# “How many?”: Object Individuation in Canines (*Canis Familiaris*) Using Spatiotemporal, Property/ Kind, and Verbal Cues

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**Abstract**

While there is considerable evidence that language does not shape cognition, it nevertheless seems to serve as a cognitive tool, perhaps allowing us to easily manipulate otherwise complex concepts. The field of numerical cognition provides evidence for the interaction of language and thought, particularly in the domain of counting and representing exact large numerosities. There is likewise strong evidence for the role of language in *kind*-based object individuation, with some suggesting that language is necessary for the development of *sortal* concepts, which are, in turn, necessary for *kind* distinctions. Although evidence from prelinguistic human infants and from nonlinguistic primates, chicks, and canines indicates that language is not required for object individuation, we suggest that it may still provide a helpful and significant cue. Using a manual search method, we studied canine object individuation. Dogs provided a particularly intriguing set of participants because they have been shown to have some level of comprehension of human verbal information, allowing us to examine the role of linguistic information in a nonhuman species. We presented dogs with spatiotemporal, property/kind, and verbal cues for object individuation. Our results indicate that dogs can use spatiotemporal, but not property/kind or verbal, cues to individuate objects.

## 1. Background

### 1.1. Language & Thought

Almost a century ago, Edward Sapir and Benjamin Whorf claimed that language underlies cognition as much as cognition underlies language (Bloom & Keil, 2001; Pinker, 2007; Sapir, 1921; Whorf, 1956). Their claim, known as the Sapir-Whorf hypothesis, remains one of the strongest characterizations of the interplay of language and thought, offering a version of linguistic determinism (Bloom & Keil, 2001; Pinker, 2007; Sapir, 1921; Whorf, 1956). According to linguistic determinism, language does not reveal, but rather structures, thought (i.e., the way we *think* depends upon the way we *speak*) (Pinker, 2007). Consequently, much of the research on linguistic determinism highlights differences across languages: if language determines thought, then variations among languages will result in empirical differences in speakers' cognitions (Bloom & Keil, 2001; Pinker, 2007; Sapir, 1921; Whorf, 1956). For example, while Russian contains separate words for "light blue" and "dark blue," English possesses only one word for all shades of "blue." As a result, according to linguistic determinism, Russian-speakers and English-speakers should literally see the world in different ways (Bloom & Keil, 2001; Pinker, 2007; Sapir, 1921; Whorf, 1956; Winawer et al., 2007).

Many in the cognitive science community now discount the strong Sapir-Whorf hypothesis, the evidence for which has been undermined by circular logic and methodological confounds (Bloom & Keil, 2001; Pinker, 2007). Nevertheless, a much weaker hypothesis remains probable: although the specifics of *any given* language may not dictate thought, language in general seems a powerful cognitive tool, providing our species with a means to label, abstract, and manipulate concepts (Bloom & Keil, 2001; Pinker, 2007; Xu, 1999; Xu, 2002; Xu, Cote, & Baker, 2005; Xu, 2007; Xu, 2010).

**1.2. Language & Number**

Numerical cognition provides a compelling case study of the interaction of language and thought, as it straddles the most mundane (e.g., 2 + 2 = 4) and the most abstract (e.g., countable versus uncountable infinities) aspects of human thinking. Recognizing that there are two jars on a table is an extraordinarily trivial task, while counting the exactly 317 jellybeans in those jars is more challenging– or at least less instantaneous (Dehaene, 1992; Dehaene, 2011; Feigenson, Dehaene, & Spelke, 2004; Wynn, 1992; Wynn; 1995).

There are varied theories about the processes that drive our species' representations of the smallest quantities (i.e., one through four). Some, including Mandler and colleagues, suggest that our species instantaneously perceives the smallest natural numbers through subitizing – an innate, automatic process perhaps driven by low-level visual pathways (Jensen, Reese, & Reese, 1950; Mandler and Shebo, 1982; Piazza, Mechelli, Butterworth, & Price, 2002). However, subitizing remains controversial, and Feigenson and colleagues have suggested that our species represents small numbers in the same manner in which we represent large numbers. They argue that the rapid and precise processing of small quantities, which might suggest a distinct, automatic process, is instead due to the fact that there is less noise in the signal (Feigenson, Dehaene, & Spelke, 2004).

Regardless, there is a consensus that in order to grapple with larger numbers, our species relies on an innate approximate number system (Dehaene, 2011; Feigenson, Dehaene, & Spelke, 2004; Wynn, 1992; Wynn; 1995). Using a mental *accumulator* (i.e., a continuous, rather than discrete, mental process), we track quantities of any size (Dehaene, 2011; Feigenson, Dehaene, & Spelke, 2004; Wynn, 1992; Wynn; 1995). Such a system can allow us to compute comparisons between sets, knowing, for example, that set A has *some amount* more than set B (Dehaene, 2011; Meck & Church, 1983; Wynn, 1992; Wynn, 1995). We can determine that a jar with 17 jellybeans has many fewer jellybeans than a jar with 300, even if we do not know exactly how many.

These general numerical abilities – both with exact small and approximate large numerosities – are not unique to humans. They can be found in bees (Chittka & Geiger, 1995; Dacke & Srinivasan, 2008; Gross et al., 2009; see Pahl, Si, Zhang, 2013 for a review), chicks (Haun, Jordan, Vallortigara, & Clayton, 2010), and rats (Dehaene, 2011; Meck & Church, 1983), among many other species. Notably, these species, along with prelinguistic human infants, lack language but nonetheless possess basic quantitative facilities (Dehaene, 2011; Feigenson, Dehaene, & Spelke, 2004; Wynn, 1992; Wynn, 1995).

In fact, the possession of *certain aspects* of language seems to mark a divide in numerical abilities: without language, we can approximate, but only with language can we count out precisely 317 jellybeans (Dehaene, 1992; Dehaene, 2011; Frank, 2008; Frank, 2012; Gordon, 2004; Wynn, 1990; Wynn, 1992). Almost every human culture has some sort of count system, ranging from English's infinitely recursive system to the Oksapmin's finite system, which uses body parts to represent numbers (Everett, 2013; Frank, 2012). Most powerfully, the few cultures, such as the Pirahã, whose language does not possess a count system, have been shown to fail certain simple numerical tasks (Everett, 2013; Pica, Lemer, Izard, & Dehaene, 2004; Frank et al., 2008; Frank, 2012; Gordon, 2004). For example, after watching an experimenter place a specific number of spools into an opaque bucket, Pirahã participants were asked to place that same number of rubber balloons on a table (spools and balloons were chosen as objects with which the Pirahã were already familiar) (Frank, 2008). Unable to see the spools in the bucket, the Pirahã placed a number of balloons close to, but not exactly, the target number. As with prelinguistic infants and nonlinguistic species, the Pirahã easily represent an approximate quantity, but without language they were unable to track and remember an exact amount (Frank et al., 2008). Thus, aspects of language, specifically a count system, may underlie exact quantification of large numbers (Dehaene 2011; Frank, 2008; Pinker, 2007; Wynn, 1990; Wynn, 1992).

**1.3 Beyond Counting: Sortals**

However, not everything can be counted. English, among other languages, makes this distinction in its nouns: while some nouns (e.g., suitcase) are *count nouns* such that they can be made plural (e.g., suitcases) and qualified by an exact quantity (e.g., two suitcases), others are *mass nouns* such that they cannot (e.g., luggage but not *luggages) (Gillon, 1999). Indeed, philosophers and psychologists have identified a subset of concepts – *sortals* – that correspond to count nouns; like count nouns, each *sortal* refers to a different set of countable things (Hirsch, 1982; Xu, 1997; Xu, 2007; Xu, 2010). For example, our concept of "cup" is a *sortal* one, while our concept of "coffee" is not. We can distinguish among different cups but cannot subdivide coffee into numerically distinct entities. We can think of *sortals* (and count nouns) as referring to any *kind* about which we would ask "how many?" (e.g., "how many cups?" in contrast to "how much coffee?", see Xu, 2007 for greater discussion). *Sortals* encompass our expectations about identity and about individuation, allowing us to determine which things are of the same "sort" but nonetheless distinct (Hirsch, 1982; Xu, 2007; Xu, 2010).

In considering the acquisition of *sortals*, Xu and others have suggested that, once again, language underlies the formation of concepts. Specifically, Xu claims that the acquisition of count nouns enables the development of *sortals*. She suggests that labels provide us with the means to break down our world into countable sets.[1] In order to examine the interaction of language and thought broadly and to consider the role of language in numerical cognition specifically, we can examine the ways in which species categorize and enumerate the things in their worlds. In this paper, we focus specifically on object individuation – the process of distinguishing among distinct objects involved in an event or series of events.

**1.4. Object Individuation**

Object individuation serves as one of the fundamental means by which we constitute our world (Xu & Carey, 1996). Not all instances of object individuation rely upon *sortal* concepts: we also make distinctions according to basic expectations about the behavior of objects in the physical world, without any knowledge of the *kinds* of things involved (e.g., we know that one objects cannot be in two places at the same time, regardless of its kind) (Aguiar & Baillargeon, 1999; Feigenson & Carey, 2003; Spelke et al., 1994; Spelke, Kestenbaum, Simons, & Wein, 1995; Van de Walle, Carey, & Prevor, 2000; Wynn, 1992: Xu & Baker, 2005, Xu & Carey, 1996). These non-*sortal* distinctions rely upon spatiotemporal or features cues (i.e., information about the objects' motion in time and space or perceived properties). However, in many cases, in order to individuate objects, we must first recognize that they are distinct entities of different *kinds*

[1] Note that Xu and colleagues have hypothesized that there exists a single *sortal* concept that does not require language: "object" (Xu, 1997; Xu, 2007). They claim that at a very early age, infants develop this abstract notion of the set of (unspecified) objects, complete with expectations about the ways in which objects should behave and be differentiated, based not on language but on innate spatiotemporal intuitions (Spelke & Hespos, 2001; Spelke & Kinzler, 2003). For example, if a ball and a truck follow different spatiotemporal paths, then they can be counted as distinct objects; however, distinguishing the ball and truck based solely on their difference in *kind* requires other, more specific *sortals,* ones that Xu claims are language-dependent (see Xu, 1997 for a full discussion.)

(i.e., that they are based on *sortal* concepts) (Hirsch, 1982; Xu, 1997; Xu & Carey, 2004; Xu, 2007; Xu, 2010). And so, the study of *object individuation* allows us to determine if and when language is necessary to represent the items in our world. It is a process that seems to develop naturally, although the types of cues recruited vary and increase over time (e.g., Xu & Carey, 1996; Xu & Carey, 2004; Xu, 2007).

The vast majority of research on object individuation uses one of two experimental tasks: violation-of-expectation (VOE) (e.g., Dewar & Xu, 2007; Xu, 1997) or manual search (e.g., Brauer & Call, 2011; McCurry, Wilcox, & Woods, 2009; Mendes, Rakoczky, & Call, 2007). The VOE method is predicated upon the notion that we – and other species – look longer at surprising incidents (i.e., events that violate our expectations). For example, if the jar of jellybeans is overturned, and the jellybeans then float up to the ceiling, we would stare for a considerable length of time; this event would violate our expectation that objects ultimately fall to the earth (Kim & Spelke, 1999). Experimenters can use VOE to tap into infants' or nonhuman species' beliefs, regardless of their abilities to articulate those beliefs. The amount of time they spend looking at an event — called, intuitively, *looking-time* — reveals what they do and do not expect to happen.

The latter method – manual search – tests expectations of quantity, using as a dependent measure *searching-time*, or the amount of time someone persists in searching for missing objects. Manual search methods rely upon the assumption that if we want something, we will search until we find it, and if we want multiple things, we will search until we find the *last* one. So, if Ann expects there to be ten jellybeans in a jar, Ann will continue to search after finding the ninth jellybean. The manual search method takes advantage of this phenomenon to determine participants' perceptions of quantity: infants or nonhuman species are presented with N objects, after which one is surreptitiously removed, leaving N-1. The longer the infant or nonhuman animal searches for that missing Nth object, the likelier it is that she recognized that she was indeed initially presented with the total N.

### 1.4.1. Human infants

Studies of object individuation in human infants allow us to determine what preexisting cognitive structures exist and which cues are utilized at which stages of development. Moreover, in studying prelinguistic infants, we can evaluate the eventual impact of language acquisition on object individuation. In particular, by examining the role that language plays in *kind*-based object individuation, we can implicitly explore the impact of language on the development of *sortal* concepts.

The earliest instances of object individuation in humans occur in the presence of spatiotemporal information (Aguiar & Baillargeon, 1999; Feigenson & Carey, 2003; Spelke et al., 1994; Spelke, Kestenbaum, Simons, & Wein, 1995; Van de Walle, Carey, & Prevor, 2000; Wynn, 1992: Xu & Baker, 2005, Xu & Carey, 1996). Our species possesses a set of fundamental assumptions about the way objects physically act (Spelke & Hespos, 2001; Spelke & Kinzler, 2003). For example, even very young infants have a basic knowledge of *object continuity*: they know that objects cannot jump through space or time without that jump being observed. In fact, four-month-olds look significantly longer when an object moves behind one of two separated screens and then emerges from the other, without appearing in the gap between them (Spelke et al., 1994; Spelke, Kestenbaum, Simons, & Wein, 1995). However, infants' surprise at this event disappears if they are initially shown two objects (Spelke, Kestenbaum, Simons, & Wein, 1995).

While a single object must pass through the gap in order to move from one screen to the other, the presence of two objects provides a cheat: the first object moves behind the first screen, but then the second object emerges from the second screen, without either object having to pass through the gap. These young infants recognize that the presence of two (or more) objects can explain seeming discontinuity.

Does apparent discontinuity, in turn, dictate the number of objects infants expect to see? That is, do infants use spatiotemporal events that would be impossible given a single object as cues that there are, in fact, two objects? Indeed, several experiment have found this to be the case (Aguiar & Baillargeon, 1999; Feigenson & Carey, 2003; Spelke et al., 1994; Spelke, Kestenbaum, Simons, & Wein, 1995; Van de Walle, Carey, & Prevor, 2000; Wynn, 1992: Xu & Baker, 2005, Xu & Carey, 1996). Spatiotemporal information is likely the earliest and strongest cue that infants are not seeing the same object multiple times but rather multiple objects each shown a single time (Xu & Carey, 1996). This pattern holds for a slew of spatiotemporal cues: discontinuity (Spelke, Kestenbaum, Simons, & Wein, 1995; Xu & Carey, 1996; Van de Walle, Carey, & Prevor, 2000), when a series of objects are removed from one container and placed in another (Feigenson & Carey, 2003), and when multiple objects are shown simultaneously (Xu, 1999). In situations with explicit spatiotemporal information, even prelinguistic infants correctly individuate the involved objects, suggesting that language is unnecessary for this type of individuation and for the concepts that underlie it.

However spatiotemporal information is not the only cue for individuation: we often rely upon property/kind information, particularly in the absence of spatiotemporal input (Bonatti, Frot, Zangl, & Mehler, 2002; Krojgaard, 2004; McCurry, Wilcox, & Woods, 2009; Van de Walle, Carey, & Prevor, 2000; Wilcox & Baillargeon, 1998; Xu, 1997; Xu, 1999; Xu, 2002; Xu & Baker, 2005; Xu & Carey, 1996; Xu, Carey, & Quint, 2004). Consider when objects differ in type (e.g., a toy car versus a rubber duck). Even if these objects act in a way consistent with a single object, we know they are different (Xu, 1999). If Ann reaches for her cup and instead grabs a spoon, she will assume someone switched her cup for a spoon. She will not assume her cup miraculously transmuted into another kind of object. We may distinguish between a cup and spoon either by the properties that they possess (e.g., color, size, shape) or by the *kinds* that they represent (e.g., the class of cups or the class of spoons) (Santos, Sulkowksi, Spaepen, & Hauser, 2001). In practice, objects of different kinds often possess different properties (Santos, Sulkowksi, Spaepen, & Hauser, 2001). Xu and colleagues have, however, attempted to dissociate property information from *kind* information. They found that infants use *between-kind* differences to individuate objects well before they use *within-kind* property differences (e.g., infants can distinguish between a ball and truck before they can distinguish between a red ball and a blue ball) (Xu, Carey, & Quint, 2004). Property-based individuation seems, then, somewhat predicated on *kind*-based individuation (Xu, Carey, & Quint, 2004). This relationship may be intuitive: objects of certain *kinds* may have changing properties (e.g., a flower), while remaining the same object, making it necessary to represent the *kind* before individuating based upon property information (Xu, Carey, & Quint, 2004; Xu, 2007; Xu, 2010). Therefore, we often may be able to conflate property and kind, considering them a single cue for individuation.

There is converging evidence that infants, perhaps as young as 10-months, use property/kind cues to individuate objects. While the precise age at which infants succeed on property/kind individuation varies by task, it is clear that infants develop this ability within their first year of life (Bonatti, Frot, Zangl, & Mehler, 2002; Krojgaard, 2004; McCurry, Wilcox, & Woods, 2009; Van de Walle, Carey, & Prevor, 2000; Wilcox & Baillargeon, 1998; Xu, 1997; Xu, 1999; Xu, 2002; Xu & Baker, 2005; Xu & Carey, 1996; Xu, Carey, & Quint, 2004).[2] When shown a ball emerging from the left side of a screen and a toy car from the right side, infants look significantly longer when the screen is lifted to reveal a single object: they expect to see *both* the ball and the toy car behind the screen. They do not expect the ball to transform into the car and back again. The differences in the objects' kinds implied that there were two objects (Xu, 1999; Van de Walle, Carey, & Prevor, 2000; Xu & Baker, 2005).

How do infants develop this ability to use property/kind information? How do they represent that objects belong to particular *kinds*? How do they develop the *sortal* concepts that allow them to identify and distinguish among different types of things? Language may provide a cognitive tool that aids in the development of these concepts (Xu, 1997; Xu, 1999; Xu, 2002; Xu, Cote, & Baker, 2005; Xu, 2007; Xu, 2010). In fact, early language acquisition coincides with infants' first use of property/kind information (Xu, 1999). Xu's "language hypothesis" suggests that these converging timelines may not be a coincidence, and she argues that language underlies the use of *sortal* concepts, creating *kind* distinctions among objects (Xu, 1999; Santos, Sulkowski, Spaepen & Hauser, 2002; Xu, 2007; Xu, 2010).

Xu and Carey have directly correlated the acquisition of relevant count nouns with success on property/kind individuation. Although most 10-month-olds failed to use property/kind cues in an individuation task, the infants that succeeded were those who had already acquired the words for the specific objects used (Xu & Carey, 1996). While most 10-month-olds could not

[2] See Xu & Baker, 2005 for a discussion of the differing evidence for the age at which infants begin to use property/kind information.

individuate a rubber duck and toy car based only on the fact that they were different kinds of objects, the 10-month-olds who already knew the words "duck" and "car" could. Moreover, although 10-month-olds do not yet use property/kind information unprompted, 9-month-olds can successfully differentiate between a duck and a ball when the objects are labeled as such (i.e., "duck" and "ball" spoken aloud) (Xu, 2002). Additionally, while 10-month-olds use verbal labels, they do not use distinct emotional expressions or musical tones, suggesting that language is uniquely valuable – perhaps necessary – to *kind*-based object individuation (Xu, 2002; Xu, Cote, & Baker, 2005).

**1.4.2. Primates**

However, work in nonlinguistic species, specifically rhesus macaques (*Macaca mulatta*), chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), and gorillas (*Gorilla gorilla*), has undermined the alleged importance of language in property/kind individuation. Although they are nonlinguistic species, primates still succeed in various iterations of individuation tasks, which have used both the VOE and manual search methods (Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, & Xu, 1997). Like even the youngest human infants, primates use spatiotemporal information to individuate. For example, after watching an experimenter twice take a piece of food from a pouch and place it into a container, macaques expect *two* pieces of food to be in the container (Santos, Sulkowski, Spaepen, & Hauser, 2002). They recognize that the first piece of food cannot jump back to the pouch without their noticing; therefore, they surmise there must be two distinct pieces of food in the container. In another study, great apes were shown two grapes at the same time and then watched as the two grapes were put into a container. Relying upon the basic assumption that a single grape cannot be in two places at once, the great apes recognized that they saw two distinct grapes and so continued searching the container after finding only the first grape (Mendes, Rakoczy, & Call, 2008). With both VOE and search methods, experimenters have robustly demonstrated that primates use spatiotemporal cues in object individuation (Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, & Xu, 1997).

Additionally, and more tellingly, primates also use property/kind cues to individuate objects (Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, & Xu, 1997). In one condition, macaques watched as an experimenter placed two items, each a different type of food, one at a time, into a container. In keeping with the manual search method, one treat was removed, leaving only a single treat in the container. The macaques searched significantly longer in this condition than in a control condition, suggesting that they used property/kind cues to individuate the treats and realized that two distinct treats had been placed in the container (Phillips & Santos, 2006; Sulkowski, Spaepen, & Hauser, 2002). This study in particular informed the development our own methodology, and these results have been replicated with great apes and other primates (Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, &

Xu, 1997). Multiple nonlinguistic primate species succeeded in using property/kind information, undermining Xu's language hypothesis.[3]

**1.4.3. Canines**

The success of primates and of chicks in property/kind individuation tasks necessitates a reevaluation of Xu's "language hypothesis." Language is clearly not required for property/kind individuation. However, human infants demonstrate a specific reliance on verbal cues (Xu, 1997; Xu, 1999; Xu, 2002; Xu, Cote, & Baker, 2005; Xu, 2007; Xu, 2010). The question remains: what is the role of language in object individuation?

We turn to domesticated canines (*Canis familiaris*) to understand the role of verbal cues in object individuation. Unlike nonhuman primates, such as macaques, domestic canines exist in the same social context as humans (Bensky, 2013). Differences in theirs and wolves' mitochondrial DNA suggest the two species diverged over 100,000 years ago, as dogs were integrated into the social fabric of human life (Vila, 1997; Bensky, 2013). Moreover, there is evidence that this domestication fundamentally altered the way in which canines evaluate and comprehend their world; they quite literally evolved to understand the human context (Bensky, 2013; Frank, 2011). Given the complexity of human and dog interaction, which often includes verbal information, it seems possible that dogs could unlock the role that language plays in property/kind individuation.

Only one prior study has explored object individuation in canines. Brauer and Call (2011) specifically examined the role of property/kind information in canine object individuation,

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[3] In fact, success in object individuation tasks extends beyond human and nonhuman primates. Fontanari and colleagues have found that chicks are likewise able to use property information (e.g., color, size, and shape) and kind information (e.g., food or social entity) to individuate objects (Fontanari, Rugani, Regolin, & Vallortigara, 2011; Fontanari, Rugani, Regolin, & Vallortigara, 2014).

replicating previous work with primates. After watching as an experimenter placed a treat into a cup, dogs found either that treat (i.e., expected outcome) or a different treat (i.e., unexpected outcome). Dogs searched significantly longer after they found the unexpected treat, as if looking for the treat they expected, than after they found the expected treat. These results suggest that dogs made a distinction between the two types of treats (Brauer & Call, 2011). No study, as of yet, has explored the roles of spatiotemporal or verbal information in canine object individuation.

Dogs nevertheless possess the prerequisite skills for individuation (Bensky, 2013). First, they have demonstrated a basic understanding of objects (see Bensky, 2013 for a full review). There is copious evidence that dogs possess the concept of object permanence (Bensky, 2013). If an object is occluded, dogs know that the object still exists (Triana & Pasnak, 1981). Additionally, dogs have shown a basic ability to distinguish among objects. Researchers trained dogs with two objects (a blue Lego and an orange plastic coffee jar top), one of which was associated with a reward; in order to earn the reward, dogs then had to discriminate between these two objects. Dogs succeed at this trained discrimination task, demonstrating that they possess some ability to differentiate visually distinct objects, at least when taught to do so (Bensky, 2013 Milgram, Head, Weiner, and Thomas, 1994). The differences between objects need not be as obvious or varied as those between a blue block and an orange lid. Dogs, in fact, distinguish among objects that differ in only color or size (Bensky, 2013; Burman et al., 2011; Tapp et al., 2003).

Dogs have also demonstrated abilities to distinguish between sounds, both linguistic and otherwise. For example, dogs distinguish between sounds that originate from a dog and sounds that do not (Bensky, 2013; Heffner, 1975). More relevant to the specific role of language in individuation, dogs have shown relatively rich linguistic abilities (Bensky, 2013; Kaminski, Call, & Fischer, 2004). Anecdotally, dogs receive and respond to verbal commands, such as "sit" or "stay." In addition, Kaminski, Call, and Fischer (2004) documented the "fast-mapping" ability of Rico, a border collie. Rico possesses a vocabulary of over 200 words, and when presented with a set of objects, all of which were familiar except one, Rico infers that the novel word corresponds to the novel object. Another set of experimenters replicated and expanded upon these findings with another border collie, Chaser (Pile & Reid, 2011). Thus, dogs seem perhaps the likeliest nonhuman species to utilize linguistic information as a means of individuating objects. Our study will use canines' unique capabilities and socialization to probe the relationship between language and individuation.

In particular, we are interested in whether dogs use verbal cues, independent of other information, to individuate objects. While nonhuman species' success in object individuation has suggested that language is not necessary for individuation, it remains possible, if not probable given the work of Xu and colleagues, that language is as powerful a cue for individuation as any other.

## 2. Methods

### 2.1. Participants

We tested 44 dogs (24 females) of various breeds (*Table 1*), plus an additional 12 dogs who were excluded due to food allergies/preferences (7), warm-up failure (1), guardian error (2), or experimenter error (2). All canine subjects were pets of human volunteers, who had registered via an online system and consented to their dogs' participation. The guardians received a certificate or small present (e.g., a bumper sticker) in return for their dogs' involvement. All dogs

| Name | Breed | Gender | Condition |
|---|---|---|---|
| Arrow | Border Collie x Labrador Retriever | F | Control |
| Blue | Golden Retriever | M | Control |
| Boomer | Beagle | M | Verbal |
| Boone | Black Lab x Great Dane | M | Spatiotemporal |
| Callie | Weimaraner | F | Property/Kind |
| Chelsea | Australian Shepherd | F | Spatiotemporal |
| Cody | Shiba Inu | M | Property/Kind |
| Cora | Australian Shepherd | F | Control |
| Dallas | Cocker Spaniel | F | Control |
| Darby | Chesapeake Bay Retriever | F | Control |
| Dodger | King Charles Cavalier Spaniel | M | Control |
| Fin | Chesapeake Bay Retriever | M | Property/Kind |
| Gus | Border Terrier Mix | M | Property/Kind |
| Harley | Jack Russell Mix | M | Property/Kind |
| Havalah | King Charles Cavalier Spaniel | F | Verbal |
| Jacob | Australian Shepherd Mix | M | Verbal |
| Jasmine | Beagle Mix | F | Spatiotemporal |
| Jessie | Labrador Retriever | F | Control |
| Kia | Labrador Retriever x Pit Bull x Pointer | F | Property/Kind |
| Kito | Rhodesian Ridgeback | M | Property/Kind |
| Leroy | Boxer x Pit Bull | M | Verbal |
| Lincoln | Standard Poodle | M | Spatiotemporal |
| Lori | Maltipoo | F | Control |
| Maggie | Poodle x Schnauzer | F | Spatiotemporal |
| Markl | Pomeranian | M | Spatiotemporal |
| Matilda | Beagle Mix | F | Control |
| Maya | Miniature Lab x Pit Bull x Sato | F | Property/Kind |
| Mia | Husky | F | Control |
| Mickey | Golden Retriever | M | Verbal |
| Minnie | Golden Retriever | F | Verbal |
| Oliver | Corgi | M | Property/Kind |
| Penn | Labradoodle | M | Verbal |
| Penney | Norfolk Terrier | F | Verbal |
| Pietrus | Golden Retriever x Bernese Mountain x Chow Chow | M | Verbal |
| Rosie | Pembroke Welsh Corgi | F | Spatiotemporal |
| Sadie | Black Lab Mix | F | Spatiotemporal |
| Sammy | Labrador Retriever | F | Property/Kind |
| Skye | Australian Shepherd | F | Verbal |
| Sophia Maria | Beagle x Corgi | F | Property/Kind |
| Sophie | Bichon Frise | F | Spatiotemporal |
| Toby | Labrador Retriever Mix | M | Control |

| Name | Breed | Gender | Condition |
|---|---|---|---|
| Ty | Boxer x Schnauzer | M | Spatiotemporal |
| Vader | Labrador Retriever x Pit Bull | M | Spatiotemporal |
| Viola | Australian Shepherd | F | Verbal |

*Table 1*. Name, breed, gender, and condition of all dogs included in the study.

and guardians had visited the Canine Cognition Center (CCC) prior to this study for an initial visit, which allowed experimenters to acquaint them with the facilities and to evaluate their willingness and ability to participate.

**2.2. Apparatus**

We used two types of dog treats: pieces (1 x 1 x 1 cm) of Natural Balance Beef Formula food roll and Milk-Bone mini flavor snacks (*Figure 1*). The treats were placed in a plastic container with an open top (28.5 x 18 x 13 cm or 26 x 15 x 8.5 cm), depending upon the size of the dog), which was made opaque with purple duct tape adhered to its exterior and filled with a standardized amount of paper shredding.


*Figure 1*. Image of the Milk-Bone and the piece of Natural Balance.

**2.3. Setup**

Each dog was tested using a manual search task (McCurry, Wilcox, & Woods, 2009; Santos et al., 2002; Xu et al., 2005) and received a single test trial from one of four conditions: spatiotemporal, property/kind, verbal, or the control. Prior to the test trial, each dog underwent a warm-up procedure and participated in another, unrelated study. Both the warm-up and the test trial took place in a large room in the CCC (3.5 x 3.15 m) with the guardian present. The guardian sat on a chair in the corner of the room and held the dog's leash, which was attached to a hook in the wall, such that the dog was prevented from freely moving about the room (*Figure 2*). While guardians were allowed to watch the warm-up, they were instructed to keep their heads down and eyes closed throughout the duration of the test trial.

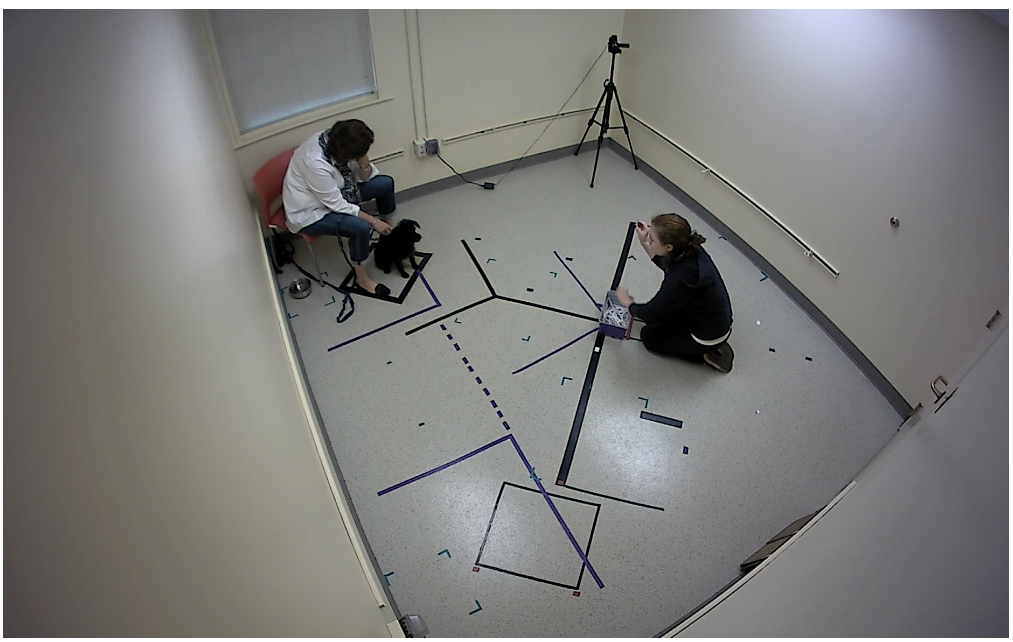

*Figure 2*. Image of room setup.

**2.4. Warm-up**

The purpose of the warm-up was twofold: we wanted to reacquaint the dogs with the CCC and with the apparatus we use, and we wanted to ascertain the dogs' ability to complete the test trial. During the warm-up, dogs were allowed to search the purple container for a good reward. An experimenter (MB, CT, or AF) began by placing the container on the ground about 1.4 m in front of the dog. The container was positioned far enough from the dog that the dog could not approach it until the guardian released the leash. The experimenter, crouching behind the container, held up a Milk-Bone in full view of the dog, calling for the dog's attention by saying, "[Name], look." The experimenter next placed the Milk-Bone in the container and then stepped out of the room. The guardian, who had been instructed to release the dog only after the door shut behind the experimenter, released the dog, allowing him or her to approach the container and search for the Milk-Bone.

If the dog was unable to find or showed a dislike for the Milk-Bone, leaving it uneaten, the experimenter ran the warm-up a second time. If, after a second try, the dog did not complete the warm-up successfully, then the dog was excluded from the test trial. Only one dog was excluded as a result of warm-up failure.

**2.5. Test trials**

Before each of the test trials, a second experimenter (EF) placed a piece of Natural Balance and a Milk-Bone into the purple container, which already contained paper shredding. She then entered the large room, in which the guardian and dog were waiting, putting down the container in front of the dog as in the warm-up and commencing one of the following conditions.

**2.5.1. Spatiotemporal condition**

This condition tested whether dogs use spatiotemporal cues to determine the number of distinct objects involved in an event. Accordingly, EF showed the dogs two treats simultaneously, providing clear spatiotemporal evidence that there were two separate treats (one treat cannot be in two places at one time). Given robust evidence that dogs possess basic expectations about objects (Bensky, 2013), we believed it particularly likely that the dogs are able to use the spatiotemporal cues.

Kneeling directly behind the container, EF removed the Milk-Bone with her right hand, lifting it about 0.3 m above the container, while saying, "[Name], look!" Without returning the Milk-Bone to the container, she then repeated the same procedure with the Natural Balance on her left side. In this way, both the Milk-Bone and Natural Balance were held above the container in full view of the dog at the same time. EF then returned the Milk-Bone to the container, followed by the Natural Balance. While returning the Natural Balance, she surreptitiously maneuvered it into the palm of her hand and removed it from the container without the dog's knowledge (*Figure 3*). If dogs use spatiotemporal information to individuate objects, then they will recognize that the experimenter placed two, distinct objects into the container. Accordingly, they will search for a significant amount of time after finding the first treat, looking for the second.

*Figure 3.* Illustration of the spatiotemporal condition.

### 2.5.2. Property/kind condition

This condition examined whether dogs can individuate treats based exclusively on property/kind information.  In this case, property and kind differences were conflated: EF presented different *kinds* of treats that accordingly had different *properties*, including shape and color. In order to provide only property/kind information, EF presented the two treats consecutively, in a manner consistent with a single object repeatedly being removed from the container. Thus, the only way to distinguish between the two treats was to use their differences in property/kind. Brauer and Call (2011) have found that dogs succeed in this type of individuation task.

As in the spatiotemporal condition, the experimenter began by kneeling directly behind the container. She then removed the Milk-Bone with her right hand, lifting it about 0.3m above the container, while saying, "[Name], look!" She then returned the Milk-Bone to the container *before* repeating the same procedure with the Natural Balance on her left side. Thus, the dogs watched as two different types of treats were lifted out from the box, crucially, not at the same time. In order to individuate the two treats, dogs needed to recognize differences in their properties or kinds. As in the spatiotemporal condition, while returning the Natural Balance to the container, the experimenter surreptitiously removed it from the container without the dog's knowledge (*Figure 4*). If dogs rely upon property/kind cues to individuate, then they will continue to search for a significant amount of time after finding the Milk-Bone in the container.

*Figure 4*. Illustration of the property/kind condition.

### 2.5.3. Verbal condition

We found the verbal condition especially exciting as it allowed us to probe the role of language in object individuation in a nonhuman species. Specifically, we wanted to determine whether dogs would individuate treats based only on different verbal labels. EF showed the dogs two identical treats but called each treat by a distinct unfamiliar label, thus providing exclusively verbal cues for individuation. If dogs searched for a significantly longer time in this condition than in the control condition, then we would conclude that the dogs used the different labels and can rely upon language for individuation.

Prior to entering the room, the experimenter removed the piece of Natural Balance from the container. Although Natural Balance is not used in this condition, it was momentarily placed in – and, in fact, shaken around – the container in order to control for olfactory input. Thus, in every condition, the dogs encountered the same two smells in the container, and so any differences in searching-time would not be due to the number of scents.

Upon entering the room, the experimenter positioned the container as described and knelt directly behind it. She first lifted the Milk-Bone with her right hand about 0.3 m above the container, while saying, "[Name], look! It's a dax! It's a dax!" She then replaced the Milk-Bone to the container. She then raised the same Milk-Bone with her *left* hand, this time saying, "[Name], look! It's a blicket! It's a blicket!"[4] EF repeated this procedure exactly one more time, once more lifting the treat on both the right and the left. Finally, the experimenter pretended to smuggle a treat out of the container, replicating her actions in the spatiotemporal and property/ kind conditions (*Figure 5*). If the dogs use language to individuate objects, they should think

[4] Note that "dax" and "blicket" were chosen as words that would be unfamiliar for all canine participants. These two nonsense words are frequently used in psychology research (e.g., Kobayashi, 1997).

there are two treats inside the container and so persist in searching after finding a single Milk-Bone.

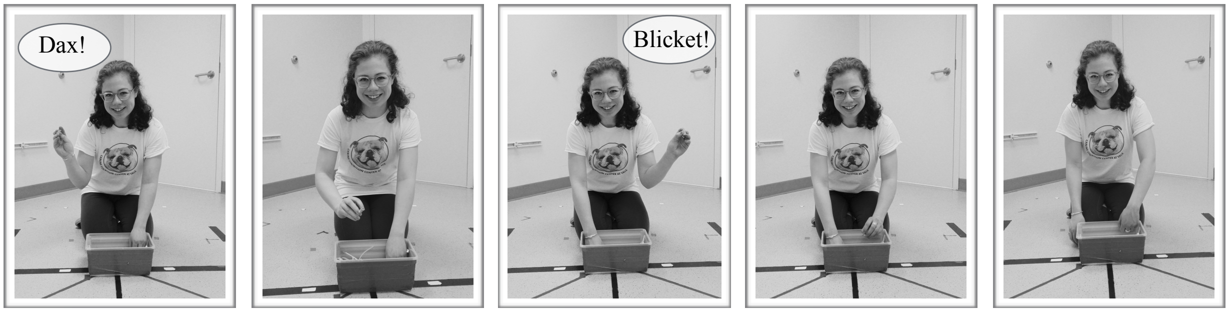


*Figure 5.* Illustration of the verbal condition.

### 2.5.4. Control condition

The control condition served as a baseline for the other three conditions. The experimenter provided no evidence that there were two distinct objects in the container, merely showing the dogs an identical treat twice. Without any cues for individuation, dogs should not expect two treats in the container and so should finish their search after finding one treat. The control condition was identical to the verbal condition except for the fact that the Milk-Bone was shown only once on each side without any verbal cues (*Figure 6*).

*Figure 6*. Illustration of the control condition.

After each condition, the experimenter exited the room. The guardian then released the dog when s/he heard the door close, allowing the dog to search the container. Note that in all conditions, there was always exactly one treat left in the container. Accordingly, the dog's search-time was an effective dependent measure, as if they expected to find two treats in the container, they would persist in searching for some time.

There were overhead cameras (HD Everfocus) and handheld cameras (Panasonoic HC-V210) in the room to record the test-trial. The overhead cameras also broadcast the trial in real-time to a monitor in a separate room. Another experimenter (MB), who had not witnessed the trial and was thus blind to the condition, watched the monitor and notified EF when the dogs completed searching. EF could then re-enter the room in order to end the study and thank the participants.

**2.6. Coding**

To ensure that coding was blind to condition, we first trimmed videos so that only the search footage was present. Each video file was then assigned a random sequence of letters, eliminating any identifying information. Videos were viewed in MPEG Streamclip. Coders marked the beginning of the search when the dog first broke the plane of the top of the container and marked the end of the search when the dog lifted her head out of the container and did not return to the container within 3 seconds. An additional coder (KG) reviewed ten of the videos to verify coding reliability, and inter-rater reliability was high, with a correlation of $r = .96$.

**3. Results**

We analyzed searching-times (in seconds) across condition using a one-way analysis of variance (ANOVA). We assumed equal variance in each condition based on a non-significant Levene's test ($p = .11$). Our analysis revealed a significant main effect of condition ($F(3, 40) = 7.2$, $p < .001$). Specifically, dogs searched longer in the spatiotemporal condition ($M = 29.6$, $SD = 10.2$) than in the control condition ($M = 17.6$, $SD = 7.9$), the property/kind condition ($M = 16.4$, *SD* = 4.1), and the verbal condition (*M* = 17.0, *SD* = 7.7) (*Figure 7*). Post-hoc comparisons with Bonferroni's adjustment further confirmed that the dogs searched significantly longer in the spatiotemporal condition than in the control condition ($p$ = .005), the property/kind condition ($p$ = .002), and the verbal condition ($p$ = .003). The length of searching-time did not significantly differ between the control condition and the property/kind condition ($p$ = 1), the control condition and the verbal condition ($p$ = 1), or the property/kind condition and the verbal condition ($p$ = 1).

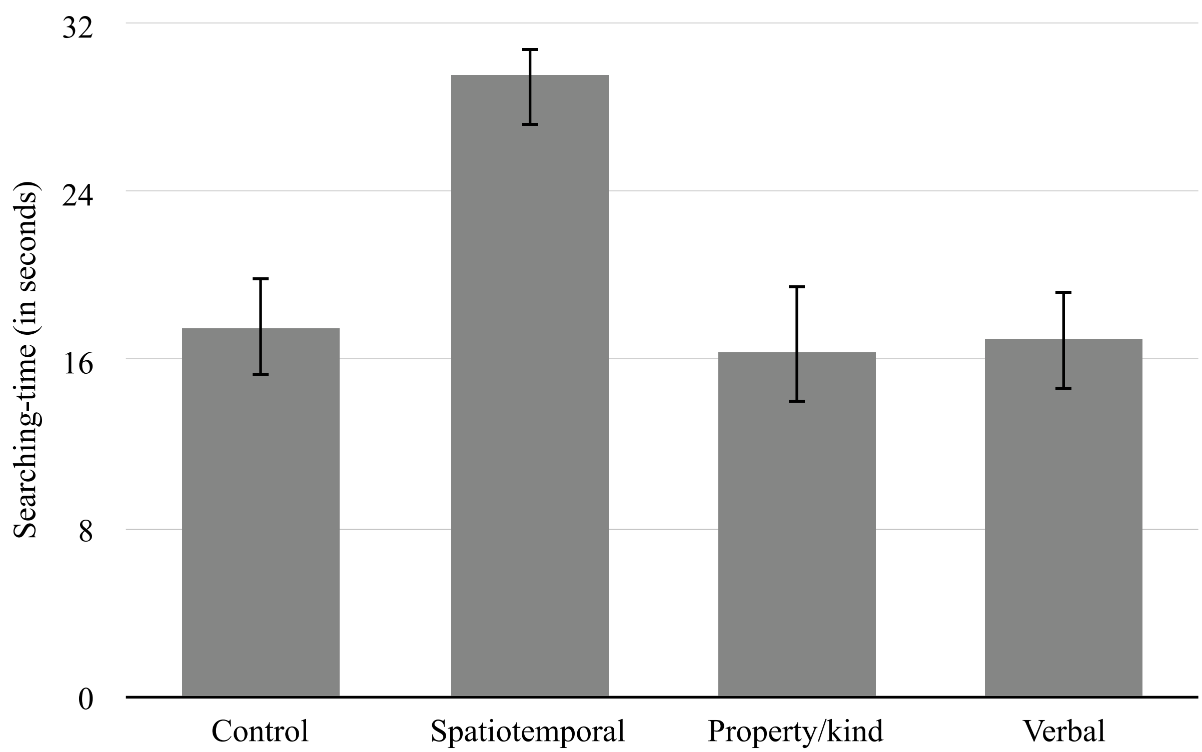


*Figure 7.* Mean (± standard error) time spent searching in the container (in seconds) across conditions.

**4. Discussion**

We sought to determine which, if any, cues dogs recruit for object individuation. We used a manual search method: if a dog successfully used the given cue, s/he would believe that the experimenter placed two distinct treats into the container and would expect to find both;

therefore, s/he would persist in searching even after finding the first treat, leading to a longer searching-time. As the dependent measure, searching-time served as a proxy for dogs' expectations of quantity. Dogs were given three different types of cues for individuation, which corresponded to three of our four conditions: spatiotemporal, property/kind, and verbal. The control condition, in which the experimenter supplied no individuating information, provided a baseline for the amount of time the dogs spend searching the container. We found that dogs searched significantly longer in the spatiotemporal condition than in the control condition. We conclude, therefore, that dogs were able to successfully individuate objects using spatiotemporal information. However, dogs searched no longer in the property/kind and verbal conditions than in the control condition, indicating that they did not use either of these cues.

Our primary motivation for studying canine object individuation derived from dogs' unique position as a nonhuman species that nevertheless displays some level of comprehension of verbal information. We wanted to determine whether dogs, like human infants, could rely upon verbal cues to individuate objects (Rivera & Zawaydeh, 2006; Xu, 2002; Xu, Cote, & Baker, 2005). Xu and colleagues have suggested that language underlies *sortal* concepts and, in turn, *kind* distinctions, making language necessary for individuation based on property/kind cues (Xu & Carey, 1996; Xu, 2002; Xu, 2007; Xu, 2010). However, converging results from other infant studies (Wilcox & Baillargeon, 1998), primate studies (Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, & Xu, 1997), chicks studies (Fontanari, Rugani, Regolin, & Vallortigara, 2011; Fontanari, Rugani, Regolin, & Vallortigara, 2014), and even canines studies (Brauer & Call, 2011) suggest that language is, in fact, *not* necessary for property/kind distinctions.

Prelinguistic and nonlinguistic species make these distinctions and individuate objects accordingly. Although there is overwhelming evidence that language is not necessary for object individuation, it nevertheless may remain a helpful – and, as Xu's research suggests, a particularly powerful – cue (Rivera & Zawaydeh, 2006; Xu, 2002; Xu, Cote, & Baker, 2005).

In order to isolate the role of language in object individuation, we designed the verbal condition such that the dogs would have to rely solely on verbal cues. Brauer and Call (2011) have shown that dogs successfully use property/kind cues to individuate objects without any additional input. Accordingly, we provided the dogs with distinct verbal cues while presenting them with otherwise identical treats, eliminating any nonlinguistic individuating information. However, in contrast to Brauer and Call (2011), we found that dogs do *not* use property/kind information alone to individuate objects. Thus, we propose a follow-up condition in which dogs are exposed to different labels for different treats. Rivera and Zawaydeh (2006) have, in fact, suggested that different labels are only effective when applied to different objects, claiming that labels serve as the "glue" between perceived differences and conceptualized differences among objects. Additionally, we suggest that perhaps the identical Milk-Bones indicated that there was a single treat, overriding the distinct labels. A condition in which different labels are given each to the Milk-Bone and the piece of Natural Balance will resolve this concern.

While we offer concerns about the use of identical treats in the verbal condition, we nonetheless remain confident that the unfamiliarity of the verbal labels ("dax" and "blicket") has no effect on dogs' performance. We intentionally used unfamiliar labels, avoiding a situation in which some but not all dogs knew a specific word. In fact, much of the research on dogs' linguistic abilities has involved unfamiliar words. The border collie Rico's success in fast-mapping (i.e., mapping a novel word onto a novel object) provides one of the strongest examples of dogs' linguistic facility (Kaminski, Call, & Fischer, 2004).

However, the study of Rico simultaneously illustrates a problem with our foundational assumptions about dogs' linguistic prowess. Much of the research on dogs' linguistic abilities focuses on the achievement of a single dog or breed. As Bloom (2004) discusses, dogs, at least as a whole species, may not possess rich linguistic capabilities, unable to grasp true semantic content. Indeed, if we think of the distinct labels as *distinct but meaningless* sounds, then dogs' failure to use so-called verbal cue fits within the literature. Xu and colleagues found that only words – either familiar or unfamiliar – and sounds related to the object's function were effective cues for individuation for human infants. Infants could not use other sounds, such as musical tones or emotional expressions (Xu, 2002; Xu, Cote, & Baker, 2005). Dogs' apparent inability to use verbal cues may demonstrate that, for objective individuation, verbal information must possess true meaning about the nature of the object. Xu and others implied a sort of causal chain: count nouns lead to *sortal* concepts lead to property/kind object individuation (Xu & Carey, 1996; Xu, 1999; Xu, Carey, & Quint, 2004; Xu, 2007; Xu, 2010). While there is overwhelming research that this chain is not the only one that produces property/kind individuation (Brauer & Call, 2011; Fontanari, Rugani, Regolin, & Vallortigara, 2011; Fontanari, Rugani, Regolin, & Vallortigara, 2014; Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, & Xu, 1997), there remains the possibility that this chain holds. If verbal cues underlie *sortals*, it is intuitive that verbal cues must contain true semantic content. Therefore, dogs' failure to use verbal cues may suggest that our species possesses a unique ability to represent meaning and manipulate *sortal* concepts (Xu & Carey, 1996; Xu, 1999; Xu, Carey, & Quint, 2004; Xu, 2007; Xu, 2010).

Although our primary goal was to explore the role of language in object individuation, we also included spatiotemporal and property/kind conditions. We found, in fact, that dogs use spatiotemporal cues in object individuation, although we acknowledge that the simultaneity of the presentation of the treats could serve as a confound. By design, only in the spatiotemporal condition did dogs see two treats at the same time. In this condition, they may not have encoded the treats as two *distinct* treats but rather as more "treat stuff." If this is the case, then the dogs did not truly individuate; instead, they continued to search the container for more "treat stuff," without keeping track of exact numerosity. However, given other species' success on a variety of spatiotemporal tasks (Fontanari, Rugani, Regolin, & Vallortigara, 2014; Mendes, Rakoczy, & Call, 2008; Mendes, Rakoczy, & Call, 2011; Phillips & Santos, 2006; Santos, Sulkowski, Spaepen, & Hauser, 2002; Uller, Carey, Hauser, & Xu, 1997), and given the robust evidence for dogs' basis of knowledge about objects (Bensky, 2013), we find this confound unlikely and suggest that dogs did indeed individuate treats based on spatiotemporal information.

Finally, our results also indicate that dogs do not use property/kind cues, which contradicts the findings of Brauer and Call (2011). We note that our task differed from that of Brauer and Call. Brauer and Call only showed a single type of treat to the dogs. Brauer and Call then exchanged this treat for one of another type, which the dogs encountered only in the container. The dogs then, only had to represent the first treat, realizing that the treat in container was not the first without forming any understanding of what the second treat was. In contrast, in our property/kind condition, we initially showed *two* distinct treats to the dogs. As a result, in our study, the dogs had to represent two distinct kinds. Thus, our study may have proven more cognitively complex, diminishing the dogs' ability to individuate using property/kind information.

**5. Conclusion**

The study of object individuation in canines provides a unique perspective into the interaction of language and thoughts. Canines, or at least specific dogs, possess basic linguistic abilities and so allow us to examine the role of language in a nonhuman species' conceptualization and categorization of distinct objects (Bensky, 2013; Kaminski, Call, & Fischer, 2004). Although Xu and colleagues have suggested that property/kind individuation wholly depends upon language (e.g., Xu, 2007), results from prelinguistic and nonlinguistic species indicate otherwise (e.g., Santos, Sulkowski, Spaepen, & Hauser, 2002). However, although it may not be necessary, we suggest that language continues to provide a cognitive tool, at the disposal of species that possess it. For example, infants can use distinct verbal labels alone to individuate objects (e.g., Xu, 2002). However, in contrast to human infants, we found that dogs cannot use verbal labels; instead, they seem to only be able to use spatiotemporal information to individuate objects, suggesting that the use of language as a cognitive technology may be unique to humans.

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**Bibliography**

Bensky, M. K., Gosling, S. D., & Sinn, D. L. (2013). The world from a dog's point of view: a review and synthesis of dog cognition research. Adv Study Anim Behav, 45, 209-406.

Bloom, P., & Keil, F. C. (2001). Thinking through language. *Mind & Language*, 16(4), 351--367.

Bloom, P. (2004). Can a dog learn a word. *Science*, 304(5677), 1605-1606.

Bonatti, L., Frot, E., Zangl, R., & Mehler, J. (2002). The human first hypothesis: Identification of conspecifics and individuation of objects in the young infant. Cognitive psychology, 44(4), 388-426.

Boroditsky, L. (2001). Does language shape thought?: Mandarin and English speakers' conceptions of time. *Cognitive psychology*, 43(1), 1-22.

Boroditsky, L. (2011). How language shapes thought. *Scientific American*, 304(2), 62-65.

Bräuer, J., & Call, J. (2011). The magic cup: Great apes and domestic dogs (Canis familiaris) individuate objects according to their properties. *Journal of Comparative Psychology*, 125(3), 353.

Burman, O., McGowan, R., Mendl, M., Norling, Y., Paul, E., Rehn, T., & Keeling, L. (2011). Using judgement bias to measure positive affective state in dogs. *Applied Animal Behaviour Science*, 132(3), 160-168.

Carey, S. (2000). The origin of concepts. *Journal of Cognition and Development*, 1(1), 37-41.

Dehaene, S. (1992). Varieties of numerical abilities. *Cognition, 44*(1-2), 1-42.

Dehaene, Stanislas. *The number sense: How the mind creates mathematics*. OUP USA, 2011.

Dewar, K., & Xu, F. (2007). Do 9-month-old infants expect distinct words to refer to kinds?. *Developmental psychology*, 43(5), 1227.

Everett, C. (2013). *Linguistic relativity: Evidence across languages and cognitive domains* (Vol. 25). Walter de Gruyter.

Feigenson, L., & Carey, S. (2003). Tracking individuals via object-files: evidence from infants' manual search. *Developmental Science, 6*(5), 568-584.

Feigenson, L., Dehaene, S., & Spelke, E. (2004). Core systems of number. *Trends in cognitive sciences*, 8(7), 307-314.

Fontanari, L., Rugani, R., Regolin, L., & Vallortigara, G. (2011). Object individuation in 3‐day‐old chicks: use of property and spatiotemporal information. *Developmental science*, 14(5), 1235-1244.

Fontanari, L., Rugani, R., Regolin, L., & Vallortigara, G. (2014). Use of kind information for object individuation in young domestic chicks. *Animal cognition*, 17(4), 925-935.

Frank, M. C., Everett, D. L., Fedorenko, E., & Gibson, E. (2008). Number as a cognitive technology: Evidence from Pirahã language and cognition. *Cognition, 108*(3), 819-824.

Frank, Michael. "Cross-cultural differences in representations and routines for exact number." (2012).

Gillon, B. S. (1999). The lexical semantics of English count and mass nouns. In *Breadth and depth of semantic lexicons* (pp. 19-37). Springer Netherlands.

Gordon, P. (2004). Numerical cognition without words: Evidence from Amazonia. *Science, 306*(5695), 496-499.

Haun, D. B., Jordan, F. M., Vallortigara, G., & Clayton, N. S. (2010). Origins of spatial, temporal and numerical cognition: Insights from comparative psychology. *Trends in cognitive sciences*, *14*(12), 552-560.

Hirsch, E. (1992). *The concept of identity.* Oxford University Press.

Jensen, E. M., Reese, E. P., & Reese, T. W. (1950). The subitizing and counting of visually presented fields of dots. *The Journal of Psychology, 30*(2), 363-392.

Kaminski, J., Call, J., & Fischer, J. (2004). Word learning in a domestic dog: evidence for" fast mapping". *Science*, 304(5677), 1682-1683.

Kim, I. K., & Spelke, E. S. (1999). Perception and understanding of effects of gravity and inertia on object motion. *Developmental Science*, 2(3), 339-362.

Kobayashi, H. (1997). The role of actions in making inferences about the shape and material of solid objects among Japanese 2 year-old children. *Cognition*, 63(3), 251-269.

Krøjgaard, P. (2004). A review of object individuation in infancy. *British journal of developmental psychology*, 22(2), 159-183.

Mandler, G., & Shebo, B. J. (1982). Subitizing: an analysis of its component processes. J*ournal of Experimental Psychology: General, 111*(1), 1.

McCurry, S., Wilcox, T., & Woods, R. (2009). Beyond the search barrier: A new task for assessing object individuation in young infants. Infant Behavior and *Development*, 32(4), 429-436.

Meck, W. H., & Church, R. M. (1983). A mode control model of counting and timing processes. *Journal of Experimental Psychology: Animal Behavior Processes, 9*(3), 320.

Mendes, N., Rakoczy, H., & Call, J. (2008). Ape metaphysics: Object individuation without language. *Cognition*, 106(2), 730-749.

Mendes, N., Rakoczy, H., & Call, J. (2011). Primates do not spontaneously use shape properties for object individuation: a competence or a performance problem?. *Animal cognition*, 14(3), 407-414.

Milgram, N. W., Head, E., Weiner, E., & Thomas, E. (1994). Cognitive functions and aging in the dog: acquisition of nonspatial visual tasks. *Behavioral neuroscience*, 108(1), 57.

Phillips, W., & Santos, L. R. (2007). Evidence for kind representations in the absence of language: Experiments with rhesus monkeys (Macaca mulatta). *Cognition*, 102(3), 455-463.

Piazza, M., Mechelli, A., Butterworth, B., & Price, C. J. (2002). Are subitizing and counting implemented as separate or functionally overlapping processes?. *Neuroimage*, 15(2), 435-446.

Pica, P., Lemer, C., Izard, V., & Dehaene, S. (2004). Exact and approximate arithmetic in an Amazonian indigene group. *Science, 306*(5695), 499-503.

Pilley, J. W., & Reid, A. K. (2011). Border collie comprehends object names as verbal referents. *Behavioural processes*, 86(2), 184-195.

Pinker, S. (2007). *The stuff of thought: Language as a window into human nature*. Penguin.

Rivera, S. M., & Zawaydeh, A. N. (2007). Word comprehension facilitates object individuation in 10-and 11-month-old infants. *Brain research*, 1146, 146-157.

Santos, L. R., Sulkowski, G. M., Spaepen, G. M., & Hauser, M. D. (2002). Object individuation using property/kind information in rhesus macaques (Macacamulatta). *Cognition, 83*(3), 241-264.

Sapir, E. (1921). *Language. An introduction to the study of speech.*

Spelke, E. S. (1990). Principles of object perception. *Cognitive science, 14*(1), 29-56.

Spelke, E. S., Breinlinger, K., Macomber, J., & Jacobson, K. (1992). O*rigins of knowledge. Psychological review, 99*(4), 605.

Spelke, E. S., Katz, G., Purcell, S. E., Ehrlich, S. M., & Breinlinger, K. (1994). Early knowledge of object motion: Continuity and inertia. *Cognition, 51*(2), 131-176.

Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology, 13*(2), 113-142.

Spelke, Elizabeth S., and Susan Hespos. "Continuity, competence, and the object concept." *Language, brain, and cognitive development: Essays in honor of Jacques Mehler* (2001): 325-340.

Spelke, E. S., & Kinzler, K. D. (2007). Core knowledge. *Developmental science*, 10(1), 89-96.

Tapp, P. D., Siwak, C. T., Estrada, J., Head, E., Muggenburg, B. A., Cotman, C. W., & Milgram, N. W. (2003). Size and reversal learning in the beagle dog as a measure of executive function and inhibitory control in aging. *Learning & Memory*, 10(1), 64-73.

Uller, C., Carey, S., Hauser, M., & Xu, F. (1997). Is language needed for constructing sortal concepts? A study with nonhuman primates. In *Proceedings of the 21st annual Boston University conference on language development* (Vol. 21, pp. 665-677).

Van de Walle, G. A., Carey, S., & Prevor, M. (2000). Bases for object individuation in infancy: Evidence from manual search. *Journal of Cognition and Development, 1*(3), 249-280.

Wallace, J. R. (1965). Sortal predicates and quantification. *The Journal of Philosophy, 62*(1), 8-13.

Whorf, B. L. (1956). *Language, thought, and reality: selected writings of….*(Edited by John B. Carroll.).

Wilcox, T., & Baillargeon, R. (1998). Object individuation in infancy: The use of featural information in reasoning about occlusion events. *Cognitive psychology, 37*(2), 97-155.

Wilcox, T., Woods, R., Tuggy, L., & Napoli, R. (2006). Shake, rattle, and… one or two objects? Young infants' use of auditory information to individuate objects. *Infancy, 9*(1), 97-123.

Winawer, J., Witthoft, N., Frank, M. C., Wu, L., Wade, A. R., & Boroditsky, L. (2007). Russian blues reveal effects of language on color discrimination. P*roceedings of the National Academy of Sciences*, 104(19), 7780-7785.

Wynn, K. (1990). Children's understanding of counting. *Cognition, 36*(2), 155-193.

Wynn, K. (1992). Children's acquisition of the number words and the counting system. *Cognitive psychology, 24*(2), 220-251.

Wynn, K. (1992). Evidence against empiricist accounts of the origins of numerical knowledge. *Mind & Language, 7*(4), 315-332.

Wynn, K. (1995). Infants possess a system of numerical knowledge. *Current Directions in Psychological Science*, 172-177.

Xu, F., & Carey, S. (1996). Infants' metaphysics: The case of numerical identity. *Cognitive psychology, 30*(2), 111-153.

Xu, F. (1999). Object individuation and object identity in infancy: The role of spatiotemporal information, object property information, and language. *Acta psychologica, 102*(2), 113-136.

Xu, F. (2002). The role of language in acquiring object kind concepts in infancy. *Cognition, 85*(3), 223-250.

Xu, F., Carey, S., & Quint, N. (2004). The emergence of kind-based object individuation in infancy. *Cognitive Psychology, 49*(2), 155-190.

Xu, F., & Baker, A. (2005). Object individuation in 10-month-old infants using a simplified manual search method. *Journal of Cognition and Development, 6*(3), 307-323.

Xu, F., Cote, M., & Baker, A. (2005). Labeling guides object individuation in 12-month-old infants. *Psychological Science, 16*(5), 372-377.

Xu, F. (2007). Sortal concepts, object individuation, and language. *Trends in cognitive sciences, 11*(9), 400-406.

Xu, F. (2010). Count nouns, sortal concepts, and the nature of early words. *Kinds, things, and stuff: new directions in cognitive science, 13*.