

Origins and Evolution of Language

Week 6: vocal learning and grammar learning

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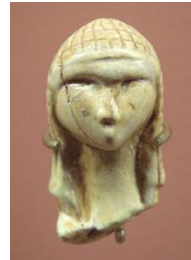
While you are waiting: join wooclap.com, code INMRBS,
there will be an early discussion question today

An exam-related question from the pre-lecture quiz

“I realise it is still relatively early in the year to be worried about the exam, but the lack of past papers available online makes me nervous. Would it be at all possible (nearer the time!) to try an example paper, even if it's just half a paper, just to see the format of the exam? I completely understand this is a lot of work but I know a few people that are also apprehensive, particularly about the kind of content that we need to know for the exam (knowing readings inside out, understanding more complex biological concepts etc.).”

Finishing up on art and cumulative culture

Upper Paleolithic Revolution “Great Leap Forward”, 100-40KYA (?)

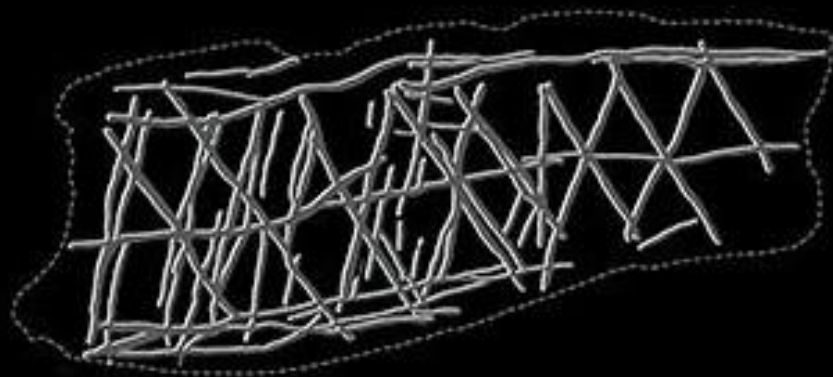




Blombos cave, South Africa

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From Henshilwood, C.S. *et al.* (2018) An abstract drawing from the 73,000-year-old levels at Blombos Cave, South Africa. *Nature*, 562, 115–118.

“evidence for modern cognition at c. 77–55 ky. In particular, we highlight the shell beads and engraved ochres from Blombos Cave as being examples of artifacts with clear **symbolic meaning**. A number of authors have previously suggested that the Blombos ochre pieces and the marine shell beads equate with information being stored outside of the human brain ... and that **the transmission and sharing of the symbolic meaning of these items must have depended on “syntactical” language**” (Henshilwood & Dubreil, 2009, p. 60-61)

Henshilwood, C.S. & Dubreuil, B. (2009). Reading the artefacts: Gleaning language skills from the Middle Stone Age in southern Africa. In R. Botha & C. Knight (Eds.), *The Cradle of Language* (pp. 41-60). Oxford: Oxford University Press.

“We argue that the **capacity to represent how an object appears to another person** ... enables the invention of symbolic artifacts like beads and engraved ochres, but also of other artifacts whose symbolic component remains contentious, such as bone tools, bifacial points, and engraved ostrich egg shell. Because **recursion is essential to articulate in language [this] kind of meta-representations** ..., we predict that the presence of syntactic language can now confidently be “read” from some of the Blombos artifacts. ” (Henshilwood & Dubreuil, 2009, p. 61)

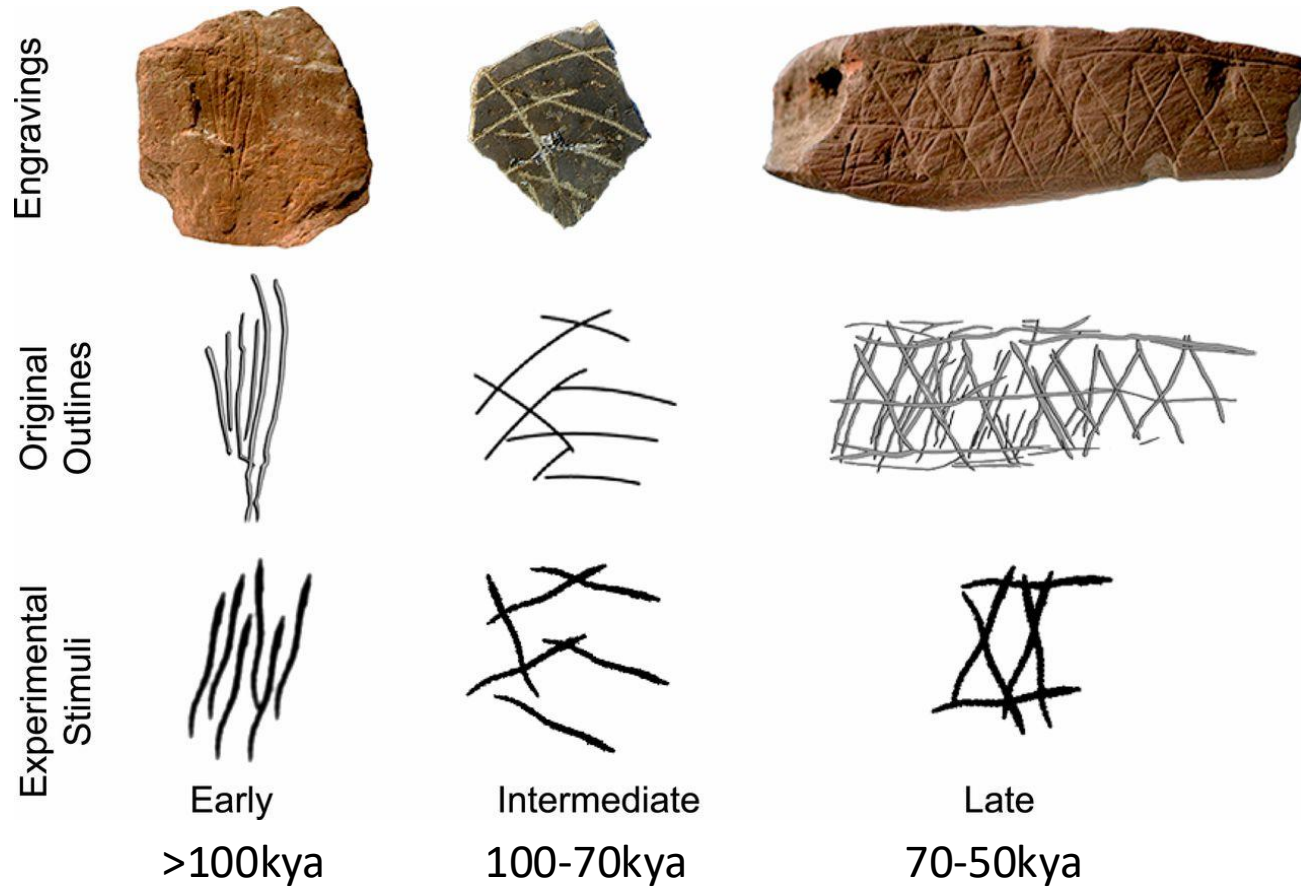
Henshilwood, C.S. & Dubreuil, B. (2009). Reading the artefacts: Gleaning language skills from the Middle Stone Age in southern Africa. In R. Botha & C. Knight (Eds.), *The Cradle of Language* (pp. 41-60). Oxford: Oxford University Press.

From these, we can infer...

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1. Nothing about language
2. Presence of syntax
3. Presence of meta-representation
4. Syntax + meta-representation (“the full Henshilwood”)

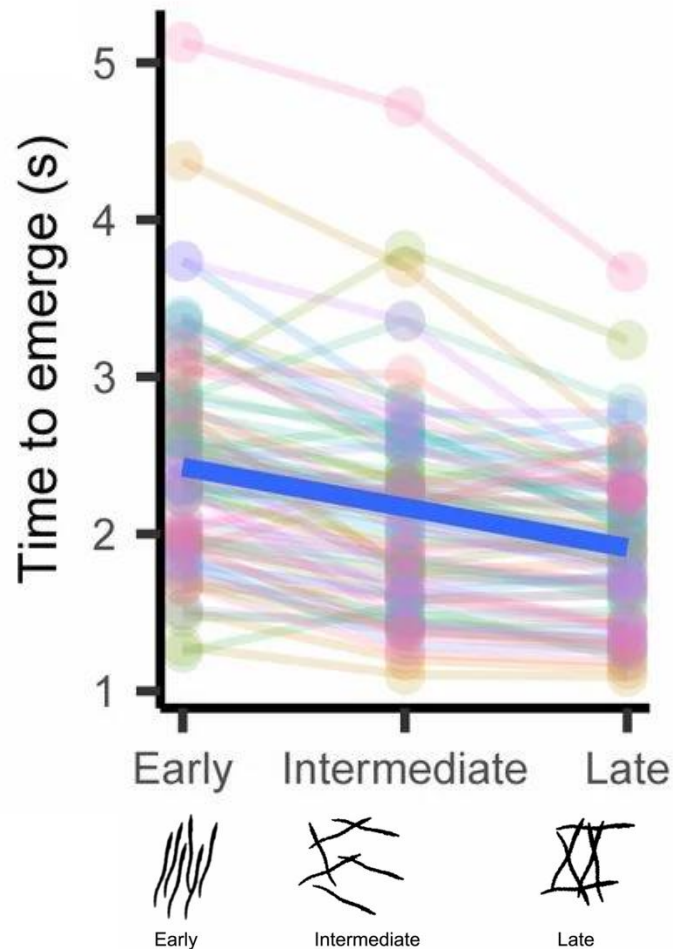




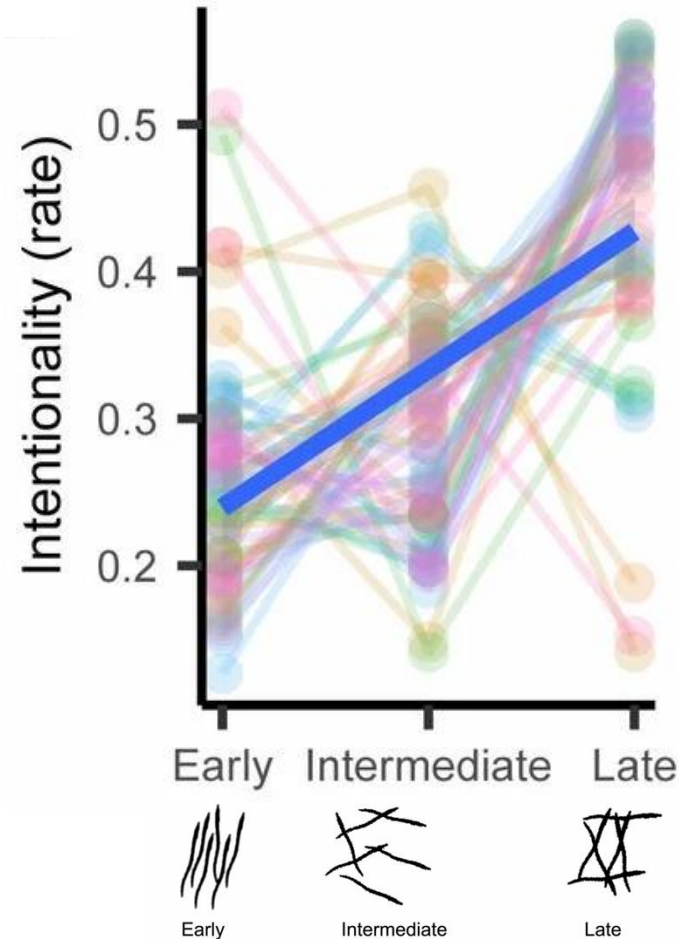
Tylén, K., Fusaroli, R., Rojo, S., Heimann, K., Fay, N., Johannsen, N. N., Riede, F., & Lombard, M. (2020). The evolution of early symbolic behavior in Homo sapiens. *Proceedings of the National Academy of Sciences*, 117, 4578-4584.

Experiment 1: time to emerge under continuous flash suppression

- Measure of salience to human visual system



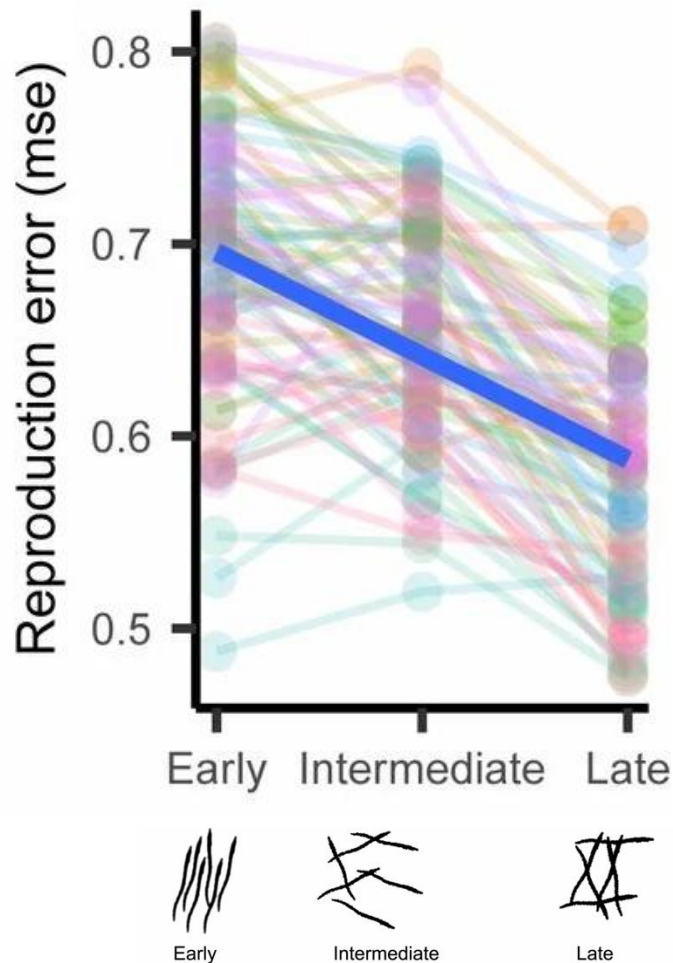
Experiment 2: “which is more likely to have been purposefully made by a human”

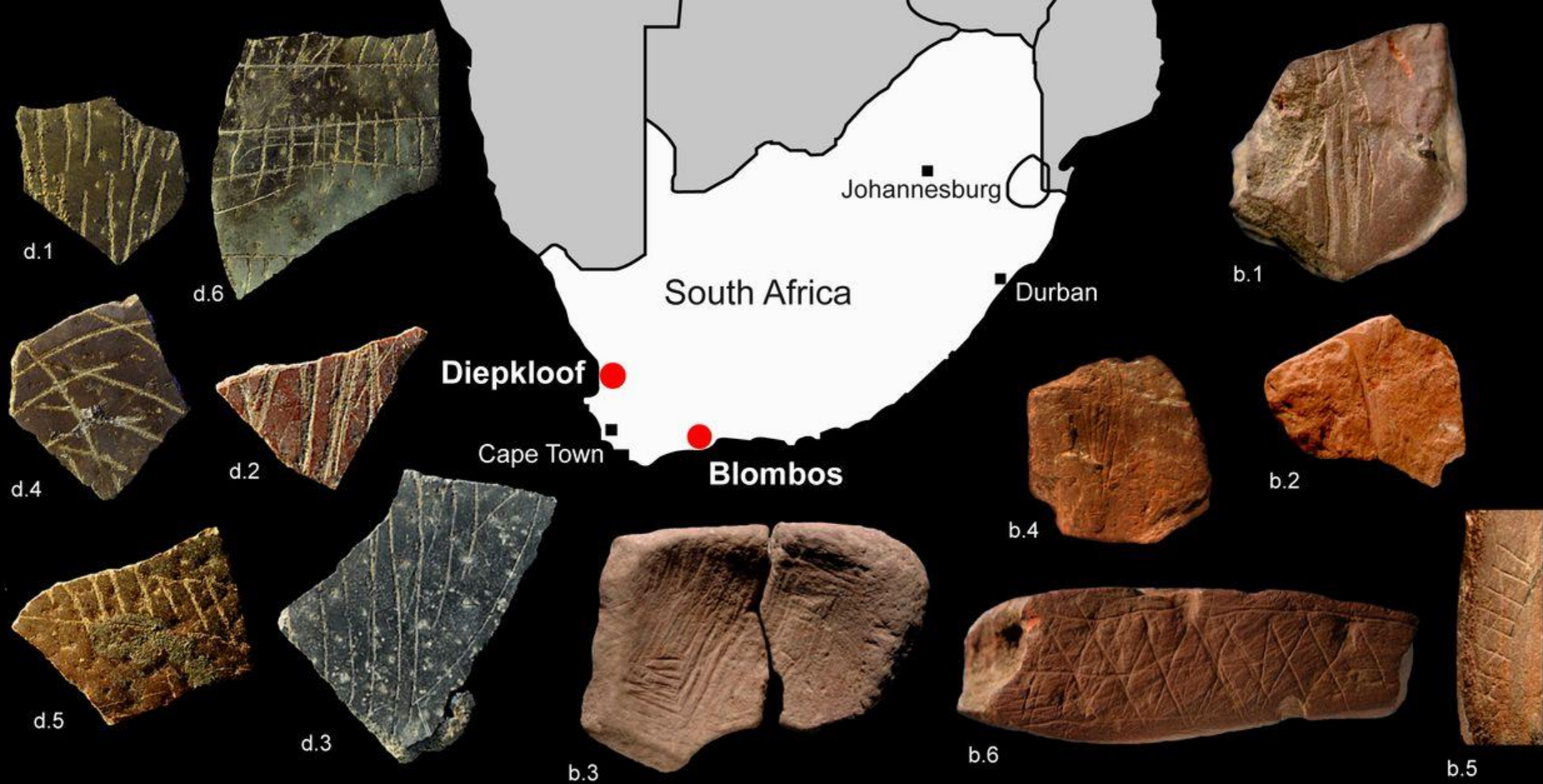


Experiment 3:

delayed reproduction

- Measures salience / learnability / structure?

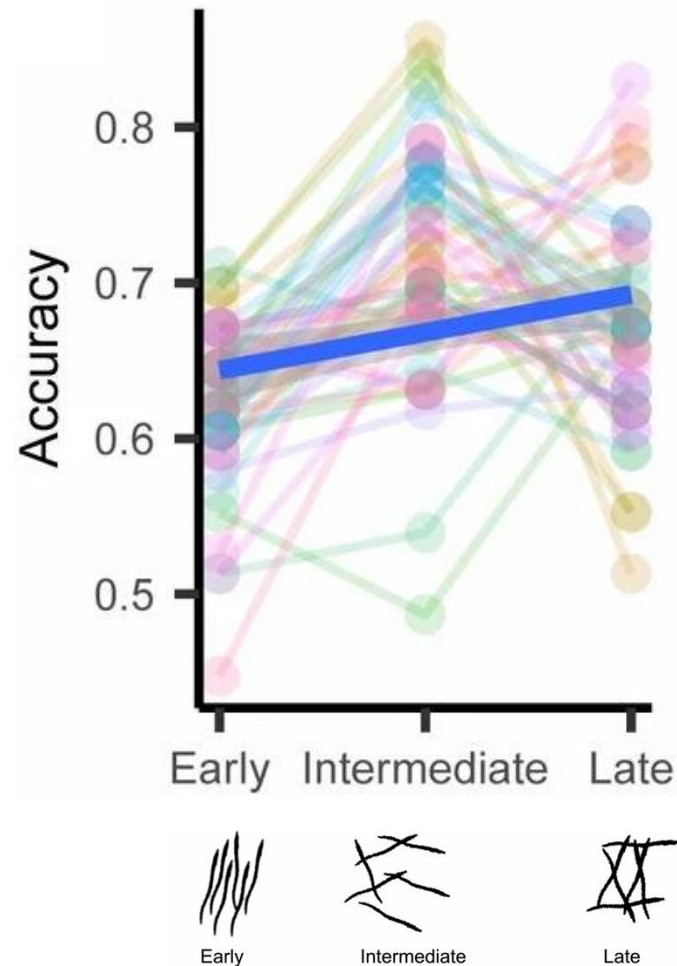




Tylén, K., Fusaroli, R., Rojo, S., Heimann, K., Fay, N., Johannsen, N. N., Riede, F., & Lombard, M. (2020). The evolution of early symbolic behavior in *Homo sapiens*. *Proceedings of the National Academy of Sciences*, 117, 4578-4584.

Experiment 4: stylistic similarity between sites

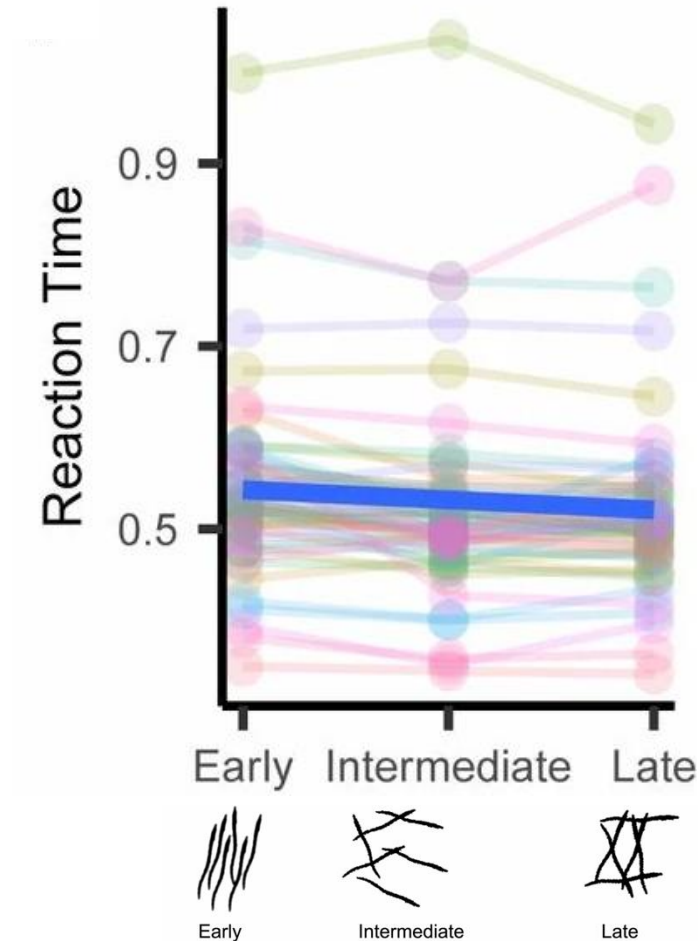
- Measures emergence of distinctive styles at different sites?



Experiment 5:

differentiation of
different carvings
within sites

- Measures potential **communicative** function?



“Our findings [Experiments 1-4] support a view of the engravings as products of a cumulative cultural development toward more complex patterns with increasingly structured and symmetric line crossings, which make them more salient to the human eye, more recognizable as intentionally made, easier to reproduce from memory, and easier to recognize as belonging to a specific group. These properties have been shown to make symbolic forms easier for the visual system to process ... In other words, they track Middle Stone Age H. sapiens becoming increasingly skilled in producing engravings that resonate with the human cognitive system in effective ways.” (Tylén et al., 2020, p. 4582)

Tylén, K., Fusaroli, R., Rojo, S., Heimann, K., Fay, N., Johannsen, N. N., Riede, F., & Lombard, M. (2020). The evolution of early symbolic behavior in Homo sapiens. *Proceedings of the National Academy of Sciences*, 117, 4578-4584.

“there was also evidence that they evolved to become easier to remember and reproduce (Experiment 3), suggesting they have been subject to adaptive pressures for learnability. Similarly, the later patterns were easier to recognize as belonging to the same archeological site compared to the earlier patterns (Experiment 4). This suggests that the engravings were part of a cultural practice—a style—in which they were reproduced, transmitted, and learned within a social group” (Tylén et al., 2020, p. 4582)

Tylén, K., Fusaroli, R., Rojo, S., Heimann, K., Fay, N., Johannsen, N. N., Riede, F., & Lombard, M. (2020). The evolution of early symbolic behavior in *Homo sapiens*. *Proceedings of the National Academy of Sciences*, 117, 4578-4584.

“We found no evidence that the engraved patterns became increasingly discriminable within the two archeological sites. This suggests that the patterns were not under adaptive pressure to evolve affordances for a referential function linked to semantic contents.” (Tylén et al., 2020, p. 4582)

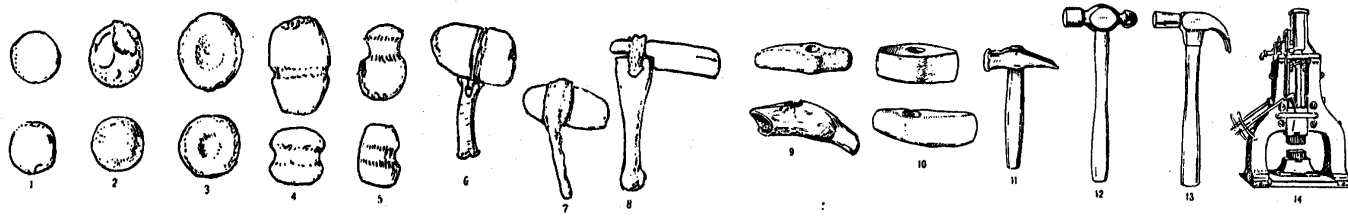
Tylén, K., Fusaroli, R., Rojo, S., Heimann, K., Fay, N., Johannsen, N. N., Riede, F., & Lombard, M. (2020). The evolution of early symbolic behavior in Homo sapiens. *Proceedings of the National Academy of Sciences*, 117, 4578-4584.

Take-home message from Tylén et al (2020) (for me)

- You can do better than looking at artefacts and speculating
- But the kinds of conclusions you can support with evidence might be quite different in character from those of Henshilwood & Dubreuil (2009)

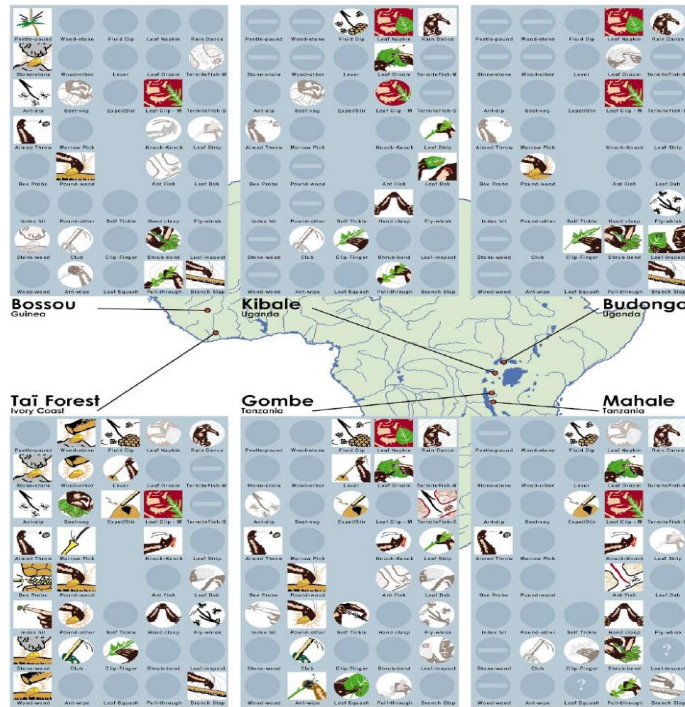
Cumulative cultural evolution in non-humans?

Behaviour and artefacts become increasingly complex, such that each generation uses techniques and objects they could never have invented by themselves (“the cultural ratchet”)



Products of CCE: technology, complex societies, **language**, ...

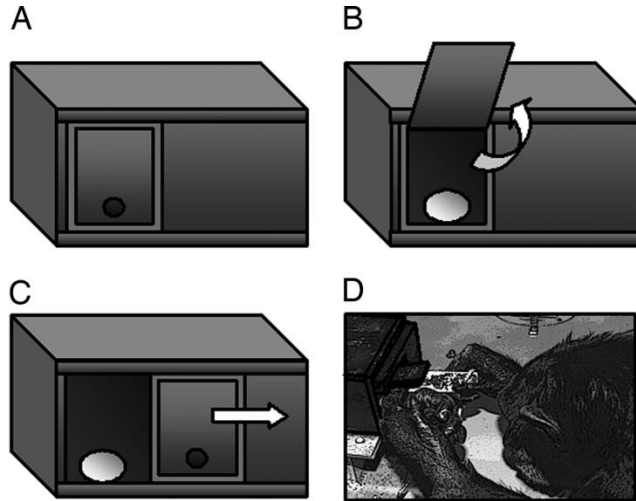
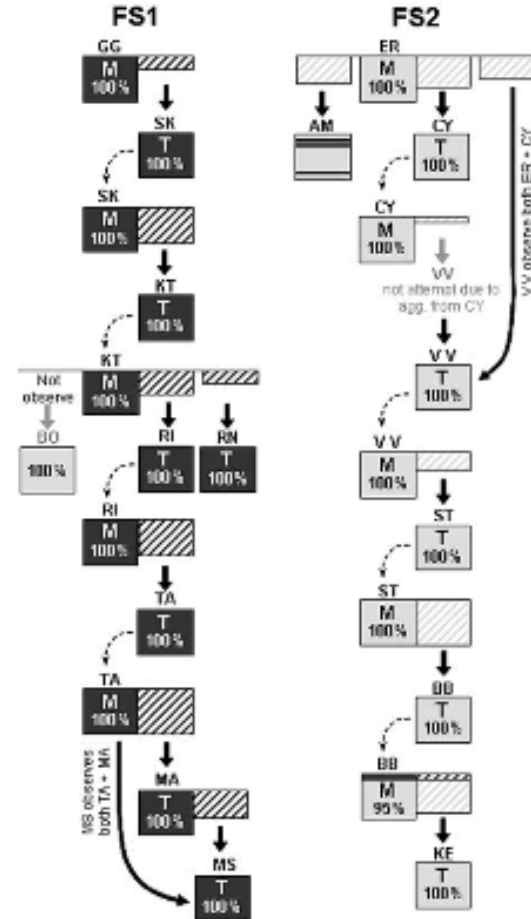
Social learning and culture in chimpanzees



Behavioural variation in chimpanzee populations

- E.g. some groups crack nuts, some don't
- Some variation hard to explain due to differences in environment
- Probably (?) cultural

Social learning and culture in chimpanzees



Social learning and culture in bumblebees (!)



Alem, S. et al, (2016) Associative Mechanisms Allow for Social Learning and Cultural Transmission of String Pulling in an Insect. *PLoS Biology*, 14, e1002564.

Social learning and culture in bumblebees (!)



Alem, S. et al, (2016) Associative Mechanisms Allow for Social Learning and Cultural Transmission of String Pulling in an Insect. *PLoS Biology*, 14, e1002564.

Cumulative cultural evolution in non-humans?

“Undoubtedly, given the investigative and manipulative tendencies of the young chimpanzee and his ability to learn through trial and error, almost all of the feeding and tool using behaviours I have described could be invented anew by each individual” (Goodall, 1970)

Goodall, J. (1970). Tool using in primates and other vertebrates. *Advances in the Study of Behaviour*, 3, 195-250.



Cumulative cultural evolution in non-humans?

“the human attributes that are described as ‘cultural’ in ordinary discourse, seem to be a good deal more complex than, for example, potato washing and termite-fishing...and it is plausible that their greater complexity derives from the accumulation of modifications”
(Heyes, 1993)

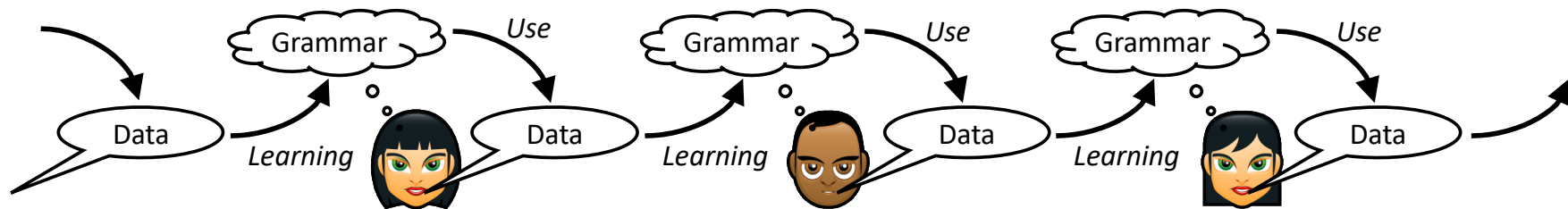


Summary of last week

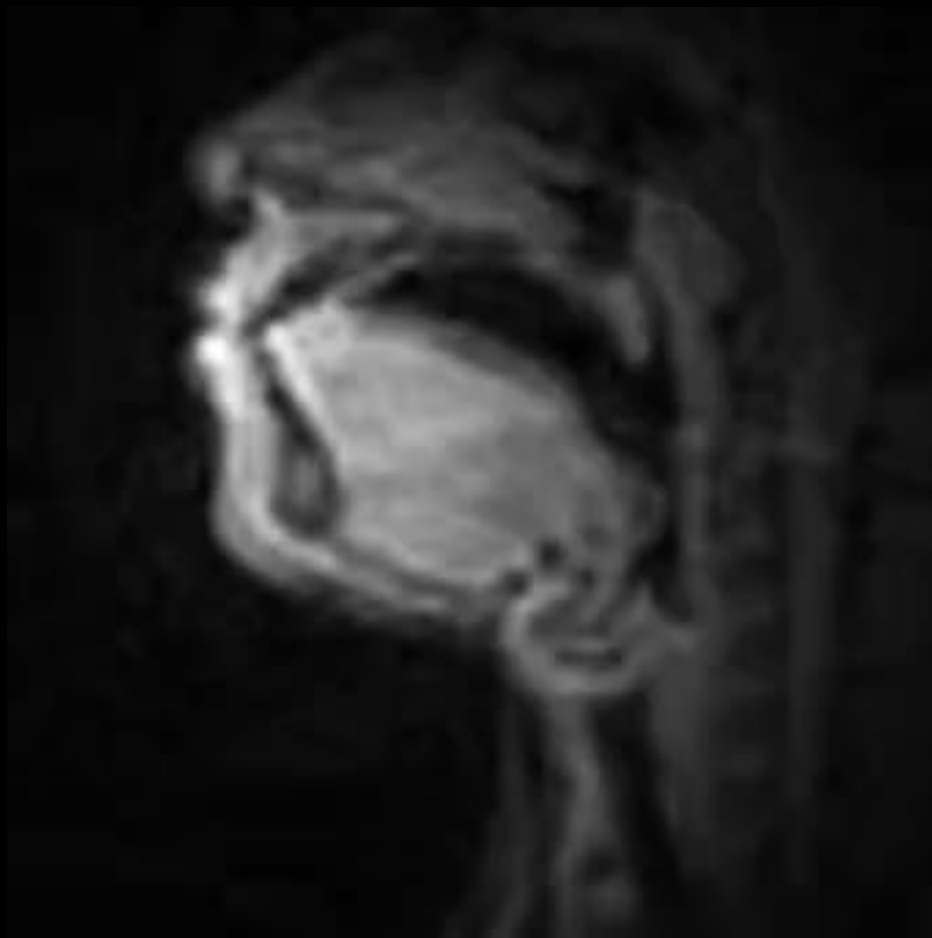
- Human evolution
 - Bushy, not linear
 - Rapid evolution of brain size
 - Evolution of technology and art, The Great Leap Forward
- Social learning, art and tool use, and language
 - What can be inferred from the archaeological record?
 - Are there better methods than just guessing?

Plan for the rest of today

- A quick look at the vocal apparatus for speech
 - Descended larynx, thoracic vertebral canal, air sacs
- Comparative psychology of language learning
 - Complex vocal imitation
 - Grammar learning
 - Are humans special in our language learning abilities?

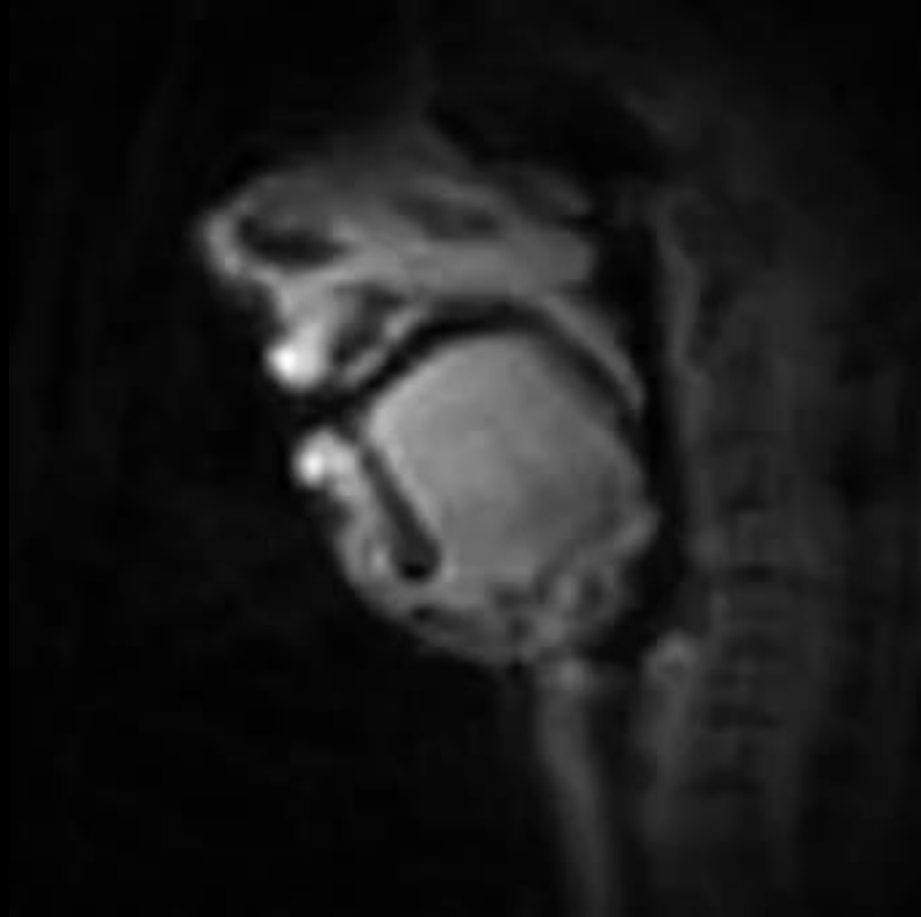


Evolution of speech: the vocal apparatus



The human articulators at work

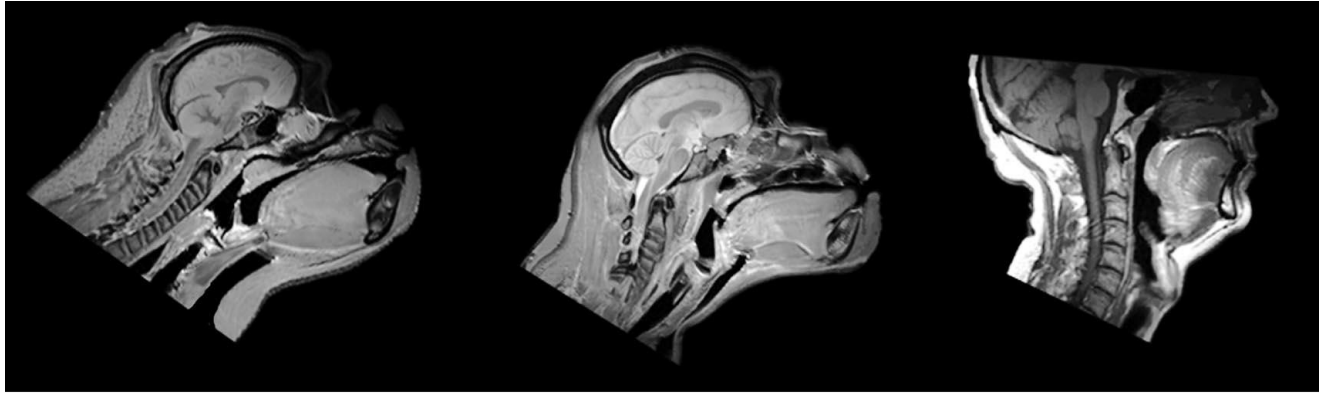
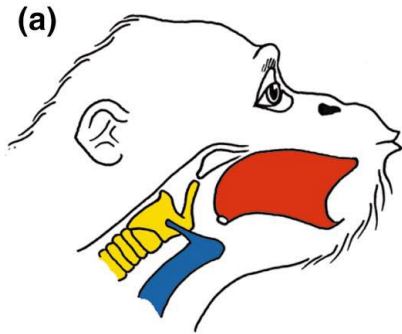
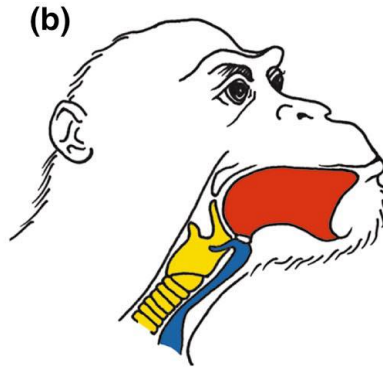
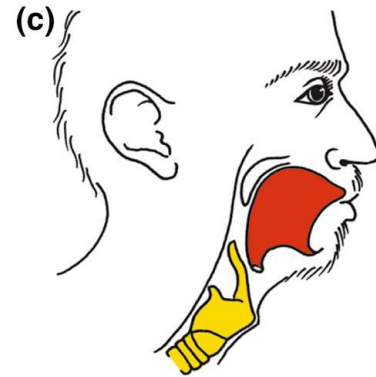
From the rtMRI gallery at USC's Speech Production and Articulation knowledge group



The human articulators at work

From the rtMRI gallery at USC's Speech Production and Articulation knowledge group

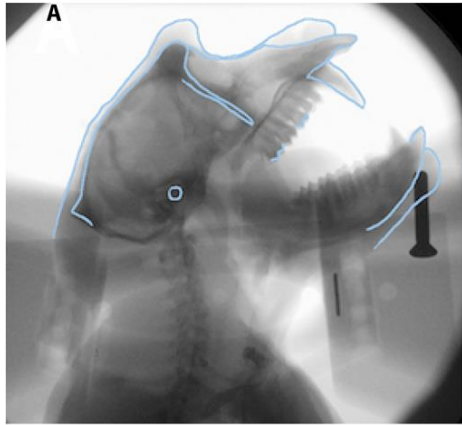
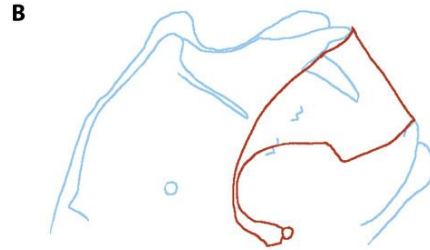
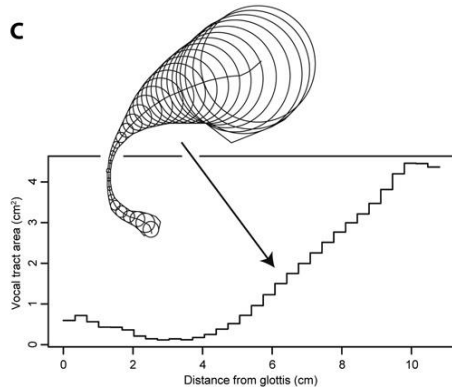
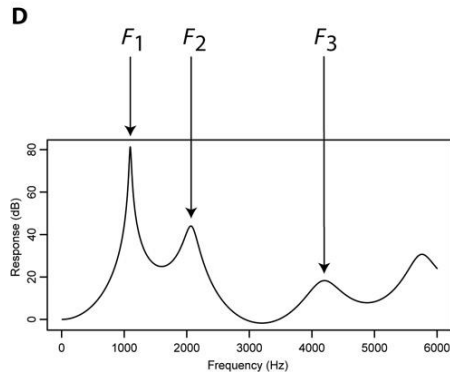
The descended larynx and the two-chamber vocal tract



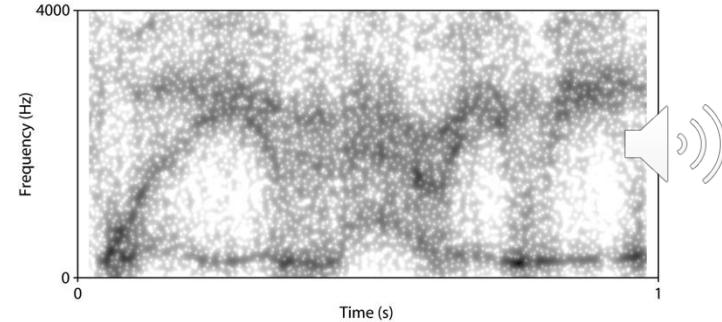


Fitch, W.T. and D. Reby, The descended larynx is not uniquely human.
Proceedings of the Royal Society B, 268, 1669-1675

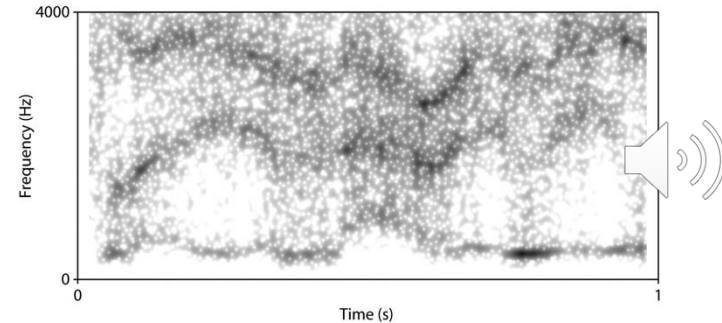
And a monkey vocal tract is probably good enough



A "Will you marry me" - Human version



B "Will you marry me" - Macaque monkey version



Fitch, W. T., De Boer, B., Mathur, N., & Ghazanfar, A. A. (2016).
Monkey vocal tracts are speech-ready. *Science Advances*, 2, e1600723.

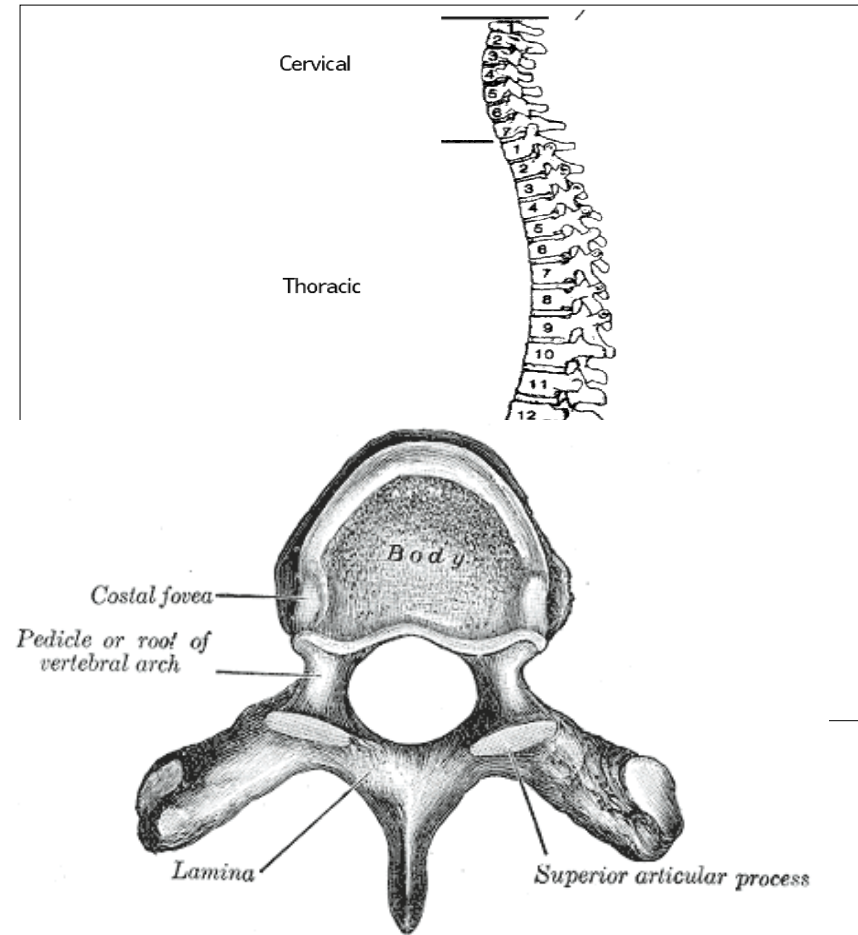
A question from the pre-lecture quiz

“Given that Fitch et al. (2016) proved many language vocalisations in macaques to be possible, is it not evidence that language is innate in humans through natural selection?”

Breathing control

“[M]odern humans and Neanderthals have an expanded thoracic vertebral canal compared with australopithecines and *Homo ergaster*, who had canals of the same relative size as extant nonhuman primates. ... [T]here was an increase in thoracic innervation during human evolution.”

- Date: 1.6M to 100k years ago

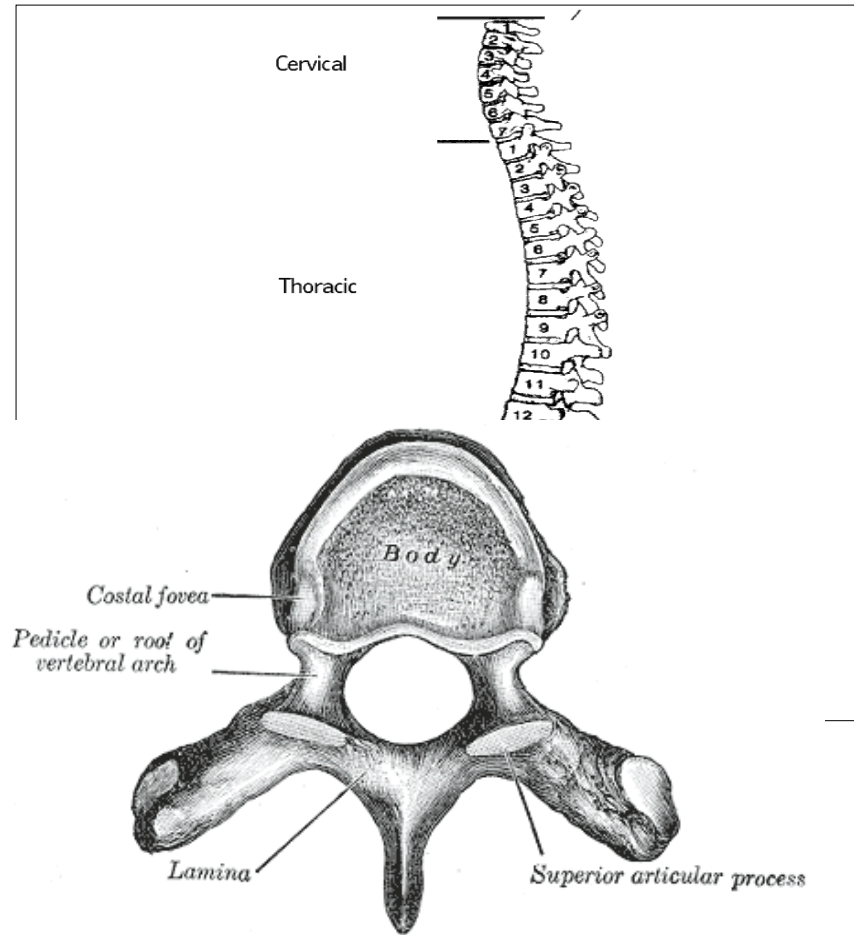


MacLarnon, A. & Hewitt, G. (1999). The evolution of human speech: the role of enhanced breathing control. *American Journal of Physical Anthropology*, 109, 341–363.

Breathing control

“Possible explanations for this increase include postural control for bipedalism, increased difficulty of parturition, respiration for endurance running, an aquatic phase, and choking avoidance. These can all be ruled out, either because of their evolutionary timing, or because they are insufficiently demanding neurologically. **The remaining possible functional cause is increased control of breathing for speech.**”

- Date: 1.6M to 100k years ago

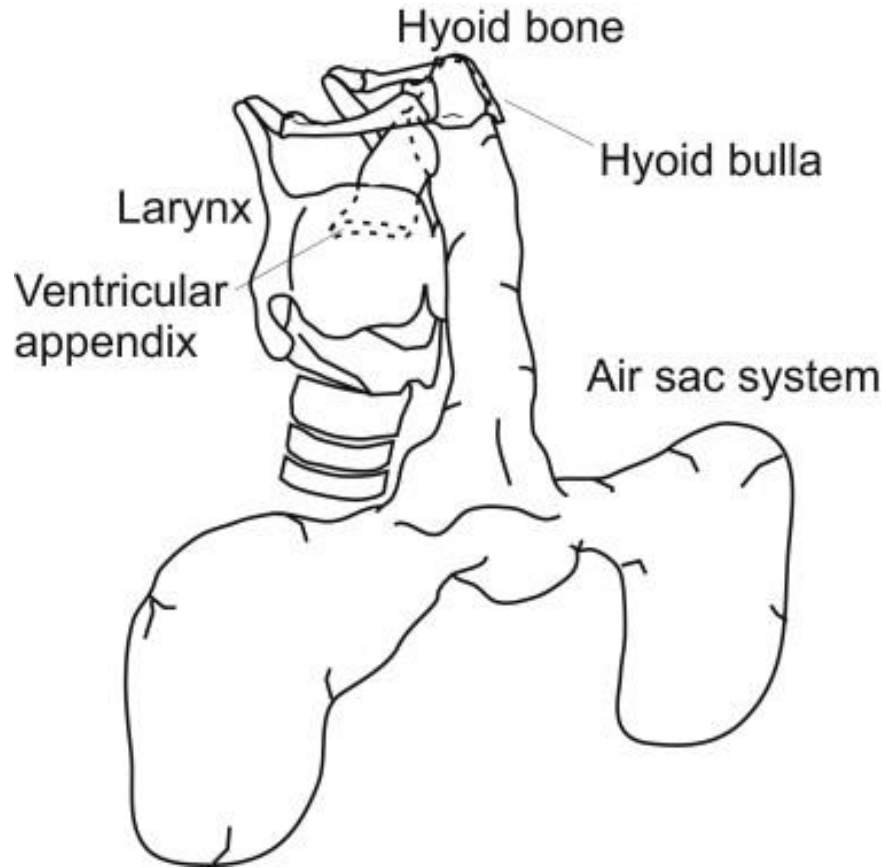
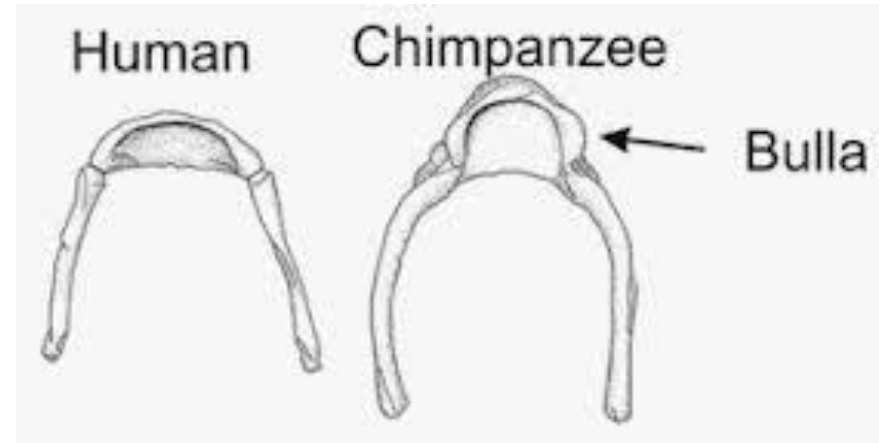


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Air sacs

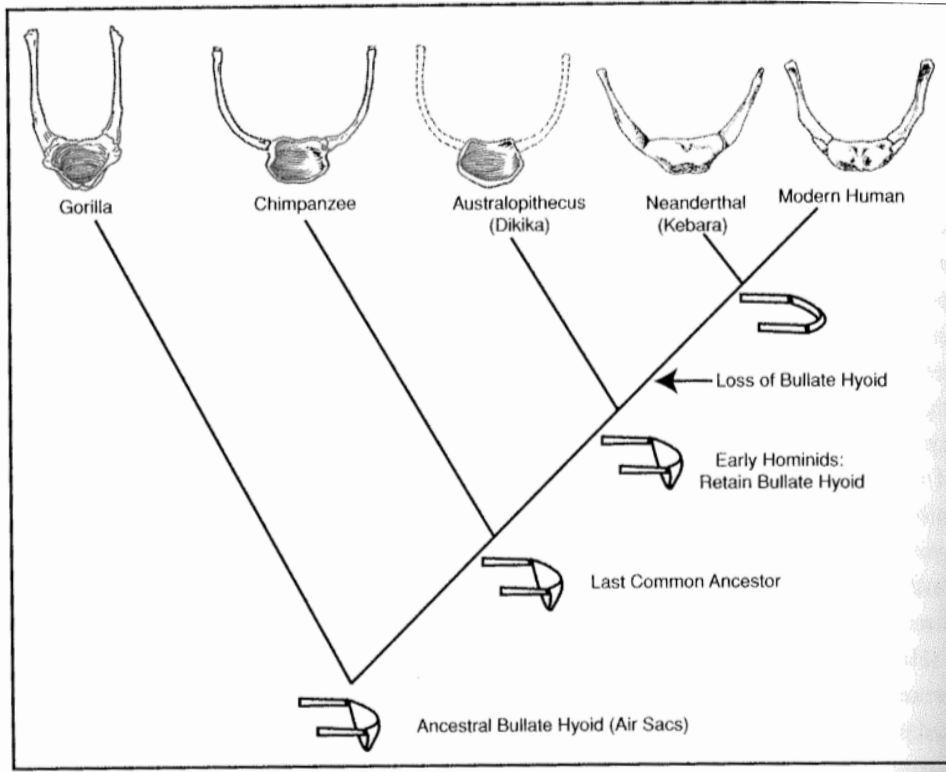
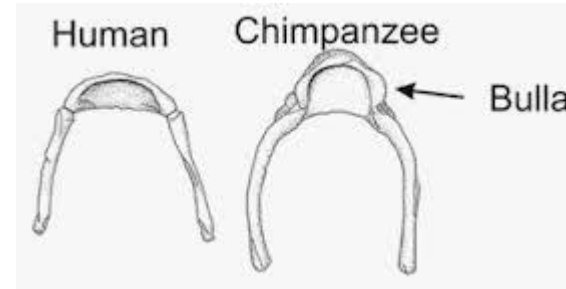


Air sacs



De Boer, B. (2012). Loss of air sacs improved hominin speech abilities. *Journal of Human Evolution*, 62, 1–6.

Air sac evolution

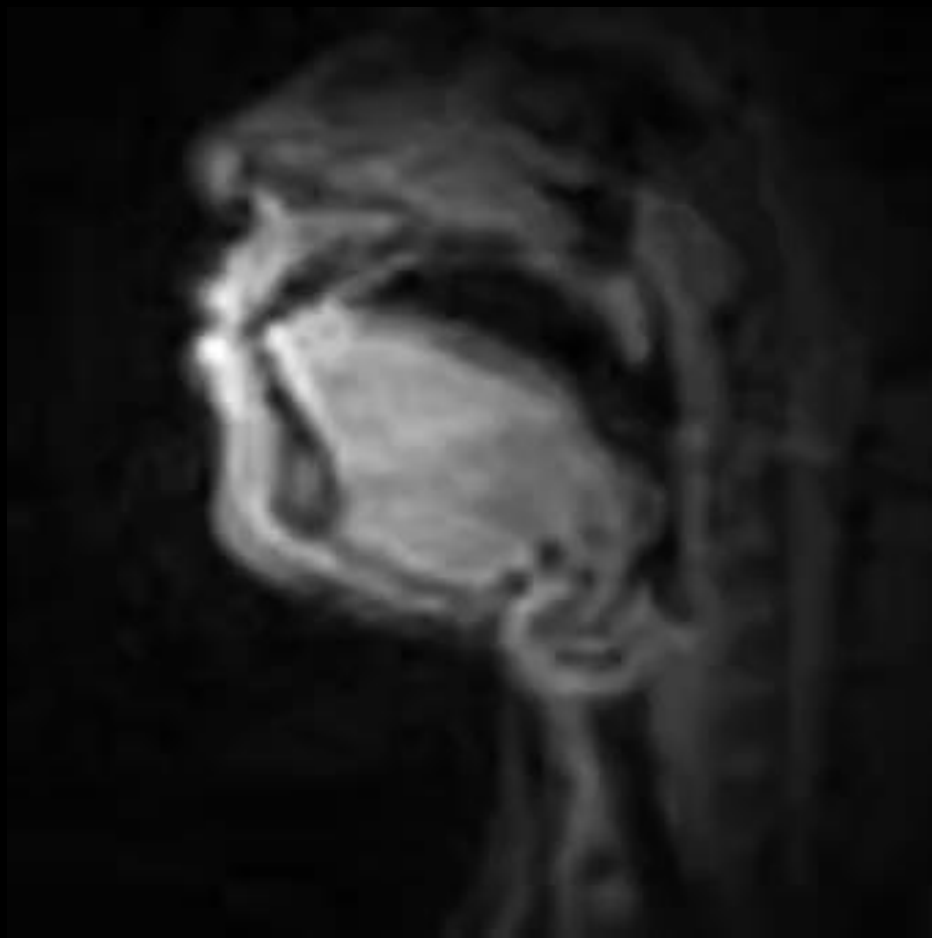


Date: 3.3M to 500k years ago

Cause of the loss of air sacs?

- Descended larynx as an alternative mechanism for size exaggeration?
- Pressure for reliable production of distinctive signals? See De Boer, B. (2012). Loss of air sacs improved hominin speech abilities. *Journal of Human Evolution*, 62, 1–6.

Complex vocal imitation



Complex vocal imitation

Complex vocal imitation in non-humans



<https://www.youtube.com/watch?v=VjE0Kdfos4Y>

Ridgway, S., Carder, D., Jeffries, M., & Todd, M. (2012). Spontaneous human speech mimicry by a cetacean. *Current Biology*, 22, R860-R861.

Rawls, K., Fiorelli, P., & Gish, S. (1985). Vocalizations and vocal mimicry in captive harbor seals, *Phoca vitulina*. *Canadian Journal of Zoology*, 63, 1050-1056.

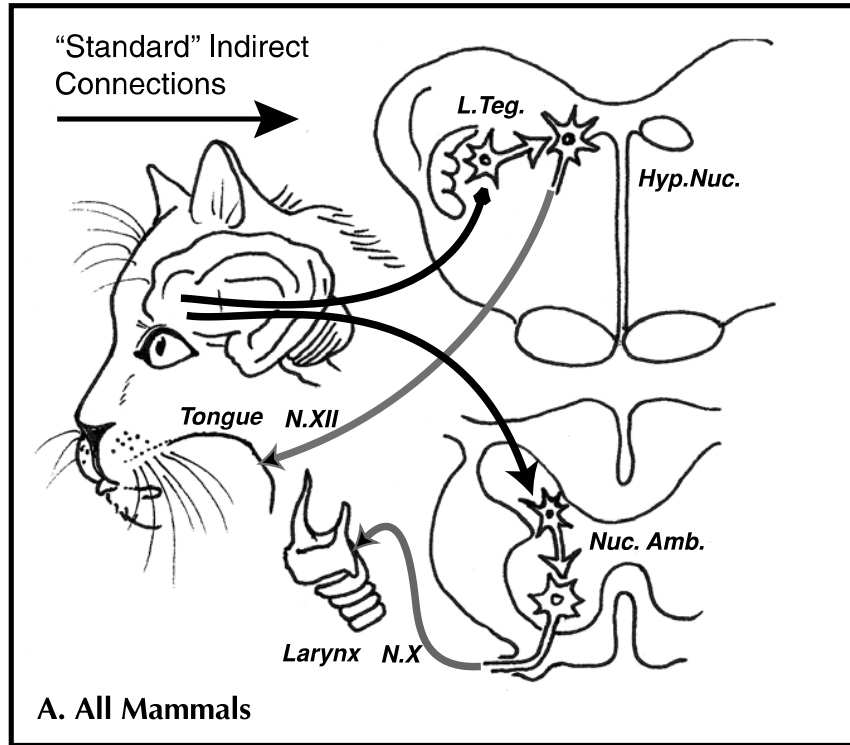
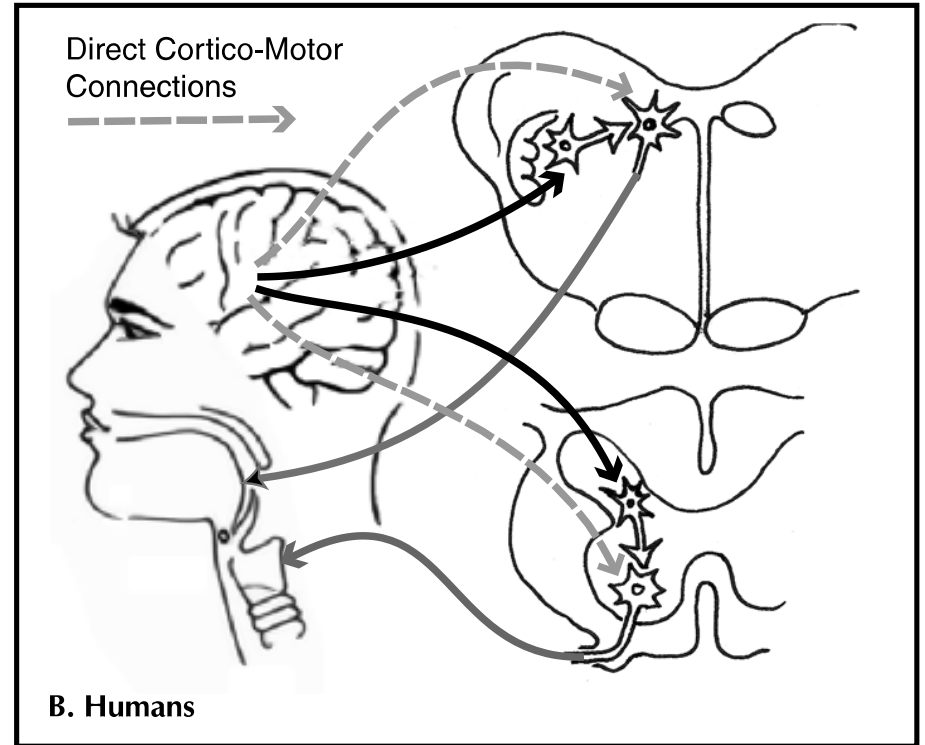
A question from the pre-lecture quiz

“In the definition of production learning, "This can lead to signals that are either similar or dissimilar to the model", does 'model' refer to the individual producing the signal that the learner hears it from (who is 'modelling' the signal)...?”

A question from the pre-lecture quiz

“Which neural pathway would limited vocal learning [the topic of the Tyack paper] use? Is it the second neural circuit in the standard wiring diagram from your explanation (with additional features to allow fine-tuning based on the environment)?”

The neural basis of vocal learning in humans



A question from the pre-lecture quiz

“How can we distinguish true vocal production learning from vocal imitation that is partly shaped by conditioning or reinforcement? For example, could Koshik have learned to produce Korean words through repeated rewards without necessarily understanding the sounds he was imitating?”



Functions of vocal learning?

Adaptation to noisy conditions?

Complexity?

- Create elaborate repertoire: complexity as an end in itself

Index of group membership?

- *Password* hypothesis
- Dialects and accents, and early learning

Pair / group bonding?

- Duetting birds
- Functions of music?

Fitch, W. T. (2000). The evolution of speech: a comparative review. *Trends in Cognitive Sciences*, 4, 258-267.

Tyack, P. L. (2008). Convergence of calls as animals form social bonds, active compensation for noisy communication channels, and the evolution of vocal learning in mammals. *Journal of Comparative Psychology*, 122, 319-331.

A question from the pre-lecture quiz

“Among mammals, vocal production learning appears to be particularly well documented in marine mammals. Could specific characteristics of the aquatic environment, such as the propagation of sound over long distances and limited visibility, have favoured the evolution of this ability? If so, what selective advantages might vocal production learning provide over innate vocalisations, and how might these interact with the social complexity of marine mammals?”

Some reading!

Jarvis, E. D. (2006). Selection for and against vocal learning in birds and mammals. *Ornithological Science*, 5, 5–14.

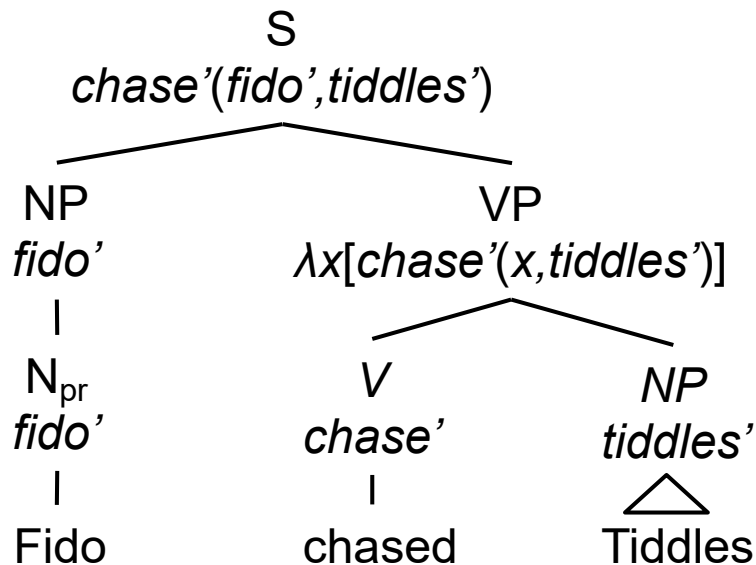
Cook, P. F., Rouse, A. A., Sawyer, E., Miller, K. & Berns, G. (2026). Seal and sea lion brains have evolved to support volitional control of vocal behavior and learning. *Science*, 391, 1146–1150.

Grammar learning

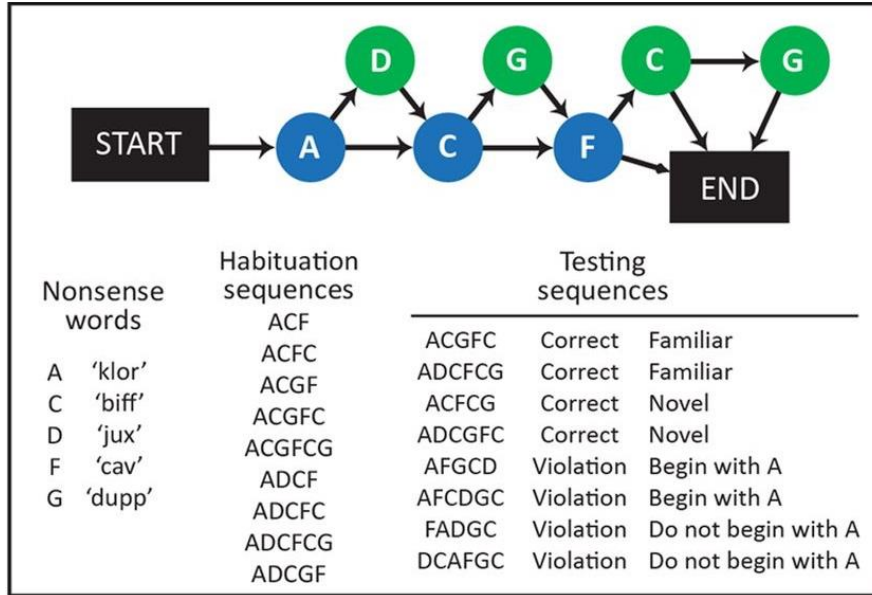
Reminder: Language's communicative power comes from its **structure**

Compositionality: the meaning of an expression is a function of the meaning of its parts and the way in which they are combined

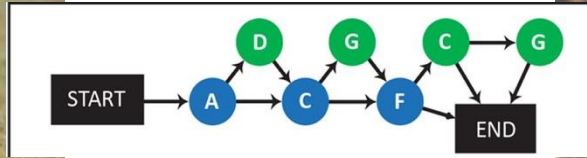
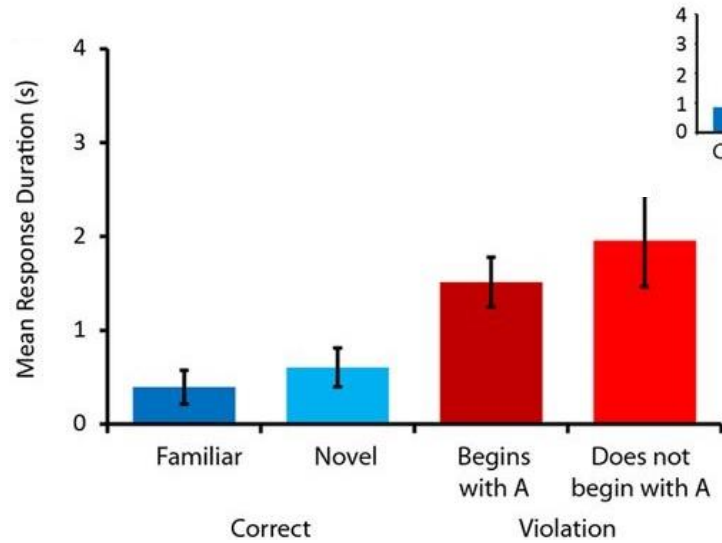
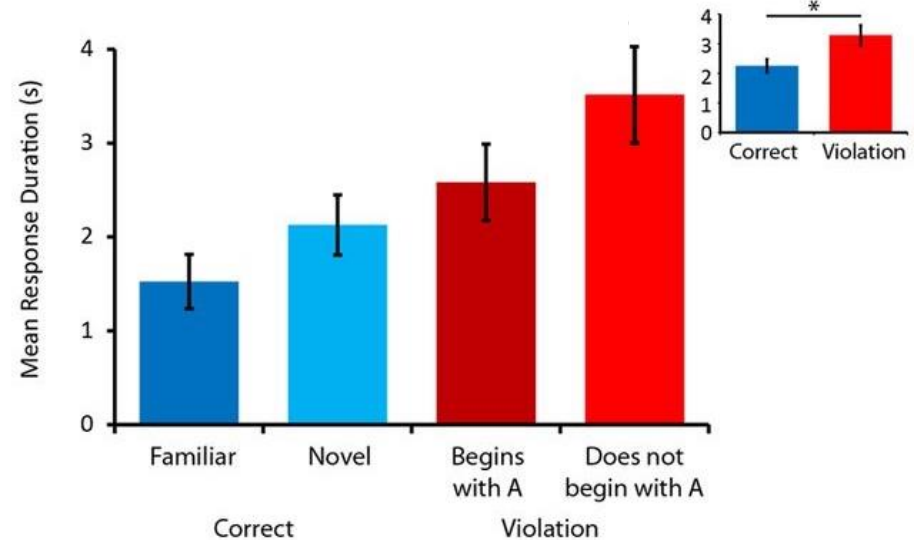
$S \rightarrow NP VP$	$VP'(NP')$
$NP \rightarrow N_{pr}$	N'_{pr}
$N_{pr} \rightarrow \text{Fido}$	$fido'$
$N_{pr} \rightarrow \text{Tiddles}$	$tiddles'$
$VP \rightarrow V NP$	$V'(NP')$
$V \rightarrow \text{chased}$	$\lambda x [\lambda y [(chase'(x,y))]]$



Artificial Grammar Learning in non-humans



Wilson, B., Slater, H., Kikuchi, Y., Milne, A., Marslen-Wilson, W., Smith, K., & Petkov, C. (2013). Auditory artificial grammar learning in macaque and marmoset monkeys. *Journal of Neuroscience*, 33, 18825-18835.
 For review see e.g. Petkov, C. I., & Ten Cate, C. (2020). Structured Sequence Learning: Animal Abilities, Cognitive Operations, and Language Evolution. *Topics in Cognitive Science*, 12, 828– 842.

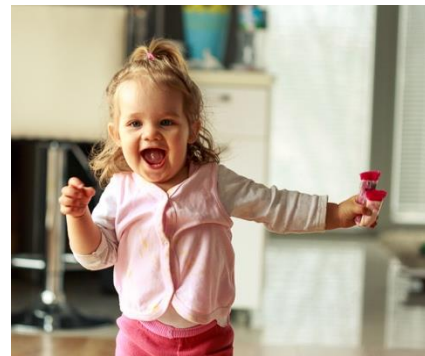


Wilson, B., Slater, H., Kikuchi, Y., Milne, A., Marslen-Wilson, W., Smith, K., & Petkov, C. (2013). Auditory artificial grammar learning in macaque and marmoset monkeys. *Journal of Neuroscience*, 33, 18825-18835.

Non-adjacent dependency learning

Training

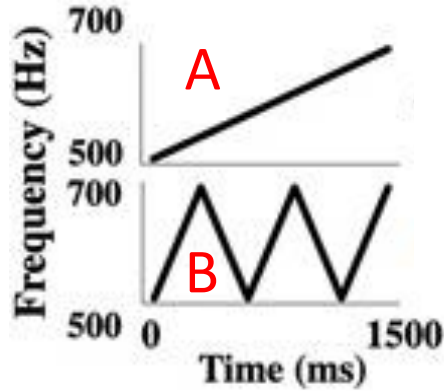
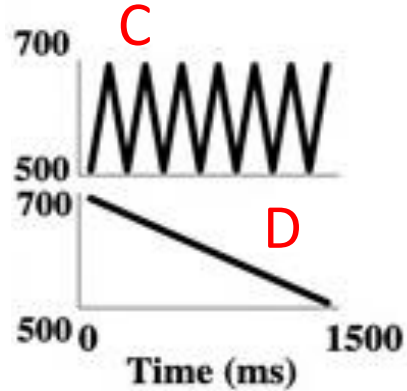
pel wadim rud... vot kicey jic... pel feenam rud...
vot wadim jic... vot puser jic... pel puser rud...
vot kicey jic... vot skiger jic... pel kicey rud ...



Test

pel wadim rud
pel wadim jic?
vot wadim jic
vot wadim rud?

Non-adjacent dependency learning



Non-adjacent dependency learning

Sequence type Example AD Example Non-AD

Familiarization

$A_1 - B_7$

$A_1 - X_{24} - B_7$

$C_5 - D_1$

$C_5 - X_{11} - D_1$

Generalization

$A_{13} - B_{11}$

$A_{13} - X_{115} - B_{11}$

$C_{10} - D_{16}$

$C_{10} - X_{214} - D_{16}$

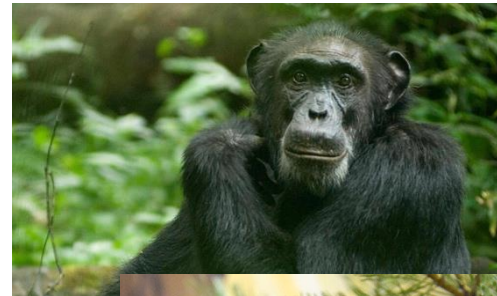
Violation

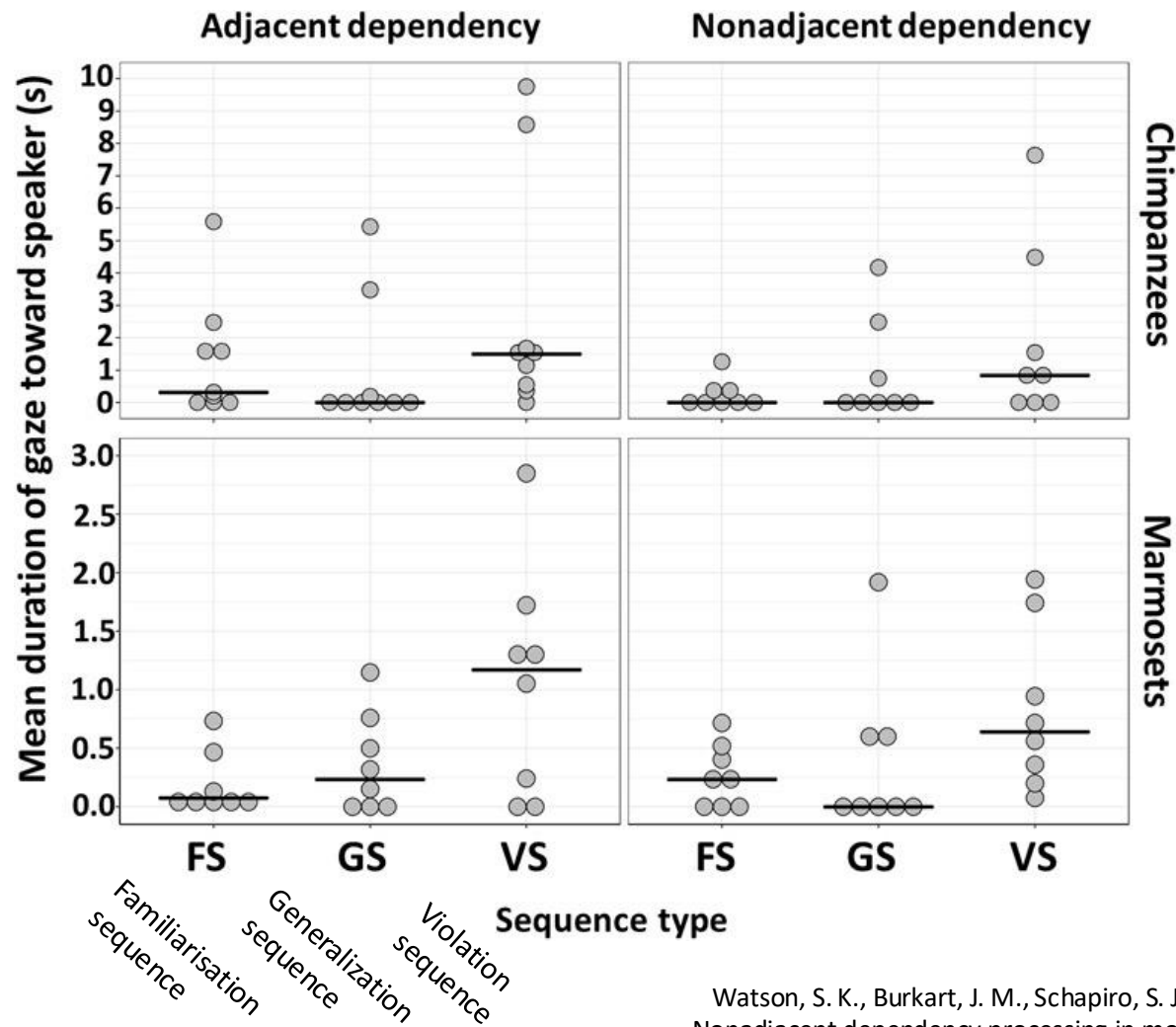
$A_{13} - D_{11}$

$A_{13} - X_{115} - D_{11}$

$C_{10} - B_{16}$

$C_{10} - X_{214} - B_{16}$





How about learning of **meaningful** sequences?



“ball fetch”
“stick point”

Ramos, D., & Ades, C. (2012). Two-item sentence comprehension by a dog (*Canis familiaris*). *PLoS ONE*, 7, e29689.



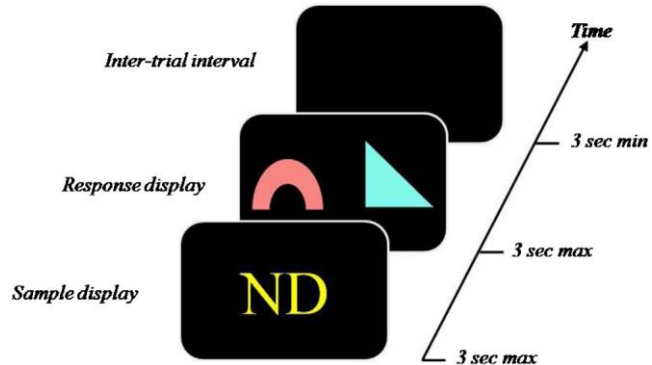
“to sugar take decoy”
“to decoy take sugar”

Pilley, J. W. (2013). Border collie comprehends sentences containing a prepositional object, verb, and direct object. *Learning and Motivation*, 44, 229-240.

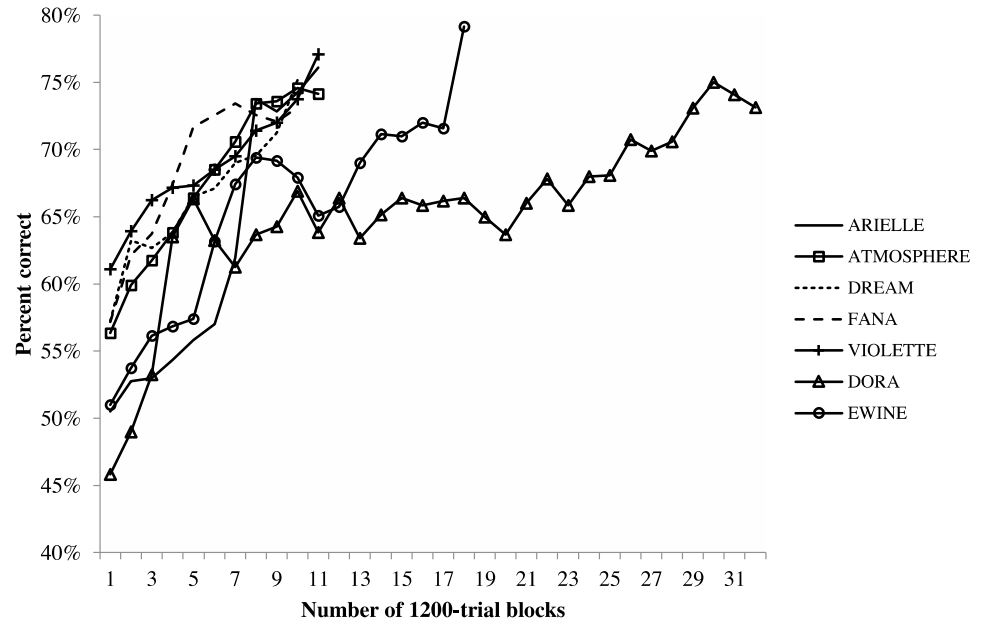
<https://youtu.be/2Dhc2zePJFE>

Savage-Rumbaugh, E. S., Murphy, J., Sevcik, R., Brakke, K., Williams, S., Rumbaugh, D., & Bates, E. (1993). Language comprehension in ape and child. *Monographs of the Society for Research in Child Development*, 58, 1–252.

Puzzling failures in (most) baboons



6 letters (3 for shapes, 3 for colours)
3 shapes, 3 colours



Medam, T., & Fagot, J. (2016). Behavioral assessment of combinatorial semantics in baboons (*Papio papio*). *Behavior Processes*, 123, 54-62.

How about **production** of meaningful sequences?

A man with glasses and a dark shirt is looking down at a laptop screen. The background is a plain, light-colored wall. The text "She answers with gesture and vocalization" is overlaid on the image.

She answers with gesture and
vocalization

Copyright 2006 Dr. Sue Savage-Rumbaugh

<https://www.youtube.com/watch?v=UfHWTFlqEUE>





Summary on grammar learning

Artificial Grammar Learning suggests abilities to learn sequence constraints are present in other animals (including other primates)

- Grammars tested to date are quite simple
- Interpretation can be contentious

Language-trained animals can interpret complex (i.e. multi-part) expressions

- But larger-N lab studies surprisingly scarce, and these tasks seem to be hard

Humans are not unique in our ability to process meaningful sequences

- **But we may be uniquely proficient**

Next up

- Tutorial: song learning and universal grammar in zebra finches
- (Also week 7 tutorial: dendrophobia in a language-trained ape)
- Next lecture: the evolution of social cognition
 - Sharing, theory of mind, intentionality