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The cocktail party effect in the domestic dog (*Canis familiaris*)

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Abstract
Like humans, canine companions often find themselves in noisy environments, and are expected to respond to human speech despite potential distractors. Such environments pose particular problems for young children, who have limited linguistic knowledge. Here, we examined whether dogs show similar difficulties. We found that dogs prefer their name to a stress-matched foil in quiet conditions, despite hearing it spoken by a novel talker. They continued to prefer their name in the presence of multitalker human speech babble at signal-to-noise levels as low as 0 dB, when their name was the same intensity as the foil. This surpasses the performance of 1-year-old infants, who fail to prefer their name to a foil at 0 dB (Newman in Dev Psychol 41(2):352–362, 2005). Overall, we find better performance at name recognition in dogs that were trained to do tasks for humans, like service dogs, search-and-rescue dogs, and explosives detection dogs. These dogs were of several different breeds, and their tasks were widely different from one another. This suggests that their superior performance may be due to generally more training and better attention. In summary, these results demonstrate that dogs can recognize their name even in relatively difficult levels of multitalker babble, and that dogs who work with humans are especially adept at name recognition in comparison with companion dogs. Future studies will explore the effect of different types of background noise on word recognition in dogs.

Keywords Dogs · Canines · Speech perception in noise · Hearing in noise

Introduction

Noise is ubiquitous in modern society: the sounds of airplanes, road traffic, and crowds can be found in most urban, public settings. A great deal of work has examined how adults cope with such environments, and more specifically their ability to understand speech in noisy settings. Yet adults are not the only ones facing this challenge, so too are both young children and our canine companions. How do dogs contend with noise when given commands from their owner, and what can this tell us about infant language comprehension in noise?

Dogs are an interesting population to study for several reasons. Dogs have co-evolved alongside humans to pay attention to human behavior. Dogs, like infants, pay attention to gaze, pointing gestures, and facial expressions, which all help dogs connect and communicate with humans (Albuquerque et al. 2016; Soproni et al. 2001). Their attentiveness extends not only to human behavior, but also human vocalizations. Dogs have brain regions specifically tuned to human vocal productions (Andics et al. 2014), as well as temporal area activation for human faces (Cuaya et al. 2016), and they use this information to determine emotional valence and meaning behind human language (Albuquerque et al. 2018, for emotion; Andics et al. 2016, for words). They are not only sensitive to humans' communicative behaviors, but also make communicative bids of their own, making eye contact with humans to demand attention and communicate their needs (Merola et al. 2012). Their direct ancestor, the wolf, does not do this, indicating that the domestication process and interactions with people have brought about this human-like behavior. Dogs' ability to recognize and respond to human communicative behaviors allows them to inhabit a number of roles in society, from companion animals in our homes to working as seeing-eye dogs, police dogs, search-and-rescue dogs, and more. Understanding dogs' ability to respond to human speech in difficult listening environments is important information for dog trainers, particularly for those who train service and working dogs,

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who must perform tasks in a variety of distracting environments and listening conditions. Dogs' social behaviors and attention to human communicative vocalizations and gestures also make them ideal for use in comparisons with human infants and children.

Cross-species comparisons for word recognition in noise are useful in shedding new light on the relative influences of linguistic experience and infants' various developing systems. In particular, investigating word recognition in a non-human species that does not acquire language in the same way young children do may help us to disentangle the contributions of auditory processing and attentional systems from linguistic processing. Despite a large body of research documenting infants' and children's difficulty listening in noise, it remains uncertain what factors contribute most to individual differences in performance on speech-recognition-in-noise tasks. While immaturity in the auditory processing system could explain infants' poorer performance at listening-in-noise tasks, infants' basic auditory abilities are already adult-like by 6 months of age (for a review, see Werner 2007). Their deficits could alternatively be explained by lack of cognitive maturity and relatively small linguistic and lexical knowledge, but it is difficult to tease apart these factors from auditory causes or from one another (Erickson and Newman 2017). Using an animal model to examine speech perception in noise can aid in distinguishing linguistic and auditory factors, as animals do not have complex linguistic systems like humans and would be most affected by auditory, cognitive and attentional issues in speech perception.

Dogs are particularly well suited for comparison with young children on speech-in-noise tasks. Dogs have the ability to quickly assign a label to a novel object and retain that connection in memory, as do young children (Kaminski et al. 2004). Work with individual dogs has suggested that some may acquire vocabularies that are similar in size to those of young children (Pilley and Reid 2011). Dogs have evolved alongside humans to be particularly attentive to human behaviors and are highly socially motivated, characteristics that are useful in adapting existing research tasks. Several classic paradigms originally designed for young children have been utilized with dogs with minimal modifications (particularly, tasks designed for preverbal children; see Fugazza and Miklósi 2014). For example, one study looked at dogs' numerical understanding using the same preferential-looking technique and study design as an earlier study that examined infant numerical understanding (West and Young 2002, for dogs; Wynn 1992, for infants). Another study that examined dogs' ability to recognize familiar human faces, dogs, and objects used a preferential looking paradigm in which the dogs were shown two images on a large television screen, similar to the design of many infant studies (Racca et al. 2010, for dogs; Rhodes et al. 2002, for face stimuli shown to infants).

The current work examines canine companion performance at understanding a spoken word in the presence of noise, using a very similar paradigm used to test infants' abilities. The ability to understand speech in the presence of noise is critical for both species. For dogs, this is most apparent when considering service dogs, who must face a number of different noisy environments with their handler. In cities, they will hear traffic, machinery, and constant low-level noise from pedestrians; it is also likely the case for pets, whose owners may call to them from a distance. Police dogs must also contend with gunfire, sirens, and loud voices. These noises can all compete for attention with the actual commands and tasks a service dog must perform, and if the dog does not pay attention properly, the dog can potentially endanger the handler. Anecdotally, these dogs perform very well in these situations and correctly complete their tasks when given commands from their handler. In this set of studies, we aim to quantify the level of background noise at which it becomes difficult for service dogs and pet dogs to pay attention to an important, salient word. We test dogs raised in a home environment, for whom attending to human speech is a natural behavior, as compared to dogs raised in a more impoverished laboratory setting (see Fugazza and Miklósi 2014, for more on this point).

In addition to exploring how well dogs can understand speech in these environments, the current study also serves as a useful comparison to young humans. Infants and young children are notably poorer at speech recognition and language processing in the context of background noise compared to adults. Infants have poorer auditory thresholds for speech than adults, meaning that they need speech to be louder than adults would typically need before they can detect it (Thehub et al. 1981). Greater speech intensity is also needed for infants to distinguish between speech sounds embedded in noise (Nozza et al. 1991, for quiet; Nozza et al. 1990, for noise). These limitations also occur when speech is in the presence of other environmental sounds (Polka et al. 2008) or background speech (Newman 2005, 2009; Newman and Jusczyk 1996). Infants between 5 and 8 months of age generally need the target speech to be louder than the background speech to comprehend it (Newman and Jusczyk 1996).

It remains unclear whether the source of such difficulties is purely the result of poor auditory and attention skills, or might also be affected by having a limited language system. While some have argued that attention is a critical factor (Erickson and Newman 2017), other evidence supports the role of language experience. For example, bilinguals perform worse than monolinguals at hearing-in-noise tasks, even if they are highly proficient in their languages, with data indicating that this deficit in performance may be due to slightly reduced experience with the language as compared to monolinguals (Schmidtke 2016). By comparing infant performance with that of dogs, we can gain a better understanding of the relative role of auditory and cognitive skills versus language-specific skills in infants' listening-in-noise difficulties.

Experiment 1: mild noise (+ 5dB SNR) versus quiet

To identify whether a listener can comprehend speech in the presence of noise, it is first critical to find a speech sound that the individual would comprehend in quiet. For this study, we utilized dogs' own names as the critical stimuli. These names were spoken by a novel talker, either in quiet or in noise, in a manner nearly identical to previous work with infants (Newman 2005, 2009). Although dogs often have a great deal of experience hearing their name, they generally only hear it spoken by a relatively small number of people. Using a novel talker meant that the dog would need to generalize their knowledge of their name across different speakers, as the person doing the recording would not sound identical to the way the dog normally hears its name. If dogs can recognize their own name when spoken by a novel talker, they should listen longer to this name than another dog's name when both names are presented in quiet.

If dogs succeed at this generalization task when presented in quiet, then by presenting these same names in the presence of noise, we can identify whether the noise is sufficiently distracting to limit their performance. Instead of using white noise or another artificial noise, we instead used a background of nine voices blended together. Multitalker babble such as this is a background noise that dogs may encounter in many situations when a crowd of people are present, like restaurant patios or in parks. We examined dogs' ability to separate and attend to target speech while there are multiple voices speaking in the background. By varying the difficulty level of the background noise, we can examine dogs' speech-in-noise abilities in conditions in which infants are successful or unsuccessful on this same task. To start with, we examined a relatively low level of noise, one that is akin to the ambient noise inside an urban home (McAlexander et al. 2015).

Participants

Twenty dogs (6 male) participated in the study. To be included, dogs must have had their name for at least 10 months prior to participating. We excluded any dogs that were taking psychiatric medication, and dogs whose owners noticed any signs of hearing loss. On average, participating dogs were 4.37 years old, and had been hearing their names for 3.97 years (i.e., the dogs had not been recently adopted such that they received a name change). Three of these dogs were bomb detection K9s, and one was a search-and-rescue dog; the remaining 16 were all pet dogs. Three dogs had a one-syllable name, 2 had a three-syllable name, and 15 had a two-syllable name. Of the three-syllable name dogs, one had an unstressed–unstressed–stressed pattern and one had an unstressed–stressed–unstressed pattern. All the two-syllable dog names had a trochaic stress pattern (stressed–unstressed).

To determine whether performance differed by breed, we also collected owner report information on dog breed, and sorted the dogs into the seven AKC breed group categories based on their breed, or in the case of mixed-breed dogs, the most predominant breed. We had one dog in the herding group, one dog in the hound group, one dog in the non-sporting group, two dogs in the terrier group, six dogs in the sporting group, five dogs in the toy group, and four dogs in the working group. Data from five additional dogs were excluded from the study: four for noncompliance (e.g., failing to orient to sounds, falling asleep), and one due to experimenter error. All dogs were tested in the presence of their owner, to reduce stress and ensure optimal performance (Fugazza and Miklósi 2014).

Test materials

Stimuli consisted of a target sound stream and a distractor sound stream. The distractor stream was the same as the multitalker babble used in the Newman (2005) study that examined infants' perception of their names in noise. For that study, nine women were recorded reading passages from books using a Shure SM51 microphone in a sound-attenuated room. These recordings were adjusted to have the same root-mean-square amplitude and then mixed together at equal ratios to create nine-voice multitalker babble. With this number of speakers, the babble converges to being a relatively constant intensity level over time. Moreover, it is impossible to make out individual words from this type of babble.

The target speech stream consisted of a name repeated 15 times: either the dog's own name or that of another dog. Prior to the study visit, each dog owner was asked the name or nickname that their dog was most commonly called. This name was recorded in advance of the appointment date and formed the target stream for the study stimuli. The names for each dog were recorded individually by a female native English speaker from eastern Pennsylvania. The speaker was recorded saying the dog's name in dog-directed speech with a variety of inflections and durations (Ben-Aderet et al. 2017). Each name was matched with a foil name. To prevent any bias caused by the speaker producing target names in a more lively manner, each foil was chosen from the existing set of recorded dog names, which were target names for other scheduled participants. The foil was matched to the target name in the number of syllables and stress pattern, and the names were chosen to be as phonetically dissimilar as possible from the original name in phonemes (e.g., Henry was matched with the foil name Sasha). A total of 15 tokens were selected out of the original recording of target names, matched to the 15 tokens of the foil name file as closely as possible for pitch, duration, intonation contour, emotionality, and vocal quality. Pauses between tokens of dog names were adjusted such that the target and foil files had the same overall duration of 22 s. There was an initial silence period for 0.5 s.

The intensity and amplitude of the target and foil name streams were measured and altered to match each other and to establish a set signal-to-noise ratio between the names and multitalker babble. Name streams contained silence in between the name tokens, and although tokens were selected to have similar duration, the overall amount of silence in the target and foil streams was not necessarily identical. Therefore, to eliminate any influence of the silent periods on amplitude measurements, a copy was created of each name stream in which all the pauses between name tokens were removed. Average RMS amplitude was measured across this file, which contained only speech, and necessary amplitude changes were calculated and applied to the original stream containing pauses. In this way, the name streams could be amplified such that the speech, rather than the entire stream, matched in average amplitude. These streams constituted the “quiet” name stimuli.

In addition to the quiet name streams, each stream was mixed with a 22-s clip of the multitalker babble to create names in noise. The average RMS amplitude of the noise clips was set prior to mixing such that specific signal-to-noise ratios between the target speech (names) and babble were achieved. In Experiment 1, the noise was adjusted to be 5 dB softer than the target speech (+ 5 dB SNR). This is a level used in infant studies at which 1-year-old infants are generally successful at name recognition (Newman 2005).

Apparatus

The experiment took place in a 4-feet by 6-feet three-sided test booth made of pegboard. In the front of the booth, there was a hole cut out for the lens of a video camera. Above the camera, a light was mounted in the center of the panel. The video camera recorded each session and allowed the coder to see the dog’s behavior inside the booth. The side walls each had a light mounted in the center and a speaker directly behind the light to play stimuli for the dog. A tan curtain hung from the ceiling to the top of the booth to ensure that the dog could not see over the booth. A Mac computer was used behind the front wall of the booth for coding. The experimenter used a button box to start trials and code the dog’s looking behavior.

Procedure

The dogs sat on the owner’s lap or directly in front of them, depending on the dogs’ size and the owners’ opinion as to what would be most comfortable. The dogs either sat facing toward the camera (facing the front of the booth) or toward the owner (facing the back of the booth). In either case, the dog’s 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 a loudspeaker, was to turn its head 90° to face that sound source. There were two practice trials to familiarize the dogs with the procedure. In these trials, the dogs heard two different passages of classical music. Their listening time was judged by the amount of time they spent looking at the sound source (the wall behind which the speaker was mounted).

The test phase began immediately after the practice trials. The dogs heard four types of stimuli: repetitions of their own name without background noise, a foil name, their name in the multitalker babble noise, and the foil in noise, four times each. The 16 trials were presented in four, four-trial blocks, and the 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). At the start of the test trials, the light in the front of the booth was turned on, and the Attention experimenter rang a bell located behind the light. The combination of a light plus a bell served to attract the dog’s attention. Although work with infants typically uses only lights, pilot work suggested that neither the light nor the bell was a sufficient attention getter for all dogs. The light also served as the apparent source of the sound. Once the dog attended to the front, a light turned on in either the left or right side of the booth. The Attention experimenter rang a bell on that side. Once the dog attended to that side, the stimulus played from the speaker on that side. The stimulus played for a full 22 s or until the dog looked away for two consecutive seconds, whichever occurred first. Any time the dog spent looking away was subtracted from the dog’s overall looking time. The coder used a button box to code the dog’s looks toward and away from the sides. 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 (Fig. 1).

Results

Mean listening times were calculated for each of the four trial types (name, foil, name in noise, foil in noise) across the four blocks. A 2 × 2 analysis of variance (ANOVA) examined the effect of Noise Level (quiet versus + 5 dB signal-to-noise ratio) and Item (name versus foil).

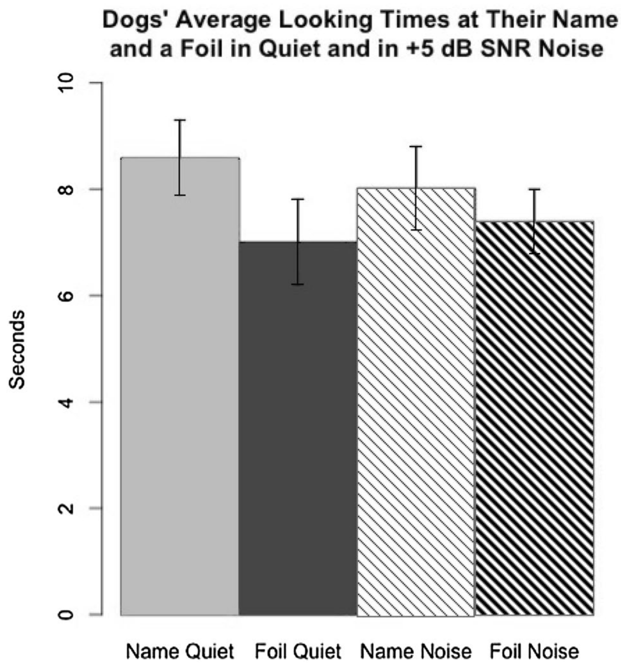

Fig. 1 Dogs' performance in Experiment 1. Dogs listen significantly longer to their name than the foil

We found an overall effect of Item, $F(1, 19) = 8.5$, $p < 0.001$, such that dogs listened longer to trials containing their name (8.3 s) than trials containing another dog's name (7.2 s). This suggests that dogs recognize their name, even when spoken by a novel talker. Thus, dogs are capable of generalizing known words across different talkers.

There was no overall effect of Noise Level ($F(1, 19) = 0.02$, $p > 0.05$); dogs listened just as long in quiet trials (7.8 s) as noise trials (7.71 s). Critically, there was no interaction ($F(1,19) = 0.59$, $p > 0.05$). That is, dog's preference for their name over another name was the same in quiet as in noise. This pattern of results suggests not only that dogs recognize their own name, but also that the noise did not impact their ability to do so. Dogs apparently have little difficulty distinguishing their name from a foil name in either quiet or in the presence of this level of background noise.

This experiment showed that dogs are quite adept at generalizing language information across different talkers, and can thus successfully recognize their name as spoken by a novel voice. Moreover, since the names were matched for prosodic pattern, the dogs must be doing so based on the sounds or phonemes making up their name, rather than by the way the name was said (its emotional valence, or its pitch pattern). While there are clear anecdotal reports of dogs recognizing their name, this is the first time this has been shown experimentally in a task requiring generalization across talkers.

This experiment also showed that dogs also succeed at this task when in the presence of a quiet background babble. In the following study, we increased the level of the background distractor by 5 dB, resulting in a more difficult level of noise: 0 dB SNR. This particular level is useful for comparing canine performance with infant performance. Prior work has suggested that infants aged 13 months (but not aged 9 months) can succeed at this task at the + 5 dB SNR tested in Experiment 1. However, infants at this age do not succeed with a 0 dB SNR. Thus, if dogs are successful, it would demonstrate that their ability to understand speech in noise is beyond that of a 1-year-old child.

Experiment 2: target and background noise of equal amplitude (0 dB SNR)

Experiment 1 demonstrated that dogs were successful at recognizing their name when it was louder than the co-occurring background noise. The current experiment increased the level of the background noise by 5 dB. This resulted in the names and the noise being of equivalent amplitude.

Participants

Twenty dogs (16 male) participated in this study. The dogs met the same requirements as in Experiment 1. They were an average of 5.3 years old. They had been hearing their names for 4.74 years on average. There were 2 dogs in the herding group, 1 dog in the non-sporting group, 1 dog in the terrier group, 5 dogs in the working group, and 11 dogs in the sporting group. Fourteen of these dogs had jobs: 4 were therapy dogs, 3 were search-and-rescue dogs, 1 was a retired police dog, 1 was a service dog, and 5 were service dogs in training.

Materials

These were the same as in Experiment 1, except that in the names-in-noise streams, the noise was adjusted to be equal in amplitude to the target speech (0 dB SNR).

Apparatus and procedure

These were the same as in Experiment 1 (Fig. 2).

Results

The data were analyzed in the same manner as in Experiment 1. Mean listening times were calculated for each of the four trial types (name, foil, name in noise, foil in noise) across the four blocks. A 2×2 analysis of variance (ANOVA) examined the effect of Noise Level (quiet versus + 0 dB signal-to-noise ratio) and Item (name versus

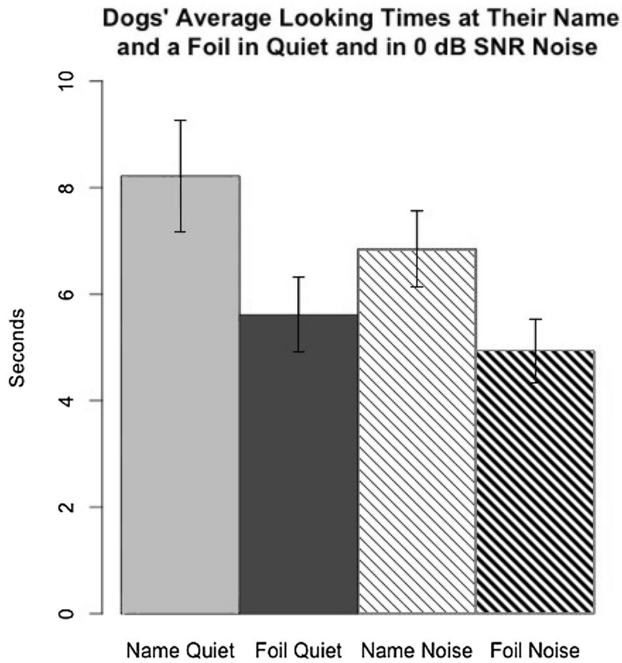

Fig. 2 Dogs' performance in Experiment 2. Dogs listen significantly longer to their name than the foil

foil). We found an overall effect of Item, $F(1, 19) = 15.53$, $p < 0.001$, such that dogs listened longer to trials containing their name (7.52 s) than trials containing another dog's name (5.27 s).

There was no effect of Noise Level ($F(1, 19) = 2.28$, $p > 0.05$), as dogs listened just as long to items in quiet as they did items in noise. There was also no interaction between Noise Level and Item ($F(1, 19) = 0.25$, $p > 0.05$); this suggests that dogs continued to prefer their name to the foil despite the noise.

Experiment 3: background noise louder than target (− 5 dB)

Experiment 1 demonstrated that dogs were successful at recognizing their name when it was louder than the co-occurring background noise. Experiment 2 showed that dogs were likewise successful at name recognition when their name and the background noise are of equal intensity. One-year-old infants do not succeed when the target is as loud as the background noise; since dogs succeed at this level, their ability to recognize their name in noise surpasses that of an infant. The current experiment increased the level of the background noise by 5 dB, resulting in the noise being louder than the target name. This will help determine at what point dogs fail to perceive their name in noise.

Participants

Twenty-two dogs (11 male) participated in the study. They were an average of 5.3 years old, and had been hearing their names for an average of 4.74 years. Data from six dogs were dropped from this study. Two did not have their name long enough, and four were uncomfortable in the booth and the experiment had to be discontinued. Five of these dogs were service dogs in training, and one was a therapy dog. Five dogs had a one-syllable name and the remaining 17 dogs had a two-syllable name. All the two-syllable dog names had a trochaic stress pattern (stressed–unstressed).

Two dogs in the hound group, six dogs in the non-sporting group, three dogs in the terrier group, eight dogs in the sporting group, and three dogs in the working group participated in this study. Data from five additional dogs were excluded from the study. Three dogs were excluded for non-compliance (e.g., failing to orient to sounds, falling asleep), one was excluded because the dog was too young, and one was excluded due to experimenter error.

Materials

These were the same as in Experiment 1 and 2, except that in the names-in-noise streams, the noise was adjusted to be 5 dB louder than the target speech (− 5 dB SNR).

Apparatus and procedure

These were the same as in Experiment 1 and 2 (Fig. 3).

Results

The data were analyzed in the same manner as Experiment 1 and 2. Mean listening times were calculated for each of the four trial types (name, foil, name in noise, foil in noise) across the four blocks. A 2×2 analysis of covariance (ANOVA) examined the effect of Noise Level (quiet versus −5 dB signal-to-noise ratio) and Item (name versus foil). We found no significant effect of Item ($F(1,21) = 0.63$, $p > 0.05$). There was a significant effect of Noise Level, $F(1\ 21) = 6.199$, $p < 0.05$, such that dogs prefer to listen to the quiet items (8.9 s) more than the items in noise (6.8 s). However, there was no interaction between Item and Noise ($F(1,21) = 1.088$, $p > 0.05$).

Unlike in the prior two studies, the dogs here did not prefer their name to the foil name when the noise was present. This might suggest that the level of noise presented here posed too much difficulty for the dogs. But surprisingly, the dogs also did not show an interaction between Item and Noise, implying that they also did not prefer their name to the foil name even in quiet. That is, the presence of the more difficult noise on some trials did not only prevent the

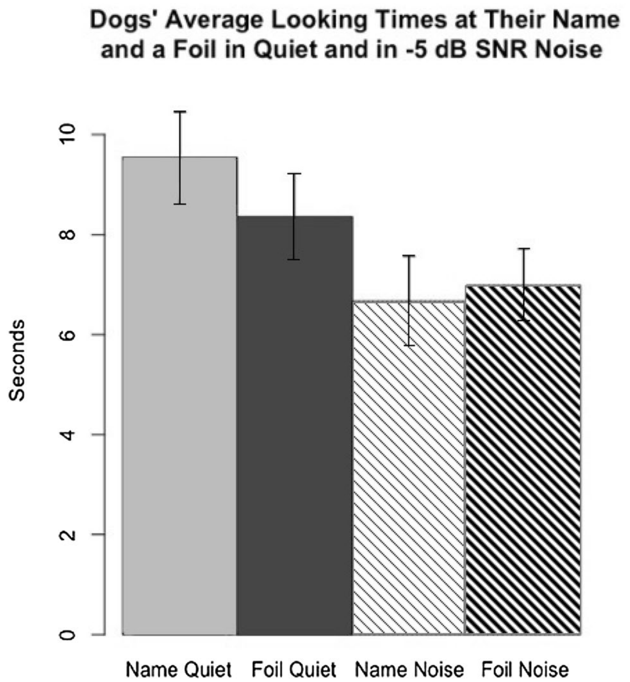

Fig. 3 Dogs' performance in Experiment 3. Dogs listen significantly longer to the quiet trials than trials in noise

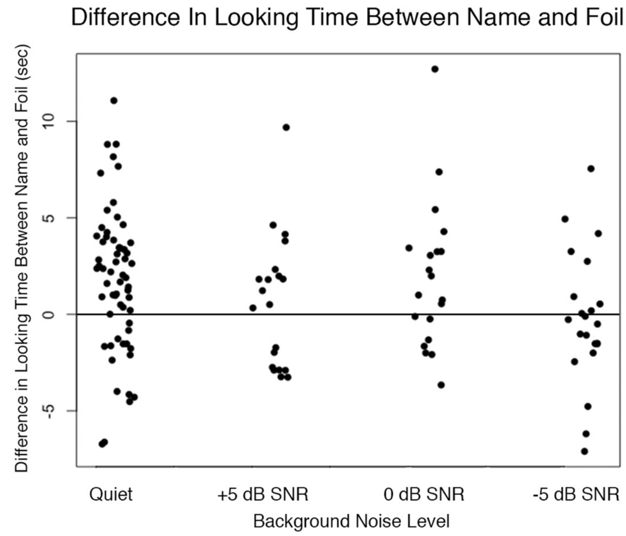

Fig. 4 A graph of individual dog's performance. Each point represents an individual dog's difference in looking time to its own name versus the foil name. Data are presented for across the three experiments in quiet, + 5 dB SNR, 0 dB SNR, and − 5 dB SNR. The distributions of individual performance in the three noise conditions appear generally similar, but with lower performance in − 5 dB SNR. There is no indication of greater variability in performance among dogs in the − 5 dB SNR, as might be expected if there was a bimodal distribution (with some dogs succeeding at the task and others not). While five dogs showed scores that appeared to be above chance performance, three dogs showed an equal performance below chance, suggesting this may have just been the result of random variability

dogs from succeeding on those particular trials; it also prevented the dogs from succeeding at all. Why might this have occurred? One possibility is that the difficulty of the task led dogs to "give up" doing the experiment. Yet the dogs did not listen to all items equivalently—they preferred listening to both names in the quiet condition over those in the noise conditions. Perhaps this more intense noise was confusing or irritating to them, and also led them to stop attending to the detailed sound patterns within the name. Or, perhaps the loud noise caused them to attend to the background (the presence or absence of noise) rather than the target (Fig. 4).

While we cannot be certain why the dogs failed in the present task, the results here are clearly quite different from those in the prior experiments. The level of noise presented here, − 5 dB SNR, appears to be sufficient to interfere with dogs' recognition of their name. Presumably, then, this level of noise would also pose problems for comprehending other speech sounds or commands.

Breed-specific results

Anecdotally, people have noticed that different breeds seem to have specific personality traits that lead them to respond to human speech differently. For example, one study showed that dogs who were bred for working purposes (Siberian Husky, German Shepherd) demonstrated more attentiveness to human communicative gestures than non-working breeds (Toy Poodle, Basenji) (Wobber et al. 2009). However, there have been studies of dogs' understanding of human gestural communication that show no breed differences (Dorey et al. 2009, no differences between the American Kennel Club groups; Mckinley and Sambrook 2000, no difference between gun dogs and non-gun dogs). We examined whether performance differed by breed group. We also examined whether performance differed for dogs that were trained as working dogs versus those that were pet dogs; other studies have suggested, for example, that dogs trained in agility tasks or Schutzhund protection work tended to be more persistent and curious, and to be more attentive to their owner (Marshall-Pescini et al. 2008, 2009). We might expect that dogs specifically trained to respond to verbal commands might be more likely to respond to their name, or more successful at doing so in noise. To explore whether our participants' performance differed based on either breed or working status, we combined the datasets from the two studies in which the dogs were successful at recognizing their name in noise (5 dB and 0 dB) to see if there are any Breed Group or Working Dog Status differences that led to better performance in name recognition. The combined dataset had 40 dogs (22 male). We performed a 2 × 2 × 2 × 7 ANOVA (Item by Noise Level by Working Dog Status by Breed Group).

Unsurprisingly, this combined dataset replicated the general pattern of results seen in the two datasets individually: we found an overall effect of Item ($F(2, 39) = 24.25$, $p < 0.001$), but no effect of Noise ($F(2, 39) = 1.558$, $p > 0.05$) and no interaction ($F(1, 39) = 0.693$, $p > 0.05$).

More importantly, we found that the interaction between Item and Working Status was marginal ($F(1,39) = 3.463$, $p = 0.07$). Overall, working dogs, which include police K9s, search-and-rescue dogs, therapy dogs, service dogs, and service dogs in training, listened longer to their name (8.16 s) and less to the foil (5.89 s) than pet dogs, who listened to their name for an average of 7.69 s and the foil for an average of 6.63 s. This may be an indication that dogs that receive more intense training, in general, also are more selectively responsive to their name (perhaps as a result of that additional training).

There was no interaction between Breed Group and Item ($F(6, 39) = 0.98$, $p > 0.05$), although this may be the result of the small number of dogs in some breed groups. Regardless of whether dogs were bred primarily for companionship, hunting, guarding, or herding, they preferred their name to unfamiliar foils, and no group performed better at this than any other group, despite the fact that working dogs tended to be in the herding or sporting groups.

Overall discussion

The current studies examined whether domestic dogs could recognize a particular, highly familiar word (their name) when spoken by a novel talker, and under what conditions they could do so. Below we discuss each of the main findings and their implications.

First, we found that dogs were successful at recognizing their name even when spoken by an unknown voice. This suggests that dogs have the capacity to generalize their lexical knowledge across talkers. Although this ability has been shown previously in individual dogs, it has not been shown to be a general capability. For example, the Yorkshire terrier in Griebel and Oller's study of word learning in dogs was able to comprehend commands given by an unfamiliar voice (2012). However, this particular dog was also highly unusual, in that she knew names for over 200 different objects and could retrieve them on command. The present study demonstrates that the ability to recognize a familiar word and generalize that across voices is found more generally among typical pet and working dogs.

Additionally, dogs demonstrated that they could respond to an unfamiliar voice even if the apparent speaker is not present in the room. While previous fMRI studies have shown that dogs display a clear neural response to the human voice, the dogs in those studies could not demonstrate any behavioral response, as they were within the fMRI (Andics et al. 2014, 2016). Our study shows that generally, dogs will behaviorally respond to their name even if a sound source is not immediately clear. This has practical implications for working dogs, like search-and-rescue dogs that may need to take commands from someone other than their handler in emergency situations, and may need to do so at a distance, when the speaker is out of view.

We also found that dogs could succeed at this task even in the context of multitalker background babble. When the noise was softer or at the same level as their name, dogs recognized and preferred to listen to their name over another dog's name. When the noise was louder than their name, dogs no longer showed that preference.

One question we asked was how similar dogs' performance at a hearing-in-noise task would be to infant performance. Infants tend to fail at this task when the signal and noise are at the same intensity, but dogs were very successful at this level. Since dogs were successful at this task, but do not have linguistic processing, they must utilize only domain-general auditory processing mechanisms for name recognition. It is possible that infants, too, rely on these domain-general mechanisms for this task as well. Clearly, though, the fact that young infants have limited linguistic skills is, of itself, not sufficient explanation for their poor performance listening in noise.

Infants' performance could also be due to their poorer attentional capabilities or deficits in auditory processing. Identifying the extent to which attention, auditory processing, and linguistic knowledge contribute to comprehension of speech in noise is necessary to understand why infants have difficulty with this task. Use of a domestic dog comparison group can highlight the separate contributions of the attention system and auditory system to speech-in-noise perception. By using dogs, we can control for linguistic prior knowledge. Future studies will compare dog and infant auditory and attentional capabilities to determine their similarities. This will allow further studies to compare dog and infant performance in listening-in-noise tasks to tease apart the attention and auditory system contribution.

We found hints that working dogs were performing better than pet dogs. While the effect was only marginal, it appears that working dogs showed both longer listening for their own name, and less listening to the foil name. One possibility is that these dogs hear their names more often than pet dogs. Perhaps when owners ask their pet dogs to perform tasks, they just state a command ("sit!") rather than specifying the dog first ("Tahoe, sit!"). Or perhaps pet owners are more variable in what they choose to call their dog, using a name in some instances and a nickname in others. In contrast, working dogs may hear just one name very often, a name that is very salient to the dog. Indeed, many search-and-rescue dog owners specified that their dog has a call name, which is consistently used while the dog is in the field, but while at home (and not working) the dog is more freely called both their name and also nicknames (as is the case for many pet dogs). It is also possible that the increased obedience and task training that working dogs receive leads to better overall attention abilities. This would lead to better attention in the task and better overall performance.

The results of the current studies have practical implications for the training and use of service dogs, search-and-rescue dogs, and other working dogs. Working dogs must contend with many different noisy environments. Cities, one common location for service dogs, tend to have ambient environmental noise at around 70 dB, which is 5 dB louder than average conversational speech (Appleyard and Lintell 1972; McAlexander et al. 2015). Dogs in the current study fail to listen longer to their own name in noise as compared to other names at − 5 dB SNR. This suggests that hearing target speech that is 5 dB less intense than background noise may be at the limit of what dogs are capable of perceiving. This noise level should be kept in mind when dogs are working in the field.

In conclusion, the present study begins an exploration of dogs' speech perception abilities in noisy environments. The findings suggest that dogs are capable of understanding and attending to an unfamiliar voice both in quiet, and in the presence of competing distractor voices. Dogs are successful when the noise is softer or at the same intensity as the target speech; however, they fail to recognize their name when the noise is louder than the target. Future work will explore dogs' speech perception capabilities in more detail and provide comparisons with infant speech perception.

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Compliance with ethical standards

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

Ethical statement 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: 1034861-6).

Informed consent Informed consent was obtained from the owners of the dogs in the study. Informed consent was not required from either the speakers that provided readings for our nine-talker background noise, nor the speaker who produced the dogs' names.

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