

# Anti-efficient encoding in emergent communication

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## 1 . Zipf Law of Abbreviation (ZLA)

### Definition

“... the magnitude of words stands in an inverse (not necessarily proportionate) relationship to the number of occurrences.” Zipf 1935; p.23

- The more frequent a word is, the shorter it tends to be.
- Natural language is an efficient encoding.

### Origin

- Functional pressures toward effort minimization [1].
- Some statistical process, unrelated to optimization [2].

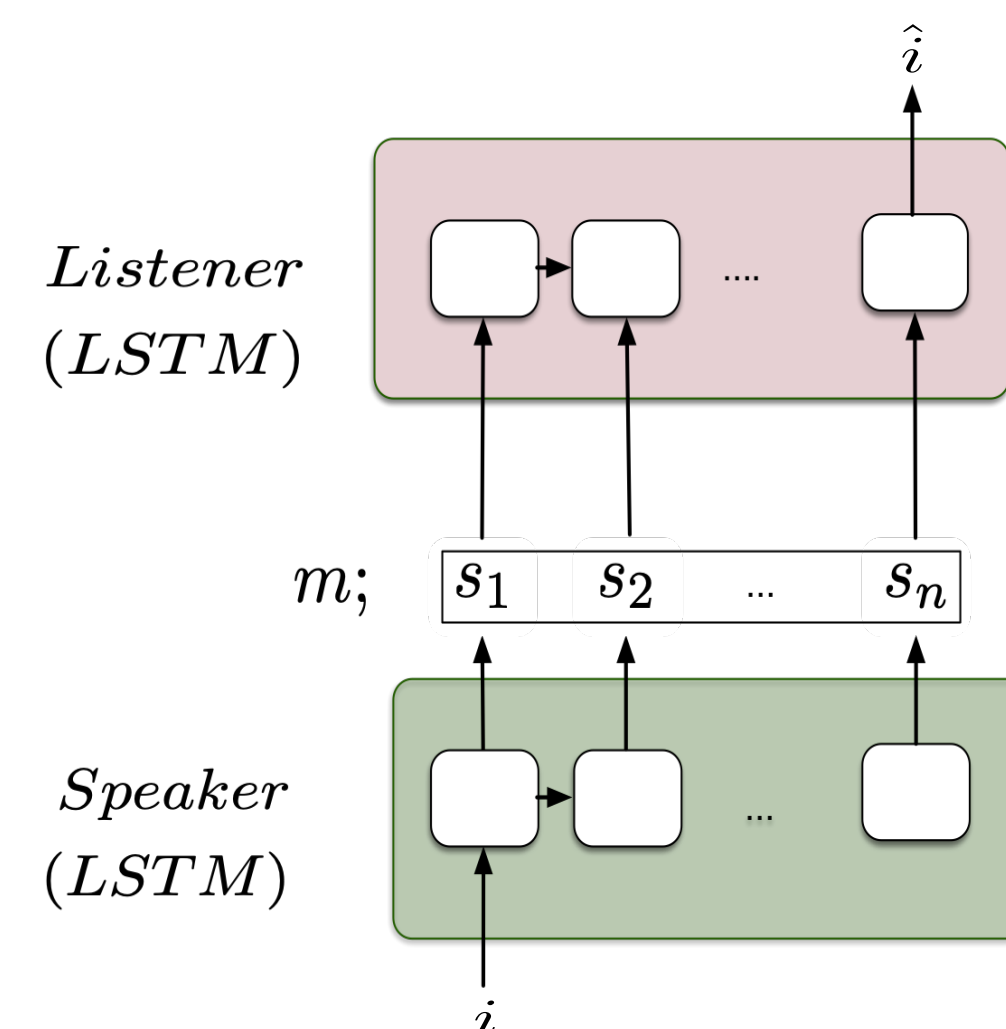
## 2 . Motivation

Understand the role of effort minimization in shaping natural language by investigating the efficiency of an alternative successful communication system, namely the emergent language of two neural networks playing a signaling game.

## 3 . Setup

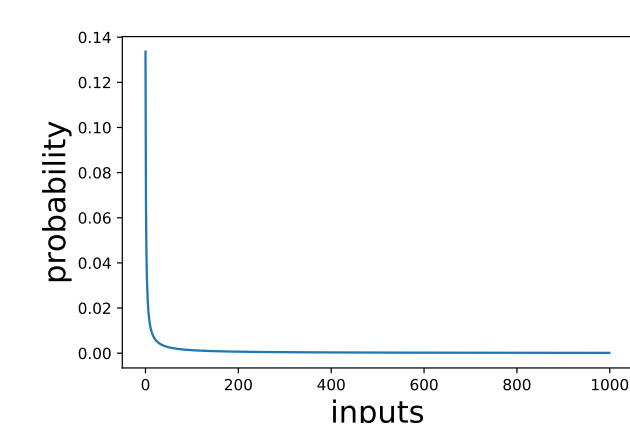
### Signaling game

- Message  $m$  is a sequence of discrete symbols sampled from a given vocabulary of size  $a$ .
- Training is performed using REINFORCE.



### Environment

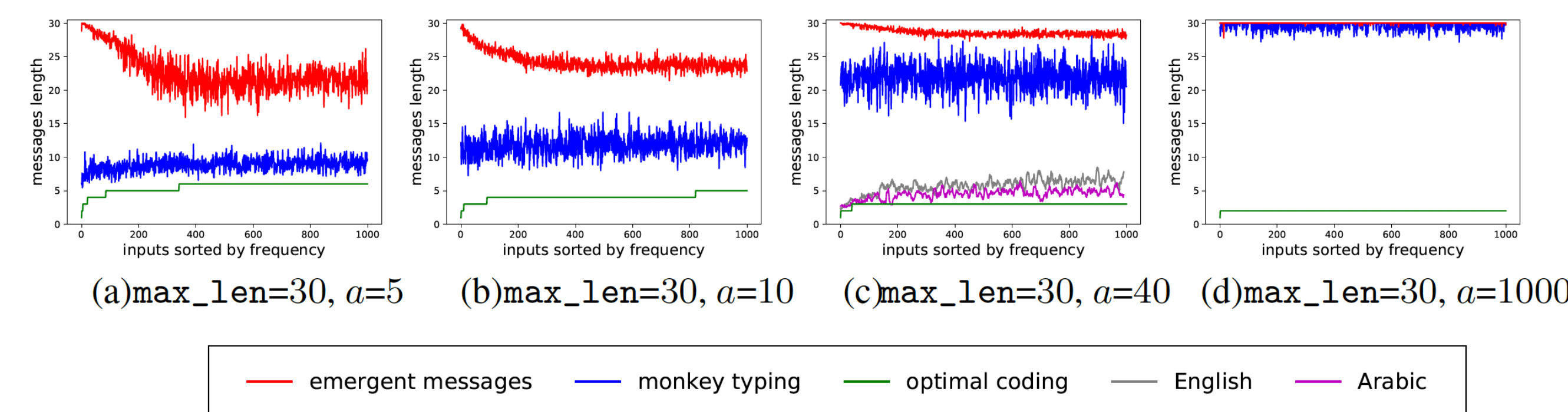
1000 different inputs;  $i_1 = [1, 0, \dots, 0]$  ...  $i_{1000} = [0, \dots, 0, 1]$  following a **power-law** distribution.



## 4 . Reference ZLA-like distributions

- Optimal coding (OC): guaranteeing the shortest average message length given a certain alphabet size and maximum length.
- Monkey typing (MT): assign a unique message for each referent by sampling informly from the alphabet.
- Natural languages: English and Arabic (extracted from <http://corpus.leeds.ac.uk/serge/>).

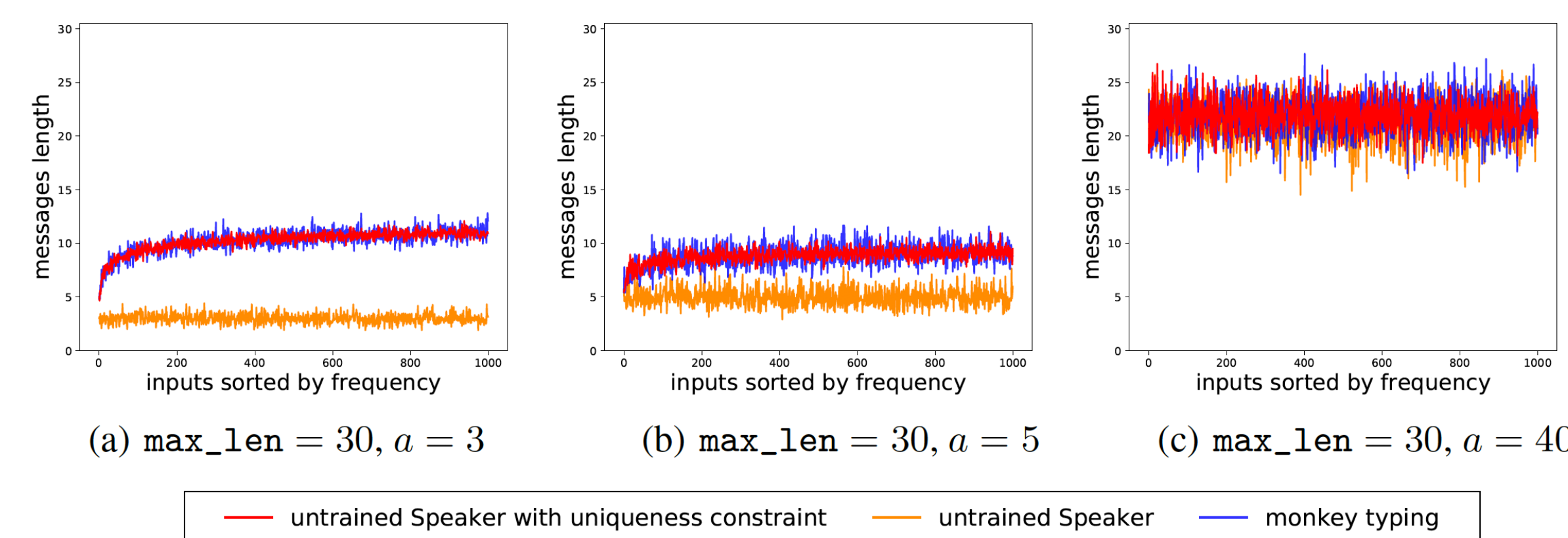
## 5 . Emergence of anti-efficient encoding



- A clear general preference for long messages.
- Emergent messages follow an “anti-ZLA”-like distribution where more frequent inputs are *significantly* associated to longer messages.

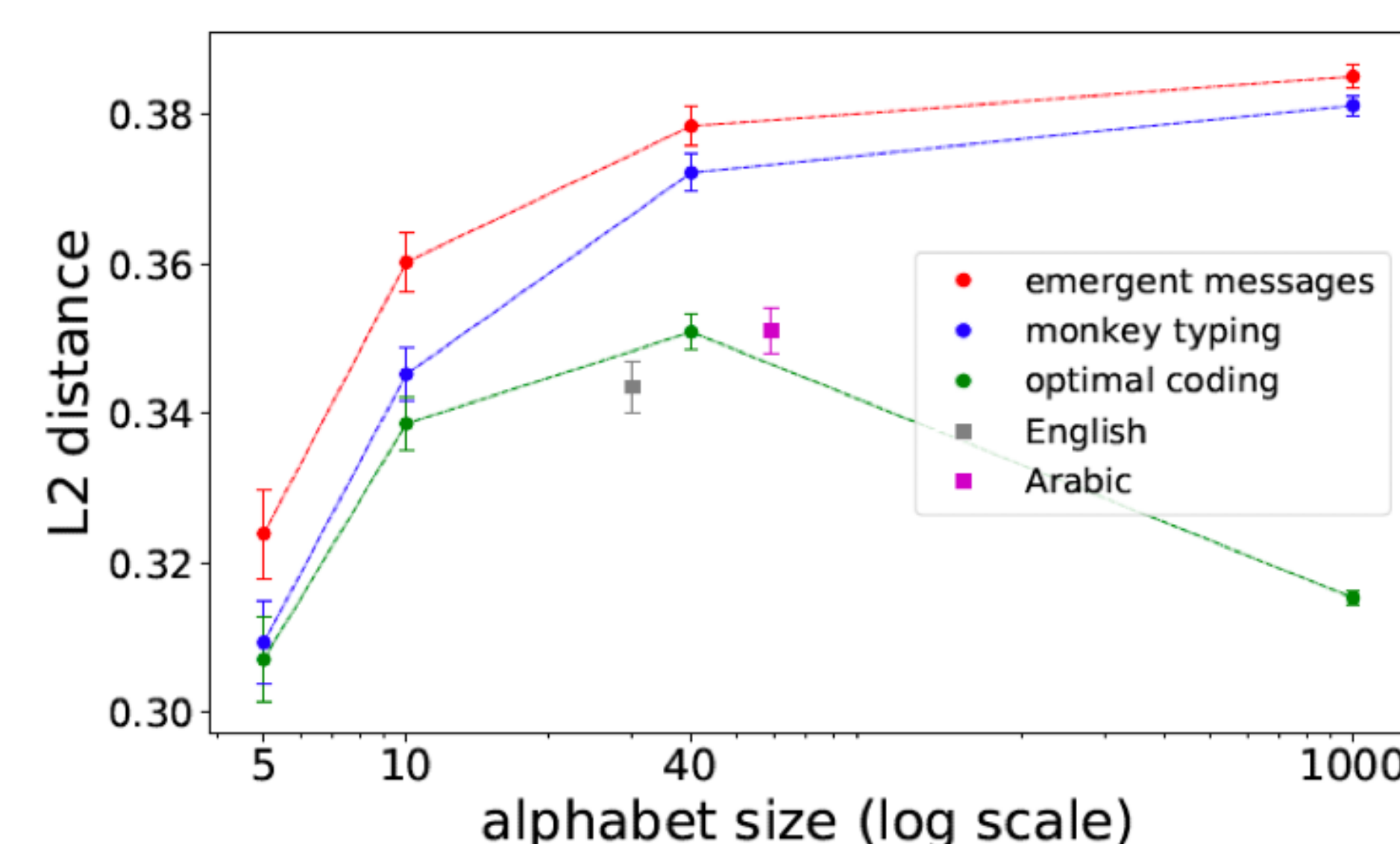
## 6 . Origin of anti-efficient encoding

### Speaker's behaviour



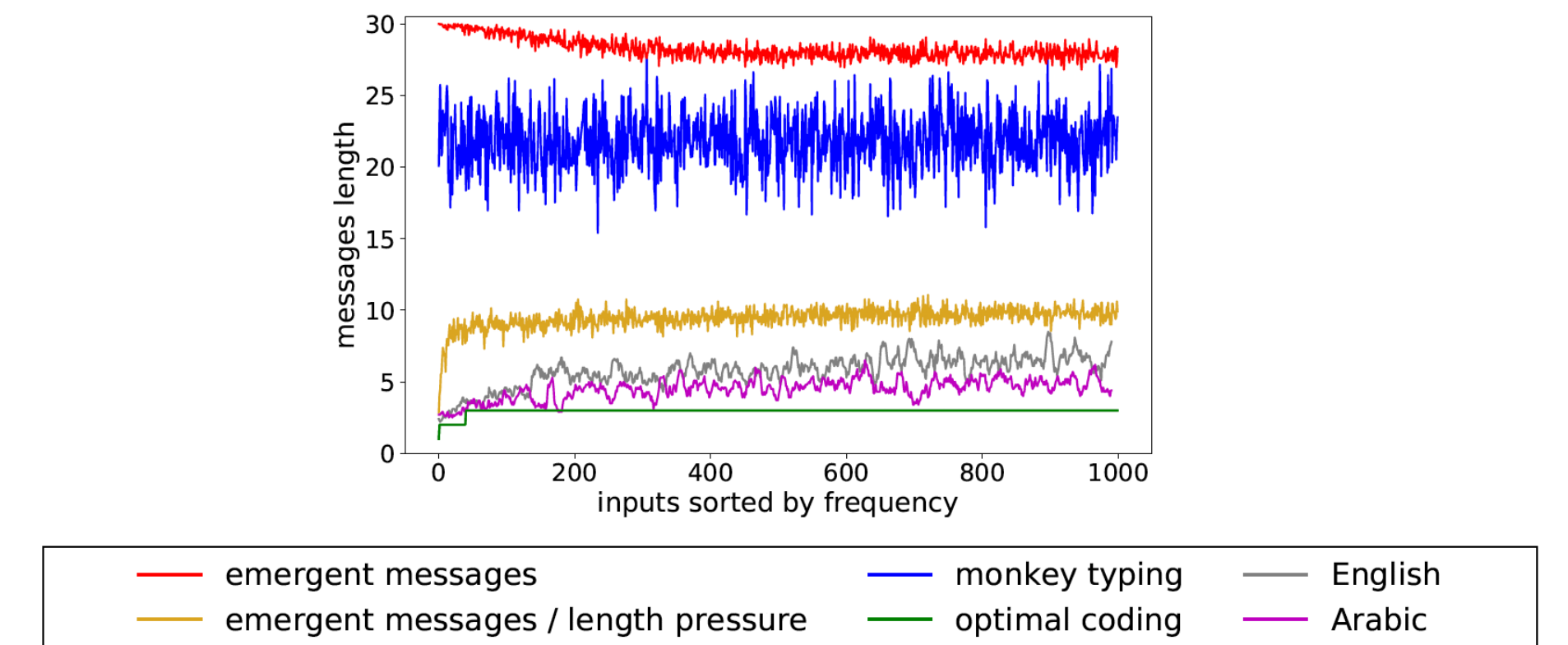
- Speakers have no prior toward outputting long messages.
- Speakers with uniqueness constraint, if vocabulary size is small, produce a ZLA-like distribution, that is lost during training.

### Listener's behaviour



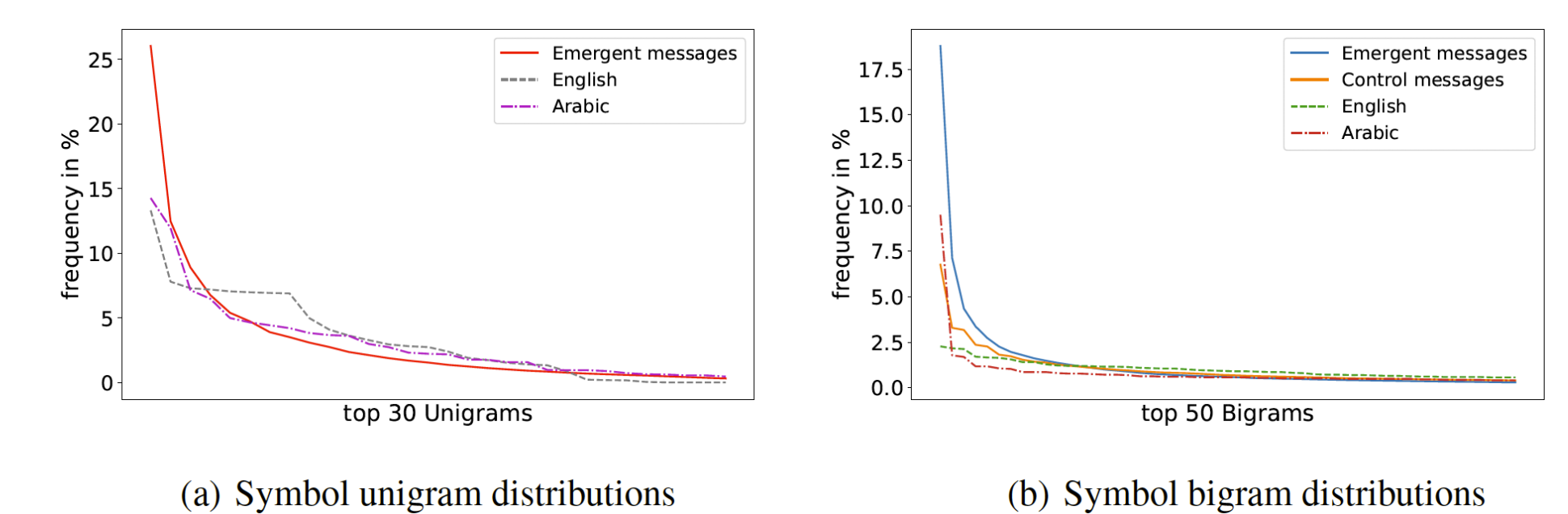
- Emergent messages are easier to discriminate for non-trained Listeners. The length of these messages could thus be explained by an intrinsic Listener's bias.

## 7 . Length minimization pressure



- Emergent messages with minimization pressure follow ZLA.
- We observe that a trade-off between (1) pressure towards successful communication and (2) pressure towards production efficiency is necessary for the emergence of ZLA.

## 8 . Symbol distributions



- LSTM agents converge to a more skewed unigram and bigram symbol distributions compared to reference codes.
- Despite the lack of phonetic pressures, Speaker respects “phonotactic” constraints that correspond to repeating the same symbol over and over.

## 9 . Conclusion

- LSTM agents produce an anti-efficient code and thus have not the right biases to develop human-like language.
- We report a successful communication system that does not exhibit ZLA, and we connect this to an asymmetry in speaker vs. listener biases (perceptual pressure for discrimination from listener without articulatory effort minimization pressure from speaker). This in turn suggests that ZLA in communication in general does not emerge from trivial statistical properties, but from a delicate balance of speaker and listener pressures.

## 10 . References

- [1] K. Mahowald, I. Dautriche, E. Gibson, and S. Piantadosi. Word forms are structured for efficient use, 2018.
- [2] R. F. i Cancho and F. M. del Prado Martín. Information content versus word length in random typing, 2011.