COGNITIVE IMPLICATIONS OF SHORT- AND LONG-DISTANCE COMMUNICATION IN ELEPHANTS

—

Nicole Trappe

COGS 143, Winter ‘19

Humans. The pinnacle of intellect, the founders of civilization, invention, language…the list goes on. We often like to imagine ourselves as the top of the food chain, holding "abilities" that most animals can only *attempt* at other than the remarkable few. Years and years ago we finally cracked open the door to the realm of superiority to let in the primates. Now, we were the single phylogenetic branch with incomparable cognitive abilities—that was…until cetaceans slipped through. As mentioned in COGS143, it has become clear that our cognitive abilities may not be a result of the profound evolution of a single branch, but may in fact be a convergence of similar solutions, requiring extraordinary cognition, because of a highly social environment. Elephants drive this point home: our last common ancestor was approximately 100 million years ago[7], and yet, for quite a *distant* species, they share large brains, long life spans, (empathetic) social bonds, and cognitive abilities that cannot be understated.

This paper takes the opportunity to step away from a primate-centric viewpoint and to focus on elephants—great lumbering creatures jokingly labeled as having peanut-sized brains—and their uniquely, impressive cognition. Specifically, this paper will explore how both long- and short-distance vocal communication have lent themselves to the development of this cognition. We will first go through how these different communicative styles function through the auditory mechanisms involved, how they are used in regards to the social structure, and why it matters through a cognitive lens.

To understand how elephants communicate, we must begin with the tools that made this possible. The auditory system of elephants is remarkably similar to us—and mammals in general—however, they differ greatly in terms of size. This starts with one of their most prominent features: pinnae (or the great flapping ears most imagine). The pinnae of elephants serve to funnel sound into the auditory canal thereby amplifying it and enhancing localization abilities (Byrne & Bates, 2009). Sound then passes through the expansive auditory canal, enlarged tympanic membrane, and spacious middle ears with massive, weighty ossicles. Interestingly, elephants do not share the style of cochlea of most mammals, but it resembles that of a reptile in

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

its curvature. Because the ratio of the cochlear base to the apes is rather large, this selects for a higher sensitivity to low frequency sounds[1]. In addition to this ratio, the massive ossicles and conduction allow for elephants to have extreme sensitivity to vibrations—especially seismic ones known as "Rayleigh Waves" that have a range of 10 to 40 Hz (Byrne & Bates, 2009). Elephants hear within a range of 5 to 9,000 Hz although most calls by adult males average 12 Hz as compared to adult human males at 110 Hz ("Elephant Communication", n.d).

However, it does not end there; elephants have a few more hearing tricks up their sleeve. The first is "acoustic fat", and while this is still being contended, it is hypothesized that elephants had an aquatic common ancestor that gave them cartilage and dense fat around their head and feet (somewhat comparable to dolphins) that assist in receiving sound (O'Connell-Rodwell, Hart, & Arnason, 2001). Going back to the aforementioned topic of vibrations, elephants also have mechanoreceptors, specifically Pacinian corpuscles, densely packed in their trunk and foot. When these corpuscles are deformed, even by slight vibrations, they send signals to the brain. This may also play a role in the ability for elephants to detect seismic activity and receive low frequency sounds, such as rumbles, that pass through the ground. Finally, because elephants seem to detect sounds using their full body rather than just their inner ears, they are working with a distance of 2.5 m rather than 0.5 which helps to detect phase differences—something rather useful when dealing with low frequencies—and localizing vocalizations (O'Connell, et al., 2001).

With all of these auditory mechanisms in play, elephants are able to wield two types of communication: short-distance and long-distance. The former is mainly categorized by trumpets and barks and the latter by rumbles. Long-distance communication enables the use of vocalizations that may be heard over 10 km away, traveling in the air at speeds of 309 m/s, even at 112 dB, or underground at 260 m/s ("Elephant Communication", n.d.). This is astounding and only possible because of their heavy reliance on low frequency communication. Low frequencies are able to travel farther as they attenuate less, and in biomes like the open savannah with has

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

sparse foliage, these frequencies can carry far unlike high frequencies that are highly absorbed in the dense vegetation of a forest (O'Connell, et al., 2001).

Before we dive into the usage of these auditory mechanisms in communication, it is pertinent to first understand the social setting of elephants. These creatures are the third longest-living mammals, after us and Bowhead Whales, with *Loxodonta africana* averaging 70 years of age[1]. Additionally, elephants live in a fission-fusion society meaning coalitions are constantly forming and splitting, individuals migrate from one group to the next, and their environments are always changing. Because of this high level of social fluidity coupled with a lengthy lifespan, elephants encounter hundreds of individuals over their lifetime and are able to recognize the calls of more than a 100 (Byrne & Bates, 2009). Elephant society is comprised of 5 social tiers: 1) the "unit:" mother-calf relationships, 2) "family:" relatives, which concentrates on the role of females in helping to raise the calves as they act as "allomothers," 3) "bond-groups:" super-group of families, 4) "clans" and 5) "sub-population" (Bates, Poole, & Byrne, 2008). The family is considered the core of their social lives (Altenmüller, Schmidt, & Zimmermann, 2013).

The fission-fusion lifestyle comes into play in multiple ways. First, around age 14, males leave the group and form alliances with other adolescent males until they have matured enough, predominantly in terms of size (the bigger the better) for females to engage in mating behavior (Bates et al., 2008). Communication may even be an important consideration in mate selection as the farthest rumbles are produced by the largest males, although this is all conjecture. Additionally, elephant clans must migrate in search of watering holes so it is not uncommon for groups to split up depending on whether they want to seek a new watering hole or remain. Finally, coalitional behavior is common as elephants will form bond-groups against another family.

The best example of this social setting is of the matriarch, the oldest female, who holds the top position in the hierarchy. To be respected, she must be both wise and very well connected socially. Wisdom is a highly-prized resource in times of drought or scarcity, and the matriarch must decide, based on past experiences, and knowledge of other watering holes, whether she will

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

lead her clan across distances as far as 600 km to certain holes (Byrne & Bates, 2009). Additionally, she must be able to recognize numerous individuals, their relationships, and be able to form bonds with them for support ("Elephant Communication", n.d.).

In this paper, we will focus on the two main communicative calls: contact calls and alarm rumbles. Contact calls are used in near proximity and highlight the role and importance of relations over rank or reproductive state in elephants—a topic we will cover later ("Elephant Communication", n.d.). Some claim that elephants have over 30 different contact calls (Bates et al., 2008) while others claim just 6 in their repertoire (Stoeger-Horwath, Stoeger, et al., 2007). It is clear what should constitute a contact call and how to differentiate them is highly debatable. In this paper, I focus on the calls defined by Stoeger-Horwath et al. (2007) as they carve out six very distinguishable categories for each call of which the thirty identified by Bates et al. (2008) seem to be subtypes of. These six calls are categorized by their origin: those produced by the larynx are the rumble, bark, grunt, and roar, or the trunk like snorts and trumpets. They may be further discriminated by their unique structures (contour), frequencies, and duration. Rumbles are, by far, the most pervasive call as they are utilized highly in social contact calls but also for alerts of danger.

Let us begin with contact calls. Due to the nature of their fission-fusion society and because they range widely during the rainy seasons, there are often long periods of separation among individuals, so, when they return or re-group, they have "reunions" or "greeting ceremonies" (McComb, Moss, et al., 1999). These are often large displays of high arousal seen through both ear flapping and urination, but mainly through the use of rumbles and trumpeting. The groups involved approach each other, first uttering soft low rumbles, and eventually all chorus, gaining intensity, and add trumpets—loud blaring noises—to punctuate their excited state (Altenmüller et al., 2013). If we were able to ascribe emotion to this display, it would most likely be categorized as excitement and joy. This is also an example of a positive feedback loop in that the more high arousal content, the more vocalizations, and so forth. It may even be possible that the longer the separation, then the more vocal and "emotional" the reunion,

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

however this has never been tested. Curiously, this seems to indicate that elephants must not only recognize another group, their relation to them, but also that they had been separated for a period of time that warrants a greeting ceremony.

To continue, contact calls are used constantly in elephant daily life. The more intriguing aspect of this is how and why elephants decide to respond to these calls. Rumbles are often associated with long-distance communication (which we will discuss later), however, Soltis, Leong, & Savage (2005), studied how it is used in short-distances, specifically in spontaneous, alternating, vocal exchanges called "antiphonal calling". Female elephants wore collars with microphones to record the calls produced by each individual, and endocrine data was taken to determine their reproductive state. First, they found that vocalizations—rumbles—were not produced at random as they had no overlaps but occurred within 30 seconds of one another, and the majority were between two individuals (dyadic). 70% of the responses to a rumble were done by the two individuals most closely affiliated with the caller (Soltis et al., 2005). In comparing dominance rank, reproductive status, and affiliation, they found that only affiliation was indicative of whether an elephant would respond to the rumbles of another. Those with the closest relations to the caller (like family unit versus population level) were likely to respond while those who were not close, would not. They were even found to be familiar with over 100 calls of other females even after 20 years had passed. This indicates both that calls seem deliberate and responses depend on the social affiliation one has with the caller and a high dependence on auditory memories.

Furthermore, in an experiment performed by McComb, Moss, et al. (1999), they played recording of contact calls of those in their 1) family unit, 2) bond-group, and 3) population. The first goal was to determine if elephants could discriminate the contact calls of their own family unit compared to individuals in their bond-groups or population. Females visibly appeared extremely agitated in the presence of non-family or non-bond-group members when their small calves were in the vicinity. This task would require knowing the relational-level of the caller (like family versus bond-group) to determine whether they felt comfortable or not. Moreover,

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

when a call from a family member or bond-group was heard, the elephant would return a call and approach the loudspeaker. Again, we see a preference towards individuals of a closer relation.

Additionally, we even see that subordinate females will emit contact calls—coined as "growls" by some—if approached by a dominant to communicate both her distress and, possibly, to alert those affiliated with her as a form of recruitment (Soltis et al., 2005). This indicates that elephants must be able to recognize and individual, their relative rank, give out a call, and expect certain individuals to possible come to their aid.

While there are many variations of contact calls, the same can be said for alarm rumbles. One example is of the "bee alarm call" used to alert all elephants in the vicinity of a swarm of bees. Although this rumble may have originated as just a cue—a byproduct of high arousal—like erratic breathing patterns, it has now taken the form of a more elaborate and precise vocalization. Selection may have helped to fine tune vocal shifts and those listening to associate that shift to a threat from the environment (Altenmüller et al., 2013). Like the greeting ceremonies, alarm rumbles engage a high emotional content, which, in this case, provides information about the level or urgency and threat posed. Specifically, the more fear, the more nonlinear phenomena we see; this phenomena is defined as showing "chaos and bifurcation", which, in simpler terms, means that the vibration of the vocal cords becomes erratic and irregular much like when babies or heavy metal singers scream. This vocalization is so jarring that it instantly attracts and holds attention which makes it a far more successful alarm (Soltis, King, et al., 2014).

Now, let us discuss long-distance communication which is categorized by rumbles that produce seismic waves that travel underground. Living in a highly fluid society and having the need to migrate to different territories for survival presents a challenge as individuals must be able to re-group. To combat this problem, elephants utilize rumbles that can carry as far as 10 km away ("Elephant Communication", n.d.). Thanks to the grassy Savannah, low-frequency sound travels farther because it attenuates less so it is highly useful for *Loxodonta africana.* This allows

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

sub-groups to stay in contact as they roam in search of watering hole, mates, or to associate with a different group for a time. There is even tentative evidence that elephants have become so

sensitive to these seismic vibrations that they can feel the onset of an earthquake or hear thunder in the distance and use that as an indicator of where to search for water next (O'Connell-Rodwell et al., 2001). Additionally, elephants are extremely good at localizing sounds, possible due in part to their ability to register rumbles with their whole body—which produces a larger "inter-aural" distance ("Elephant Communication", n.d.; O'Connell-Rodwell et al., 2001). This may help them be able to call out to others within the radius and understand their location relative to the current group. Because we know that elephants can recognize the calls of hundreds of individuals, especially family, this localizing ability may help to constantly keep track of their affiliates.

Time for a quick recap: elephants utilize enormous ears to amplify close sounds as well as mechanoreceptors to sense seismic waves. We illustrated the social hierarchy of elephants, with a family-first mentality and a highly fluid social structure. We have also touched on a few examples of short-distance communication in the form of greeting ceremonies, contact calls and responses to them, and alarm rumbles. For long-distance communicate, we briefly covered how seismic rumbles are utilized. Overall, elephants live a highly-dynamic life, their world is constantly shifting both physically and socially, and as survival and social affiliations are highly prized—as seen through the matriarch—this creates quite a few cognitive hurdles.

It is clear that elephants can categorize: they hear a contact call and can identify how that individual relates to them—which tier they belong in. And this social standing outweighs all other components that typically would rule the lives of other animals, like reproduction or rank. Because individuals are constantly leaving a group to mate, socialize, or watering holes, their affiliations are always shifting. This requires a lot of mental capacity and skill in creating bonds, monitoring them, and maintaining them.

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

Moreover, affiliations determine whether an elephant will respond to a contact call, an interaction which is highly complex as it is characterized by turn taking. Additionally, the elephants in the vicinity of the caller must be evaluating each others' relationships to the caller as only the closest ones respond. This is quite a feat in itself as elephants are showing both self-control in analyzing the situation before responding, but, once again, paying attention to everyone engaged.

Even the greeting ceremonies are something to appreciate. They involve high emotional displays on both sides that indicate an ability to recognize that a sub-group had split off, those individuals went away, time had passed, and they returned. Although it is impossible to conclude anything as little research has been done, this display seems to demonstrate that elephants acknowledge the return of a group as they can recognize those involved and welcome them back to the group. This is both highly socially but indicates an elaborate communicative display.

For the alarm rumbles, unlike most animals, elephants not only indicate that there is *a* threat, but can indicate the level of urgency and the threat itself. Utilizing nonlinear phenomena, they make alarm rumbles conspicuous and overt which aids in a sudden response by others, promoting survival. Although I only covered the bee alarm, elephants have many, including ones for humans like the Maasai[4] and Samburu tribesmen (Soltis et al., 2014).

Finally, long-distance communication utilizing rumbles both allows for and relies on a dynamic, fluid, social situation. With males often leaving the clan to pursue mates, groups splitting in search of different watering holes, or general migrations, elephants must be able to communicate across far differences to both keep track of their family—or close members—and come back together. Although this was not mentioned earlier, the task of simply traveling hundreds of kilometers away, on top of the need to localize individuals, requires the use of spatial memory, possibly cognitive mapping, and categorization to know the status of each individual in that split sub-group in terms of the five tiers.

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

In conclusion, I hope that it has become evident that elephants are incredible creatures from the plethora of communicative abilities they have at their disposal to their dynamic social world. Communication has both enabled them to be able to express emotion, imminent danger, and their relationships to others as well as remain connected to individuals that have split off. These abilities have flourished in parallel to their complex social structure as it is highly fluid, with ever-changing bonds, kinship, and interactions. There is so much that has yet to be discovered and dug deeper into, but, at this moment, I can confidently state that elephants have an immense cognitive capacity in managing and navigating this socially and environmentally changing world.

[7] Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

References:

1. African Bush Elephant: Loxodonta africana. (n.d.). *The Nature Conservancy.* Retrieved from https://www.nature.org/en-us/explore/animals-we-protect/african-bush-elephant/

2. Altenmüller, E., Schmidt, S., & E. Zimmermann. (2013). *The Evolution of Emotional Communication: From Sounds in Nonhuman Mammals to Speech and Music in Man.* Oxford: OUP Oxford.

3. Bates, L. A., Poole J. H., & R. W. Byrne. (2008). Elephant cognition. *Current Biology*, vol 18 (13), pg. 544-546. doi:10.1016/j.cub.2008.04.019

4. Bates, L., Sayialel, K., et al. (2007). Elephants Classify Human Ethnic Groups by Odor and Garment Color. *Current Biology*, vol 17 (22), pg. 1938-1942. doi:10.1016/j.cub.2007.09.060

5. Byrne, R. W. & L. A. Bates. (2009). Elephant cognition in primate perspective. *Comparative Cognition and Behavior Reviews,* vol 4, pp. 65-79. doi:10.3819/ccbr.2009.40009

6. Elephant Communication. (n.d.). *Elephant Voices.* Retrieved from https://www.elephantvoices.org/elephant-communication/acoustic-communication.html

7. Goodman, M., Sterner, K. N., et al. (2009). Phylogeneomic analyses reveal convergent patterns of adaptive evolution in elephant and human ancestries. *PNAS*, vol 106 (49). doi*10.1073/0911239106*

8. McComb, K., Moss, C., et al. (1999). Unusually extensive networks of vocal recognition in African elephants. *Animal Behaviour,* 2000, vol 59 (6), pg. 1103-1109. doi:10.1006/anbe.2000.1406

9. O'Connell-Rodwell, C. E., Hart, L. A., & B. T. Arnason. (2001). Exploring the Potential Use of Seismic Waves as a Communication Channel by Elephants and Other Large Mammals. *American Zoology*, vol 41 (5), pg. 1157-1170. doi:10.1093/icb/41.5.1157

10. Soltis, J., King, L. E., et al. (2014). African Elephant Alarm Calls Distinguish between Threats from Humans and Bees. *PLOS ONE,* vol 9 (2). doi:10.1371/journal.pone.0089403

11. Soltis, J., Leong, K., & A. Savage. (2005). African elephant vocal communication I: antiphonal calling behaviour among affiliated females. *Animal Behaviour,* vol 70 (3), pg. 579-587. doi:10.1016/j.anbehav.2004.11.015

12. Stoeger-Horwath, A., Stoeger, S., et al. (2007). Call repertoire of infant African elephants: first insights into the early vocal ontogeny. *The Journal of the Acoustical Society of America*, vol 121 (6), pg. 3922-9331. doi: 10.1121/1.2722216

13. Vanderbilt University. (2008). Low-frequency Hearing Linked To Shape Of The Cochlea. *ScienceDaily*. Retrieved from www.sciencedaily.com/releases/2008/04/080425151819.htm