies, the experimenter did not begin labeling until infants had clearly established a selective preference for one of the two novel objects, by pointing, reaching, or looking. Furthermore, trials in which infants did not clearly indicate a preference for one of the two objects or were not attentive to the experimenter or object during were not included in the analyses. Thus, heightened preference for objects and general attentiveness alone cannot explain infants’ enhanced fast mapping skills during trials in which they had pointed.

A second possible explanation for infants’ enhanced fast mapping following their pointing gestures is that when infants pointed, they were initiating joint attention with the experimenter. During these point trials, infants may have been more socially engaged and thus more motivated to learn, since research has shown that infants learn words best in the context of joint attention (Tomasello, 1995). To test this possibility, we directly compared infants’ fast mapping performance in trials in which they had first pointed towards objects to trials in which they did not gesture, but simply gaze alternated – another behavior considered to be involved in infants’ engagement in joint attention with others (Carpenter et al., 1998). However, infants were only more likely to map labels onto objects if they had first pointed towards those objects, but not if they had alternated their gaze between that object and the experimenter without gesturing.
To interpret the above findings, it is important to consider the longstanding debate surrounding infants’ use of gaze alternations (Akhtar & Gernsbacher, 2007a). It has been argued that in addition to being a declarative act, gaze alternations can also be used by infants to seek out information (i.e., social referencing; Feinman, 1982). However, the evidence is mixed as to whether infants gaze alternate because they are seeking comfort, or because they are seeking information (Striano, Vaish, & Benigno, 2006). Moreover, while there is direct evidence that infants’ pointing gestures reliably elicit conceptual information (e.g., labels) from caregivers (Wu & Gros-Louis, 2014), there is no evidence that infants’ gaze alternating behavior also reliably elicits conceptual information about the object of shared attention from caregivers. Until research classifies caregivers’ responses to infants’ gaze alternating behavior, compared to infants’ direct looks towards objects, it remains unclear as to whether infants would have the opportunity to acquire the expectation that their gaze alternations reliably elicit information in the same way that their pointing gestures do (Begus & Southgate, 2012).

Another potential explanation for the current findings has nothing to do with the act of pointing. Namely, it is possible that infants who pointed during our task were simply more linguistically advanced (i.e., had higher pre-existing vocabulary sizes) or “smarter” than those who did not point. As a result, these infants were better “fast mappers” from the start. There are several reasons why this explanation falls short. First, the average fast mapping success of “pointing
infants” (i.e., infants who pointed at least once), in trials in which they did not point did not differ from chance, and did not differ from the fast mapping success of “non-pointing infants” (i.e., infants who never pointed during the study). Additionally, only five of the 18-month-olds in Study 1 pointed across all three trials of the experiment, indicating that the current results were not driven by a subset of precocious, always-pointing infants. Secondly, pointing did not always result in superior learning. If infants who point are simply better learners, as opposed to the act of pointing itself reflecting a readiness to learn, then these more advanced, “pointing infants” should have mapped labels onto objects in Study 2, regardless of whether the pointed-to objects were labeled or not. This was not the case. Lastly, infants’ vocabulary size alone did not predict fast mapping success – infants who came into the study with larger vocabulary sizes were not more likely to map labels onto objects than infants with smaller vocabulary sizes.

There are several reasons why we may not have found a relation between vocabulary size and fast mapping success. First, not all studies assessing the link between vocabulary size and fast mapping find a relation between the two abilities (e.g., Bergelson & Swingley, 2013; Swingley & Aslin, 2000; Wilbourn & Sims, 2013). Secondly, many of the studies that do find a relation between vocabulary size and fast mapping find that this relation only exists after children reach their second birthday, but not earlier (Bion, Borovsky, & Fernald, 2013). Moreover, much of the work on the relation between vocabulary size and fast
mapping has been conducted on infants from diverse socioeconomic backgrounds (i.e., infants with diverse vocabulary sizes; Fernald et al., 2013). Thus, it is possible with a sample of older infants, or infants from more diverse socioeconomic backgrounds, a significant relation between vocabulary size and fast mapping success would have been evident.

Ultimately, the current findings demonstrate that the communicative behavior produced *within* each trial (as opposed to behavior across trials, or preexisting linguistic abilities) is the strongest predictor infants’ fast mapping success. Taken together, this suggests that the *act* of pointing, or what motivates infants *in the moment* they point towards an object, leads to enhanced fast mapping. One potential reason why infants may have pointed towards novel objects in the current task was to obtain information about that object. Indeed, experimental evidence strongly suggests that one of the primary motivations governing infants’ pointing behavior is a desire to obtain information (Begus et al., 2014; Kovács et al., 2014). Moreover, research consistently demonstrates that an interest in obtaining information supports memory of that information (Adcock et al., 2006; Gruber & Otten, 2010; Kang et al., 2009; Loewenstein, 1994). These studies offer one potential explanation for the current findings: if infants produce pointing gestures to obtain information, and an interest in obtaining information supports memory of that information, then infants’ pointing gestures should signal a readiness to learn.
Finally, it is important to consider that the act of pointing, in and of itself, facilitates infants’ learning directly. It is possible that infants pointed, reached, or looked for the same reasons. However, theories of embodied cognition (Barsalou, 2008; Goldin-Meadow & Alibali, 2012) suggest that the physical act of producing a pointing gesture might induce a heightened or increased preparedness to learn for children. For instance, some have argued that infants’ and young children’s pointing gestures serve a cognitive regulatory function similar to Vygotsky’s (1962) “private speech”, in which children use egocentric language as a way to self-organize their behavior (Begoña Delgado, Gómez, & Sarriá, 2011). Observational research has shown that infants, as young as 12 months, engage in non-communicative, private pointing (Bates et al., 1975; Delgado et al., 2011). Ultimately, this type of private pointing may assist preverbal infants in individuating objects from the visual field and regulating their own attention (Bates et al., 1975; Delgado et al., 2011). In verbal toddlers (i.e., 2-4-year-olds), this type of private pointing has been found to directly enhance performance on cognitive tasks (Delgado et al., 2011). Delgado and colleagues (2009) contend that children’s private pointing enhanced their performance because it focused their attention on the relevant aspects of a problem, thereby modulating attention and action. Thus, a task for future research is to determine whether younger infants’ private pointing serves a similar attentional regulatory function and enhances learning.
Importantly, the current study did not rule out the possibility that infants’ pointing gestures serve a variety of functions, making it possible that the combination of these functions may have been what contributed to enhanced learning. For instance, infants may have pointed towards novel objects in the current task because they wanted to obtain that object, receive information about that object, and focus their attention on that task – all of which may have played an interactive role in helping infants learn about objects in the moment they pointed towards those objects. To pinpoint precisely why infants’ pointing gestures reflected an optimal state for learning, future research is needed to disentangle these possibilities.

Future Directions

While the current study was unable to pinpoint precisely why pointing and learning are related, it confirms that a robust and direct relation exists. While the null findings from the 12-month-olds in Study 1 suggest that pointing gestures are not related to learning for this age group, it does not necessarily rule out the possibility of a relation between pointing and learning at this age. Instead, this null result may be due to a variety of factors. For instance, the task may have simply been too difficult for 12-month-olds. Had the task been easier (e.g., included a more extensive labeling phase), a relation between pointing and learning may have been found in 12-month-olds as well. Importantly, however, a study conducted by Pruden and colleagues (2006) found that even 10-month-olds can successfully fast map under very similar, minimal learning conditions —
even when given a more stringent test of word learning (i.e., a disambiguation task). Thus, it is unlikely that the 12-month-olds failure to fast map was solely due to the difficult nature of the task, since learning in this context is possible. Alternatively, since 12-month-olds have just begun to produce pointing gestures, they may not have not had sufficient experience pointing and receiving information in response to have acquired the expectation that their pointing gestures will *reliably* elicit information from others (Bates et al., 1975). Thus, it may be the case that 12-month-olds’ pointing gestures towards objects did not result in superior learning about those objects since they have not yet acquired an expectation that information is consistently provided about pointed-to objects.

To directly test this hypothesis, future research must examine the relation between infants’ experience pointing (e.g., age of pointing onset) and ability to learn in response to their pointing gestures.

Similarly, while the null findings from Study 2 suggest that the relation between pointing and fast mapping is tailored to the object that the infant pointed towards, as opposed to pointing reflecting a general, heightened state of preparedness to learn, there are other, alternative explanations. For instance, infants’ failure to provide evidence of learning labels for not-pointed-to objects could have been due to a lack of interest in those objects or a heightened focus on the preferred/not-labeled object. Future research should aim to disentangle these hypotheses.
Future research should also investigate the extent to which infants’ pointing gestures reflect a readiness to learn and the depth of that learning. While 18-month-olds’ pointing gestures towards objects did signal that they were in an optimal state to fast map labels onto objects in a live setting, under minimal learning conditions, this finding does not prove that they truly learned that novel label, in the symbolic sense. Fast mapping represents a crucial first step in word learning, yet retention and extension after fast mapping is another vital step for vocabulary development (Carey & Bartlett, 1978).

**Pointing as a Mechanism to Boost Early Vocabulary**

In addition to the theoretical contributions to the literature, the current study also has potential implications for intervention research. To help boost children’s early vocabulary, parents are currently being inundated with messages about talking more often, in more diverse ways, with their young children. However, the current findings demonstrate that there is even more that caregivers can do. By increasing caregivers’ awareness about when their infants are seeking out information through pointing and encouraging them to provide labels in response to those points, caregivers will be better equipped to provide their infants with a more appropriate level of scaffolding for word learning. These moments, when infants seek out information with their pointing gestures, reflect specific windows of time when infants are both able and ready to fast map labels onto objects. If infants’ attempts to request information lead to superior learning, the next task for researchers is to figure out how to encourage infants to
request information more often, so that caregivers have even more opportunities to capitalize on these unique and powerful teaching moments. This is particularly important for lower-income, at-risk groups (Hart & Risley, 1995; Rowe & Goldin-Meadow, 2009).

One way to encourage infants to request information more often would be to train infants to point more frequently. However, to date, studies testing the effectiveness of a pointing-training intervention on infants’ vocabulary development have yielded mixed results. For instance, Matthews and colleagues (2012) trained 14-month-old infants to point more and did not see gains in infants’ subsequent vocabulary. More recently, Lebarton and colleagues (2014) trained 18-month-old infants to point more and found the exact opposite result: training infants to point more led to increases in their subsequent vocabulary size. The current findings suggest that rather than training infants to increase their use of pointing gestures, it may be more effective to train parents to increase their responsiveness to infants’ pointing gestures. This may help infants more fully understand the information-eliciting function of pointing gestures, which may in turn help them use their points as word-learning tools. While some research has focused on increasing parental responsiveness to infants’ pre-linguistic communicative acts, that responsiveness is undifferentiated in terms of which communicative acts (e.g., pointing, reaching, vocalizations) parents are responding to (Yoder & Warren, 2002). The findings of the current study suggest
that an intervention focused on infants’ pointing gestures specifically may be the most fruitful.

**Conclusion**

The current study represents an important step in determining how infants’ early pointing gestures impact early vocabulary development. Importantly, these findings are the first to show that infants’ overall use of pointing gestures is not only related to their overall vocabulary size, but also that the actual act of producing a pointing gesture uniquely signals that infants are in an optimal state to map labels onto objects. This finding drives home the importance of these gestures in the key transition from nonverbal to verbal communication.
Chapter 3. The Focus of Infants’ Early Information Gathering through Pointing

Introduction

Infants dive into language hands first. Months before they produce their first words, infants begin to communicate with their gestures in complex ways (Bates et al., 1975). Pointing gestures, in particular, are at the forefront of language development. Infants’ pointing gestures do not only precede their spoken words, they also predict when those words will emerge (Colonnese et al., 2010). Most recently, research has established that pointing gestures do more than just precede and predict the onset of early word learning. There is now evidence to suggest that infants’ pointing gestures play a direct and causal role in word learning (Begus, Gliga, & Southgate, 2014; Sauer Lebarton, Goldin-Meadow, & Raudenbush, 2015; Lucca & Wilbourn, 2016). For instance, infants trained to increase their rate of pointing have significantly larger vocabulary sizes eight weeks later, compared to a control group of infants exposed to music training (Sauer Lebarton et al., 2015).

To pinpoint the mechanism behind the established relationship between pointing and vocabulary development, recent research has tested the direct link between pointing and learning. For instance, a study by Lucca and Wilbourn (2016) showed that infants learn best if they are taught the label of an object immediately after they point toward that object. Similarly, pointing also reflects a heightened readiness to learn the function of an object (Begus et al., 2014).
Both object functions and labels are rich and meaningful sources of information that help infants learn about the world around them (Bloom, 1998; Gentner, 2003; Nelson, 1974). Learning how an object functions equips infants with a way to appropriately interact with their environment, whereas learning an object’s label provides infants with a way to communicate about their environment. Although labels and functions can serve distinct roles, they are both integral to how infants form representations of objects (Booth & Waxman, 2002; Keil, 1989; Piaget, 1952). Infants routinely utilize both labels and functions to form categories of objects (Riggs, Mather, Hyde, & Simpson, 2015), individuate objects (Kingo & Krøjgaard, 2012; Xu, Cote, & Baker, 2005), and extend category membership to new objects (Childers & Tomasello, 2003; Riggs et al., 2015). By their first birthday, infants recognize that both labels and functions can be used in a decontextualized manner (Riggs et al., 2015; Schafer, 2005). Rather, both labels and functions are not necessarily tied to the specific objects they refer to or to the contexts in which they were first introduced. Given that infants’ pointing gestures reflect an heightened readiness to learn about functions and labels, both of which are vital to infants’ representations of objects, these findings help underscore the importance of pointing as a key driver of cognitive development.

The strong link between infants’ ability to learn different types of information and their pointing gestures has led researchers to investigate why infants are motivated to point. Research in this area has revealed that infants point for a variety of reasons (Colonnesi et al., 2010). Infants point (1)
imperatively to obtain objects from others (Bates et al., 1979), (2) declaratively to initiate episodes of joint attention with their caregivers (Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004), and (3) informatively to provide others with needed information (Liszkowski, 2005). Most recently, research has demonstrated that infants also point interrogatively to obtain information from others (Begus & Southgate, 2012; Southgate, van Maanen, & Csibra, 2007). The current study investigates the role of interrogative pointing in infants’ acquisition of new information.

**Infants Point to Obtain Information**

The first direct evidence for an interrogative, or information-requesting, motive of pointing came from a study by Begus and Southgate (2012) that showed infants are more likely to point for individuals they know to be knowledgeable, rather than ignorant. Another recent study demonstrated that infants prefer to point for individuals that tend to respond to their pointing gestures with informing behavior compared to individuals who don’t (i.e., individuals who respond to their pointing gestures with shared attention around pointed-to objects, but no information; Kovács, Tazin, Téglás, Gergely, & Csibra, 2014). Observational research also supports the hypothesis that infants point for information-requesting reasons: when infants point toward objects, caregivers respond by contingently providing information for those objects (Hannan, 1992; Kishimoto et al., 2007; Leung & Rheingold, 1981; Wu & Gros-Louis, 2015).
Although infants can request information in many different ways, their pointing gestures are the most effective and reliable way to do so: caregivers are significantly more likely to provide information in response to infants’ pointing gestures, compared to other communicative behaviors (e.g., reaching or object-directed vocalizations; Kishimoto et al., 2007; Wu & Gros-Louis, 2015). The precision of the index-finger allows infants to clearly highlight an object or referent of interest to their caregiver, making pointing a unique and especially useful tool for information gathering. Because caregivers systematically respond to infants’ points with information about pointed-to objects, these gestures allow infants to receive information at a time when they are most receptive to it (i.e., when they are explicitly requesting it). Since a desire to obtain information directly translates into an enhanced ability to process that information (Gruber & Otten, 2010), pointing gestures reflect a heightened readiness to learn (Begus, Gliga, & Southgate, 2014; Lucca & Wilbourn, 2016).

The Current Study

Despite the importance of infants’ pointing gestures as a way for them to acquire new information, researchers have only just begun to investigate infants’ pointing gestures as an information-requesting behavior. Thus, there exist many questions surrounding the nature of infants’ early information requesting via pointing, and the subsequent impacts this has for learning.

While previous research has independently shown that pointing reflects a readiness to learn functions (Begus et al., 2014) and labels (Lucca & Wilbourn,
2016), it remains unknown whether pointing signals a heightened readiness to preferentially learn one of these types of information over the other. Here, we tested this question by examining whether infants are more likely to map a label or a function onto an object directly after they point toward that object. Given that both functions and labels are important sources of information for infants, that they are able to readily learn from an early age, we predicted that infants would learn both functions and labels equally well. Testing infants’ ability to learn functions compared to labels in response to their pointing gestures will illuminate the extent to which pointing reflects a heightened readiness to learn various types of information.

Another open question pertains to the type of information that infants request with their pointing gestures. In the current study, we tested whether infants’ pointing gestures are requests for a specific type of information by measuring infants’ satisfaction with receiving functions, labels, or no information for objects after pointing toward those objects. We hypothesized that infants would point to specifically request labels for two reasons: (1) 18 months represents a time in which labels may be particularly essential source of information, as infants are entering the vocabulary burst and are rapidly expanding their vocabularies (Bloom, 1973; Nelson, 1973), and (2) at this age, caregivers systematically respond to infants’ requests for information with labels, compared to other types of information (Chouinard, 2007). Infants may expect, and therefore also potentially desire, to receive labels in response to their
pointing gestures. This prediction is in contrast to findings with older children (2-4 years), who prefer to receive functions, rather than labels, in response to their requests for information (Nelson, Egan, & Holt, 2004). Older children have already acquired the labels for many of the objects in their environment and may thus be looking for more explanatory information about objects (e.g., functions). Understanding which type of information infants prefer to receive in response to their pointing gestures will provide insights into the type of information they find most relevant and important before they are able to verbally request it.

A third open question concerns the association between infants’ satisfaction with receiving information and their ability to learn that information. Rather, is the relation between pointing and learning specifically tailored to the type of information infants request? Or, does pointing reflect a heightened state of attention for learning, regardless of whether the information provided is the type of information infants had initially requested? In the current study we tested this by examining the correlation between infants’ behavioral satisfaction after receiving information and their subsequent ability to learn that information.

A final open question is whether infants use other behaviors, in addition to pointing, to request information. Here, we investigated this by testing infants’ satisfaction with receiving information and their ability to learn information when they first point toward an object, compared to when they first express interest in an object, but don’t point toward it (e.g., when they reach toward it). If infants’ pointing gestures are selectively used as a way to request information,
then we would predict that when infants don’t point, but express interest in an object, they would be just as satisfied to receive no information about that object as they would to receive information (labels or functions) about that object. Moreover, we would only expect infants to successfully learn about objects when they first point toward those objects (i.e., when they explicitly request information), but not when they express their interest in those objects in other ways (e.g., reaching, when they are not explicitly requesting information).

A final way to disentangle pointing’s unique role as an information-requesting gesture is to measure the behavioral characteristics that accompany pointing gestures. If pointing, but not other gestures, is used as a way to transfer linguistic information (i.e., to request information, and labels in particular), we would expect pointing gestures to be produced more often alongside other forms of linguistic communication (e.g., speech-like vocalizations; Grünloh & Liszkowski, 2015; Leavens & Hopkins, 1998).

To summarize, the current study aims to answer four central questions: (1) Does pointing lend itself to learning functions and labels equally? (2) Do infants prefer to receive functions or labels in response to their pointing gestures? (3) What is the association between infants’ satisfaction with receiving information and their ability to learn that information? (4) Are pointing gestures unique in their information-requesting function? The current study aimed to answer these questions by examining the link between infants’ pointing and their satisfaction with and learning of information. We tested infants at 18 months because this
represents a critical time in the development of gesture use and vocabulary. At 18 months, infants are pointing frequently and entering the “vocabulary burst” (Bates et al., 1979; Bloom, 1973; Nelson, 1973). Moreover, 18 months is a time at which the relation between pointing and vocabulary development is most robust (Colonnesi et al., 2010). By addressing these open questions, this study aims to provide new insights into the role that pointing gestures play in infants’ language development.

**Method**

**Participants**

Participants were recruited from public birth records in the southeastern part of the United States. The final sample included 36 full-term, healthy 18-month-olds (18 females, $M = 18.15$ months, $SD = .22$, range = 17.60-18.45 months). Data was collected between April and October 2016. The sample was comprised of monolingual, English-speaking infants from predominantly middle-class households (70% Caucasian, 15% did not report, 9% biracial, 6% African American). Data from four additional infants were excluded because they refused to participate ($n = 2$) or there was an equipment failure ($n = 2$).

**Materials, Stimuli, and Apparatus**

Caregivers completed consent, the MacArthur Communicative Development Inventory (MCDI; Fenson et al., 1994), an early gesture inventory, and a demographic survey. After completing these forms, participants and their caregivers were taken into a 3.6 m by 2.6 m testing room (Figure 4A). High-
definition cameras placed at two different angles captured the entire scene. Infants were seated at a small table (60 x 60 cm) across from the experimenter. A bookshelf (71 x 36 x 91 cm) was positioned directly behind the experimenter. Two remote-operated flashing lights were placed on each side of the bookshelf.

During the task, infants were presented with nine pairs of toy-like novel objects (Figure 4B). The attractiveness and saliency of these objects were rated by an independent sample of ten adults and deemed to be of equal novelty (mean rating = 4.88/7) and saliency (mean rating = 4.78/7). Before participating, parents confirmed that their infants had no previous experience with any of the test objects. The objects were given nonsense labels (“blicket”, “modi”, “toma”), novel functions ([head tap], [arm scratch], [slide a piece of paper]), or no information. Nonsense labels were selected from a novel noun/novel label database (Horst & Hout, 2015). These labels are phonotactically similar to English words and are frequently used in word learning studies (Soja, Carey, & Spelke, 1991). Novel functions were selected also based on their frequent use in previous word learning studies (e.g., Childers & Tomasello, 2002) and pilot data confirming that infants could easily perform them.
Procedure

In the testing room, parents sat beside their infants and were instructed to remain completely neutral and to not interfere with their infants’ behavior in any way. There was a brief warm-up period before the experiment began that lasted approximately 2.5 min. During the warm-up, the experimenter and infant played with a wooden, latch-board puzzle. The experimenter then introduced a stuffed animal (bird) named “Sam” to play the “game” with the infant.

The experimental session was divided into four phases: familiarization, choice, training, and test (Figure 5). The four phases were repeated nine times with nine different novel object sets. Thus, each infant had the potential to provide data across nine trials. Thirty-eight of the trials (12%) were excluded because infants were fussy and/or unwilling to participate. The experiment lasted approximately 20 min per participant.
Figure 5. Experimental Procedure.

**Familiarization Phase.** Infants were presented with two novel objects, one at a time, and allowed to play with each object for approximately 18 s. This was done to ensure that infants explored each object, visually and physically, before being asked to select one.

**Choice Phase.** After removing the objects from the familiarization phase, the experimenter reintroduced both objects, placing them on the shelf directly behind her (Figure 5). The experimenter used a remote control to turn on a set of flashing lights that were positioned on each side of the shelf, directly behind
where each toy was placed. To encourage infants to choose one of the objects, the experimenter prompted, *Wow! See these! Point to one of these! Which one?* Once infants clearly chose an object, either by pointing or reaching toward the object, the experimenter initiated the training phase with the selected object (hereafter, “target object”). The non-selected object (hereafter, “non-target object”), remained on the shelf in the infants’ view. If infants did not produce a manual gesture toward an object, the experimenter initiated the training phase with the object that the infant looked toward first. All videos were re-coded off-line to establish inter-rater reliability on infants’ choice of object. Any trial in which there was disagreement about infants’ choice of object (i.e., the experimenter misinterpreted the infants’ choice of object during the task or the infant did not clearly establish interest in one of the two objects) was excluded from the analyses (n = 6 out of 286). On average, it took infants 8 s to choose an object.

**Training Phase.** The training phase lasted approximately 10 s and consisted of within-subject three trial types: Label, Function, No Information. The experimenter only initiated the training phase once infants were fully attentive to both the experimenter and target object.

During *Label Trials*, the experimenter taught infants the target object’s label (e.g., *This is a blicket! See the blicket! Look, it’s a blicket! Look at this blicket!*). During *Function Trials*, the experimenter taught infants the target object’s function (e.g., *It goes like this [head tap]! See [head tap]! Look what it does [head tap]! Wow [head tap]!*). During *No Information Trials*, the experimenter acknowledged
infants’ interest in the target object (e.g., *Oh wow! See this one! You like this one, huh! Yeah! See this one!*), but did not provide any information about the object. Across all conditions, the experimenter held the target object while engaging in joint attention with the child, using the same type of enthusiastic, child-directed speech. This was to ensure that regardless of the type of information being given or how infants initially referenced the target object (i.e., by pointing or not), they were equally attentive during training. As soon as the experimenter finished the training phase, she used a remote control to turn off the flashing lights on the bookshelf behind her.

Each participant received each trial type three times in a three block design. Trial type order within each block was counterbalanced (e.g., FUNCTION–LABEL–NO INFO / LABEL–NO INFO–FUNCTION / NO INFO–LABEL–FUNCTION). In *No Information Trials*, the experimenter did not proceed to the test phase, since there was no information for the infant to be tested on. Rather, the experimenter ended the trial immediately after training by putting the target and non-target objects away and initiating a new trial with a new set of objects.

**Test Phase.** After putting the target and distractor objects from the training phase away, the experimenter presented a 12 s distraction by flying Sam, the bird from the warm-up across the table, allowing infants to pet Sam, prompting, *Wow! Here’s Sam! Do you want to play with Sam? Ooo! Would you like to pet Sam? Look!* Following this distraction, infants were tested on their ability to learn the target object’s label or function in a preferential looking paradigm (PLP;
The experimenter placed the target and distractor objects on each side of the table directly in front of her, with Sam placed in the middle. During *Function Trials*, the experimenter prompted, *Wow, see these! Which one goes like this [head tap]? Like this [head tap]? Where is the one that goes like this [head tap]? Like this [head tap]?,* using Sam to perform the function’s movement. During *Label Trials*, the experimenter prompted, *Wow, see these! Which one is the blicket? The blicket? Where is the blicket? The blicket?*. To ensure that the *Label* trials were as visually dynamic as the *Function* trials, the experimenter bounced Sam each time she said the target label. The experimenter ended the test phase by putting Sam, the target and distractor objects away and initiated a new trial with a new set of novel objects.

**Coding**

We coded three categories of infants’ behavior during the experiment: (1) the type of initial communicative behavior they produced during the choice phase, (2) the type and frequency of additional communicative behaviors they produced during training, and (3) the amount of time spent looking toward the target and non-target objects during the test phase.

**Initial Communicative Behavior.** The initial communicative behavior produced by infants during the choice phase, in response to the experimenter’s prompt, *Point to one of these!*, was coded as either a point, reach, or look (based on Lucca & Wilbourn, 2016; Matthews, Behne, Lieven, & Tomasello, 2012). Behaviors were coded as a *point* if the infant extended both their arm and index
finger toward the target object, a reach if the infant extended all fingers in an open hand toward the target object or extended their body toward the target object with all fingers extended, or a look if the infant looked toward the object, but did not produce a manual gesture (Table 6).

**Table 6. Coding of Infants’ Communicative Behavior During the Choice Phase**

<table>
<thead>
<tr>
<th>Communicative Behavior</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td>Infant extended their arm and finger toward an object of interest while maintaining an upright posture (i.e., the infant did not lean toward the object).</td>
</tr>
<tr>
<td>Reach</td>
<td>Infant extended their arms and fingers toward an object of interest while leaning their entire body forward, as if attempting to grab the object, often accompanied by a grasping motion of the hand.</td>
</tr>
<tr>
<td>Look</td>
<td>Infant did not produce a manual gesture. Interest in an object was defined as the object the infant looked at longer. If the infant did not clearly fixate their attention on one object, the target object was defined as the object the infant looked at first.</td>
</tr>
</tbody>
</table>

We also coded whether infants paired their initial communicative behavior with a vocalization and/or a gaze alternation. Vocalizations were coded as speech-like if they resembled adult-like phonetics with vowel and syllabic consonants (e.g., baba, wa, ga; Snow (2004)), or non-speech like if they followed no speech-like transcriptions or were single long vowels (e.g., comfort sounds; Grünloh and Liszkowski (2015)). Infants’ gaze alternations were operationalized as alternating looks between the experimenter and one of the toys (e.g., look at experimenter → look at toy; Carpenter, Nagell, & Tomasello, 1998).
Twenty percent of videos were re-coded off-line to establish high inter-rater reliability on infants’ type of initial communicative behavior (point, reach, or look; Cohen’s Kappa = .85; Landis & Koch, 1977), type of vocalization (speech-like or non-speech like; Cohen’s Kappa = .80), and presence of a gaze alternation (yes or no; Cohen’s Kappa = .74).

**Persistence during the Training Phase.** The type and frequency of behaviors produced by infants during the 10 s training phase (i.e., directly following the onset of training) were coded. The types of communicative behaviors, hereafter persistence behaviors, were coded as points, reaches, vocalizations, or table hits. As in prior research, these behaviors were chosen as persistence behaviors because they represent infants’ dissatisfaction with the experimenter’s response of their initial communicative behavior (Golinkoff, 1986; Liszkowski et al., 2004). Twenty percent of videos were re-coded off-line to establish excellent inter-rater reliability on the frequency of infants’ persistence behaviors (intraclass correlation = .91; Bartko, 1966).

**Looking time during the Test Phase.** Infants’ visual fixation during test, in which the experimenter prompted the infant to look toward the target object, was coded offline using DataVyu (www.datavyu.org). At each 33 ms block of time, coders identified whether infants were fixated on the target object, distractor object, experimenter, or elsewhere. Inter-rater reliability was high (intraclass correlation = .88). Any block of time in which infants were not attending to one of the two novel objects was excluded from the analyses.
For the purpose of analyses, we divided the test phase into two portions, a baseline window and a critical window. The baseline window consisted of the first 5 s of the test phase before the experimenter presented the target information. During this time, infants could freely look at the target and distractor objects while the experimenter prompted, Wow, see these! Which one is the...?. As in prior word learning studies (e.g., Yurovsky, Hidaka, Yu, & Smith, 2010), the critical window consisted of the last 8 s of the test phase, immediately following the onset of the target information, in which the experimenter prompted, ...blicket! The blicket? Where is the blicket? The blicket? (Label Trials) or ...[head tap]? Like this [head tap]? Where is the one that goes like this [head tap]? Like this [head tap]? (Function Trials).

We calculated the proportion of time infants spent looking at the target object, compared to the distractor, during both the baseline and critical window of the test phase, and used the difference between these numbers as a “difference score” in subsequent analyses. As is in prior research (Shukla, White, & Aslin, 2011), successful fast mapping was operationalized as a significant increase in looking toward the target object during the critical window relative to the baseline window (i.e., difference scores greater than zero). This method ensures that infants’ looking toward the target object during the test phase was not a result of selective interest in the target object, but rather due to infants’

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1 Although previous fast mapping studies have also used 8 s test windows (e.g., Yurovsky et al., 2010), this is slightly longer than the norm in looking time studies (i.e., 5-6 s, Pruden, Hirsh-Pasek, Golinkoff, & Hennon, 2006).
association of objects with their respective label or function (Reznick & Goldfield, 1992).

**Results**

**Analysis.** Four sets of analyses were conducted to examine infants’ behaviors during each phase of the experiment. Together, these analyses aimed to assess how infants’ choice phase behavior (i.e., point, reach, or look) and condition (i.e., label, function, or no information) influenced their subsequent (1) persistence during training and (2) performance during test. A summary of these analyses is presented in Table 8.

**Table 7. Summary of Analytic Plan**

<table>
<thead>
<tr>
<th>Analysis Set</th>
<th>Experimental Phase</th>
<th>Key IV</th>
<th>Key DV</th>
<th>Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Choice Phase</td>
<td>Choice Phase Behavior</td>
<td># Trials</td>
<td>Document the types of communicative behaviors produced during the Choice Phase.</td>
</tr>
<tr>
<td>2</td>
<td>Training Phase</td>
<td>Condition &amp; Choice Phase Behavior</td>
<td># of Persistence Behaviors</td>
<td>Test the influence of condition and choice phase behavior on the number of subsequent persistence behaviors.</td>
</tr>
<tr>
<td>3</td>
<td>Test Phase</td>
<td>Condition &amp; Choice Phase Behavior</td>
<td>Proportion of Target Looking</td>
<td>Assess the influence of condition and choice phase behavior on subsequent fast mapping</td>
</tr>
<tr>
<td>4</td>
<td>Training + Test Phase</td>
<td># of Persistence Behaviors</td>
<td>Proportion of Target Looking</td>
<td>Explore the relation between persistence behaviors and subsequent learning</td>
</tr>
</tbody>
</table>

All analyses were performed in the R statistical programming package (R Development Core Team, 2014) using the functions chisq.test, cor.test, aov, wilcox.test, shapiro.test, glmer and lmer of the packages lme4 (Bates & Maechler, 2010). Shapiro-Wilk tests were used prior to each analysis to test for normality.
When normality assumptions were violated, non-parametric tests were used. All Figure error bars represent standard errors of the mean.

**Analysis Set 1: Communicative Behaviors produced during the Choice Phase**

During the choice phase, in response to the experimenter’s prompt, *Point to one of these*, infants either pointed (27% of trials, \( n = 75 \)), reached (17% of trials, \( n = 47 \)), or looked (56% of trials, \( n = 158 \)) toward the target object (Table 9). The majority of infants (67%, \( n = 24 \)) did not produce the same communicative behavior across all nine trials (e.g., switched from pointing to looking). Appendix B presents the different combinations of communicative behaviors that infants produced across the experiment, as well as how these various behavioral combinations relate to infants’ pre-existing vocabulary size and performance during the experiment.

**Table 8. Proportion of Trials (\( n = 280 \)) in which each Communicative Behavior was Produced.**

<table>
<thead>
<tr>
<th>Communicative Behavior</th>
<th>% Trials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point</td>
<td>27</td>
</tr>
<tr>
<td>Reach</td>
<td>17</td>
</tr>
<tr>
<td>Look</td>
<td>56</td>
</tr>
</tbody>
</table>

Infants paired these communicative behaviors with (1) speech-like vocalizations (40% of trials), (2) non-speech like vocalizations (14% of trials), or (3) no vocalizations (46% of trials). Infants produced a gaze alternation in 75% of trials. Of interest was whether speech-like vocalizations and/or gaze alternations were more likely to occur during pointing trials (i.e., trials in which infants
produced a pointing gesture during the choice phase), compared to non-pointing trials (i.e., trials in which infants did not point during the choice phase).

A chi-square test revealed that the percentage of trials produced with a speech-like vocalization differed significantly based on whether infants had also pointed, $\chi^2(1) = 13.83, p = .0002$. Pointing trials were paired with speech-like vocalizations 59% of the time, whereas non-pointing trials were paired with speech-like vocalizations only 33% of the time (Figure 6A). An additional chi-square test revealed that the percentage of trials produced with a gaze alternation did not differ based on whether infants had pointed, $\chi^2(1) = .73, p > .05$. Pointing trials were paired with gaze alternations 71% of the time and non-pointing trials were paired with gaze alternations 77% of the time (Figure 6B).

![Figure 6. Mean Proportion of Trials Paired with a Speech-Like Vocalization (A) or Gaze Alternation (B) based on whether Infants had also Pointed or Not.](image-url)
Analysis Set 2: Persistence during the Training Phase

The next set of analyses tested whether infants’ production of persistence behaviors (i.e., points, reaches, vocalizations, table hits) during the training phase varied as a function of (1) the initial communicative behavior they produced during the corresponding choice phase of that trial (point, reach, look), and (2) the type of information (function, label, no information) given in response. The number of times the infant produced a persistence behavior was analyzed by fitting a generalized linear mixed-effects model with a Poisson error structure using a log link function. The number of times infants produced persistence behaviors during the training phase was modeled as a function of the following fixed effects: infants’ initial communicative behavior during the choice phase (point vs. reach vs. look), information type (function vs. label vs. no information), the interaction between the two, and sex. Infants’ ID was included in the model as a random effect to account for repeated observations of infants across the nine trials. We controlled for infants’ pre-existing vocabulary size and fatigue in later trials by including productive MCDI scores and trial number (1-9) in the model.

The model including trial number and the interaction of information type and communicative behavior as a predictor fit substantially better than the null model that did not include any fixed effects (likelihood ratio test, $\chi^2(9) = 38.42, p < .0001$). The model did not improve in fit when sex and MCDI scores were

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2 Infants’ productive vocabulary size, as opposed to receptive, was included in the model because it was more strongly related to infants’ production of additional behaviors (productive vocabulary: $r = -.18, p = .35$; receptive vocabulary: $r = .16, p = .35$).
included (likelihood ratio test, \( \chi^2(2) = 1.98, p > .05 \)). Trial number was a significant predictor of persistence behaviors: infants were more likely to produce persistence behaviors in later trials, compared to earlier trials (\( Z = 3.88, p = .0001 \)). No main effects of sex or MCDI scores emerged (\( p > .05 \)). The effect of infants’ initial communicative behavior on the number of persistence behaviors produced varied as a function of the type of information they received during training (\( Z = -2.31, p = 0.02 \); Figure 7). To probe this interaction, the next sets of analyses tested the influence of information type on the production of persistence behaviors within each type of initial communicative behavior that was produced.

During point trials, there was a significant main effect of information type, such that infants were significantly more likely to produce persistence behaviors in no information trials (\textit{mean number of persistence behaviors} = 2.89, \( SE = .30; Z = 3.34, p = .0008 \)) and function trials (\( M = 2.77, SE = .63; Z = 3.03, p = .002 \)), compared to label trials (\( M = 1.50, SE = .49 \)). See Figure 7B. There was no significant difference in persistence behaviors during function compared to no information trials (\( p > .05 \)). During reach trials, there was no significant main effect of information type\(^3\), such that infants did not differ in their likelihood of producing persistence behaviors as a function of the type of information given (\( M_{\text{no-info}} = 2.92, SE = .54; M_{\text{function}} = 1.64, SE = .28; M_{\text{label}} = 2.05, SE = .31 \), all \( p’s > .05 \),

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\(^3\) In Appendix B we rule out the possibility that this null finding is due to a lack of power (i.e., small \( N \) in reach trials).
Figure 7C). Similarly, during look trials, there was no significant main effect of information type ($M_{\text{no-info}} = 1.48, SE = .19; M_{\text{function}} = 1.53, SE = .21; M_{\text{label}} = 1.55, SE = .23$, all $p's > .05$, Figure 7A). Thus, it is only when infants pointed toward an object that the presentation of different types of information led to differential persistence.

Figure 7. Average Additional Behaviors Produced during Training as a Function of Whether Infants First Looked (A), Pointed (B), or Reached (C) During the Choice Phase.
Analysis Set 3: Performance during the Test Phase

**Baseline window analyses.** Infants’ proportion of looking toward the target object during the baseline window of the test phase (i.e., prior to the onset of target information) was calculated by dividing the total amount of time spent looking at the target object by the total amount of time spent looking at both the target and non-target objects. Tests against chance (.50) revealed that during point trials, infants looked at the target object at rates below chance (*mean proportion of target looks* = .38, *SE* = .04, *W* = 146, *p* = .04; Figure 8). During look and reach trials, infants also tended to look at the target object less than the distractor object, but these values did not differ significantly from chance (*M*$_{look}$ = .46, *SE* = .03; *M*$_{reach}$ = .47, *SE* = .05, all *p’s* > .05; Figure 8).

![Figure 8. Time Course of Infants’ Target Looking During Test as a Function of Whether they had Pointed (blue line) or Not (red line) During the Choice Phase.](image-url)
Infants initial bias for looking at the non-target object is not surprising because during the training phase, infants were directed to look only at the target object. Thus, when the target and non-target objects reappeared during the test phase, the non-target object may have been more novel to the infants, leading them to look at it first and for longer.

**Critical window analyses.** The next sets of analyses controlled for infants’ baseline preferences for the distractor object and tested whether infants successfully mapped the target information onto the target object during the critical window of the test phase (i.e., the portion of the test phase after the onset of the target information). To adjust for infants’ baseline preferences, we analyzed whether infants significantly increased their looking toward the target object during the critical window of the test phase, relative to the baseline window of the test phase.

Prior to conducting analyses, we evaluated the distribution of our data. A Shapiro-Wilk test revealed that infants’ looking time did not follow a normal distribution ($W = .91, p < .0001$). Infants’ looking time followed a bimodal distribution (i.e., infants tended to either look only at the target object or only the non-target object). Thus, as in prior research (Goldin-Meadow, Shield, Lenzen, Herzig, & Padden, 2012; Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014; Wakefield & James, 2015), for purpose of analyses we recoded infants’ looking time into a binary value: target looking (i.e., proportion of target looking
greater than .50) or non-target looking (i.e., proportion of target looking less than .50).

We ran generalized linear mixed models with infants’ target looking (yes vs. no) as the dependent variable. Our key fixed effect was test phase portion (baseline vs. critical window). Sex, MCDI scores⁴, information type (function vs. label) and trial number (1-9) were also included as fixed effects in the model. Infants’ ID was included in the model as a random effect to control for repeated observations of infants across the nine trials. Three models were run, one for each communicative behavior infants produced during the choice phase (point, reach, look).

During point trials, there was a significant main effect of test phase portion, such that infants significantly increased their looking toward the target object during the critical window of the test phase, compared to the baseline window (*mean increase in proportion of looks to the target object = .17, SE = .08, Z = -2.07, p = .04*, Figure 9). There were no main effects of sex, MCDI scores, information type, or trial number (all *p’s > .05*). The model including the effect of test phase portion fit substantially better than the model without this term (likelihood ratio test, $\chi^2(1) = 4.46, p = .03$).

During look trials, there was no significant main effect of test phase portion, such that infants did not significantly increase their looking toward the

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⁴ Infants’ productive vocabulary size, as opposed to receptive, was included in the model because it was more strongly related to infants’ mapping scores (productive vocabulary: $r = .42, p = .01$; receptive vocabulary: $r = -.20, p = .25$).
target object during the critical window of the test phase relative to the baseline window \((M = .04, SE = .06, Z = -.18, p = .85, \text{Figure} \ 9)\). There was a main effect of trial number, such that infants looked longer at the target object during later trials, compared to earlier trials \((Z = 2.34, p = .02)\), and no effect of sex, information type, or MCDI scores (all \(p\)’s > .05). During reach trials, there was again no significant main effect of test phase portion, such that infants did not make significant increases toward the target object during the critical window of the test phase, relative to baseline \((M = .05, SE = .11, Z = -.88, p = .38, \text{Figure} \ 9)\). There were also no main effects of sex, information type, trial number, or MCDI scores (all \(p\)’s > .05).

Figure 9. Test Performance based on Infants’ Choice Phase Behavior. Values Greater than Zero Indicate Successful Fast Mapping.
**Effects of Information Type and Communicative Behaviors on Learning.** Follow up analyses directly compared whether infants more readily mapped information onto objects as a function of the initial communicative behavior they produced during the choice phase (point vs. reach vs. look) or the type of information presented (function vs. label). To do so, we ran linear mixed model with infants’ difference scores as the dependent variable. Difference scores were calculated by subtracting the proportion of time infants spent looking at the target object, compared to the distractor object, during the critical window, from the proportion of time infants spent looking at the target object, compared to the distractor object, during the baseline window. Communicative behavior (point vs. reach vs. look), information type (function vs. label), the interaction between communicative behavior and information type, sex, trial number, and MCDI scores were included as fixed effects. Infants’ ID was included in the model as a random effect. No significant main effects or interactions emerged (all p’s > .05).

Although we did not find a significant difference in performance between the different types of information or communicative behaviors (Figure 10), we wanted to test whether any group successfully mapped the target information onto the target objects. A difference score significantly greater than zero represents successful mapping, since a score of zero indicates no change in looking toward the target object from baseline to the critical window. Three one-

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5 Appendix B visualizes how these difference scores were calculated (i.e., plots of baseline vs. critical window patterns of looking).
sample t-tests against a chance value of zero revealed that it was only during point trials that infants’ difference scores were significantly greater than zero, \( t(29) = 2.05, p = .02 \). During look and reach trials, infants’ difference scores did not significantly differ from zero, look trials: \( t(68) = .61, p = .27 \); reach trials: \( t(26) = .46, p = .32 \). Two additional one-sample t-tests, collapsing across communicative behaviors, revealed that infants’ difference scores differed marginally from zero during function trials (\( M_{\text{function}} = .09, SE = .07, t(61) = 1.41, p = .08 \)), but were no different than zero during label trials (\( M_{\text{label}} = .05, SE = .06, t(63) = .83, p = .21 \)).

Figure 10. Test Performance based on Infants’ Choice Phase Behavior and Information Type.

Analysis Set 4: Relation Between Persistence and Learning

\(^6\) Although this analytic method does not take into account repeated observations across individuals, as the earlier analyses did, this analytic method is common to fast mapping studies (e.g., Reznick & Goldfield, 1992; Swingley & Aslin, 2007) and provides us with an additional estimate of which groups differed from chance.
The final analysis tested whether infants’ production of persistence behaviors during the training phase influenced their ability to map information onto objects during the corresponding test phase of that trial. To do so, we ran a linear mixed model\(^7\), with infants’ difference score during the test phase as the dependent variable. Fixed effect predictors included infants’ initial communicative behavior during the choice phase (point vs. reach vs. look), information type (function vs. label vs. no information), the number of persistence behaviors produced during the training phase and the interaction between these three variables. This allowed us to test whether infants’ persistence impacted learning only during certain trial types or only if they had pointed before receiving information or not. Sex was also included as a fixed effect predictor. Infants’ ID was included in the model as a random effect to account for repeated observations of infants across the nine trials. We controlled for infants’ pre-existing vocabulary size and fatigue in later trials by including productive MCDI scores and trial number (1-9) in the model.

No significant interactions or main effects emerged. The only marginal main effect to emerge was of MCDI scores, such that infants with higher MCDI scores also had higher difference scores, \(t(118) = 1.98, p = .05\), see Figure 10.

\(^7\) This model differs from the generalized linear mixed model described earlier in that instead of using infants’ overall proportion of target looking during the test phase (i.e., baseline and critical window looking) as the dependent variable, we used infants difference score (i.e., critical minus baseline window looking) as the dependent variable. Infants’ overall proportion of target looking was used to determine whether infants’ significantly increased target looking during the critical window relative to the baseline window, infants’ difference scores were used to determine the extent to which other variables, such as number of persistence behaviors, impacted fast mapping. Unlike infants’ overall proportion of looking at the target object, a Shapiro-Wilk test confirmed that infants’ difference scores followed a normal distribution \((p > .05)\).
Infants’ production of persistence behaviors during the training phase did not influence their ability to map objects onto objects during the corresponding test phase of that trial ($p > .05$), see Figure 11.

![Figure 11. Scatter Plot Displaying the Relation between MCDI scores and Difference Scores.](image1)

![Figure 12. Scatter Plot Displaying the Relation Between Persistence Behaviors and Difference Scores Within Trials. Each Point Represents One Trial.](image2)
Discussion

The goal of the current study was to investigate the role of infants’ pointing gestures as an information-requesting behavior. Results revealed that when infants pointed toward an object and subsequently received information about that object, they learned that information – regardless of whether the information was a function or a label. However, infants had different behavioral responses to receiving the various types of information. In other words, when an experimenter responded to infants’ pointing gestures with labels, they were satisfied (i.e., they did not persist in their communicative attempts). Alternatively, when an experimenter responded to infants’ pointing gestures with functions or no information about pointed-to objects, they were not satisfied (i.e., they persisted in their communicative attempts by producing additional communicative behaviors, such as vocalizations). Interestingly, there was no significant relation between infants’ behavioral satisfaction with receiving information and subsequent learning of that information. Even when infants received a type of information they were not explicitly requesting (i.e., a function), they were still able to successfully learn that information – highlighting the extent to which infants’ pointing gestures reflect a readiness to learn.

These results not only strengthen previous findings demonstrating that pointing is an important way for infants to acquire new information, but they also expand on prior research by demonstrating, for the first time, that infants
may selectively use their pointing gestures to request information. In the current experiment, if infants did not spontaneously point prior to receiving information, and instead reached or looked toward objects of interest, they did not successfully map labels or functions onto objects. Moreover, when infants first reached or looked toward a novel object of interest, they were equally satisfied with receiving that object’s function or label, or no information about that object. The unique function of pointing as an information-requesting behavior was corroborated by the finding that pointing gestures, but not other communicative behaviors (i.e., reaching, looking), were routinely produced along with speech-like vocalizations. The unique pairing of points with speech-like vocalizations distinguishes pointing from other behaviors and suggests that pointing may be deployed with a more linguistic objective (i.e., to obtain labels). Interestingly, we did not find that pointing gestures were uniquely produced alongside gaze alternations, which are another marker of communicative sophistication and intent (Bates et al., 1975). This may have been the result of a ceiling effect: regardless of the behavior infants initially produced during the choice phase of the experiment, they were also very likely to have gaze alternated.

Taken together, these findings demonstrate that infants’ pointing gestures are directly and uniquely related to their ability to map information onto objects. Given that fast mapping is a critical skill that underlies word learning (Carey, 2010; Woodward, Markman, & Fitzsimmons, 1994), these findings help explain how pointing gestures work to shape infants’ early language acquisition. These
findings also provide new insights into why infants may be motivated to produce pointing gestures, a topic that has been extensively debated (D’Entremont & Seamans, 2007; Gómez, 2007; Southgate et al., 2007; Tomasello, Carpenter, et al., 2007). In addition to many other functions, infants’ pointing gestures may also serve as a unique way for them to request information about objects, and labels in particular, from their caregivers.

**Information Seeking Drives Cognitive Development**

Infants’ inclination to explicitly request information is not surprising. Decades of research have demonstrated that infants, from a very early age, demonstrate biases that suggest a motivation to acquire information (Csibra & Gergely, 2006; Morton & Johnson, 1991; Vouloumanos & Werker, 2004). For instance, by 8 months, infants tend to focus on and interact with stimuli that have the most potential for information gain (e.g., objects that have previously violated their expectations), compared to other interesting stimuli (Kidd et al., 2012; Stahl & Feigenson, 2015). By the end of the first year of life, infants acquire the understanding that human adults are particularly vital and abundant sources of information (Homer & Tamis-Lemonda, 2013; Vaish et al., 2011).

Infants’ ability to seek out information from their other individuals is rather sophisticated. Infants will only look to adults for information in situations in which information transfer is both necessary (i.e., when they actually need it; Goupil, Romand-Monnier, & Kouider, 2016) and possible (i.e., the individual providing information is reliable and capable; Begus, Gliga, & Southgate, 2016;
Tummeltshammer, Wu, Sobel, & Kirkham, 2014). While these biases all help infants *attend* to informative sources in their environment, it is not until infants begin pointing that they are afforded with a precise and targeted way to *request* information from their caregivers.

The drive to request information has long been regarded as a key driving force of cognitive development and the acquisition of culture (Davis, 1932; Gopnik & Meltzoff, 1997; Piaget, 1926). However, much of the research on information-requesting has been focused on older children in the form of question asking (Chouinard, 2007). This research has centered on the types of questions children ask, when they ask them, and the types of responses they want (Frazier, Gelman, & Wellman, 2009; Gelman, 2009; Nelson, Egan, & Holt, 2004). While older children’s requests for information are to obtain object functions (Asher & Kemler Nelson, 2008; Nelson, Frankenfield, Morris, & Blair, 2000), the current findings demonstrate that earlier in development infants’ requests for information is to obtain object labels. Interestingly, these developmental differences directly map on to children’s cognitive and linguistic development. At 18 months, infants are entering the “vocabulary burst” and are rapidly adding new labels to their vocabulary (Bloom, 1973; Nelson, 1973). Thus, these infants are acquiring the utility of labels (e.g., labels help them get needs met), and may be particularly interested in acquiring new labels. Older children, alternatively, already know many labels and may be seeking out more explanatory principles about objects.
These findings also correspond with how caregivers respond to their children’s requests for information at different points in development (Chouinard, 2007). Before children’s second birthday, caregivers tend to respond to information requests with labels more often than functions. After children’s second birthday, caregivers switch strategies and respond with functions more often than labels. A question for future research is to disentangle why these developmental patterns exist. Are infants’ requests for information specific to labels because that is the type of information they are accustomed to receiving when they request information, or are parents attuned to the types of requests their infants are making, and tailoring their responses to fulfill those requests? Moreover, future research should also investigate the decoupling of persistence and learning. In other words, why is infants’ satisfaction with receiving information not related to their ability to learn that information?

Conclusion

Bruner (1983) notably declared that infants’ pointing gestures provide a setting that is “extraordinarily rich for the growth of the language” (p. 106). The current study provides new insights into this claim by identifying potential mechanisms by which infant pointing supports language development. First, the current findings demonstrate that pointing, but not other gestures, results in successful learning of both labels and functions. In doing so, these findings highlight that infants’ pointing gestures reflect a heightened readiness to learn various types of information. These results also provide important insights into
infants’ motivation for pointing, a topic that has been extensively debated (Gómez, 2007; Southgate, van Maanen, & Csibra, 2007; Tomasello, Carpenter, & Liszkowski, 2007). These findings deliver new insights into this debate by providing evidence that infants’ pointing gestures may be a unique way for them to request information, and labels in particular, from caregivers. Together, this work provides a comprehensive account of infants’ pointing gestures as an early-developing, information-requesting behavior that facilitates the acquisition of new information.
Chapter 4. The Development and Flexibility of Gaze Alternations in Bonobos and Chimpanzees

Introduction

There is a well known proverb that states: “the eyes are the window into the soul”. Though cliché, this saying makes an important point: the eyes offer a powerful way to connect with others. Indeed, even human infants, before they can communicate with their words or gestures, engage with others using their eyes. For instance, infants will often alternate their gaze between an object of interest and another individual who is also attending to that object (Bates, Camaioni, & Volterra, 1975; Bruner, 1982; Tomasello, 1995). As early as ten months, infants will produce these “gaze alternations” almost exclusively when others are attentive, as opposed to inattentive (Striano & Rochat, 2000). These gaze alternations are often regarded as the “hallmark” of joint attention because they reflect infants’ desire to share attention with a partner (Carpenter et al., 1998; Desrochers et al., 1995; Leung & Rheingold, 1981). This has led researchers to argue that infants’ gaze alternations help provide the foundation upon which more complex social-cognitive skills, such as theory of mind and language, develop (Akhtar & Gernsbacher, 2007; Bruner, 1983; Tomasello, Carpenter, & Liszkowski, 2007).

To better understand the origins of these uniquely social-cognitive skills, researchers have tested which aspects of human social cognition are shared with our closest living nonhuman primate relatives, bonobos and chimpanzees. While
very young children (i.e., two-year-olds) do not differ from bonobos and chimpanzees in some non-social tasks, such as discriminating numerical quantities (Wobber, Herrmann, Hare, Wrangham, & Tomasello, 2013), young children consistently outperform bonobos and chimpanzees in social-cognitive tasks, such as following communicative cues to locate a hidden reward (Herrmann, Call, Hernandez-Lloreda, Hare, & Tomasello, 2007). For humans, many of these social-cognitive skills are already in place by 9-12 months (Carpenter et al., 1998). Thus, not only do humans have more advanced social-cognitive skills than nonhuman primates, but they also develop them very early in development. This has led researchers to argue that the distinctively early emergence of social-cognitive skills may provide a foundation for the development of other uniquely aspects of human cognition, such as language and culture (Herrmann et al., 2007; MacLean, 2016; Tomasello, 1999).

While previous research has demonstrated that nonhuman primates produce gaze alternations, the ontogenetic trajectory of these behaviors, and the flexibility with which they are used are not well understood. Both experimental and observational research on captive and wild chimpanzees has revealed that gaze alternations are a recurrent part of chimpanzees’ daily activities (Call & Tomasello, 1994; Leavens & Hopkins, 1998). For instance, gaze alternations are produced most frequently during communicative exchanges (e.g., food requesting contexts; Plooij, 1978) and collaborative group activities (e.g., group travel as a recruitment strategy; Gruber & Zuberbühler, 2013). An observational
study on a set of five wild chimpanzees revealed that the production of gaze alternations increases across development (Tomasello, George, Kruger, Farrar, & Evans, 1985).

Whether nonhuman apes take the attentional state of their communicative partner into consideration while gaze alternating remains unknown. Relatedly, previous work has demonstrated that nonhuman apes produce communicative signals in the modality that is most relevant for their communicative partner. That is, they produce more visual signals when a communicative partner is only able to see them, and produce more auditory signals when a communicative partner is only able to hear them (Hostetter, Hopkins, & Cantero, 2001; Tomasello et al., 1994). That nonhuman apes have the requisite skills for understanding the perspectives of others when deploying visual and auditory signals suggests that they may also do so when producing gaze alternations.

Recent work with nonhuman primates more distantly related to humans, namely squirrel monkeys, has found that monkeys also produce gaze alternations (Anderson et al., 2007). Interestingly, they are most likely to gaze alternate while they are gesturing (Anderson et al., 2007), or when a communicative partner is visually attentive (Bourjade et al., 2014). Together, these studies provide further evidence for the hypothesis that nonhuman apes may take the attentional state of a communicative partner into consideration while gaze alternating.
The Current Study

While previous research has documented the presence of gaze alternations in nonhuman primates, these studies often relied on small sample sizes and/or a single species and setting. As a result, we know relatively little about the development of gaze alternations, the contexts in which they are produced, and whether they are produced differently across taxa. To address these questions, the current study assessed the production of gaze alternations in a large developmental sample of bonobos and chimpanzees, using a method similar to studies with human infants. This paradigm measures gaze alternations between a desirable object and an experimenter who is either facing toward, or away from, the participant (as in Striano & Rochat, 2000).

By ten months, infants show a sensitivity to an adult’s attentional stance and will preferentially gaze alternate when an experimenter is attentive, compared to inattentive (Striano & Rochat, 2000). This pattern suggests that infants’ gaze alternations are not simple “checking back” behaviors that allow infants to see what other individuals are doing. Rather, infants’ early gaze alternations are used in intentionally communicative ways to share their attention with others. If gaze alternations provide the foundation for uniquely-human abilities, then we would expect that nonhuman apes will not show this pattern, and if they do it will develop in a trajectory that is later-emerging than that seen in humans. Alternatively, if the last common ancestor of humans and Panins exhibited human-like use of gaze alternations, then bonobos and
chimpanzees should also begin to gaze alternate at an early age and demonstrate a sensitivity to the attentional state of a communicative partner by gaze alternating more for an attentive, rather than inattentive, communicative partner.

In the current study, we tested bonobos and chimpanzees because as our closest living relatives they provide the most powerful opportunity for making inferences about our last common ancestor (Hare, 2007; Hare & Yamamoto, 2015). Although equally related to humans, bonobos and chimpanzees have been shown to differ in cognitive development. Bonobos in particular have been observed to show developmental delays relative to chimpanzees in skills relating to foraging, such as spatial navigation (Hare et al., 2012; Rosati & Hare, 2012; Wobber et al., 2010). Thus, these two species may also differ in their development of gaze alternations, suggesting that this skill may have evolved differently between ape species.

Method

Subjects

Fifty-two semi-free-ranging apes: 17 bonobos (Pan paniscus; 7 female, mean age = 7.71 years, range: 3 - 11) from Lola ya Bonobo Sanctuary in Kinshasa, Democratic Republic of Congo and 35 chimpanzees from Tchimpounga Chimpanzee Sanctuary in Pointe Noire, Republic of Congo (Pan troglodytes; 16 female, mean age = 7.48 years, range: 3 – 11) participated in the study. Twelve additional individuals were tested, but excluded because the mesh enclosure precluded detailed coding of the face (Maclean & Hare, 2014). Primarily, these
apes are orphans of the bushmeat or pet trade and arrived at the sanctuary at an early age. They spend the majority of their time with conspecifics in large forested enclosures at the sanctuaries, in species-typical social groups. All apes had regular contact with humans through routine feedings and medical care. A full description of these populations is provided in Wobber and Hare (2011).

**Procedure and Paradigm**

Subjects were tested individually in a food-requesting task (Figure 12). The subject was positioned behind a mesh enclosure wall, facing a human experimenter. A video camera was positioned at the subject’s eye level to capture a direct recording of eye movements for offline coding. A banana was positioned directly in front of the experimenter, out of the subject’s reach. The test consisted of two conditions. In ‘attentive’ trials the experimenter faced the subject, whereas in the ‘inattentive’ trials the experimenter turned his back to the subject (Figure 12). Each trial was 30 seconds long, with 4 trials per subject; the order of conditions was counterbalanced within subjects in an ABBA design (A = ‘attentive, B = ‘inattentive’). At the beginning of the experiment, and again in between each trial, an experimenter fed the subject bananas for 30 seconds. These feeding breaks were designed to ensure that the subject was interested in obtaining the food and to create a situation in which the subject viewed the experimenter as a potential cooperative partner for obtaining the food.
Coding of Gaze Alternations

Coding was done using Datavyu software (www.datavyu.org). Videos were watched at half-speed. As in previous research with human infants and nonhuman primates, gaze alternations were defined as alternating looks between the experimenter and a target object (in this case food) within a 5-second period (Carpenter et al., 1998; Leavens & Hopkins, 1998; Tomasello et al., 1985). Looks to the food were operationalized as eye saccades and/or head movements in the direction of the food. Looks to the experimenter were operationalized as eye saccades and/or head movements in the direction of the experimenter. To distinguish looks between the food and experimenter, the food was placed below subjects’ eye level, and the experimenter’s face was above subjects’ eye level (Figure 12). Looks were coded as “away” if the subject did not look at either the food or the experimenter. Twenty percent of all videos were re-coded by an
independent coder to establish inter-rater reliability, which was excellent (Cohen’s Kappa = .81; Landis & Koch, 1977). If the subject looked to the food and looked to the experimenter within a 5-second period at least once during a single trial, they were considered to have “gaze alternated” in that trial.¹

Results

Gaze alternations occurred in 81 of the 208 observed trials. On average, individuals produced gaze alternations in 1.55/4 trials. Over half of the individuals (31/52) produced a gaze alternation in at least one trial. Forty percent of individuals never gaze alternated, 15% gaze alternated in one trial, 13% gaze alternated in two trials, 10% gaze alternated in three trials, and 21% gaze alternated in all four trials.

Linear mixed models (Baayen et al., 2008) were used to test whether the number of trials in which individuals produced a gaze alternation varied as a function of the individual’s age, species, and experimental condition. Fixed-effect predictors included the individual’s age (continuous, in years), species (chimpanzee vs. bonobo), experimental condition (attentive vs. inattentive), sex, and all possible interaction terms. Four repeated observations per individual was taken into consideration by including the individuals’ ID in the model as a random effect. Likelihood ratio tests (Dobson, 2002) were used to compare the fit of the full model to the null model. Analyses were performed in R (R Core

¹We also coded subjects’ multimodal signaling (i.e., combinations of visual and auditory signals) and time spent disengaged from the task. These analyses are reported in Appendix C.
Development Team, 2014) using the function lmer of the package lme4 (Bates & Maechler, 2010).

The only significant interaction to emerge was between age and species ($Z = 2.94, p = 0.005$; Figure 14). There was a significant main effect of condition ($Z = 2.02, p = 0.04$), such that both bonobos and chimpanzees of all ages and both sexes were more likely to gaze alternate during trials in which the experimenter was attentive (average number of trials with a gaze alternation, $M = 0.81, SE = 0.10$), compared to trials in which the experimenter was inattentive ($M = 0.65, SE = 0.11$; Figure 13). There was a marginal effect of sex ($Z = 1.76, p = 0.08$), such that males were slightly more likely to gaze alternate ($M = 0.82, SE = 0.15$) than females ($M = 0.63, SE = 0.15$). Although the sex by species interaction was not significant, there was only one female bonobo, a juvenile, in the sample of female bonobos ($n = 7$) that gaze alternated. The model including condition and sex as predictors, and the interaction of species and age fit substantially better than the null model (likelihood ratio test, $\chi^2 = 51.61, df = 5, p < 0.0001$).
To probe the age by species interaction, the next two analyses tested the effect of age on gaze alternation production within each species (Figure 14). For chimpanzees, age was a significant predictor of gaze alternation production, such that older individuals were significantly more likely to gaze alternate than younger individuals ($Z = 6.49, p < 0.0001$). With each year of life, chimpanzees increased their likelihood of gaze alternating by 5%. Alternatively, for bonobos, age was not a significant predictor of gaze alternation production ($Z = 0.128, p = 0.09$). With each year of life, bonobos increased their likelihood of gaze alternating by 0%.

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2 Error bars represent within-subject standard error of the mean
Discussion

We found that similar to human infants, both bonobos and chimpanzees produce gaze alternations with a sensitivity to cues about the attentional state of a communicative partner: they produce more gaze alternations when an experimenter is facing them compared to when an experimenter is facing away from them. This suggests that bonobos’ and chimpanzees’ gaze alternations are not simple “checking back” behaviors in which they are checking to see what the other individual is doing, or alternating their gaze between the food and the other individual simply because they are interested in looking at both of them independently. Rather, these findings are consistent with the hypothesis that similar to human infants, bonobos’ and
chimpanzees’ gaze alternations may be used in flexible ways, and potentially driven by the communicative intent to share attention with others.

Despite their similar ability to gaze alternate with a sensitivity to the attentional state of a communicative partner, we found that bonobos and chimps differed in the developmental trajectory of gaze alternations. Neither bonobos nor chimpanzees produced gaze alternations frequently early in development. This is in contrast to human infants, who produce gaze alternations frequently by 9 months (Mundy et al., 2007). Indeed, a study using a requesting paradigm similar to the one here found that 18-month-olds gaze alternate in 57% of trials (Lucca & Wilbourn, 2016). Chimpanzees eventually increased their production of gaze alternations across ontogeny, but these changes occurred relatively late in development compared to humans. In contrast, there was no effect of age on the frequency of gaze alternation in bonobos, and bonobos of all ages produced relatively few gaze alternations. Thus, in contrast to humans, who rely on gaze alternations as one of their primary forms of social interaction from the first year of life, gaze alternations appear relatively rare in early Panin development. This finding builds on a growing body of evidence that humans uniquely develop skills related to sharing attention very early on in development (Herrmann, Hare, Call, & Tomasello, 2010; Wobber, Herrmann, Hare, Wrangham, & Tomasello, 2014). The early emergence of these abilities may be what allows for the development of uniquely human traits, such as language and theory of mind (Tomasello, 2009).
Why might humans, but not bonobos or chimpanzees, produce gaze alternations so frequently from so early on in development? One possibility is that bonobos and chimpanzees may not need to rely on gaze alternations as much as humans. Unlike humans, bonobos and chimpanzees gain control of their hands and are able to walk independently of their mother within the first few months of life (Doran, 1997). Thus, bonobos and chimpanzees may not need to rely on communicative skills as heavily as human infants to have their basic needs met. While human infants cannot navigate on their own or gain full control over their hands until later in development, they can control their eye muscles. The human eye is also especially useful for communication because its white sclera is much more salient than other species, making it easier for humans to detect shifts in other humans’ eye movements (Kobayashi & Koshima, 1997). One quantitative comparison found that humans’ white sclera is three times more visible than that of other great apes (Kaplan & Rogers, 2002). Thus, it is not surprising that human infants, more so than other species, rely on their eyes as a primary means to communicate with others (Tomasello, Hare, Lehmann, & Call, 2007). Future research, directly comparing the frequency of gaze alternations in human infants, bonobos, and chimpanzees in similar paradigms will allow for more direct and quantitative comparisons of gaze alternations across species.

Although bonobos and chimpanzees did not engage in high rates of gaze alternation, chimpanzees ultimately increased their production of gaze alternations across development whereas bonobos did not. This finding is
consistent with prior research demonstrating heterochronic changes in the timing of certain cognitive skills (e.g., spatial memory) between bonobos and chimpanzees (Hare et al., 2012; Rosati & Hare, 2012; Wobber et al., 2010). While bonobos have an average life expectancy of 40 years (Rowe, 1996), and typically reach adulthood by 13-14 years, the oldest bonobo in the current sample was 11-years-old. If gaze alternations develop on a similar trajectory as other cognitive skills in bonobos, then this sample might be too young to detect an increase in frequency in gaze alternations in bonobos. Indeed, prior research has found that certain socio-cognitive skills (e.g., successful social inhibition) only emerge in bonobos older than 10 years (Wobber et al., 2010). Thus, it is possible that with an older sample of bonobos, we would have found that bonobos eventually increased their production of gaze alternations. Alternatively, it may be that bonobos’ gaze alternations follow the same developmental trajectory as chimpanzees, but we lacked the ability to detect this trajectory here because we had significantly fewer bonobos (N = 17) in our sample than chimpanzees (N = 35).

Another limitation of the present study is that we measured gaze alternations during human-ape interactions, rather than mother-infant or conspecific interactions. Although the apes in the current study were mainly orphans who have routine contact with humans, it is possible that they may not have been as motivated to interact or communicate with the human experimenter as they would have been with a conspecific (see Herrmann, Hare,
Cisewski, & Tomasello, 2011). This may have limited our ability to detect their gaze alternations. In the current study, we found that female bonobos produced the fewest gaze alternations. Previous research has shown that that female bonobos, compared to males and chimpanzees, can be hesitant to interact with human experimenters (Schroepfer-Walker, Wobber, & Hare, 2015). It is unclear whether our findings are because gaze alternations are not a recurrent part of bonobos’ communicative repertoire, or whether we were unable to detect gaze alternations because individuals in the current study were not motivated to communicate and interact with the human experimenter.

Indeed, studies of animal cognition often find that small changes to a study’s design can reveal drastic differences in the underlying abilities those studies are attempting to measure (e.g., Hare, Call, Agnetta, & Tomasello, 2000; Krupenye, Kano, Hirata, Call, & Tomasello, 2016). While previous research has found that bonobos and apes will follow the gaze of both humans and conspecifics, more recent research that has found that chimpanzees, but not bonobos, are more likely to follow the gaze of a conspecific, compared to a human (Kano & Call, 2014; Tomasello, Call, & Hare, 1998; Tomasello, Hare, Lehmann, & Call 2007). Thus, future research assessing bonobos’ and chimpanzees’ gaze alternations with conspecifics will be able to provide additional insights into the nature of bonobos’ and chimpanzees’ gaze alternations.
In sum, the current findings both replicate prior research by demonstrating that chimpanzees produce gaze alternations, and build on prior work by demonstrating, for the first time, that bonobos also produce gaze alternations. These gaze alternations appeared to be produced in ways that are similar to human infants, and meet a key criterion for goal-directed communication (Bruner, 1981; Tomasello, Call, Nagell, Olguin, & Carpenter, 1994; Woodruff & Premack, 1979). That is, individuals preferentially gaze alternated when a communicative partner was attentive, as opposed to inattentive. This finding suggests that bonobos and chimpanzees took cues of the basic mental state of their communicative partner into account when deciding whether or not to gaze alternate. However, unlike humans, neither bonobos nor chimpanzees produced gaze alternations frequently early in development. Thus, what may be unique to humans is not necessarily the production of gaze alternations, but rather the early production of gaze alternations. Together with other early-developing social-cognitive skills, the distinctively early emergence of gaze alternations in humans may provide the foundation for the development of species-unique skills, such as language.
Chapter 5. Discussion

From cultures to civilizations, many of the defining innovations of our species have been made possible by our ability to communicate through language. The complexity and uniqueness of language have led scholars to ask two fundamental questions: how did humans evolve the ability to communicate through language, and how do human infants acquire language so adeptly? The research in this dissertation contributed to answering these long-standing questions by examining nonverbal communicative behaviors of human infants and nonhuman primates. These findings provide valuable insights into (1) the mechanisms by which infants’ early gestures facilitate early language learning, and (2) the aspects of human nonverbal communication are shared with our nonhuman primate relatives. Together, these findings highlight the importance of nonverbal behaviors in the transition from nonverbal to verbal communication, on both developmental and evolutionary timelines.

In this final Chapter, I first briefly summarize each study presented in the dissertation. Then, I outline implications and cross-cutting themes that were present across all studies. Finally, I discuss new research questions that emerged from these studies and offer directions for future research needed to address these questions.
Chapter Summaries

Human Infant Research

The research presented in this dissertation provides empirical support for the theoretical perspective that infants’ pointing gestures are an early-developing nonverbal behavior that helps shape language learning. Together, these findings provide new insights into why pointing gestures may be critical for early language development. In the studies presented here, an experimenter elicited communicative behaviors (e.g., pointing, reaching) toward novel objects from infants two key developmental time points: (1) 12 months, when infants first begin to point, and (2) 18 months, after infants have had months of experience pointing. In response to infants’ behaviors toward an object, an experimenter presented information about that object (i.e., labels, functions, or a no-information control), and tested infants’ learning of (Chapters 2 and 3) and satisfaction with (Chapter 3) that information.

Summary: Chapter 2 (Point-to-Learn). When 18-month-olds pointed toward an object they were more likely to learn a label associated with that object compared to when they reached toward that object, or engaged in joint attention around that object without pointing (i.e., by gaze alternating). Moreover, infants’ pointing only led to successful learning when the experimenter labeled a pointed-to object. If the experimenter redirected the infants’ attention and labeled a not-pointed-to object, infants did not form the object-label association. This finding suggests that infants’ pointing gestures do not reflect a broad, heightened state of
attention for learning. Rather, the association between pointing and learning is specifically tailored to the pointed-to-object.

**Summary: Chapter 3 (Point-for-Words).** This chapter built on the findings from the previous chapter by testing whether infants’ pointing gestures were related to their ability to map *labels* onto objects more specifically or whether pointing the effect of pointing on learning could be extended to *other* types of information. To test this question, I assessed infants’ ability to learn labels (e.g., *modi*) compared to functions (e.g., *it goes like this*) for novel objects in response to their pointing gestures toward those objects. Infants were able to map both labels and functions onto objects when they pointed toward them. However, it was only when an experimenter responded to infants’ pointing gestures with labels that they ceased communicating, demonstrating that they were satisfied with this information. Alternatively, when an experimenter responded to infants’ pointing gestures with functions or no information, they produced additional communicative behaviors (e.g., vocalizations), demonstrating that they were not satisfied with these types of information. Importantly, infants only exhibited differential communicative persistence as a function of the information type presented if they first pointed to the object. If infants did not point toward an object prior to receiving information about it, they were equally satisfied with receiving that object’s function, label, or no information. Similarly, if infants did not spontaneously point prior to receiving information, they did not successfully learn that information.
Taken together, these findings demonstrate that infants’ pointing gestures are directly and uniquely related to their ability to map information onto objects. Importantly, infants’ pointing gestures signaled their readiness to learn across domains of information: they successfully mapped both labels and functions onto objects if they first pointed toward them. However, infants had a preference for receiving a specific type of information in response to their pointing gestures. Infants demonstrated more behavioral satisfaction when they pointed to an object and then received a label, compared to a function or no information, in response.

Nonhuman Primate Research

Summary: Chapter 4 (Ape Gaze). This study expanded on the human infant research by providing an evolutionary perspective on the role of nonverbal behaviors in shaping human communication. Rather than focusing on manual gestures, as in the human infant studies, this study assessed how nonhuman primates communicated with their eyes. Specifically, I examined nonhuman primates’ use and development of gaze alternations. Gaze alternations are virtually unstudied relative to nonhuman primates’ gestural communication, despite the fact that gaze alternations have a well-documented importance in human communicative development, are routinely used as a key operational feature of early joint attention, and are argued to scaffold the development of more complex social-cognitive skills, such as theory of mind and language (Bates, Camaioni, & Volterra, 1975; Bruner, 1982; Tomasello, 1995).
However, to make claims that infants’ gaze alternations are foundational to the development of uniquely human skills, it is necessary to assess the production and development of gaze alternations in nonhuman primates. This study examined developmental differences in gaze alternations in a large sample of bonobos (N = 17) and chimpanzees (N = 35) spanning a range of ages. Bonobos and chimpanzees were selected because together they provide the best representation of our last common ancestor, and also allow us to make important, but often overlooked, comparisons within great ape species. I assessed the flexibility of gaze alternations in bonobos and chimpanzees when they were requesting food from a human who was either visually attentive or visually inattentive.

Similar to human infants, both bonobos and chimpanzees produced gaze alternations, and did so more frequently when a human communicative partner was visually attentive. Both bonobos and chimpanzees thus take the attentional state of a communicative partner into consideration while gaze alternating. This suggests that, similar to human infant gaze alternations, ape gaze alternations may be a goal-directed behavior (Striano & Rochat, 2000). However unlike humans, who gaze alternate frequently from early in development, chimpanzees did not begin to gaze alternate frequently until adulthood. Bonobos, on the other hand, produced very few gaze alternations, regardless of age. Thus, it appears to be the early emergence of gaze alternations, as opposed to gaze alternations themselves, that might be uniquely human.
Cross-Cutting Themes and Implications

Three cross-cutting themes emerged from the research presented here: (1) nonverbal behaviors offer a unique window into communicative abilities when full-fledged language has yet to develop (i.e., during infancy), or is non-existent (i.e., in nonhuman primates), (2) studying nonverbal behaviors through a developmental lens offers a richer, more nuanced understanding of communicative abilities, and (3) individuals actively contribute to their communicative and learning experiences. In these next three sections, I address the implications from each theme.

Cross-Cutting Theme 1: Nonverbal Behaviors and Communication

Researchers have long contended that language begins (developmentally) and began (evolutionarily) with nonverbal behaviors. On a developmental timeline, researchers have documented that infants dive into language “hands first” (Bates et al., 1975) by communicating nonverbally months before producing spoken words. These early nonverbal behaviors serve as building blocks for language acquisition by helping infants transition to verbal communication (Iverson & Goldin-Meadow, 2005). For instance, infants point to convey information that they are not yet able to express in speech (Ozçalişkan & Goldin-Meadow, 2005). From an evolutionary perspective, researchers have

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1This is not to say that infants are unable to learn words prior to the development of nonverbal behaviors. Indeed, infants discriminate and perceive speech sounds as early as in utero (DeCasper & Spence, 1986; Mehler et al., 1988), and comprehend their first words by 6 months (Bergelson & Swingley, 2012; Tincoff & Jusczyk, 1999). This is only to say that nonverbal behaviors help in the process of getting infants to more advanced levels of language development.
provided compelling evidence that human language evolved out of a nonverbal system of communication (Corballis, 2002; Hewes, 1973) – as evidenced by the finding that nonhuman primates have more flexible and complex communication in the visual modality, as opposed to the auditory modality (e.g., Pollick & de Waal, 2007).

The developmental and evolutionary literatures collectively demonstrate that the study of nonverbal behaviors can provide important insights into how language emerges developmentally, and how the first forms of human language might have looked evolutionarily. Thus, each study in the current dissertation capitalized on the study of nonverbal communication to provide new and unique insights into the evolution and development of language.

**Nonverbal behaviors: nonhuman primates.** This dissertation provides some of the first comparative data on one understudied form of nonhuman primate nonverbal communication – gaze alternations. Research in this domain has traditionally focused on nonhuman primates’ manual or full-body gestures (Slocombe et al., 2011). However, in humans, gestures are not the only commonly used nonverbal behavior: the eyes are also an integral component of communication. Gaze alternations, or the ability to alternate gaze between an object of interest and another individual also attending to that object, is a particularly effective and commonly used form of nonverbal communication (Bates, Camaioni, & Volterra, 1975; Bruner, 1982; Tomasello, 1995).

Despite the well documented importance of gaze alternations in human
development, outside of the current dissertation, gaze alternations in nonhuman primates have been extremely understudied. The lack of research in this area is, in part, due to the fact that the white sclera of nonhuman primates is much less salient than that of humans’, which makes it difficult to capture and study their eye movements (Kobayashi & Koshima, 1997). This gap in the literature has left open important questions about the evolutionary origins of this ability. To fill this gap, I examined gaze alternations in bonobos and chimpanzees by strategically placing cameras directly in front of and below their faces. This camera angle, combined with detailed, slow-motion video coding allowed me to accurately and meticulously capture subtle shifts in individuals’ gaze.

In this study, both bonobos and chimpanzees produced gaze alternations. Similar to human infants, they did so more frequently when a communicative partner was visually attentive, as opposed to inattentive. However, unlike humans who begin producing gaze alternations very early on in development, individuals rarely produced gaze alternations (bonobos) or only frequently gaze alternated after reaching adulthood (chimpanzees). The human eye may be an especially useful for communication because its white sclera is much more salient than other species, making it easier for humans to detect shifts in other humans’ eye movements (Kobayashi & Koshima, 1997). Thus, it is not surprising that human infants, more so than other species, rely on their eyes as a primary means to communicate with others (Tomasello, Hare, Lehmann, & Call, 2007). By documenting the use and development of nonhuman primates’ gaze
alternations, this study filled a critical gap in the literature on nonhuman primates’ nonverbal communication.

**Nonverbal behaviors: human infants.** Compared to nonhuman primates, much more is known about the nonverbal communication of human infants. Research in this domain has documented the developmental time course of infants’ nonverbal behaviors, and described the relations between these behaviors and language development (e.g., vocabulary acquisition). However, prior to this dissertation, research had yet to fully explain the development of nonverbal behaviors and how they link to language development. Specifically, it remained unknown (1) whether nonverbal behaviors are directly related to infants’ ability to acquire various components of language, (2) how the link between nonverbal behaviors and language development changes over time, and (3) what drives infants to produce various nonverbal behaviors.

The current dissertation addressed these questions by exploring the importance of one salient nonverbal behavior: pointing. I found that pointing is directly and uniquely related to infants’ ability to map information onto objects. While previous work focused on the correlation between pointing gestures and vocabulary development, these studies are the first to show a direct relationship between pointing and fast mapping (i.e., in-lab learning). When infants point toward an object of interest, they are more likely to learn that object’s label or function compared to when they don’t first point to that object. Given that fast mapping is a critical component of word learning (Gershkoff-Stowe & Hahn,
2007), this finding brings us closer to understanding why infants’ early pointing gestures are so closely tied to their word learning and language development more broadly.

Why might infants’ pointing gestures signal a heightened readiness to map information onto objects? First, it is possible that infants pointed toward novel objects to obtain information about those objects. Prior research has demonstrated that a desire to obtain information is directly related to learning because it triggers a heightened state of preparedness to receive and subsequently process information (Gruber & Otten, 2010; Kang et al., 2009). Thus, because infants were requesting information in the moment they pointed, they were also best equipped to learn that information when it arrived. Alternatively, the physical act of pointing may have influenced infants’ ability to learn. Pointing toward an object may have honed in infants’ attention on that object, which would have then facilitated the subsequent processing of that object’s information. It is also possible that a combination of these mechanisms caused pointing to reflect a heightened readiness for learning. The design of the studies in this dissertation could not pinpoint a single mechanism that drove pointing to reflect enhanced learning. Additional research is needed to determine precisely why infants’ pointing gestures reflected a heightened readiness for learning.

These studies also contributed to our understanding of nonverbal behaviors and language development by highlighting that not all nonverbal
behaviors are created equal. In these studies, when an infant pointed toward an object, they learned that object’s label or function. However, when an infant produced another nonverbal behavior directed toward an object (e.g., a reaching gesture, a gaze alternation), they did not learn that object’s label or function. This suggests that the act of pointing, and/or what motivates infants in the moment they point toward an object, as opposed to general interest that can be accomplished through a variety of nonverbal behaviors, leads to enhanced fast mapping.

Findings also demonstrated that when infants pointed toward a novel object and an experimenter acknowledged the infants’ interest in that object without providing any information, or showing infants that object’s function, infants persisted in their communicative attempts – indicating that the communicative goal underlying their pointing gesture had not been met. Alternatively, when infants pointed toward an object and an experimenter provided that object’s label, infants ceased communicating – indicating that their communicative goal had been met. These findings suggest that infants’ pointing gestures may be specific requests for labels. Importantly, this pattern only emerged when infants pointed before they received information, suggesting that pointing gestures, but not other nonverbal behaviors, are requests for information.

In sum, the current dissertation capitalized on nonverbal behaviors as a way to study the communicative abilities of human and nonhuman primates. In
doing so, it provides new insights into how nonverbal behaviors transition into full-fledged language on both a developmental and evolutionary scale.

Cross-Cutting Theme 2: Insights from Development

Nonverbal behaviors offer one powerful way to gain unique insights into communicative abilities. An additional way to provide novel insights into communicative abilities is by examining them through a developmental lens. In this dissertation, in both the studies on human and nonhuman primates, key developmental differences in nonverbal behaviors emerged. In the human research, infants’ pointing gestures were only related to their learning at 18 months, but not earlier. In the nonhuman primate research, adults, but not younger individuals produced gaze alternations. Thus, across studies, if a developmental approach had not been used, key aspects of infants’ and nonhuman primates’ communicative behaviors would have been missed.

Insights from development: nonhuman primates. Detailing developmental changes in communicative behaviors is critical because it provides insights into the processes or mechanisms underlying these behaviors (West-Eberhard, 2003). For comparative psychology research, a developmental approach is critical because it allows for more direct comparisons with and inferences about human cognition and communication (Tinbergen, 1963). Despite the clear importance of conducting comparative psychology research with multiple age groups, much of the existing comparative psychology research has focused on a single age range (Anderson et al., 2007; Krause & Fouts, 1997;
Recall that in Chapter 4 (Ape Gaze), gaze alternations were only frequently produced by older chimpanzees. If only younger individuals were tested, it may have misleadingly appeared that gaze alternations are not a part of nonhuman primates’ communicative repertoire. Alternatively, if only older individuals were tested, it may have looked like gaze alternations are a routine part of their communicative repertoire, regardless of age and experience. Thus, if this study had not tested the development of gaze alternations, a critical part of the story would have been missing. That is, it is not gaze alternations themselves that are uniquely human, but rather their early emergence. This distinctive early emergence of gaze alternations in humans may be a critical underpinning for the development of uniquely human social-cognitive abilities, such as theory of mind and language. This finding echoes a recent shift in how biologists and psychologists view evolution: many, arguably most, important evolutionary changes are a product of alterations in developmental pathways (“Evo-Devo”; West-Eberhard, 2003).

**Insights from development: human infants.** In the studies on human nonverbal communication, developmental differences emerged once again. The studies in Chapter 2 (Point-to-Learn) assessed infants’ nonverbal communicative behaviors at two critical developmental milestones: (1) at 12 months, as infants are first beginning to produce words and pointing gestures and (2) at 18 months,
as infants’ vocabularies are rapidly expanding and have had months of experience pointing (Bates et al., 1975). The findings from these studies revealed that only 18-month-olds’ pointing gestures were directly related to their learning. More specifically, 18-month-olds, but not 12-month-olds, were significantly more likely to map a label to an object if they had first pointed to that object than if they had not first pointed to it.

One possible explanation for this developmental difference is that the infants at different ages were pointing for different reasons. Eighteen-month-olds, because they have had months of experience pointing and receiving information in response (Kishimoto et al., 2007; Wu & Gros-Louis, 2015), may have been pointing for an information-requesting motive. Alternatively, 12-month-olds, who are only beginning to point, may not accumulated enough communicative experiences (e.g., pointing and receiving information in response) to understand that information is reliably provided contingent on their pointing (Bates et al., 1975). Thus, these younger infants may not be pointing in information-requesting ways. If pointing reflects a readiness to learn because infants deployed their gestures with the goal of obtaining information, then it is not surprising that pointing would lead to successful learning for 18-month-olds, who are pointing in information-requesting ways, but would not lead to
successful learning for 12-month-olds, who may not yet be pointing in information-requesting ways.

The study in Chapter 3 (Point-for-Words), unlike those in Chapters 2 (Point-to-Learn) and 4 (Ape Gaze), was conducted with only one carefully selected age group: 18-month-olds. This age group was chosen because it represents a gap in our knowledge of the developmental trajectory of information gathering behaviors. The findings from Chapter 2 suggested that it is only by around 18 months that infants begin to point in an information-requesting way. After infants reach their second birthday, much is known about information-requesting behaviors, mostly in the form of question asking (Callanan & Oakes, 1992; Chouinard, 2007; Davis, 1932; Greif, Kemler Nelson, Keil, & Gutierrez, 2006). Thus, 18 months represents a critical gap in our knowledge in the nature of information-requesting behaviors.

The previous research conducted on young children’s information-requesting behaviors has focused on the type of information that young children want to receive after they ask questions. This research revealed that when children ask, “what’s that?” they want to know the object’s function (Nelson et al., 2004). The current research found that when young children are beginning to seek out information via pointing gestures, they are not requesting objects’

\[\text{It is important to note that the current findings can only provide only preliminary support this proposal, since the design could not directly measure the infants’ motives or goals in the moment they produced a pointing gesture. Additional explanations for the observed developmental difference in the relation between pointing and learning are considered in the discussion section of Chapter 2.}\]
functions. Rather, infants’ pointing gestures appear to be specific requests for labels. Although these contrasting findings cross methodologies, and therefore limit our ability to make direct comparisons, they point to meaningful developmental differences in the types of information infants and young children find most relevant and important.

These developmental differences in information-requesting behaviors are not surprising because they directly map on to children’s cognitive and linguistic development. Infants enter the “vocabulary burst” at 18 months and are rapidly adding new labels to their lexicon (Bloom, 1973; Nelson, 1973). Thus, it follows that they would actively prefer to receive labels over other types of information. Older children, alternatively, have already acquired the labels for many of the objects in their environment. These children may be shifting towards deeper, more explanatory investigations about objects (e.g., functions).

These developmental differences in preferences for labels and functions also correspond with caregivers’ responses to requests for information at different points in development (Chouinard, 2007). Prior to children’s second birthday, caregivers respond to information requests with labels more frequently than with functions. After children’s second birthday, caregivers switch strategies, and tend to respond to information requests with functions more frequently than labels. In sum, the research presented throughout this dissertation highlights the importance of assessing change over time.

Cross-Cutting Theme 3: The Active Child
A key objective of developmental science is to explain change over time. In other words, why and how do humans develop the way they do? Countless theories have been put forth to answer this question. The research presented in this dissertation drew on a variety of those theories, some of which include: The Active Child (Gopnik & Wellman, 2012; Piaget, 1954; Xu & Kushnir, 2012, 2013), Evo-Devo (West-Eberhard, 2003), Gestural Origins of Language (Corballis, 2002; Hewes, 1973), Natural Pedagogy (Csibra & Gergely, 2006, 2009; Gergely et al., 2007), and Cultural Learning (Tomasello, Kruger, & Ratner, 1993; Tomasello, 2016; Tomasello, Carpenter, Call, Behne, & Moll, 2005). In this section, I explore how one of these theoretical perspectives, The Active Child, impacted the development of the current dissertation. Specifically, I explain how this perspective shaped the research questions that motivated each study, and the ways in which each study were designed. I close this section by analyzing how the findings from each study contribute to and build on this theoretical perspective.

The Active Child: constructing knowledge through exploration. One of the founding ideas of modern developmental psychology, famously put forth by Piaget, is that children are active learners (Piaget, 1954). Piaget maintained that children do not passively absorb the information in their environment, but rather actively construct their learning experiences. When children reach gaps in their knowledge, or disequilibrium, they seek ways to fill those gaps. To do so, children engage with their environment in ways that directly contribute to and enhance
their learning. One common way children do this is by exploring and interacting with their surroundings in ways that help them construct their knowledge. For instance, a child will shake a rattle to understand its physical properties. These deliberate actions help children understand how the world around them works.

**The Active Child: constructing knowledge through question-asking.** Unfortunately, not everything that children need to learn can be acquired through exploration directly. Fortunately, however, both infants and older children understand that information can also be transmitted socially, and are highly motivated to access that information (Gergely et al., 2007; Homer & Tamis-Lemonda, 2013; Vaish et al., 2011). This social-information gathering has been studied extensively in older children (2-7 years). When older children reach a gap in their knowledge, they ask questions that are finely-tuned to resolve that gap (Chouinard, 2007; Davis, 1932; Nelson & O’Neil, 2005). This motivation to request information has long been regarded as a fundamental driving force of cognitive development and the acquisition of culture (Davis, 1932; Gopnik & Meltzoff, 1997).

**The Active Child: preverbal information-seeking.** Children’s questions afford them with an effective way to fill in gaps in their knowledge. But how do infants, who are unable to verbally request information, access information from others? One strategy infants use is to selectively attend to potential sources of information in their environment (Morton & Johnson, 1991; Vouloumanos & Werker, 2004). A robust and consistent finding supporting this claim is that
during ambiguous learning situations, infants will consult adults for information (Baldwin, 1991). For instance, when a referent of a spoken label is unclear, or when searching for a hidden object, infants will look to an adult’s gaze direction to assist them in locating the correct object (Baldwin, 1991; Goupil, Romand-Monnier, & Kouider, 2016; Vaish, Demir, & Baldwin, 2011).

Importantly, infants’ information-seeking is rather sophisticated. In other words, it is finely tuned to ensure the accurate transfer of information: infants will only seek out information in situations in which information transfer is both necessary and possible. For instance, infants only engage in information-seeking behaviors when they actually need information from adults – if infants already know the solution to a problem, they will attempt to solve that problem without referring to an adult for help (Goupil et al., 2016). Moreover, infants will preferentially seek out information from adults they know to be reliable (Tummeltshammer et al., 2014) and capable (Begus, Gliga, & Southgate, 2016). Together, these findings suggest that infants are highly motivated to engage with others in ways that optimize their potential for information gain. However, it is not until infants begin pointing that have access to a particularly effective means of requesting information from others.\(^3\)

**The Active Child: constructing knowledge through pointing.** Pointing gestures afford infants with an effective way of signaling adults’ attention and

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\(^3\) As stated earlier in this dissertation, pointing is not the first way infants can request information (infants can also request information by showing gestures, reaching, vocalizing), but pointing is the first way they can request information in a targeted and precise way.
eliciting information from them because they are clear and salient markers of their interest and attention (Southgate, van Maanen, & Csibra, 2007). Indeed, observational work has revealed that caregivers respond to infants’ pointing gestures, more often than other preverbal communicative behaviors, with information (Kishimoto et al., 2007; Wu & Gros-Louis, 2015). Recent experimental work has provided evidence that infants’ pointing gestures do not only happen to elicit information from others. Instead, this process may be more active: infants have been shown to point with the specific goal of obtaining information from others. For instance, infants are more likely to point for communicative partners they know to be knowledgeable (i.e., individuals they have previously seen correctly label a familiar object), than for communicative partners they know to be ignorant (i.e., individuals they have previously seen incorrectly label a familiar object; Begus & Southgate, 2012). Infants are also more likely to point for communicative partners that tend to respond to their pointing gestures with informing behaviors (i.e., providing emotional information about objects), rather than with non-informing behavior (i.e., sharing attention around objects; Kovács et al., 2014). Together, these findings provide compelling evidence that infants point to obtain information from others.

The current dissertation builds on the proposal that infants’ pointing gestures serve as a way for them to actively construct their knowledge. Findings from the human infant studies revealed that, because pointing gestures are explicit requests for information, they reflected a heightened readiness to learn.
When infants point toward a novel object, they are more successful at learning that object’s label than when they don’t point toward that object (i.e., when they reach or just look toward that object). Pointing facilitates learning because it allows infants to receive information at a time when they are most receptive to it (i.e., when they are actively requesting it). These findings also provide the first insights into the type of information infants are requesting with their pointing gestures. Previous research had demonstrated that young children’s verbal requests for information about objects are requests for functions of objects (Nelson et al., 2004). Yet, prior to this dissertation, it remained unknown what type of information infants prefer when they request information earlier in development, by pointing. The current findings revealed that at 18 months, infants pointing gestures are specific requests for labels. This finding is directly in line with infants’ existing cognitive structures and development: 18 months represents a point in development when labels are particularly important sources of information (L. Bloom, 1973). Thus, these findings reveal, for the first time, infants make requests that are tailored to their developing cognitive abilities.

**The Active Child: a place for nonhuman primates?** The final study presented in this dissertation was conducted with nonhuman primates, making it difficult to draw direct comparisons to The Active Child theoretical perspective (Piaget, 1954; Xu & Kushnir, 2012). However, there is still an important connection to be made. More specifically, this study highlighted that nonhuman primates, across species, are actively engaged in their communicative
interactions. In this study, both bonobos and chimpanzees produced gaze alternations, and did so more frequently when a human communicative partner was visually attentive than visually inattentive. If individuals had been producing gaze alternations passively, without taking the attentional and/or mental states of their communicative partner into consideration, there would not have been differential production of gaze alternations as a function of their communicative partner’s attentional state.

**Open Questions and Future Directions**

The studies presented in the current dissertation advance our understanding of the relation between nonverbal behaviors and the origins of language. At the same time, these studies also generated new research questions. In this final section, I address open questions that emerged from all of the studies more broadly, and address ways in which future research may be able to answer these questions.

**Pointing Gestures and Human Uniqueness**

The current dissertation aimed to provide new insights into human-uniqueness by investigating the origins and development of language. Since infants’ pointing gestures are one of the very first ways they are able to communicate with others, the studies presented here examined the ways in which pointing gestures influence language acquisition. These studies tested the relation between infants’ pointing gestures and their fast mapping abilities. However, fast mapping is only one small part of word learning, and word
learning itself is only one component of language acquisition. Children must not only retain the meaning of new words across time and contexts, but also learn how to put those words together to create meaningful sentences.

A challenge for future research will be to investigate the relation between pointing and other essential components of language acquisition. A study could accomplish this by examining the extent to which infants’ pointing gestures signal a heightened readiness to learn more complex features of language. For instance, research could test whether pointing reflects a heightened readiness to also learn “harder words”, or words that characterize events, properties, or relations (i.e., not just concrete nouns, as the current studies tested; Gentner, 2006; Gleitman, Caddisy, Nappa, Papafragou, & Trueswell, 2005). Relatedly, research could examine whether pointing also signals a learner’s readiness to acquire new morphological or syntactic rules. Findings from these types of studies would build on the current work by providing a more complete explanation of the relation between pointing and language acquisition.

Just as fast mapping is only one part of language acquisition, language is only one part of what makes humans unique. Tomasello (2003; 2006; 2008) has repeatedly stressed that looking at language as the defining feature of human uniqueness is akin to looking at skyscrapers in trying to understand why humans make tall buildings. To truly understand the link between pointing and human uniqueness, researchers must study the many facets of human socio-cognitive abilities that are not seen in nonhuman animals (e.g., theory of mind,
cultural learning; Tomasello et al., 1993). Future research could investigate this issue by testing the role that pointing plays, if any, in the acquisition of other uniquely human abilities. More specifically, a study could test whether infants’ pointing gestures also reflect a heightened readiness to acquire advanced social-cognitive skills (e.g., components of false belief understanding). Since pointing requires some level of “mindreading” or perspective taking (Tomasello et al., 2007), it may be that pointing prepares infants, or signals that they have a heightened preparedness, to acquire more advanced social-cognitive skills. Indeed, pointing is not only correlated with infants’ vocabulary development, but it is also correlated with infants’ emerging social-cognitive abilities (e.g., attention following; Carpenter et al., 1998). Thus, it is likely that there may also be a direct link between pointing and the acquisition of social-cognitive skills. Findings from research like this would expand on the current research by demonstrating that pointing is not only directly and related to the learning of conceptual information (i.e., labels and functions), but they also contribute to the development of other skills that are uniquely human.

Participant Diversity

One powerful tactic that psychologists can use to identify uniquely human abilities is to measure the extent to which these abilities are present across cultures. The studies presented in the current dissertation are unable to speak to uniquely human trends because they focused on a select group of subjects. In the infant studies, participants were primarily from WEIRD backgrounds (i.e.,
Western, Educated, Industrialized, Rich and Democratic; Henrich, Heine, & Norenzayan, 2010). This lack of participant diversity also limits the extent to which these findings can be generalized. Specifically, the current findings that infants point to request information may be a direct result of the culture-specific socialization experiences that occur when infants point. Caregivers from predominately WEIRD backgrounds socialize and communicate with their infants differently than caregivers from non-WEIRD backgrounds (Tamis-LeMonda, Song, Leavell, Kahana-Kalman, & Yoshikawa, 2012). In WEIRD societies, caregivers respond to their infants’ pointing gestures by providing information for pointed-to objects (Wu & Gros-Louis, 2015). Thus, it is not surprising that infants from these families would point for information-requesting reasons.

Although research has established that infants from non-WEIRD societies point (Callaghan et al., 2011; Liszkowski et al., 2012), we currently know very little about the motives underlying their pointing gestures. Future research can fill in this gap by replicating the current research with infants from non-WEIRD societies. Specifically, future research can test whether these infants’ pointing gestures also reflect a heightened readiness for learning, and if their points are also driven by an information-requesting motive. Findings from these types of study will build on the current dissertation by revealing the extent to which the pointing-learning link, and pointing with an information-requesting motive, is universal.
To better understand cross-cultural similarities, or differences, in pointing, future work can also assess how caregivers from non-WEIRD societies respond to their infants’ pointing gestures. More specifically, future research can use observational techniques to test whether caregivers from non-WEIRD societies systematically respond to their infants’ pointing gestures with information, as caregivers in WEIRD societies do. If caregivers from non-WEIRD societies similarly respond to their infants’ pointing gestures with information, it will be important to investigate what type of information they provide their infant with. This will reveal whether there are cultural differences in the value placed on differences forms of information, which may map on to children’s preference for and ability to learn different types of information.

Cross-cultural research on infants’ pointing gestures, and specifically on the early socialization experiences that surround those gestures, has the potential to build on the current dissertation by illuminating why infants point to request information. For instance, if caregivers from non-WEIRD societies don’t respond to their infants’ points by providing information, and infants’ points are not produced for information-requesting motives, it would suggest that pointing with an information-requesting motive is socially-mediated by experiences that promote this type of pointing.

**Experimental vs. Naturalistic Settings**

The studies presented in the current dissertation not only relied on a select group of participants, but also relied on a select context. More specifically, each
study presented in the current dissertation was conducted in a tightly controlled laboratory environment. However, as Thelen and Smith (1996) famously articulated, “real infants live and develop in a world filled with people, things, and events in continuous interaction” (p. xii). This begs the question: would the same results have been found if this study had been conducted in infants’ “real world”?

Infants’ everyday word learning experiences are messy: at any given moment, infants are hearing long streams of speech, often from multiple individuals concurrently. Infants’ visual field is also complex: they are typically surrounded by many different objects and individuals. For an infant to successfully map a label onto an object in this kind of dynamic environment, they must overcome several challenges. First, they must extract the relevant word from the many sounds they are hearing. Next, they must select the correct referent of that word from the many objects in their surroundings.

Not surprisingly, a laboratory setting makes the task of word learning markedly easier. When an infant learns a new word in a controlled laboratory environment, their word learning space is highly constrained: there are typically only a few objects and a few words they must choose from to successfully form their word-object mapping. In the current dissertation, infants’ pointing gestures signaled a heightened readiness to learn in this type of controlled laboratory setting, leaving open an important question: would infants’ pointing gestures also reflect a heightened readiness for learning in a more naturalistic setting?
To answer this question, future research could examine the link between pointing and learning in infants’ home environment during a naturalistic parent-child interaction. Specifically, a study could test whether infants are more likely to retain information when they spontaneously point and caregivers provide information, compared to when they express interest in objects but don’t point (e.g., by looking or reaching toward them) and caregivers provide information. If the effect of pointing on learning transfers to a more challenging learning context, it would build on the research in the current dissertation by demonstrating that the link between pointing and learning is not fragile, but strong and present across contexts.

Similar to the research on human infants, the study on nonhuman primates’ gaze alternations was also conducted in a tightly controlled laboratory setting. Moreover, this study tested nonhuman primates’ gaze alternations with human, instead of conspecific, communicative partners. These constraints leave open questions as to whether similar patterns of gaze alternations would emerge in individuals’ natural environment and/or with conspecific communicative partners. There may be something about a cage, and/or interacting with human experimenters, that lends itself to increased or decreased production of gaze alternations. This is important because studies of animal cognition often find that small changes to a study’s design can reveal drastic differences in the underlying abilities those studies are attempting to measure (e.g., Hare, Call, Agnetta, & Tomasello, 2000; Krupenye, Kano, Hirata, Call, & Tomasello, 2016).
One way that future research could probe this issue is by investigating nonhuman primates’ production and development of gaze alternations in a more ecologically valid context, such as in their natural habitat and/or with conspecifics. In the current study, bonobos and chimpanzees were assessed on their ability to gaze alternate when there was an explicit reward (food) involved. However, human infants spontaneously gaze alternate when there is no explicit reward involved. Thus, by assessing bonobos’ and chimpanzees’ gaze alternations in their natural habitats and with conspecifics, we can determine whether they also gaze alternate when there is no explicit reward involved, such as during play activities.

In sum, by testing whether the current findings extend to different groups, domains, and contexts, we will be better equipped to formulate hypotheses with more clarity about the link between nonverbal behaviors and the origins and development of language.

Conclusion

Language is a uniquely human achievement. The “royal road to language” is often argued to be paved by nonverbal behaviors (Butterworth, 2003; Corballis, 2003; Goldin-Meadow, 2007; Liebal & Call, 2012; Tomasello, Carpenter, & Liszkowski, 2007). The studies presented in the current dissertation build on this proposal. By integrating experimental evidence from both humans and nonhuman primates, the studies presented here illuminate the importance of nonverbal behaviors in the origins and development of language.
Appendix A

This appendix reports supplementary analyses from Chapter 2.

Pointing and Gaze Alternations

Of additional interest was whether infants’ pointing gestures were more likely to reflect an optimal state for fast mapping if points were produced while infants alternated their gaze between the object of interest and the experimenter (i.e., Point + Gaze Alternation), compared to if infants fixated their attention solely on the object of interest, without looking back at the experiment (i.e., Point only). To test this question, we used a generalized linear mixed model to test whether 18-month-olds in Study 1 were more likely to look to the target object during test if they had first pointed and gazed alternated, compared to if they had only pointed towards the object without gaze alternating. This analysis was conducted with data from the 18-month-olds in Study 1, since this was the only group in which pointing led to successful fast mapping. Moreover, this analysis only included trials in which infants pointed. Consistent with the analyses reported in the manuscript, fixed effects included: MCDI score, trial number, and gaze alternating (i.e., yes vs. no); random effect: infants’ ID; dependent variable: look at target during Test (i.e., yes vs. no). The findings revealed that infants were not significantly more likely to look at the target object during test if they had first pointed towards the target object while gaze alternating ($M = .81, \ SE = .10$, number of trials $= 15$), compared to if they had first pointed towards the target object without gaze alternating ($M = .64, \ SE = .11, n = 19$; point with gaze...
alternation vs. point without gaze alternation: $Z = .41, p = .68$). See Figure 15A. Since these groups did not significantly differ from each other, all analyses in the manuscript have combined pointing with a gaze alternation and pointing without a gaze alternation into one group.

![Proportion of Target Looks](image)

**Figure 16A**: Proportion of Target Looks during Test based on Pointing + GA vs. Pointing without GA during the Choice Phase.

**Controlling for Baseline Looking Preferences During the Test Phase**

To assess baseline preferences for the target and non-target objects, binomial tests of proportion against chance on infants’ looking behavior (i.e., looks to the target compared to looks to the non-target object) during the Pre-Word Test Phase were conducted. The Pre-Word Test Phase was comprised of first part of the Test Phase, prior to the onset of the target label, while both the target and non-target object were in the infants’ view (i.e., the first 2,400 ms of the 161
Test Phase). This tested whether infants’ increased looking time during the Post-
Word Test Phase was due to initial salience of and preference for the target object
or due to true fast mapping. If infants simply prefer to look at the target object,
then they should look at the target object at rates above chance before they hear
the target label, during the Pre-Word Test Phase. If infants truly fast mapped the
label onto the target object, then their looking toward the target object should be
at chance during the Pre-Word Test Phase, but not during the Post-Word Test
Phase. The time course of infants’ looking towards the target object is portrayed in
Figure 16A.

**Expressions of Preference Models.** Twelve-month-olds in Study 1 were
not more likely to look at the target or non-target object during the Pre-Word
Test Phase, regardless of how they expressed their preference for objects during
the Choice Phase (point: $M = .55, SE = .10, Z = .51, p = .61, 95\% CI = .34 - .74$;
reach: $M = .40, SE = .08, Z = 1.25, p = .21, 95\% CI = .25 - .57$; look: $M = .51, SE = .08,$
$Z = .13, p = .90, 95\% CI = .35 - .67$). Eighteen-month-olds in Study 1 were not
more likely to look at the target or non-target object during the Pre-Word Test
Phase, regardless of how they engaged in joint attention around the objects
during the Choice Phase (point: $M = .56, SE = .07, 95\% CI = .38 - .73, Z = .70, p = .48$;
reach: $M = .54, SE = .11, 95\% CI = .32 - .75, Z = .38, p = .71$; look: $M = .50, SE = .07, 95\% CI = .36 - .64, Z = .00, p = 1.00$). Eighteen-month-olds in Study 2 were not
more likely to look at the target or non-target object during the Pre-Word Test
Phase, regardless of how they engaged in joint attention around the objects
during the Choice Phase (point: $M = .53$, $SE = .08$, $Z = .38$, $p = .70$, 95% CI = .37 - .69; reach: $M = .32$, $SE = .10$, $Z = 1.76$, $p = .08$, 95% CI = .15 - .54; look: $M = .46$, $SE = .08$, $Z = .38$, $p = .71$, 95% CI = .31 - .63).

**Engagement in Joint Attention Models.** Twelve-month-olds in Study 1 did not have an initial preference for looking at the target or non-target object during the Pre-Word Test Phase, regardless of how they engaged in joint attention around the objects during the Choice Phase (point: $M = .55$, $SE = .10$, $Z = .51$, $p = .61$, 95% CI = .34 - .74; gaze alternate without a gesture: $M = .51$, $SE = .10$, $Z = .10$, $p = .92$, 95% CI = .30 - .72; no joint attention: $M = .44$, $SE = .07$, $Z = .91$, $p = .36$, 95% CI = .31 - .58). Eighteen-month-olds in Study 1 did not have an initial preference for looking at the target or non-target object during the Pre-Word Test Phase, regardless of how they engaged in joint attention around the objects during the Choice Phase (point: $M = .56$, $SE = .09$, 95% CI = .38 - .73, $Z = .70$, $p = .48$; gaze alternate without a gesture: $M = .52$, $SE = .09$, 95% CI = .34 - .70, $Z = .23$, $p = .82$; no joint attention: $M = .51$, $SE = .08$, 95% CI = .35 - .67, $Z = .13$, $p = .90$). Eighteen-month-olds in Study 2 did not have an initial preference for looking at the target or non-target object during the Pre-Word Test Phase, regardless of how they engaged in joint attention around the objects during the Choice Phase (point: $M = .53$, $SE = .08$, $Z = .38$, $p = .70$, 95% CI = .37 - .69; gaze alternate without gesturing: $M = .48$, $SE = .09$, $Z = .23$, $p = .82$, 95% CI = .30 - .66; no joint attention: $M = .33$, $SE = .09$, $Z = 1.86$, $p = .06$, 95% CI = .17 - .52).
Figure 17A: Time Course of Infants’ (18-month-olds, Study 1) Looking Behavior during Test based on Choice Phase Communicative Behavior (point vs. no point) *p < .05

"Where is the Blicket? See the Blicket? Find the Blicket!"
Appendix B

This appendix reports supplementary analyses from Chapter 3.

Choice Phase Behaviors: Additional Analyses

In Chapter 3 (Point-for-Words), infants spontaneously altered the type of communicative behaviors they produced across the nine choice phases of the experiment (i.e., point vs. reach vs. look). Only 33% of infants produced the same behavior across all of their choice phases. Thus, we were interested in assessing the types of switches that infants made, and exploring why those switches may have occurred. There were seven different types of behavioral combinations, or “gesture profiles”, infants could have made: point only (8% of infants), look only (25%), reach only (0%), point + reach (11%), point + look (19%), reach + look (14%), point-reach-look (22%). The percentage of infants (represented by triangle area size) that produced each gesture profile is presented in Figure 17B.

![Figure 18B. Proportion of Infants Producing Each Type of Gesture Profile.](image-url)
The next set of analyses tested whether infants in different gesture profile groups differed in any systematic ways. A one-way ANOVA, with gesture profile as a between-subject variable, revealed that the average productive MCDI score did not differ significantly across the six gesture profile groups, $F(5, 30) = .10, p = .99$ (see Figure 18A; dashed horizontal line represents mean MCDI score across all participants).

![Figure 19B. Violin Plot of Infants' MCDI Scores based on Gesture Profiles.](image)

An additional one-way ANOVA with gesture profile as a between-subject variable revealed that the average fast mapping score (i.e., difference score) across the experiment did not differ significantly across the six gesture profile groups, $F(5,28) = .22, p = .95$ (see Figure 19B). Difference scores greater than zero indicate successful fast mapping. Together, these findings rule out the possibility that any “pointing advantage” seen during our task is not due to infants who point more often either (1) having more advanced linguistic abilities or (2)
generating higher fast mapping scores than infants who point less often. Rather, it is the act of pointing within the task that drives fast mapping success.

Figure 20B. Violin plot of Infants’ Average Fast Mapping Scores based on Gesture Profiles.

Persistence Behaviors during Training: Additional Analyses

Types of Persistence Behaviors

Chapter 3 presented infants’ persistence behaviors as a function of the type of gesture they produced prior to receiving information, and the type of information they received in response. However, not all persistence behaviors are created equal. When infants persist in their communicative attempts, they can do one of two things. Most simply, infants can continue to produce the same behavior they initially produced (i.e., “repetitions”). Alternatively, if infants are aware that their initial communicative behavior was not effective in eliciting a desired response, they can switch strategies and produce new, different communicative behaviors (i.e., “augments”). Thus, these next analyses test whether the results found in Chapter 3 were driven by persisting in the form of
“repetitions” or “augments” during training. Since it is not possible to measure repetitions with infants’ looking behaviors, since they never produced an initial behavior, we can only assess infants’ augments during look trials.

Infants produced a total of 281 additional communicative behaviors across all training phases of the experiment\(^1\). Of these, 79% were augments and 21% were repetitions. See Figure 20B (The area of each triangle is proportional to the number of the number of trials in which each behavior was observed).

![Figure 21B](image)

**Figure 21B. Frequency of Different Types of Additional Communicative Behaviors Produced During Training, based on Choice Phase Behavior (point vs. reach) and Persistence Type (augment vs. repetition).**

Of primary interest was whether infants’ persistence behaviors during training varied as function of whether those behaviors were repetitions or augmentations. To test this question, we ran two regression models: one with the number of repetitions produced during the training as the dependent variable

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\(^1\) This does not include the 240 additional communicative behaviors that were produced during “look” trials.
and the second with the number of augments produced during the training phase as the dependent variable. These count data were analyzed by fitting a generalized linear mixed-effects model with a Poisson distribution using a log-link function. Fixed effect predictors included infants’ initial communicative behavior during the choice phase (point vs. reach), information type (function vs. label vs. no information), the interaction between initial communicative behavior and information type, and sex. Infants’ ID was included in the model as a random effect to account for repeated observations of infants across nine trials. We controlled for infants’ pre-existing vocabulary size and fatigue in later trials by including productive MCDI scores and trial number (1-9) in the model. When examining infants’ repetitions of their initial communicative behavior as the dependent variable, no significant main effects or interactions emerged, for both point and reach trials (all p’s > .05, see Figure 21B).

![Figure 22B](image)

**Figure 22B. The Average Number of Repetitions Produced during Training as a Function of Information and Gesture Type.**

Alternatively, when examining infants’ augmentations as the dependent variable, a significant interaction between gesture and information type emerged
Rather, the effect of information type on the number of augments produced during training varied as a function of the initial gesture infants had produced during the choice phase. To probe this interaction, we tested the main effect of information type on augments within each initial gesture type. When infants first pointed, they were less likely to augment their behaviors with new communicative behavior when they got labels ($M = .96; SE = .30$), compared to when they were given functions ($M = 2.19, SE = .59; Z = 3.46, p = .0005$) or no information ($M = .42, SE = .42; Z = 3.82, p = .0001$). When infants first reached towards objects, they were equally likely to augment when they got labels ($M = 1.67; SE = .24$), compared to when they were given functions ($M = 1.43, SE = .53$) or no information ($M = 2.42, SE = .48; all p's > .05$). See Figure 22B.

![Figure 23B. The Average Number of Augments Produced during Training as a Function of Information and Gesture Type.](image)

**Power Analysis of Findings During “Point Trials”**

During point trials (i.e., trials in which infants pointed during the choice phase), the type of information presented during training (i.e., label, function, no-information) significantly predicted the number of persistence behaviors infants...
produced. Alternatively, during reach trials (i.e., trials in which infants reached during the choice phase), the type of information presented during training (i.e., label, function, no-information) did not significantly predict the number of persistence behaviors infants produced. One possible explanation for the null findings in the reach trials is that there were a smaller number of trials when infants reached ($n = 47$) compared to when infants pointed ($n = 75$). This may have reduced our power to detect a true effect during reach trials that was at least as strong as the effect detected in the trials when infants pointed.

To test this hypothesis, we conducted 1,000 iterations in which we randomly subsampled the point trial data to the same sample size as the reach trial data ($n = 47$; note that this technique is commonly used, e.g., Bertrand, Duflo, & Mullainathan, 2004; Johnson & Creech, 1983; Wisz et al., 2008)). For each subsample iteration that was generated, the number of times infants produced persistence behaviors during the training phase was modeled as a function of the following fixed effects: MCDI scores, trial number, and information type (function vs. label vs. no information). Infants’ ID was included in the model as a random effect. Our analyses show that we had high power to detect a significant ($p < 0.05$) effect of the predictor variable information type even at a sample size of $n = 47$ (90.5% power for label vs. no-info; 79.7% power for labels vs. functions; Figure 23B). This analysis demonstrates that the null findings during reach trials are likely not a function of a small sample size, and
that a sample size of 47 is sufficient to detect an effect that at least as strong as the effect detected in the point trials.

![Distribution of Z Scores](image)

Figure 24B. Distribution of Z Scores for 1,000 subsample iterations of “point trials” comparing Label Trials to No Information (A) and Function Trials (B).

In Figure 23B, solid vertical lines represent observed z-scores from the full point trial model \( (n = 75) \), and the red dashed vertical line represents a z-score of 1.96 (anything greater than 1.96 is significant a p-value < 0.05). With the same sample size as our reach trial \( (n = 47) \) we had 90.4% power to detect an effect of label vs. no information (904/1000 iterations had \( p < 0.05 \)) and 79.7% power to detect an effect of label vs. function (797/1000 iterations had \( p < 0.05 \)).

**Test Phase Behaviors: Additional Analyses**

Infants’ fast mapping performance during the Test Phase was operationalized by a positive difference score. Difference scores were calculated by subtracting the amount of time infants spent looking towards the target object during the baseline window of the test phase (i.e., pre-presentation of target information) from the amount of time infants’ spent looking towards the target...
object during the critical window test phase (post-presentation of target information). However, difference scores can be misleading. For instance, a difference score of 0% could indicate 0% looking at the target object during the baseline window, and 0% looking at the target object during the critical window. Alternatively, a difference score of 0% could result from 100% looking at the target object during the baseline window, and 100% looking at the target object during the critical window. In Figure 24A, I visualize how difference scores were calculated across information types (functions vs. labels) and infants’ choice phase behaviors (look, point, reach).

<table>
<thead>
<tr>
<th></th>
<th>Function</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportion of Looking Time Towards Target</td>
<td>look</td>
<td>point</td>
</tr>
<tr>
<td>Pre</td>
<td>Post</td>
<td>Difference</td>
</tr>
<tr>
<td>0.00</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>0.00</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>0.00</td>
<td>0.25</td>
<td>0.50</td>
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</table>

**Figure 25A.** Infants' Difference Score Calculations During Test as a Function of Baseline (pre-information) and Critical Window (post-information) Looks to Target.
Appendix C

This appendix reports supplementary analyses from Chapter 4

Controlling for Time Spent Disengaged

Results from the study presented in Chapter 4 revealed that chimpanzees were significantly more likely to gaze alternate than bonobos. We also found that older individuals were more likely to gaze alternate than younger individuals. There are two possible explanations for these findings. One possible explanation is that chimpanzees and older individuals produce more gaze alternations than bonobos and younger individuals. Alternatively, these groups may gaze alternate at similar rates, but the species and age differences detected here were artifacts of the design of the study. In other words, chimpanzees and older individuals may have simply been more engaged with the task and experimenter than bonobos and younger individuals, which is why we were able to detect more gaze alternations in chimpanzees and older individuals.

To test this hypothesis, we ran a generalized linear mixed model with the amount of time (in ms) individuals spent disengaged from the experimenter during the task was the dependent variable, fit with a Poisson distribution function. Fixed effects included subject’s age, gender, species, trial type (experimenter attentive vs. inattentive), and all interaction terms. A significant main effect of age emerged, such that individuals became less likely to spend time disengaged with age ($Z = -3.85, p < .0001$; Figure 25C).
Although there was a main effect of species, such that bonobos spent 14.5 s ($SE = 3.6$) disengaged and chimpanzees spent 7.7 s ($SE = 1.9$) disengaged, this main effect was qualified by a significant species by trial type interaction. The amount of time spent disengaged during each trial type varied as a function of species ($Z = -160.32, p < .0001$). To probe this interaction, we tested the effect of trial type on time spent disengaged within each species. Chimpanzees spent more time disengaged during experimenter inattentive trials ($M = 5.3, SE = .69$), compared to experimenter attentive trials ($M = 2.3, SE = .68; Z = -193.50, p < .0001$). Bonobos, alternatively, spent more time disengaged during experimenter attentive trials ($M = 7.5, SE = 1.4$), compared to experimenter inattentive trials ($M = 7.1, SE = 1.9; Z = 15.16, p < .0001$). See Figure 26C.

Figure 26C. Scatter Plot Displaying the Significant Relation between Age and Time Spent Disengaged.
There was also a significant main effect of sex, such that females (\(M = 12.6\) seconds, \(SE = 2.5\)) spent more time disengaged than males (\(M = 8.5, SE = 2.8; Z = -3.85, p < .0001\)). However, this main effect was qualified by a significant species by age interaction (\(Z = -160.32, p < .0001\)). To probe this interaction, we tested the effect of sex on time spent disengaged within each species. Female bonobos spent significantly more time disengaged than male bonobos (\(M_{\text{females}} = 22.56, SE = 4.27; M_{\text{males}} = 8.67, SE = 5.01; Z = -279.4, p < .0001\)). Alternatively, male chimpanzees spent significantly more time disengaged than female chimpanzees. (\(M_{\text{females}} = 7.10, SE = 2.23; M_{\text{males}} = 8.23, SE = 3.07; Z = 41.97, p < .0001\)). See Figure 27C.
Supplemental Coding: Multimodal Signaling

The study presented in Chapter 4 assessed nonhuman primates’ production and development of gaze alternations. However, gaze alternations are not the only nonverbal behavior that nonhuman primates produce. Bonobos and chimpanzees will frequently communicate with vocalizations, and also with visual gestures. While much is known about how bonobos and chimpanzees use vocalizations and gestures independently, far less work has investigated how they combine vocalizations and gestures to create multimodal signals (Slocombe et al., 2011).

The lack of research on multimodal communication in nonhuman primates is surprising because it is a fundamental part of human communication. Human communication is inherently multimodal; humans routinely produce
visual gestures alongside spoken communication (Goldin-Meadow, 1999; Kendon, 2004; McNeil, 2000). Visual gestures are an important component of spoken communication because they convey information that is not available verbally. For instance, when describing the physical features of an object, speakers will often use their gestures to portray important visual features that cannot be directly captured in speech.

In human development, multimodal communication both precedes and predicts young children’s early language skills (e.g., syntactic skills – the ability to combine multiple words together; Iverson & Fagan, 2004). For instance, young children will often point towards a doll while simultaneously saying “sleep” to represent the meaning “the doll is sleeping”. This ability to combine meanings across modalities demonstrates young children’s emerging ability to represent and combine multiple sources of information, while also reflecting their ability to communicate with others in increasingly complex ways (Iverson & Fagan, 2004).

However, just because multimodal signaling is an effective way for humans to communicate, does not necessarily mean that is also an effective way for nonhuman primates to communicate. In fact, recent research suggests it may not be. When chimpanzees and bonobos produce multimodal signals they are not more likely to elicit a desired response from a communicative partner than when they use a unimodal signal alone (i.e., gestures or vocalizations alone; Genty, Clay, Hobaiter, & Zuberbühler, 2014; Hobaiter & Byrne, 2011). In this study, researchers also found that younger individuals were more likely to combine
signals than older individuals. These findings led the researchers to conclude that multimodal signaling is a “fail-safe” strategy. Early in life, individuals will produce a wide, diverse repertoire of communicative signals, often simultaneously. This is likely because individuals are not sure which of those signals will elicit the desired response. Across development, after individuals gain increased experience navigating communicative interactions, they acquire an understanding of which signals will be the most effective, and use those alone (Hobaiter & Byrne, 2011a).

Although research has begun to examine multimodal communication in nonhuman primates, important questions remain. Specifically, research has yet to conduct large scale, cross-species comparative and developmental studies on nonhuman primates’ production of multimodal signaling. Moreover, questions remain as to the context in which multimodal signals are used – are individuals more likely to produce multimodal signals when a communicative partner is visually attentive, as opposed to inattentive? Answering these questions has the potential to provide important insights into the evolutionary origins of multimodal signaling.

Given that nonhuman primates’ multimodal signaling appears to be an ineffective form of communication, I hypothesized that production of multimodal signaling would decrease across development, with younger individuals producing more multimodal signals than older individuals. I also hypothesized that production of multimodal signaling would not vary as a
function of the attentional state of the experimenter. This is because unlike gaze alternations, which are only effective if a communicative partner is visually attentive, multimodal signaling is equally effective whether a communicative partner is attentive, as opposed to inattentive.

**Multimodal Signaling Coding Scheme**

The procedure, stimuli, and subjects were the exact same as the study presented in Chapter 4. Just as in Chapter 4, bonobos and chimpanzees were tested individually in a food-requesting task. However, rather than coding Gaze Alternations, we coded the type and frequency of visual and auditory signals (see Table 9C). This coding scheme was based on prior research (Goodall, 1986; Leavens & Hopkins, 1998; Katja Liebal, Call, et al., 2004; Pollick & de Waal, 2007; Tomasello & Call, 2007). Signals were considered “multimodal” if an auditory and visual signal occurred within 5s of each other. Behaviors were coded as “Visual Signals” if they were motions that were not related to locomotion or any other apparently goal-directed behavior. “Auditory Signals” were any sounds that the individual produced with either mouth or body.

Twenty percent of all videos were re-coded by an independent coder to establish good inter-rater reliability (Cohen’s Kappa, Visual Signals = .66; Cohen’s Kappa, Auditory Signals = .62; Landis & Koch, 1977).
A generalized linear mixed model, fit with a Poisson distribution, tested whether the frequency of multimodal signals produced across trials varied as a function of species, age, and trial type, and whether there were significant interactions between these variables [Model: Frequency of Multimodal Signals ~ Species*Age*TrialType + (1|subject)]. No significant interactions emerged. There was

<table>
<thead>
<tr>
<th>Auditory Signals</th>
<th>Visual Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Bark (bk): Loud dog bark</td>
<td>• Wiggle (w): Subject spastically wiggles or rapidly moves part of body (e.g. arms, legs, head).</td>
</tr>
<tr>
<td>• Grunt (g): Low, short grunting sounds</td>
<td>• Bouncing (b): Rapid up and down movement of the body at least two times (e.g. up-down-up-down)</td>
</tr>
<tr>
<td>• Slurping (sl): Sucking, slurping sound</td>
<td>• Spinning (sp): Subject makes at least two 360 degree rotations</td>
</tr>
<tr>
<td>• Raspberry (r): Produced by expelling air forcefully through closed, somewhat protruded lips (bilabial fricative).</td>
<td>• Genital offer (go): Male leans back and presents its genital; female presents her swelling</td>
</tr>
<tr>
<td>• Pant hoot (ph): Starts with a series of low-pitched, moderately loud calls and gradually increases in amplitude. During initial hoots lips are strongly pursed (as in an “o” shape) but at end mouth may be open slightly more widely.</td>
<td>• Arm gesture (ag): Subject reaches arm or any part of hand through cage but does not touch anything (i.e., the table or barrier). Any time the subject reaches their hand outside the enclosure and touches something, that instance of reaching arm/fingers outside of cage will not count as an arm gesture. Be 100% confident that the subject isn’t reaching their arm/fingers outside to rest their arm (i.e., the arm/fingers must be moving)</td>
</tr>
<tr>
<td>• Hoot (h): A series of low-pitched, moderately loud calls that do not change in amplitude, lips are strongly pursed in an “o” shape.</td>
<td>• Throw stuff (ts): Subject throws loose material from enclosure at experimenter</td>
</tr>
<tr>
<td>• Peep (pp): Loud, brief, high-pitched vocalization</td>
<td>• Shake head (sh): Subject rapidly shakes head horizontally or vertically, at least two times (e.g., left-right-left-right or up-down-up-down).</td>
</tr>
<tr>
<td>• Foot stomp (fs): Subject slaps the ground with its feet</td>
<td>• Cage swing (cs): Subject uses cage to swing body side to side or up and down, at least two times (e.g., left-right-left-right or up-down-up-down).</td>
</tr>
<tr>
<td>• Pant (pt): Soft but rhythmic breathing, can often be visually detected by slight torso shaking; mouth is usually relaxed with lips slightly parted</td>
<td>• Running (rn): an individual runs back and forth distancing the length of the enclosure. The individual can run between the back of enclosure and front of enclosure (i.e. where the experimenter is seating) OR from the far right side of the enclosure to the far left side of the enclosure. For example, individual is standing by experimenter, then runs to back of the enclosure then back to the experimenter. Code instances of this behavior.</td>
</tr>
<tr>
<td>• Hand stomp (hs): Subject slaps the ground with its hands</td>
<td>• Lip pout (lp): Lips are pursed and protruded but remain in contact near the mouth corners and are parted in middle (duck face).</td>
</tr>
<tr>
<td>• Chest clap (cc): Subject slaps any part of its torso</td>
<td>• Bouncing (b): Rapid up and down movement of the body at least two times (e.g. up-down-up-down)</td>
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<tr>
<td>• Enclosure slap (es): Subject bangs, slaps, or rattles the enclosure audibly (i.e., subject is not just resting his hands/feet on the enclosure).</td>
<td>• Spinning (sp): Subject makes at least two 360 degree rotations</td>
</tr>
<tr>
<td>• Bow (bw): Subject moves the torso and head back and forth while stomping hands on ground.</td>
<td>• Genital offer (go): Male leans back and presents its genital; female presents her swelling</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Auditory Signals</th>
<th>Visual Signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Wiggle (w): Subject spastically wiggles or rapidly moves part of body (e.g. arms, legs, head).</td>
<td>• Arm gesture (ag): Subject reaches arm or any part of hand through cage but does not touch anything (i.e., the table or barrier). Any time the subject reaches their hand outside the enclosure and touches something, that instance of reaching arm/fingers outside of cage will not count as an arm gesture. Be 100% confident that the subject isn’t reaching their arm/fingers outside to rest their arm (i.e., the arm/fingers must be moving)</td>
</tr>
<tr>
<td>• Bouncing (b): Rapid up and down movement of the body at least two times (e.g. up-down-up-down)</td>
<td>• Throw stuff (ts): Subject throws loose material from enclosure at experimenter</td>
</tr>
<tr>
<td>• Spinning (sp): Subject makes at least two 360 degree rotations</td>
<td>• Shake head (sh): Subject rapidly shakes head horizontally or vertically, at least two times (e.g., left-right-left-right or up-down-up-down).</td>
</tr>
<tr>
<td>• Genital offer (go): Male leans back and presents its genital; female presents her swelling</td>
<td>• Cage swing (cs): Subject uses cage to swing body side to side or up and down, at least two times (e.g., left-right-left-right or up-down-up-down).</td>
</tr>
<tr>
<td>• Arm gesture (ag): Subject reaches arm or any part of hand through cage but does not touch anything (i.e., the table or barrier). Any time the subject reaches their hand outside the enclosure and touches something, that instance of reaching arm/fingers outside of cage will not count as an arm gesture. Be 100% confident that the subject isn’t reaching their arm/fingers outside to rest their arm (i.e., the arm/fingers must be moving)</td>
<td>• Running (rn): an individual runs back and forth distancing the length of the enclosure. The individual can run between the back of enclosure and front of enclosure (i.e. where the experimenter is seating) OR from the far right side of the enclosure to the far left side of the enclosure. For example, individual is standing by experimenter, then runs to back of the enclosure then back to the experimenter. Code instances of this behavior.</td>
</tr>
<tr>
<td>• Lip pout (lp): Lips are pursed and protruded but remain in contact near the mouth corners and are parted in middle (duck face).</td>
<td>• Bouncing (b): Rapid up and down movement of the body at least two times (e.g. up-down-up-down)</td>
</tr>
</tbody>
</table>

Table 9C. Multimodal Signal Coding Scheme.
also no significant main effect of Trial Type, such that both chimpanzees and bonobos did not vary their likelihood of producing a multimodal signal based on the attentional state of the experimenter (average number of multimodal signals across two trials: Attentive Trials: \( M = .86, SE = .14 \); Inattentive Trials: \( M = .84; SE = .16 \ p > .05 \); Figure 28C).

![Figure 28C](image)

**Figure 28C. Average Number of Multimodal Signals based on Experimental Condition.**

There were significant main effects of age and species. The frequency of multimodal signaling decreased with age (\( Z = -3.57, p = .0004 \); Figure 29C). Chimpanzees were significantly more likely to produce multimodal signals than bonobos (average number of multimodal signals across four trials: Chimpanzees: \( M = 3.12, SE = .51 \); Bonobos: \( M = 1.69, SE = .49 \); \( Z = 3.66, p = .0002 \); Figure 29C).
Figure 30C. Number of Multimodal Signals based on Species and Age$^1$.

These results demonstrate that production of multimodal signals declines across development, and is more frequently produced by chimpanzees than bonobos. Moreover, individuals across all ages and species were equally likely to produce multimodal signals when an experimenter was attentive, as opposed to inattentive.

Interestingly, these findings are in contrast to the findings presented in Chapter 4 on bonobos and chimpanzees’ gaze alternations. Unlike gaze alternating, which increase across development, multimodal signaling across development. Gaze alternations may represent a sophisticated communicative strategy: they serve to coordinate attention around items of shared attention. Multimodal signals, on the other hand, may be an ineffective form of communication. Individuals may rely on multimodal signals when they are unsure which unimodal (i.e., visual or gestural) signal will be most effective.

$^1$ Photos by Jingzhi Tan, reproduced with permission.
Thus, it is not surprising that we would see these contrasting developmental trends. These findings suggest that although multimodal signals are seen in nonhuman primates, they may have evolved to serve very different functions in humans.
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Biography

Kelsey Riley Lucca was born on June 16, 1990 in Hackensack, New Jersey. In the spring of 2012, she graduated from the Honor’s College of the University of Delaware with a B.S. in Cognitive Science and minors in Anthropology, Italian, and Psychology. Her undergraduate work was recognized by the University with the Louis A. Arena Award for outstanding achievement in academics and research. In the fall of 2012, she began her doctoral studies at Duke University in the department of Psychology & Neuroscience. Kelsey received her MA in May 2015, and will receive her PhD in May 2017. In the fall of 2017, Kelsey will begin a postdoctoral research position at the University of Washington in Seattle.

As a doctoral student, Kelsey was awarded the Phillip Jackson Baugh Fellowship for Research in Human Development. Kelsey’s research was also supported by fellowships and travel grants from the Society for Research in Child Development and Duke University’s Graduate School. Kelsey’s research was also recognized with two honorable mentions from the National Science Foundation. Her research on language acquisition has been published in the journals *Child Development* and *Journal of Cognition and Development*. 