


Annotated Bibliography

Organization scheme: Overall, I organized this by the gradual flow of & increase of information in this field. Near the top is when there were misconceptions about the field, and near the bottom is adding modern techniques to better understand the field as well having some contradiction to older findings. Similar topics or follow-up studies are grouped next to/near each other.

Article Reference: Yin, S. (2002). A new perspective on barking in dogs (*Canis familiaris*). *Journal of Comparative Psychology*, 2(116), 189-193. 10.1037/0735-7036.116.2.189 [L
SEP]

Article Summary: A major contributing factor to the lack of literature in the area of vocal communication of dogs is due to the immense human interaction that has led to artificial selection, which is thought to have removed any communication function of barking in dogs. It may be because the dog has more frequent and sporadic barking patterns than its close relative, the wolf (*Canis lupus*), which only barks as an alert signal or in a territorial context. This doesn't take into account the different social dynamic that dogs have been exposed to that can impact the ontogeny of their vocal behavior, which could have actually increased the diversity of contexts in which barking could be used. Outside literature indicates that exchanging vocal signals is largely shaped by social actions during development. In order to test the communicative function of dog barking, 10 dogs had their barking vocalizations recorded in three contexts: disturbance by a stranger, isolation, and play with a human or dog. Each bark had a spectrogram generated and had mean frequency and duration calculated. It was found that the mean frequency of barks during a disturbance was noticeably shorter than during isolation or play. The results also showed that the mean duration was much longer during a disturbance. Lastly, it was noted that barks were lower in pitch during disturbance situations. These results largely illustrate that the acoustic structure on barks differ based on context. Multiple dogs from different developmental backgrounds depicted similar context-dependent results in their barks, indicating that there is likely specific function for the barks in response to context. To test this further, it would be imperative to perform additional studies that look into the response of the receiver as well.

Article Contribution: This article serves as valid background information for another article in my review, so it was important to include. The research is quite different in the sense that it tackles the social implications on the development and variability in dog barking, as compared with the wolf. Better understanding how social interactions during development can influence a dog's barking behavior can help us better understand scenarios in which to raise dogs that are more conducive to positive interactions between dogs and other species.

Article Reference: Yin, S. & McCowan, B. (2004). Barking in domestic dogs: Context specificity and individual identification. *Animal Behaviour*, 2(68), 343-355.
<https://doi.org/10.1016/j.anbehav.2003.07.016> 

Article Summary: This study is seen as a follow-up to a previous study conducted by Yin et al., 2002, using a very similar formula. The previous study had shown that there does seem to be some sort of communicative function of dog barks, despite prior hypotheses indicating that centuries of domestication had effectively diluted most communicative function present within the barks of the domestic dog. In fact, recent literature has shown that individuals and contexts can be estimated through characteristics of the bark. The purpose of this experiment was to test this principle empirically. There were 10 individual domestic dogs (*C. familiaris*) sampled in this study, representing six breeds, and 4,672 total barks were recorded in contexts of disturbance, play and isolation. Next, 60 sequential frequency and amplitude measurements were taken in order to generate spectrograms of the barks. After conducting statistical and discriminate analyses, a few key results were able to be obtained. The discriminate analysis allowed for determination of which specific acoustic parameters in the barks can be used to differentiate context by separating them into groups. The statistical analysis (ANOVA) allows determination for which individual variable differed from each other. It was found that lower frequency and more sporadic barks were found in context of disturbances whereas higher frequency and more controlled barks were seen during playful or isolation contexts. Furthermore, disturbance barks also seemed to last longer than the play or isolation context. The results indicate that the acoustic parameters are malleable to different contexts and that unique, individual dogs and the context in which their bark originates can be differentiated from one another. Further studies can include more narrow contexts (i.e. subcontexts) to test whether there are other acoustic parameters that may play a role or if more specific contexts can be identified.

Article Contribution: The article was selected as it included relevant follow-up experimentation based on a previous study (also included in this literature review) that left a new direction to follow. This study seemed to further bolster the previous study, which implied that there does seem to be a communicative function of barking behavior in the domestic dog but additional testing would need to occur to see what message could potentially be being conveyed. The study showed the context and individual identification may be possible, which not only corroborates Dr. Yin's previous study, but also aligns with newer literature on the topic.

Article Reference: Riede, T. & Fitch, T. (1999). Vocal tract length and acoustics of vocalization in the domestic dog (*Canis familiaris*). *The Journal of Experimental Biology*, 20(202), 2859-2867. <https://doi.org/10.1242/jeb.202.20.2859>

Article Summary: The anatomy of vocal tract, which produces vocalizations, allows for remarkable variability in the sounds produced across various organisms. This particular study looks at vocal tract variability within the domestic dog (*Canis familiaris*) due to incredible structural diversity of breeds within the same species. Vocal tract length and shape allow for *formant* creation, which is the highest frequency peak of a vocalization, and is known to encode information about the sender's characteristics. It's thought that the diversity within *Canis familiaris* could be present within the vocal tract as well, leading to variability within their respective formants and therefore variability in the information encoded by them. To test this hypothesis, there were 47 subjects used (representing 21 breeds of the domestic dog), 33 of which were anesthetized and had their vocal tract length (VTL) measured through x-ray. They also had body mass measured. Next, 26 dogs (14 of which were not part of the original 47, bring the total subject count to 61) had their growls recorded. Growls were chosen primarily because they're low-frequency so distinguishing a high-frequency formant would be simpler. Average formant dispersion (distance between consecutive formant peaks) was calculated because it is an accurate estimator of VTL. VTL measurements had a minimum of 6.9 cm (Yorkshire Terrier) and a maximum of 22.4 cm (Rottweiler). Correlations between average formant dispersion and VTL were deemed highly statistically significant, as was the correlation with VTL and body mass. These results indicate that these three key variables are likely interdependent on one another and that formant dispersion may indirectly indicate body mass information. However, since VTL measurements came from anesthetized specimens, changes in vocal tract shape were not viewed. Further studies with additional acoustic data from conscious specimens would be required to explore the effects of vocal tract shape.

Article Contribution: This article showed there may be implications in interspecies communication that stem from the vocalization behavior of dogs. It has been previously thought that dogs may have the ability to understand formants in human vocalization, and now with the indication that anatomical variation within the same species leads to formant variation within the same species, there is now enough evidence that can lead to investigation on whether domestic dogs can discern formant variation amongst each other as a method of interspecies communication. We can also look into other possible information that may be "hidden" within the vocalizations of dogs.

Article Reference: Farago, T., Pongracz, P., Miklosi, A., Huber, L., Viranyi, Z., & Range, F. (2010). Dogs' expectation about signaler's body size by virtue of their growls. *PLoS ONE*, *12*(5), e15175. <https://doi.org/10.1371/journal.pone.0015175>

Article Summary: Earlier literature on the acoustics and phonetics of mammalian organisms indicate that mammals have the ability to embed information about physical characteristics, such as body size, in vocalizations for a receiver to interpret. It's thought that the receiver uses this embedded message about body size to generate a mental image of the sender. This image is then thought to be used in conjunction with a physical depiction of the sender to determine a response to the vocalization. Testing the presence of this phenomena in growls of the domestic dog (*C. familiaris*) is the purpose of this experiment. The experiment consisted of 96 participants, each being exposed to one of four stimuli: Dog-Growl (growl played, followed by two dog images), Dog-Noise (unrelated noise, followed by two dog images, a control group), Shape-Growl (growl played, followed by two triangle images, a control group) and Cat-Growl (growl played, followed by two cat images, a control group). Each stimuli group had 24 dogs in it. One of the images shown matched the actual size of the growler, whereas the second was either 30% larger or 30% smaller. The specific image looked at, and the duration of the "looking period" were then noted. The Dog-Growl treatment group showed that subjects spent more time staring at the dog image which resembled the actual size of the growler. The control groups didn't show preference for either image. These results show that the subjects in the Dog-Growl group may have had a mental image and upon viewing a matching physical depiction, they showed interest. In the control groups, the physical depiction may not have matched the mental description generated based on the sound, therefore there was minimal response to the stimuli. Future studies should be conducted to see if this principle applies to other vocalization behaviors.

Article Contribution: This article added to a review article conducted by Taylor et al., 2009a as it adds more information to findings contributed by them. Previously, it was found that domestic dogs were able to estimate the physical body size and stature of sender from an unknown bark and were able to formulate a response based on this. The majority of the responses were to either investigate the sender or to retreat and avoid potential conflict. The need to investigate may stem from an urge to match a physical description with a preconceived mental description of the sender.

Article Citation: Taylor, A.M., Reby, D., & McComb, K. (2009a). Size communication in domestic dog, *Canis familiaris*, growls. *Animal Behaviour*, 1(79), 205-210.
<https://doi.org/10.1016/j.anbehav.2009.10.030>

Article Summary: Cues about body size can be given through vocalization and are often heard before any perceived threat is within sight, allowing the receiver to decide whether to pursue confrontation or to retreat. In this experiment, the model organism being analyzed is the domestic dog (*Canis familiaris*). It's known that the growls of domestic dogs contain information on the physical size of the sender and receivers can discern size information based on the frequency of the *formant*. The goal of the study was testing if adult dogs interpreted formant dispersion in growls and responded accordingly. A formant is the highest peak present in the spectrogram of a particular sound or vocalization. To empirically test this phenomenon, the researchers took a sample of 26 total subjects and divided them into groups based on size. Each subject was played doctored recordings of the growls of another domestic dog and the formant frequency was manipulated in the recordings to simulate the growls of small, medium and large dogs. Each subject heard the growls of dogs that were 30% larger and 30% smaller than them, and their behavior was then monitored. Barking and whimpering (characterized as Factor One) with a minimal aggressive behavior indicated a curiosity to investigate the origin of the sound, whereas head-cocking, barking and growling (characterized as Factor Two) with minimal tail-wagging and whimpering indicated a territorial/defensive response. Large dogs were more inclined to investigate recordings that displayed the growl of smaller dogs as opposed to larger dogs. Small dogs were overall not very responsive to the growl recordings, regardless of the size of the dog being in the recording. This indicates that domestic dogs are able to discern physical information from formant dispersion and can make behavioral decisions in response to these cues.

Article Contribution: This particular article was chosen because it captures the true essence behind vocalization behavior in dogs. Many vocalizations are assumed to have very general meaning but this article showed that they can be substantially more complex than we could've imagined. This brings in the possibility of being able to acoustically break down each vocalization and potentially get several messages out of one single bark. This also sets foundation for vocal analysis in other organisms like birds or elephants to possibly decode a deeper meaning for them as well.

Article Reference: Larranaga, A., Biezla, C., Pongracz, P., Farago, T., Balint, A., & Larranaga, P. (2014). Comparing supervised learning methods for classifying sex, age, context and individual Mudi dogs from barking. *Animal Cognition*, 2(18), 405-421.
<https://doi.org/10.1007/s10071-014-0811-7>

Article Summary: It's been known for some time that barking behavior within dogs likely has some form of role in communication. Multiple studies have conducted acoustic analyses to test vocal characteristics of barks to determine the presence of any underlying pattern. There is a lack of literature on the role barking has on intra-species communication. Evidence indicates that dogs have several methods of relaying a message through actions but the purpose of this experiment is to determine the role of barking in intra-species communication. The model organism used is a breed of the domestic dog (*C. familiaris*) called the Mudi. The researchers recorded 300 barks from eight individual dogs and barks were collected in multiple behavioral contexts: alone, ball, fight, play, food, stranger & walk. Each bark had 29 acoustic parameters measured (i.e. energy, pitch, volume etc.). They employed a machine-learning technique called "supervised classification" (SP) which uses the values of the 29 parameters to estimate the value of the "30th parameter", which in this case is one of four variables: sex, age, context & individual. Across the four methods of SP, there was 85.13% accuracy in determining sex, 80.25% accuracy in determining age range, 55.50% accurate in determining behavioral context & 67.63% accurate in determining which of the eight dogs the bark originated from. The results show the effectiveness of machine learning analysis in estimating certain characteristics such as sex & age of dogs from an acoustic sample. With regards to context & individual, some of the four methods yielded higher results than others and there isn't as much universal accuracy across the four. Future studies suggested were to repeat this experiment on multiple other breeds or even a mixed breed group to see if a similar level of accuracy can be reproduced.

Article Contribution: This article was included due to its unique, machine-learning approach that is not as common within this particular field. Overall, the research was shown to be accurate and relevant as it shows the potential the approach in determining characteristics of individuals based on sound data. Modifying this technique and improving it can then result in its application in further behavioral studies in dogs such as determining aggression or estimating stress conditions in dogs to monitor overall wellbeing. The technique can also be used as a quicker method of validating prior literature.

Article Reference: Gutierrez-Serrafin, B., Perez-Espinosa, H., Martinez-Miranda, J. & Espinosa-Cureil, I. (2019). Classification of barking context of domestic dog using high-level descriptors. *Research in Computing Science*, 3(148), 23-35. 10.13053/rcs-148-3-2

Article Summary: The specific role played by barking in the communication of the domestic dog has had many interpretations, ranging from minimal role to even the slightest variation leading to an entirely different meaning. To analyze this, however, is new territory for machine learning. Machine learning has recently been implemented to analyze trends and patterns in this field. However, it has only been used to study the acoustic parameters coming from the vocal source itself (low-level descriptor), such as pitch and frequency, which fails to take into account factors like temporal structure and other high-level descriptors that don't necessarily originate from the source itself. Bringing a high-level descriptor approach to test how they may work together was the purpose of this experiment. The researchers used two previously-compiled datasets from prior literature totaling up to almost 7500 vocalizations from 92 individual dogs across several breeds under almost 20 different contexts. An automated algorithm was employed to extract both low-level and high-level descriptors in order to differentiate both the type of vocalization that occurred as well as the context in which it occurred. A validation method called 10-Fold Cross Validation was used to evaluate the success of the algorithms' classification and it generated an "F-Measure". Based on the results, there instances where the classification yields an F-Measure of 0.70 or higher. However, there were also several instances where the F-Measure was lower than the 0.70 mark, indicating that there is also potential for improvement and the results are not yet in their most reliable state. An F-Measure of 0.70 or higher shows that the algorithm was quite successful in classifying the type of vocalization and its context, whereas a value below 0.70 shows that opposite. Overall, the results show the potential, but improvements should be made in order to generate more reliable results.

Article Contribution: This article seeks to apply new technology and new techniques to an area that has existed for quite some time. It did not yield the most reliable results, however, there is potential for modification as there were some mildly promising results. It is important to include because adding new techniques to an existing field can yield results that may not have been achieved beforehand. Overall, it does support previous findings but the technique does require adjustment in order to become a staple in the field of dog vocalization.

Article Reference: Pongracz, P., Molnar, C. & Miklosi, A. (2006). Acoustic parameters of dog barks carry emotional information for humans. *Applied Animal Behaviour Science*, 3-4(100), 228- 240. <https://doi.org/10.1016/j.applanim.2005.12.004> [L]
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Article Summary: Humans have shown to be able to accurately judge the emotional and mental state of dogs based on certain acoustic features of a dogs' bark, despite not having previous interaction with that particular dog. Acoustic parameters such as the pitch, inter-bark interval and tonality have shown to influence this. This particular study is designed to see whether human estimation of dog emotionality based on barks is similar to what is hypothesized based on prior literature: High-pitched barks were typically associated with playfulness or fear, whereas low-pitched barks typically signified anger, defensiveness or aggression. Barks were organized based on their tonality and frequency (low, medium & high). When consecutive barks were being artificially assembled, special attention was given to ensure varying inter-bark interval (short, medium or long intervals between consecutive barks). Human participants were played these artificial bark sequences and asked to gauge the emotionality of the sender and categorize the mental state as aggressive, fearful, despair, playfulness or happiness. It was found that humans had very similar inferences on the mental state of the individual dog and this similarity persisted regardless of the person's prior experience with dogs. Furthermore, it was also found that humans generally classified more low-pitch barks with short inter-bark intervals as aggressive whereas high-pitch barks with longer inter-bark intervals were generally considered more happy or playful. Contrarily, tonality seemed to have minimal effect on describing emotional state to a receiver of a message. The results of this experiment depict that barking behavior in dogs may be an effective method for displaying emotional states to humans, regardless of familiarity between the dog and the receiving human. Future studies could include repeating this experiment with a different kind of vocalization, such as a growl or whimper, or by varying a different set of acoustic parameters.

Article Contribution: This article was chosen as it seemed to be a direct follow-up of another article and it delved into one of the less-explored topics from that article. The article corroborates previous work as it indicates that acoustic parameters do indeed play a role in the perception and categorization of dog barks, both in the context of inter-species and intra-species communication. This research is relevant as it can lead to future studies that may open the door to better understanding mental states and well-being of dogs, which leads to overall better health and wellness of the species.

Article Citation: Pongracz, P., Molnar, C., & Miklosi, A. (2009). Barking in family dogs: An ethological approach. *The Veterinary Journal*, 2(183), 141-147.
<https://doi.org/10.1016/j.tvjl.2008.12.010> [L1
SEP]

Article Summary: Despite barking being one of the most noticeable behaviours that are exhibited by dogs, it is seldom investigated from an ethological perspective and there is a lack of data in the primary literature on this. This review article approaches barking behaviour in domestic dogs (as well as other canids) from an ethological perspective and references primary literature from many perspectives in order to gain some insight in the behavioural component of barking in dogs. From an ethological standpoint, the conversation of whether barking is a simple consequence of domestication or whether it is reliable method for communication has been a topic of debate. The researchers believe that barking is in fact an intentional method of communication and have cited several pieces of primary literature to provide evidence. A study conducted by Yin et al., 2002, which involved thorough acoustic analysis of parameters such as frequency and amplitude, found that barks that were released by different individual dogs were context-dependent and differed substantially based on circumstance. Molnar et al., 2008, studied the barks of a single breed in six different contexts (barking at stranger, fight-training, preparing for walks, left alone leashed to trees, begging for a ball, and play) to analyze the differences between 6000 recorded barks, and a computer software was able to individualize over 52% of them and categorize them as different from one another. These studies, among many others brought forth in the review, may indicate that dogs implement acoustically different barks based on context. Another study has shown that humans can possibly recognize the inner state of a dog from its' barks despite never having interacted with it before. These results show a communication aspect is present in barking and provide the necessary grounds for possible experimental projects to better understand the behavioural aspect of it.

Article Contribution: This article in particular was very interesting because it largely outlines many of the subtopics within dog vocalization in order to gain further insight into the ethological background that may be behind it. Furthermore, this article uses other perspectives to find gaps in understanding in the ethology and compiles it a way that poses many new questions, such as "How do dogs control the acoustic variability in their barks?" as well as other things. It brings together many concepts and also use the gaps in understanding to identify future directions on the topic.

Article Reference: Taylor, A.M., Reby, D., & McComb, K. (2009b). Context-related variation in the vocal growling behaviour of the domestic dog (*Canis familiaris*). *Ethology: International Journal of Behavioral Biology*, 10(115), 905-915. <https://doi.org/10.1111/j.1439-0310.2009.01681.x>

Article Summary: With regards to the context-specificity of domestic dog growls, there's plenty of literature present favoring the idea that there are a few significant acoustic parameters (i.e. frequency, inter-growl interval etc.) present in a growl that can vary with regards to context of the growl. It's said that this variation occurs in a somewhat formulaic manner that can be estimated empirically as well as through audition by the human ear. Three related experiments were conducted by the researchers in order to test this. First, 204 individual growls were recorded from 32 dogs in an aggressive context and playful context. These growls were analyzed acoustically and temporally. Next, these growls were presented to 33 human listeners to test whether listeners could distinguish the context in which the growl originated. Lastly, 40 artificial growls were generated (20 in the aggressive context & 20 in the playful context). Aggressive growls had a 2-second inter-bark interval, whereas playful growls had a 0.5-second inter-bark interval. Results indicated that the formant frequencies as well as the overall frequencies did not vary significantly between both contexts but the temporal structure did house significant variation. Aggressive growls were longer than playful ones. According to the survey, human listeners could not accurately distinguish the context of origin of the growls but growls presumed to be aggressive were also presumed to be from large dogs. Furthermore, humans could accurately infer context from the artificial growls. Based on the results, temporal structure seems to play a bigger role than the acoustic structure and that may house more key information on context. Human subjects also tend to better identify context based on growling rate as opposed to other potential acoustic characteristics. Future studies should include similar listening tests on other species to see if the principle holds true in communication amongst species.

Article Contribution: This article was definitely the most intriguing by far, as it seemingly contradicted many of the trends seen in the other articles presented in this review. For example, the results here indicated that formant frequencies are not significantly variable amongst these two particular contexts, which is opposite to what is shown in another study conducted by the same group. Studies like this are absolutely key as it brings to light more questions that need to be answered like why results that should theoretically support each other, in fact do not.

