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Animal Cognition

ISSN 1435-9448

Anim Cogn
DOI 10.1007/s10071-020-01436-6

Springer

Animal Cognition
https://doi.org/10.1007/s10071-020-01436-6

ORIGINAL PAPER

The role of linguistic experience in the development of the consonant bias

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Received: 12 June 2020 / Revised: 18 September 2020 / Accepted: 26 September 2020

Abstract

Consonants and vowels play different roles in speech perception: listeners rely more heavily on consonant information rather than vowel information when distinguishing between words. This reliance on consonants for word identification is the consonant bias Nespor et al. (Ling 2:203–230, 2003). Several factors modulate infants' development of the consonant bias, including fine-grained temporal processing ability and native language exposure [for review, see Nazzi et al. (Curr Direct Psychol Sci 25:291–296, 2016)]. A rat model demonstrated that mature fine-grained temporal processing alone cannot account for *consonant bias* emergence; linguistic exposure is also necessary Bouchon and Toro (An Cog 22:839–850, 2019). This study tested domestic dogs, who have similarly fine-grained temporal processing but more language exposure than rats, to assess whether a minimal lexicon and small degree of regular linguistic exposure can allow for consonant bias development. Dogs demonstrated a vowel bias rather than a consonant bias, preferring their own name over a vowel-mispronounced version of their name, but not in comparison to a consonant-mispronounced version. This is the pattern seen in young infants Bouchon et al. (Dev Sci 18:587–598, 2015) and rats Bouchon et al. (An Cog 22:839–850, 2019). In a follow-up study, dogs treated a consonant-mispronounced version of their name similarly to their actual name, further suggesting that dogs do not treat consonant differences as meaningful for word identity. These results support the findings from Bouchon and Toro (An Cog 2:839–850, 2019), suggesting that there may be a default preference for vowel information over consonant information when identifying word forms, and that the consonant bias may be a human-exclusive tool for language learning.

Keywords Canine cognition · Consonant bias · Dogs · Speech perception

Introduction

If someone is telling you a story about an animal they saw recently, a *dunkey,* would you assume they are referring to a *monkey* or *donkey*? Both *monkey* and *donkey* refer to animals, and both differ from *dunkey* by one sound. Despite the similarities between these potential animal names, adults do not treat these possibilities as equally likely. Instead, they are more likely to assume that a *dunkey* refers to a donkey, rather than a monkey (Cutler et al. 2000). They will more readily accept a mispronunciation and access the intended target word when the mispronounced word differs in vowel and retains consonantal information (as in dunkey–donkey) than when it keeps the same vowel but differs in the consonant (as in monkey–dunkey). This greater reliance on consonantal information, in both identifying and learning words, is known as the *consonant bias*.

The *consonant bias* is a reliable finding in adults across different language backgrounds and in many different tasks (Cutler et al. 2000, for Spanish and Dutch; van Ooijen 1996, for English). Indeed, its consistency in adults has led researchers to theorize that the two major speech sound categories in language, consonants and vowels, serve different purposes for speech perception (Nespor et al. 2003). Vowels provide more information about prosody and speaker identity, while consonants play a large role in determining word identity.

Studies suggest that the consonant bias emerges over the course of development (Delle Luche et al. 2014; Højen and Nazzi 2016; Nazzi, Floccia et al. 2009; Poltrock and

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Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10071-020-01436-6) contains supplementary material, which is available to authorized users.

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Nazzi 2015), with very young infants typically showing the opposite pattern (a vowel bias; Bouchon et al. 2015). It is not entirely clear what drives these developmental changes. It is thought that linguistic experience is a necessary and important factor, since children raised in different language environments show different developmental patterns (e.g., Nishibayashi and Nazzi 2016; Højen and Nazzi 2016). Yet, while language exposure appears necessary for the development of the consonant bias, it is unclear whether this change can be achieved by accumulated exposure to the acoustic structuring of the input, or whether consonant bias development relies on the linguistic representations that infants develop as a result of this language exposure. Additionally, some have argued that auditory development (particularly in the area of temporal resolution) may also play a critical role in the development of the consonant bias (Poltrock and Nazzi 2015). Since linguistic and auditory development are both occurring in tandem in typically developing infants, it is difficult to assess the effect of linguistic experience alone, and determine how much exposure is required to support the emergence of the consonant bias in infants.

To attempt to unravel these different causal factors, the current study uses a dog model to examine whether dogs' linguistic experience and minimal lexicon are sufficient for consonant bias development. Other non-human animals, without regular exposure to human language, typically show a vowel bias, akin to that initially shown by young infants (Bouchon and Toro 2019). Bouchon et al. (2019) discussed the possibility that "given other appropriate experience and exposure to speech, a consonant bias would emerge in non-human animals" (p. 848). However, it is also possible that non-human animals do not possess the appropriate linguistic representations of words to develop a consonant bias, regardless of linguistic exposure. The adult domestic dog, a pet with a mature auditory system and long-term, natural exposure to language, provides an appropriate and useful model to assess whether regular exposure to language in addition to a limited lexicon is enough to spur the development of the consonant bias. We examined dogs' differential use of two categories of sounds in language, consonants and vowels, to determine word identity. By characterizing dogs' word representations, we can better understand what aspects of language can be learned through exposure to language via shared auditory processing capabilities, and what patterns can be uniquely attributed to the human linguistic system. Learning how dogs represent and perceive words can also better inform training practices for working dogs as well as companion animals.

Consonant bias in human infants

While the consonant bias is a reliable finding in adult humans, it is unclear at what point the consonant bias emerges in development. Very young infants tend to show a vowel bias (Bouchon et al. 2015; Hochmann et al. 2018), suggesting that the consonant bias emerges either with experience or maturation. The vowel bias makes sense logically as a starting point: vowels are typically longer and louder than consonants (Ladefoged 2001), and thus are more acoustically salient for infants (Mehler et al. 1996). An alteration to a vowel should then be more noticeable perceptually for infants, all other things being equal. However, a shift from a vowel to a consonant bias appears to occur relatively early in development. In word recognition tasks, studies have found a consonant bias in French, Spanish, and Italian infants before 12 months of age (Bouchon and Toro 2017; Hochmann et al. 2011; Poltrock and Nazzi 2015).

Despite the relatively consistent pattern seen in French, Italian, and Spanish infants, the emergence of the consonant bias varies cross-linguistically. This suggests that the consonant bias is modulated by native language exposure. English-learning infants only reliably show a consonant bias at 30 months of age (Delle Luche et al. 2014), and there are inconsistent results in word recognition tasks, with some suggesting that English infants demonstrate a consonant bias at 14 months (Ballem and Plunkett 2005), while others show that 15 month olds do not (yet) demonstrate this bias (Mani and Plunkett 2007). It is possible that this difference between French and English infants is due to the wide variety of accents present in Great Britain (where all prior studies of the consonant bias in English-hearing infants were conducted). As such, infants may have been tested with a voice that had an unfamiliar accent, which would make it harder for the infants to comprehend the speech they heard. As a result, it is unclear whether infants are not demonstrating the consonant bias due to difficulty comprehending the stimuli, or whether they genuinely do not develop this bias until they are much older than the French infants.

Danish infants are a particularly unique case with regard to this cross-linguistic variation. French and English both have many more consonants than vowels, resulting in these languages having more minimal pairs that must be distinguished by their consonants than ones that must be distinguished by their vowels (Hochmann et al. 2011). (Minimal pairs are pairs of words that differ by only a single phoneme; thus, *cat* and *mat* are minimal pairs that differ in their consonants; *cat* and *cut* are minimal pairs that differ in their vowels.) Danish as a language features more vowels than consonants, and the consonants are often underarticulated, which further increases the utility of vowels for word identification. This may be why Danish infants fail to demonstrate a consonant bias entirely and instead demonstrate a vowel bias at 20 months in a word-learning paradigm (Højen and Nazzi 2016).

In addition to native language exposure, theories have suggested that the development of the auditory system also aids in the emergence of the consonant bias (Poltrock and Nazzi 2015). One theory behind the emergence of the consonant bias in infants, the acoustic–phonetic hypothesis (Floccia et al. 2014), suggests that the consonant bias emerges in infants due to exposure to both the different acoustic and phonetic properties of vowels and consonants. First, the consonant bias may begin to emerge due to the development of better temporal resolution in the auditory system, which allows for better perception of (often quickly changing) consonantal information. Second, the consonant bias emergence is accelerated by the acquisition of native phonemic categories, which better indicate to the infants what consonants are informative in their language. Thus, this theory suggests that the emergence of the consonant bias may be driven by both auditory and linguistic development.

Another theory of consonant bias development, the lexical hypothesis (Keidel, Jenison, Kluender, and Seidenberg 2007), focuses on the structure of the acquired lexicon. It suggests that as infants learn more words, the distributional information they learn about the words highlights the importance of consonantal information for word identity. This would then lead to privileged processing of consonants in comparison to vowels in languages with more consonantal minimal pairs.

One way to test these theories experimentally would be to hold auditory development constant while providing different amounts of linguistic experience to different individuals. For obvious ethical reasons, this approach cannot be taken with young infants. However, it can be implemented in non-human animals, who have mature auditory processing capabilities, can gain language exposure naturalistically or in experimentally controlled conditions, and can be taught word forms. In this fashion, we can evaluate competing theories concerning the effect of linguistic experience as well as the size and structure of the lexicon on consonant bias development. If the consonant bias depends on having linguistic representations of the sort found in humans, then no amount of exposure will be sufficient for an animal to show this bias. However, if the bias depends instead on exposure to language and stored representations of lexical items, it could develop in animals who are regularly exposed to, and learn from, human language.

Previous animal models

Prior work has examined whether rats would show privileged processing of consonantal information (Bouchon and Toro 2019). Laboratory rats are a basic test case, as they have a mature auditory system but no linguistic system nor any long-term linguistic exposure to human speech. The authors argued that if rats showed a consonant bias, it would indicate that distinguishing between the physical and perceptual aspects of vowels and consonants alone allows listeners to determine that consonantal sounds are more useful for establishing word identity (Bouchon and Toro 2019). Rats were trained to nose-poke a feeder when they heard trained word forms. Researchers then compared the number of times the rats nose-poked the feeder when presented with a trained word versus a novel word form. Two other item types were also tested: a consonant mispronunciation and a vowel mispronunciation of the trained word forms. The study concluded that rats demonstrated a vowel bias, in which the rats treated consonant mispronunciations more like familiar trained words than vowel mispronunciations (i.e., treating the consonant mispronunciation *pano* more similarly to the trained word *mano* than the vowel mispronunciation *mino*). This is a similar pattern to results seen in young infants, where it is interpreted as a vowel bias. Together, these studies show the importance of language exposure on the emergence of the consonant bias (Delle Luche et al. 2014; Højen and Nazzi 2016; Nishibayashi and Nazzi 2016; Poltrock and Nazzi 2015).

The use of laboratory rats, who did not have any linguistic exposure prior to their word training sessions, only allowed for the conclusion that auditory processes alone are not sufficient for the consonant bias. This result is consistent with that of previous infant studies, which have demonstrated the importance of language exposure in the emergence of the consonant bias (Delle Luche et al. 2014; Højen and Nazzi 2016; Nishibayashi and Nazzi 2016; Poltrock and Nazzi 2015). Given the results of Bouchon's study and prior infant studies, the consonant bias requires some degree of linguistic experience, but it is unclear to what degree more mature linguistic processing (in the form of phonological representations or a lexicon of a specific size and structure) is needed in comparison to mature auditory processing. It is possible that with the appropriate linguistic exposure, animals may develop a consonant bias (see Perez et al. 2013 for vowel and consonant differentiation in animals).

A domestic dog model of consonant bias emergence

The domestic dog is a better animal model for testing the consonant bias, with two major advantages over the previous rat model. First, canine hearing is much more comparable to humans in their frequency discrimination and fine-grained temporal resolution (Bach et al. 2016), suggesting that they would be sensitive to many of the same cues for consonants and vowels as would young children. Second, dogs (at least in the US) are typically kept as pets within a human household, where they are naturally exposed to language input. This occurs both ambiently (from humans talking to one another in their environment) and from speech directed towards them (Burnham, Kitamura, and Vollmer-Conna 2002). To test whether linguistic exposure is sufficient for the emergence of a consonant bias, it is necessary to select a model organism that receives persistent human language input over a long period of time, and can learn words from that language. The domestic dog is an ideal choice. Testing dogs allows for an examination of the contribution of linguistic experience and lexicon size and structure while controlling for auditory development.

The domestic dog has been an important model species for comparative work in recent years, including in studies of human speech perception (Andics et al. 2014; Mallikarjun et al. 2019b). Through domestication, they have been selected across thousands of years to be attentive to human communicative behaviors (Hare, Brown et al. 2002); these include gaze, pointing gestures, and speech (Hare et al. 2010; Horowitz 2009; Miklösi et al. 1998).

Dogs are not only exposed to and attend to language in their environment, but they also learn individual words (Griebel and Oller 2012; Kaminski et al. 2004; Pilley and Reid 2011). Some dogs may even acquire vocabularies that are similar in size to those of young children (Pilley and Reid 2011). However, even dogs without special linguistic training have been shown to learn a number of different words. Pet dogs can recognize several commands, even at a young age (Kutsumi et al. 2012). Some of the words in a pet dog's lexicon are taught directly to the dog, like commands, and some the dog picks up via association (i.e., the dog learns that *walk* means they will go outside, because that is what usually happens when the owner says *walk*). Thus, if possessing a lexicon is a prerequisite for shifting to a consonant bias (Keidel et al. 2007), pet dogs may show this bias.

Moreover, pet dogs have been shown to learn properties of their most-often-heard, or "native", language. Studies from our lab have shown that dogs can differentiate their "native" language from unfamiliar languages that differ in rhythm and phonology, indicating that they have some awareness of the underlying features of their "native" language (see Mallikarjun et al. 2019a). This, too, suggests that dogs may have the linguistic exposure necessary to demonstrate a consonant bias.

Given dogs' mature auditory abilities in conjunction with their linguistic exposure, testing dogs' detection of consonant and vowel mispronunciations can help determine whether a smaller amount of linguistic exposure can support the emergence of the consonant bias. Conveniently, dogs can be tested using an identical method to one used to evaluate the consonant bias in infants, the Headturn Preference Procedure (HPP). HPP is an experimental paradigm generally used to test infants on their preferences for different auditory signals. In one study of the consonant bias in young infants using HPP as a method, infants' preferences were compared across two types of stimuli: their own name, and either a version of their name with the initial consonant in the stressed syllable mispronounced, or a version of their name with the vowel in the stressed syllable mispronounced (Bouchon et al. 2015). This same HPP approach has been used to demonstrate dogs' recognition of word forms (Mallikarjun et al. 2019b); dogs were presented with their name or another dog's name as spoken by an unknown voice, and showed longer listening to their own name. In this study, dogs were presented with their own name or a mispronounced version, akin to the stimuli in Bouchon et al. (2015). This allows for an evaluation of whether dogs, with their linguistic exposure and limited lexicon, show a consonant bias, like adult humans and toddlers, or a vowel bias, like both young infants and rats.

Experiment 1: dogs' preference for name with a vowel or consonant mispronunciation

This study tests dogs' preference for their own name over their name with a mispronounced vowel or consonant in the initial (stressed) syllable. French and Italian infants can detect vowel mispronunciations in their name several months before they can detect consonant mispronunciations (Bouchon, et al. 2015; Hochmann, et al. 2018). Researchers suggest this is because vowels are more salient than consonants: they are louder, longer, continuous, sonorant, and more periodic in structure (Cutler and Mehler 1993). As such, young infants may primarily focus on acoustic salience to differentiate word forms. Although similar studies have not been done with young infants in other language backgrounds, the presumption is that this early focus on acoustic salience would be universal across infants from all backgrounds. That is, young infants' low linguistic exposure, lack of native phonological categories, and poor temporal auditory processing skills would lead to infants of all language backgrounds to initially demonstrate a vowel bias; only with sufficient exposure to input prioritizing consonantal information would children's processing shift towards a consonant bias.

We expect that dogs will generally prefer to listen to their name over a mispronounced version, but this may vary depending on the type of mispronunciation. If dogs have a consonant bias, we would expect to see an interaction in which they show a stronger preference for their name in comparison to the version with a mispronunciation on the consonant than in comparison to the vowel mispronunciation.

If instead, like the 5 months old in Bouchon's study, dogs primarily rely on acoustic salience to distinguish between words and have not developed a consonant bias, we would expect that they have a stronger preference for their name in comparison to the vowel mispronunciation rather than in comparison to the consonant mispronunciation.

Methods

Participants

Forty-four dogs (23 M) participated. To be included in the study, dogs must have had their name for at least ten months prior to participating. We excluded any dogs that were taking psychiatric medication, and dogs whose owners noticed signs of hearing loss. On average, the dogs were 5.1 years old, and had been hearing their name for 4.8 years. Twelve of these dogs were therapy dogs, five were search-and-rescue dogs, and two were service-dogs-in-training. Only dogs with one-syllable or two-syllable trochaic (stressed–unstressed) names were included in this study. Thus, mispronunciations always occurred in an initial, stressed syllable.

Twenty-two dogs (11 M) participated in the Vowel Mispronunciation condition of this experiment, and twenty-two dogs (12 M) participated in the Consonant Mispronunciation condition of this experiment. Three additional dogs were tested but were excluded from the study: one due to experimenter error, and two due to noncompliance (e.g., failure to orient to sounds, falling asleep).

Test materials

Prior to the study visit, each dog owner was asked the name or nickname that their dog is most commonly called; this was used as the dog's name in the study. Every dog heard four different trial types: his or her name, a mispronounced version of his or her name, a foil name that shares minimal phonetic characteristics with his or her name, and a mispronounced version of the foil name. The owners also provided a list of the dogs' commonly called nicknames, such that we could avoid the use of foils that the dog has heard before, and could avoid testing dogs that hear the mispronounced version of their name that we would use for their study.

Including a mispronounced version of the foil name ensures that, regardless of whether dogs notice a phonetic difference or not, there are equivalent numbers of trials that are familiar to the dog (i.e., dog's name, and potentially the mispronounced name) in comparison to trials of any given name that is perceived as novel. (That is, if dogs in the Vowel Mispronunciation condition ignore vowel differences, they hear half of the trials with their name and half without; if they do not ignore these differences, they hear ¼ of the trials with their name and ¼ of the trials with each of the other three names.)

Twenty-two of the dogs heard a mispronounced name in which two or three features of the vowel in the stressed syllable were changed. Tense/lax features were maintained, and height and frontness were always changed. However, English correlates roundness with frontness/backness, so rounding was changed when necessary to maintain natural English phonemic categories (Table 1).

In the other condition, twenty-one dogs heard a mispronounced name in which two features of the onset consonant were changed. The mispronounced consonant version of the name kept manner the same, changed place, and changed voicing (Table 1). By mistake, one dog heard a mispronounced name in which only one feature, voicing, was changed. Below, we run the analyses with and without this dog, and it does not change the results of our study.

Other than the single dog with one feature change, only dogs with names that began with a stop, fricative, or affricate participated in this study, so that it would be possible to always change place and voicing. Dogs with names beginning with a nasal or approximant did not participate in the consonant study.

There were a few differences in the stimuli for this study and the infant name stimuli from Bouchon et al. (2015). First, instead of changing the first phoneme of the participants' name, we changed the vowel or consonant in the first syllable of the dog's name. To consistently change the first phoneme of the infants' names across conditions, in Bouchon et al. (2015), the infants that participated in the Vowel condition had vowel-initial names, and the infants that participated in the consonant condition had consonant-initial names. This would have been difficult for our study, because there were very few dogs visiting the lab who had a vowel as the first phoneme of their name (approximately 8% of the total dogs that have visited since the inception of the lab). As such, it would take much longer to finish the vowel condition if we tried specifically to test only dogs with vowel-initial names. We elected instead to change the vowel or consonant in the initial syllable, so there would be a greater number of dogs that could participate in both conditions.

Second, we used a larger number of feature changes in this study than in the infant studies from Bouchon (2015), because we were initially unsure whether dogs would respond to a single-feature change in either vowels or consonants. For this reason, we wanted to change more features to ensure that the change would be salient for the dogs. As such, the number of features changed in this study was more similar to the number of features changed in Bouchon's rat study (2019) rather than the infant study.

Four different female native English speakers produced recordings for this study. For each condition (vowel mispronunciation and consonant mispronunciation), two speakers

Table 1 Vowel and consonant mispronunciation

Original Consonant	Consonant used in mispronounced name
p	d
b	t
t	b
d	p
k	d
g	t
f	ð
v	θ
s	ʒ
z	ʃ
dʒ	tʃ

Original vowel	Vowel used in mispronounced name
i	o
eɪ	u
ɛ	ʊ
æ	ʊ
u	eɪ
o	i
ɑ	eɪ
ɑi	ɑu

recorded for six dogs and two speakers recorded for five dogs each. To minimize the possibility that speakers would unintentionally produce the dog's name in a more attractive manner than foil names, speakers were given names to record in sets, and were kept blind to which dog name(s) in each set would serve as a target name. Additionally, correctly pronounced and mispronounced names were intermixed within each set of names, to ensure that they were produced as similarly as possible. To obscure which names belonged to which category to the greatest extent possible, no mispronunciation was given in the same set as its corresponding correct pronunciation (to prevent speakers from attempting to guess which name was more likely). Because dog names in the US are highly diverse ("Most popular U.S. pet names" 2019), the names that were mispronounced and those that were not were likely less obvious to speakers than in analogous studies with infants. Recordings were made in a sound-attenuated room using a Shure SM51 microphone with a sample rate of 48 kHz and bit depth of 32.

For each participant, one of the four speakers would record lively, dog-directed speech of the dog's name, mispronounced name, foil, and mispronounced foil. Each dog heard only one speaker produce all four of their trial types. A total of 15 tokens were selected out of each of the original recordings. The name, mispronounced name, foil, and mispronounced foil tokens were chosen to match each other as closely as possible for pitch, duration, intonation contour, emotionality, and vocal quality, based on perceptual similarity. There was an initial silence of 0.5 s before the first name was spoken. Pauses between tokens of dog names were adjusted, such that each file had the same overall duration of 22 s. Because pauses could vary in length based on the exact length of name tokens, and the overall amount of silence could vary slightly across files, matching for amplitude was performed by considering only the speech within the stream rather than the entire length of 22 s. Silent pauses were removed from a copy of the stream and the resulting file (containing only the speech) was adjusted to match a set average RMS amplitude; subsequently, the original stream containing pauses was amplified by the same amount. In this way, the speech within the name streams was always matched for average amplitude.

Apparatus

The testing apparatus was identical to that described in Mallikarjun et al. (2019b). The experiment took place in a six-foot by six-foot three-sided test booth with 4-foot-high walls made from pegboard. To ensure that the dog could not see the researchers over the booth, a curtain hung from the ceiling to the top of each of the booth walls. On the front wall of the booth, there was a hole for a camera. The camera recorded the testing sessions and allowed the coder to see the dog's behavior inside the booth via a computer monitor. In the center of the panel, above the camera, a light was mounted. The side walls each had a light mounted in the center and a speaker directly behind the light. These speakers played stimuli for the dog. A Mac computer was used by the researcher behind the front wall of the booth for coding. The researcher used a button box to start trials and code the dog's looking behavior.

Procedure

The dog and his or her guardian were brought into the booth by an experimenter and the guardian signed consent forms. The dogs sat on the owner's lap or directly in front of the owner, depending on their size and what made them the most comfortable. The dogs initially either sat facing towards the front of the booth (towards the camera) or facing the back of the booth (towards the owner). In either case, the dogs' attention was maintained as much as possible at a point equidistant from the two sides of the booth (where the loudspeakers were located). As a result, the dog's natural inclination upon hearing a sound through one of the two loudspeakers was to turn their head or body 90° to face the source of sound. There were two practice trials, one from each of the two speakers on the sides of the booth, to familiarize the dogs with the procedure. It is common to use more than two practice trials in this paradigm for infant studies (e.g., Newman 2005; 2009), but dogs can become easily distracted and lose interest quickly with more practice trials, so only two were used here. The practice trials featured a happy, friendly female voice talking to and praising the dog. This voice was never used as a target voice in the test trials.

The test phase began immediately after the practice trials. Dogs heard four types of stimuli: repetitions of their own name, a foil name, their name with a mispronunciation, and the foil name with a mispronunciation. Each stimulus type was heard on four separate trials for a total of 16 trials, presented in four, four-trial blocks (one of each type of trial per block). Order of trials within each block was randomized. Two experimenters ran the test phase portion of the study: one to code the dog's looks (the coder) and one to produce auditory attention getters (the attention experimenter). The auditory attention getters consisted of scratching noises, knocking, whistling, and squeaky dog toy sounds.

At the start of each test trial, the light on the front of the booth turned on, and the attention experimenter made a sound to get the dog's attention to the front of the booth. Although work with infants typically uses only lights as attention getters, pilot work suggested that the light alone was not sufficient for most dogs. The light also served as the apparent "source" of the sound for the dog, and helped the coder code the dogs' looks to the sound source. Once the dog attended to the front, that light turned off, the light on either the left or right side of the booth turned on, and the attention experimenter made a sound on that side. Once the dog attended to that side, the stimulus for that trial began to play from the loudspeaker on that side. The coder wore Peltor aviation headphones playing masking music, so she would not be able to hear the trials and have that influence her coding, and used a button box to code the dog's looks towards and away from the sides. The stimulus continued to play for a full twenty-two seconds or until the dog looked away for two consecutive seconds, whichever occurred first. Dogs' listening time was judged by the amount of time they spent looking at the sound source (the wall behind which the speaker was mounted)—see *Coding,* below, for more information on our coding procedures. Any time the dog spent looking away was subtracted from the dog's overall looking time.

Coding

The coding procedure to determine whether the dog was attending to the correct side was derived from the infant HPP procedure, with some small modifications. In original infant HPP studies, the coder pressed a button if the infant turned their head at least 30° towards the stimuli source, which is marked by a flashing light (Kemler Nelson et al. 1995). However, most infants turn their heads much more than 30° and often look directly at the flashing light, which is between 60 and 90° from center. Our prior studies have shown that dogs will not look directly at the light as the source of sound, but rather anywhere on the wall where the speaker is located. As such, we instructed coders to start the trial whenever the dog turned between 45 and 135° from center towards the wall where the speaker was located. Thereafter, the coder was instructed to judge whether the dog was attending to the sound based both on the direction of their gaze and on other indicators of attention, such as pricking of the ears, tail wagging, and positioning their body towards the stimuli source; the coders were trained to look for these cues as well to help determine when the dog was attending to the source of sound. While HPP coding does require a judgement call by the live coder, we find a high rate of inter-coder reliability. A Pearson's correlation shows a correlation coefficient of 0.91 between the original coder and a second coder over ten dogs selected from this study and the following study. Two of the dogs had been randomly selected to do a reliability analysis for a different paper. These two dogs were included, as well as eight additional dogs that were randomly selected for a total of ten dogs. This is similar to the correlation coefficients seen in infant studies (0.92, Fernald 2016; 0.95, Gerken et al. 1994; 0.94, Jusczyk et al. 1993).

Results and preliminary discussion

A 2 × 3 mixed ANOVA was used to test the effect of Condition (Vowel, Consonant) and Item (Name, Mispronounced Name, Foil) on listening time. The Foil and Mispronounced Foil were combined into a single category (Foil), as they were both equally unfamiliar to the dog. We found no main effect of Condition, $F(1, 43) = 1.05$, $p. = 0.31$, or Item, $F(2, 43) = 1.06$, $p = 0.351$, but did find a significant interaction between Condition and Item, $F(2, 43) = 4.099$, $p = 0.02$. To determine the nature of this interaction, individual 1 × 3 within-subjects ANOVAs were conducted in each condition.

For the dogs in the Vowel condition, a 1 × 3 within-subjects ANOVA was used to test the effect of Item (Name, Mispronounced Name, Foil) on listening time. We found an overall effect of Item, $F(1, 21) = 4$, $p = 0.056$. Dogs listened longer to Name trials (7.37 s) than the Mispronounced Name (5.57 s; $t(21) = 2.66$, $p = 0.015$) or Foils (5.91 s; $t(21) = 2.288$, $p = 0.033$). Additionally, the foil and the mispronounced foil, which were averaged together in this analysis, did not differ from each other [$t(21) = -0.008$, $p = 0.994$]. Figure 1 shows a graph of these results. Like young infants and rats, dogs are treating a change in vowel as though it changes the meaning of a word.

For the dogs in the Consonant condition, a 1 × 3 within-subjects ANOVA was used to test the effect of Item (Name, Mispronounced Name, Foil) on listening time (see Fig. 2

for a graph of the results). We found no effect of Item, F(1, 21) = 0.981, $p = 0.383$. This suggests that dogs may not notice a change in consonant, much like young infants (Bouchon et al. 2015) and rats (Bouchon and Toro 2019).

There was a single dog in the Consonant condition with only one feature change to create the mispronounced name rather than two feature changes. When this dog is removed, the results of the analysis do not change (no effect of Item, F(1, 20) = 1.45, $p = 0.247$).

However, there is one aspect of these results that is surprising: not only did dogs not prefer their name over the version with a consonant mispronunciation, they also did not prefer their name over the foils, which clearly differed in many ways from their own name.

One possibility is that dogs may consider the mispronunciation to be the actual equivalent of their name. That is, the dogs may not be able to perceive the mispronunciations. If so, they would hear only two trial types in this study, Name trials and Foil trials, as opposed to the four different types of trials, Name, Foil, Name Mispronounced, and Foil Mispronounced, that we anticipated they would perceive. This could lead them to get bored much more quickly in the study; instead of hearing each of four trial types four times, they perceived each of the two trial types eight times each.

If this were the case, one might expect that the first two blocks (the first 4 repetitions of each of the two perceived names) would show an effect, even if the full experiment did not. (That is, since dogs in the vowel condition showed a name vs. foil preference with four repetitions of each item, as did dogs in Mallikarjun et al. (2019b), we might expect the dogs in the current study to do likewise.) We therefore examined dogs' preference in just the first two blocks of this experiment to see if they showed the basic preference for their name over a foil name (see Fig. 3). We did this analysis two ways: first, using the same 1 × 3 within-subjects ANOVA we used before (Name, Mispronounced Name, Foil), and second, collapsing name and mispronounced name, and comparing this to the combination of foil and mispronounced foil. We found no effect in either case (1 × 3 ANOVA: F(2, 40) = 0.799, $p = 0.457$; t test: t(41) = 1.05, $p = 0.3$). Thus even in the first two blocks, dogs in this study did not show a preference for their name over the foil name. It is not clear what to make of this pattern; it might suggest that dogs do not necessarily consider the name and mispronounced name or the foil and mispronounced foil to be equivalent. If the lack of preference for Name trials over Foil trials was just due to boredom because of perceived repetition, we would expect to see the Name preference in the earlier trials. Instead, we see no effect at all. Interestingly, we have seen this same pattern in other canine studies; for example, in Mallikarjun et al. 2019b, dogs heard their name and a foil name in quiet and their name and a foil name in the presence of background noise. When the noise level was low, dogs showed a preference for their name over the foil in *both* quiet and noise conditions. When the noise level was more intense, dogs not only stopped showing the preference for their name in noise, but also in quiet. Thus, it appears to be a relatively consistent finding that when a task becomes very difficult, dogs appear to "give up" on the study and look for short, equal periods towards all trials (Mallikarjun et al. 2019b). As such, the failure to show a preference for name over foil may be an indication that the inclusion of items that differ in only a consonant makes the task itself more difficult.

It is worth noting that there were two or three featural changes in the vowel items (Height, Front-Back, and

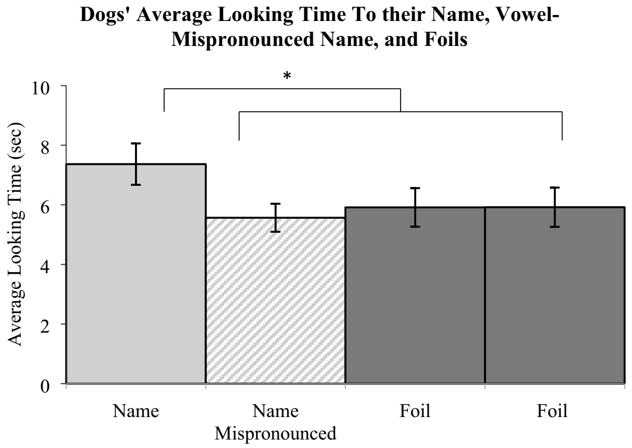

Fig. 1 A graph of dogs' average looking time in seconds to their name, their name with a vowel mispronunciation, and two foils (one foil was a mispronounced version of the other foil). Dogs preferred to listen to their name rather than the mispronounced name or foils. The error bars represent standard error

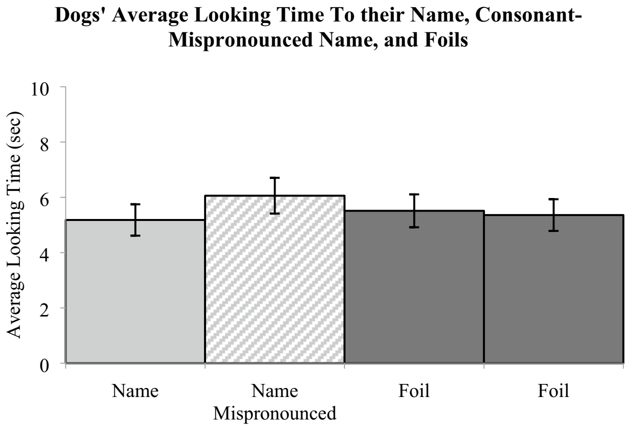

Fig. 2 A graph of dogs' average looking time in seconds to their name, their name with a consonant mispronunciation, and two foils (one foil was a mispronounced version of the other foil). Overall, there was no effect of Item (Name, Name Mispronounced, Foils). The error bars represent standard error

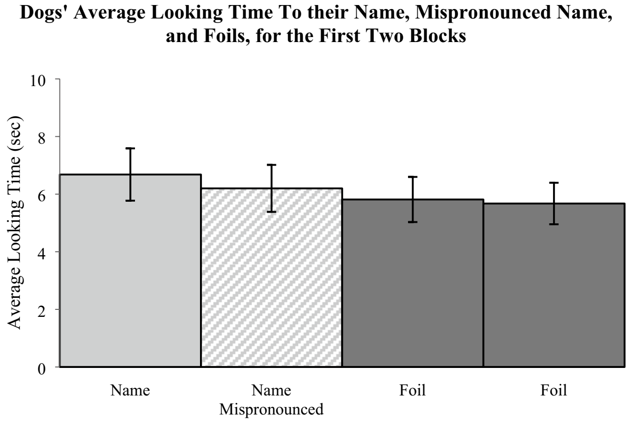

Fig. 3 A graph of dogs' average looking time in seconds for the first two blocks of the consonant condition to their name, their name with a consonant mispronunciation, and two foils (one foil was a mispronounced version of the other foil). The error bars represent standard error. Overall, there was no effect of Item (Name, Name Mispronounced, Foils)

sometimes Rounding) and only two in the consonant items (Place and Voicing). It is possible that the fewer feature changes in the consonant condition would make the consonant condition harder than the vowel condition. However, consonant categories are generally more acoustically distinct from each other than vowel categories. A spectral analysis with vowels and consonants done by Bouchon et al. (2015) indicated that, when normalized for duration and intensity, two contrasting consonants that differ in a single feature are more acoustically distinct than two contrasting vowels with a single-feature change, meaning that the two consonants are easier to distinguish from one another than the vowels, when taking duration and intensity aside. As a result, even with an additional feature change in the vowel mispronunciations, it is not necessarily the case that the consonants would be less acoustically distinct than the vowels.

Thus, the current results suggest that while dogs notice the difference between their name and one with a vowel change, they have more difficulty doing so when the names differ only in a consonant. Experiment 2 seeks to explore this issue more deeply, by examining whether dogs treat an item with a consonant mispronunciation as if it was their own name, in cases where discrimination among items is easier.

Experiment 2: preference for a name with a consonant mispronunciation in the absence of the correctly pronounced name

This study uses a different approach to determine whether dogs detect consonant mispronunciations in their name. The prior experiment suggests that while dogs prefer their name to one that has a vowel mispronunciation, they do not show a preference for their name compared to one with a consonant mispronunciation. This might suggest that the item with only a consonant mispronunciation is close enough to "count" as their name. In the current experiment, dogs are presented with the mispronounced version of their name and three foils; they never hear a correctly-produced version of their name. If dogs consider their consonant-mispronounced name to be more similar to their actual name than the foil names, we would expect them to listen longer to the mispronounced version of their name than the foils.

Methods

Participants

Twenty-two dogs (11 M) were tested in this study. We excluded any dogs that were taking psychiatric medication, and dogs whose owners noticed signs of hearing loss. On average, the dogs were 4.4 years old, and had heard their name for 4.2 years. Only dogs with one-syllable or two-syllable trochaic (stressed-unstressed) names were included in this study. Thus, mispronunciations always occurred in an initial, stressed syllable.

Three of these dogs were therapy dogs. Six dogs were excluded due to owner interference in the study (1), equipment error (1), and noncompliance during the study (4).

Test materials

The consonant-mispronounced version of the dog's name was created in the same manner as the consonant mispronunciation version of Experiment 1.

Unlike Experiment 1, this experiment does not utilize the dog's actual name. The stimuli the dogs heard consisted of the mispronounced version of the dog's own name, as well as three other dogs' names or mispronounced names that served as foils. The foils were selected to maximize perceptual dissimilarity between the consonants and vowels in the mispronounced name and the foil names. As such, 11 participants heard exclusively mispronounced foil names in addition to their own mispronounced name, and 11 participants heard a combination of correctly pronounced and mispronounced dog names in addition to their own mispronounced name; we assumed that dogs would not know whether other names were "standard" vs. mispronounced. (Since we do not tell our speakers which names are mispronounced and which are not, we do not anticipate that dogs will listen any longer to "real" names than mispronounced names.) The names were recorded and edited in the same manner as Experiment 1.

Apparatus

This study was run using the same method as the previous study (HPP), but the testing apparatus was moved to a different room and the software was updated (Newman et al. 2019). The setup remained almost identical, with three small changes: in this study, a GoPro was used instead of a low-light security camera to record the testing sessions, and a Windows computer instead of a Mac was used for coding. A keyboard, rather than a button box, was used to code the dogs' looking behavior.

Procedure and coding

Same as Experiment 1.

Results

A 1 × 2 within-subjects ANOVA was used to test the effect of Item (Mispronounced Name, Foil) on listening time. A main effect of Item was found, F(1, 21) = 6.01, $p = 0.023$, where dogs look longer at the Mispronounced Name (8.17 s) than the Foils (an average of 6.26 s over the three foils). Dogs prefer the mispronounced version of their own name to unfamiliar, phonetically dissimilar foil names. It is not possible with this study to distinguish whether dogs actually believe the mispronounced version of their name is their name, or can detect differences but decide to listen to the mispronounced name regardless. However, given that dogs have previously demonstrated the ability to distinguish between consonants that differ only in one feature (Adams et al. 1987), it is more likely that they can distinguish between this mispronounced name and their true name, but do not consider this difference meaningful.

These findings support the notion that dogs show a vowel bias, as they preferentially attend to vowel information in determining word identity. While dogs in Experiment 1 preferred listening to their own name rather than a version with a vowel mispronunciation, they did not do so for consonant mispronunciations, where the vowel remained the same but the consonant changed. Moreover, the current findings suggest that they do not perceive a change in a consonant to be a critical difference that changes the meaning of a word (making a word no longer a match to the representation of their own name). This supports the idea that non-human animals may not have the necessary lexical or phonological representations to develop a consonant bias (Fig. 4).

Overall discussion

The goal of this study was to assess in a domestic dog model whether linguistic experience and a small lexicon are adequate to support the emergence of the consonant bias. The results indicated that despite their linguistic experience, dogs did not demonstrate a consonant bias; they treated a version of their name with the initial consonant changed as essentially equivalent to their actual name. Instead, dogs showed a vowel bias, as they distinguished between their actual name and a version of their name with a change to the vowel in the stressed syllable. This is the same result seen in rats; Bouchon et al. (2015) found that rats similarly showed a vowel bias rather than a consonant bias. They argued that mature auditory processing in the absence of a lexicon or consistent linguistic exposure was not enough for consonant bias development. However, even with additional linguistic exposure, dogs fail to show a consonant bias. Evolutionarily, dogs' failure to show a consonant bias may not be a surprising result given rats' failure in Bouchon et al. (2015); rats are genetically more similar to humans than dogs, as rats and humans are both in the Superorder Euarchontoglires, while dogs are in the neighboring Superorder Laurasiatheria (Song et al. 2012). However, evolutionary closeness and genetic similarity to humans do not always imply a greater likelihood for an animal to demonstrate a specific behavior. Dogs have evolved in ways that make attending to human language functionally adaptive, and this convergent evolution could result in greater sensitivity to the different roles consonants and vowels play in communication.

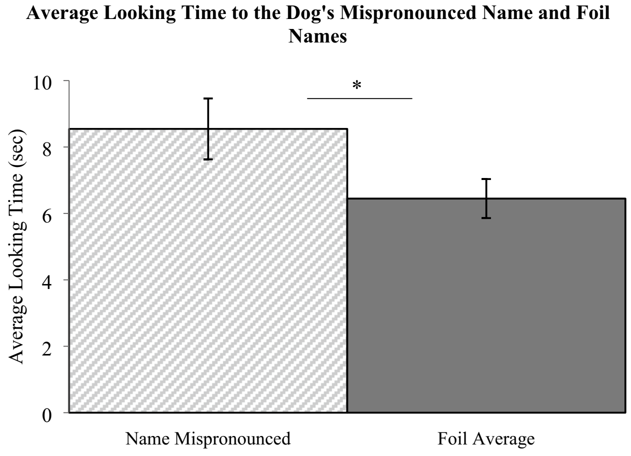

Fig. 4 A graph of dogs' average looking time in seconds to the consonant-mispronounced version of their name and an average of their looking time to three foils. Overall, dogs listened longer to the mispronounced version of their name than the foils. The error bars represent standard error

While young infants also demonstrate a vowel bias, like rats and dogs, infants generally switch from a vowel bias to a consonant bias between 8 and 15 months, depending on their native language (for a review, see Nazzi et al. 2016). Why do most infants eventually develop this consonant bias when dogs do not? During this time period of development, infants gain more language exposure, learn more word forms, develop their native speech sound categories, and improve their auditory processing abilities. While dogs' auditory processing abilities are mature, they likely differ from infants in the nature of the language exposure, the types of words that they learn, and in the process of developing speech sound categories.

While dogs, like infants, are often in an environment with a great deal of linguistic input, they are unlikely to listen to and process the input in the same way as infants. Dogs are certainly interested in human language, and have been shown to have specific brain regions for processing the emotional valence and words of human speech (Andics et al. 2014; 2016). However, human processing for lexical meaning is left-hemisphere biased, while dogs' processing for lexical meaning is right-hemisphere biased. Dogs also possess a specific area for processing of intonation cues, but this was localized in a different area than that of human intonation processing. While reasoning on the basis of neuroanatomical differences can be risky, these differences suggest that dogs' attunement to speech is likely not fully analogous to that of human infants. Moreover, dogs likely do not receive as much direct speech as infants (although the exact amount of speech directed to dogs on a daily basis is unknown) and may be less attuned to overheard speech. Recordings of speech directed to dogs in their homes and throughout their day will be needed to answer these questions.

Another potential reason why dogs might not develop a consonant bias is that pet dogs do not have a large enough or varied enough vocabulary. The lexical hypothesis suggests that knowledge of more words and different kinds of words leads to increased distributional information about consonants and vowels within the words (Bonatti et al. 2005); this in turn will help learners notice the importance of consonants for word identity. While most pet dogs know some words, they may not have a large enough vocabulary to trigger this reorganization. One way to explore this would be to look at the consonant bias in particular dogs that have been trained to have exceptionally large vocabularies. Indeed, there is some anecdotal evidence to suggest that dogs with large vocabularies may be more sensitive to changes in consonants. While the pet dogs in the current study failed to differentiate between their name and a version with a salient consonant change, Chaser, a border collie who knew over 1000 words, was able to differentiate between toys whose names were consonant minimal pairs (e.g., *tote* and *goat*) (Pilley and Reid 2011). Chaser also differentiated between toys with vowel minimal pairs (e.g., *boo* and *bow*), suggesting that this may represent a greater sensitivity to phonetic differences among consonants rather than a shift from a vowel focus to a consonant focus. Additionally, some of Chaser's known consonant minimal pairs differed by only a single feature, and some even had minimal pairs in non-stressed syllables (e.g., *odie* and *obie*). Thus, for at least one dog, a large vocabulary seems to correlate with more successful detection and learning of meaningful consonant changes within words.

It is possible that Chaser was able to learn this large number of object names because she could successfully treat these consonant changes as important for word identity. However, it is also possible that the pressure to learn the words led her to gain this ability. Thiessen and Yee (2010) suggest that experiencing phonemes in several different lexical contexts allows infants to better understand and notice the relevant phonemic contrasts. For example, hearing the d/t contrast in *duck* and *tummy* in the same vowel context might help infants detect the distinction between the minimal-pair words *bun* and *done*. Chaser's vocabulary contained a wide variety of sounds in different contexts. Her known words ranged from one to six syllables long, with varying stress patterns (e.g., *firecracker* and *gingerbreadman*). This variety of contexts may have helped Chaser learn to better differentiate consonant contrasts.

Another potential reason dogs do not develop a consonant bias is that dogs may not be able to learn native phonological categories for sounds in their ambient language; this would make it more difficult to differentiate between consonant sounds, and harder to identify the role of consonants in determining word identity. The acoustic–phonetic hypothesis suggests that the development of native phonetic categories, which makes it easier for infants to categorize native-language consonant sounds, provokes the switch from a vowel bias to a consonant bias (Floccia et al. 2014). This means that it would be easier for infants to realize that /k/ sounds produced by two different people are in the same sound category, while a /k/ and a /g/, even if produced by the same person, are different sound categories. In learning native phonetic categories, infants must also ignore phonetic sound categories that may be meaningful in other languages, but are not meaningful in their own. For example, an infant learning Hindi must recognize the distinction between a dental /d/ sound and a retroflex /d/ sound. An infant learning English would not need to learn this distinction, and would assimilate these two sounds into the same category. It is unknown whether any non-human species can narrow phonetic discrimination of sounds after exposure to a language to form a native language inventory (Yip 2006). Further experiments could assess whether dogs assimilate sounds that are not in their native language (given that

English-hearing dogs distinguish between vowels like [a] and [i], would they not perceive a difference between the Danish vowels [i], like in *beet*, and [y], a rounded version of that sound that is not a unique phoneme in English?) This would help determine whether dogs narrow their phonetic perception after prolonged linguistic exposure.

These results also may have relevance for dog owners and trainers. Since dogs have more difficulty differentiating between words that differ only in a consonant, auditory commands given to dogs, especially those that may not appear with a visual signal, should differ from one another in their vowels, or dogs may have difficulty distinguishing between them. If commands do differ in consonant alone, like *bow* and *down,* an accompanying visual signal can aid in differentiation; the current results suggest that without such a visual cue, such commands may be difficult for dogs to learn. Similarly, when selecting names for dogs, it would be best if these names differed from common commands or from names of other household members in their vowels, for ease of differentiation (e.g., having a dog named "Pitt," similar to *sit*, may be a poor choice, as would having two dogs named Rosie and Toby).

This study contributes to our understanding of the type of experience necessary for the emergence of a consonant bias in speech perception. Future studies will continue to explore the structure of speech input that allows for a consonant bias to emerge in infants, and whether, given similar input, nonhuman animals also develop a consonant bias. This will help to determine whether or not the consonant bias is a uniquely human phenomenon.

Funding This study was not funded by a grant.

Compliance with ethical standards

Conflict of interest Amritha Mallikarjun, Emily Shroads, and Rochelle S. Newman all declare that they have no conflict of interest.

Human and animal rights All applicable international, national, and institutional guidelines for the care and use of animals were followed. This study was approved by the University of Maryland Institutional Animal Care and Use Committee (approval code: 1034861–8).

Informed consents Informed consent was obtained from the owners of the dogs in the study. Informed consent was not required by the speakers who produced the dogs' names.

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