Linguistic syncopation: Alignment of musical meter to syntactic structure and its effect on sentence processing

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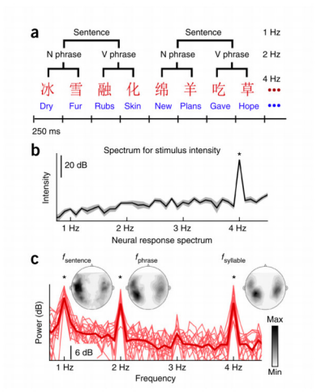
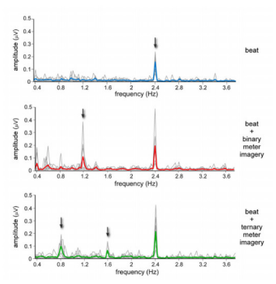
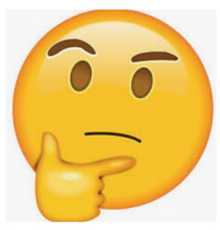
1. Delta oscillations track **syntactic phrases** in language (Ding et al, 2016)



2. Delta also tracks the perception of **musical meter** (Nozaradan et al, 2011)

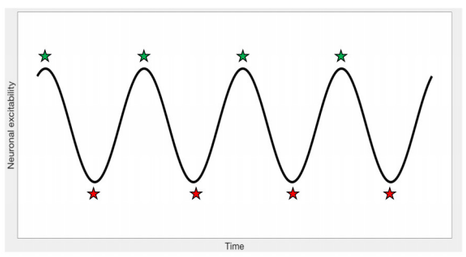


3. Syntactic processing seems **dependent on temporal predictions** of the sort defining beat/meter processing (Kotz & Schmidt-Kassow, 2015)
4. Why does this happen? What **function** does delta entrainment serve?



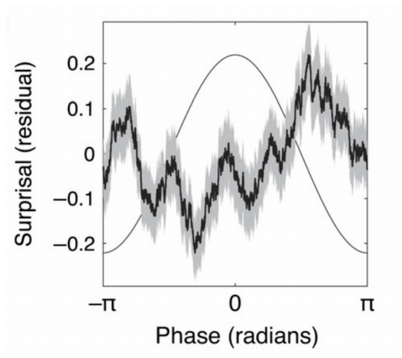
Meyer and Gumbert (2018) suggest that **delta aligns neuronal excitability with syntactic informativeness**. This combines two ideas:

1. Neuronal oscillations are fluctuations between high and low excitability states of underlying neural populations and this can be used as a mechanism of **selective temporal attention** (Lakatos et al, 2008)



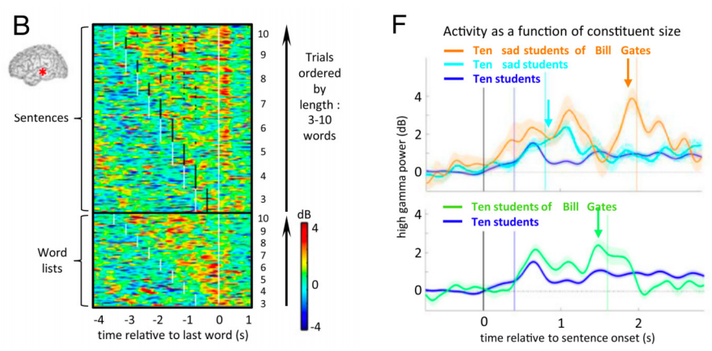
2. **Expectations** make language comprehension processing efficient and robust (Levy, 2008). And 'syntactic surprisal' is an information-theoretic way to quantify the unexpectedness and processing-difficulty of the syntactic category of an incoming word.

Meyer and Gumbert's data showed the excitable phase of delta seeming to align with the most expected parts of the phrase.



While we like their hypothesis, it seems odd that resources would be allocated to the most expected information in the phrase. In fact, we would have thought the opposite!

We suggest an alternative hypothesis inspired by a recent paper (Nelson et al, 2017) that showed a neural correlate of the Chomskian syntactic structure-building operation 'merge'.



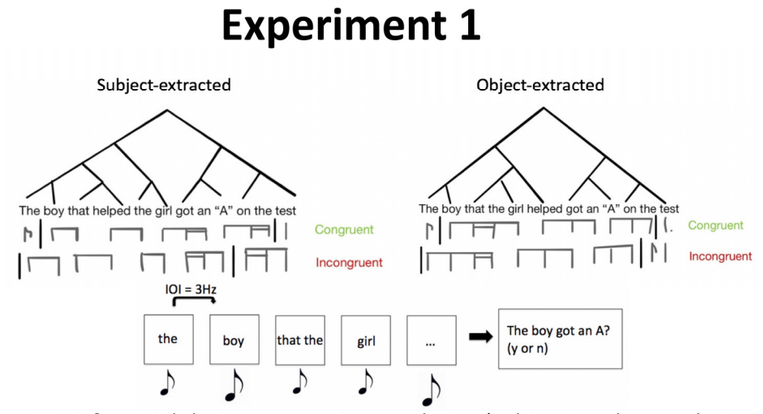
We conclude from this that:

1. Merge is resource intensive
2. Would involve communication across language network
3. Both these things would have to happen in a time-localized way.

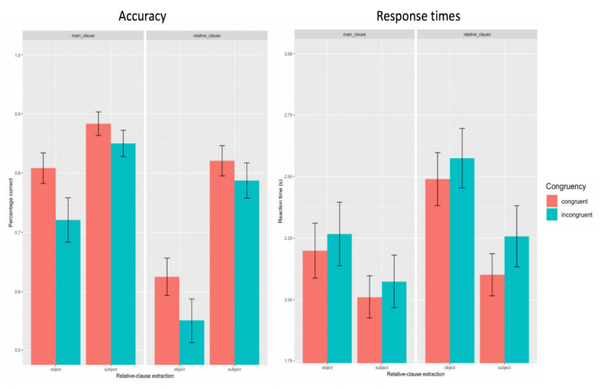
Therefore, we hypothesize that alignment of delta functions to allocate resources to support structure-building operations (merge).

To test this hypothesis, we present sentences to participants while manipulating their temporal attention using musical meter. This comes with the prediction that comprehension would be optimal when strong-beats aligns with phrase-boundaries.

Experiment 1



Design: 2 X 2 factorial design: syntactic complexity (subject vs object relative-clause) by congruency (congruent vs incongruent). 40 participants (20 female)
Materials: 48 sentences and comprehension probes, plus filler sentences. Auditory beat is 333Hz puretone amplitude modulate at 3Hz, and amplified ever 2 (binary) or 3 (ternary) beats. In each trial, sentences were visually presented as RSVP stream synchronized to beat, followed by a comprehension probe.
Hypotheses: Our main prediction was that comprehension accuracy would be lower in incongruent condition and RTs higher. And that there would be an interaction between congruency and syntactic complexity.



Results and Analysis: Logistic (Accuracy) and linear (RTs) mixed effects models were used to analyze the data:

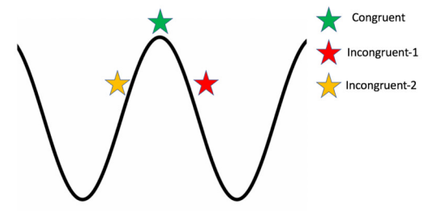
- **Accuracy:** congruency (χ^2 = 7.99, p = .005), syntactic complexity (χ^2 = 26.21, p = <.001), clause-probed (χ^2 = 40.03, p = <.001), interaction (χ^2 = 0.43, p = .513).
- **RTs:** congruency (χ^2 = 1.20, p = 0.273), syntactic complexity (χ^2 = 16.314, p = <.001), clause-probed (χ^2 = 35.796, p = <.001)

Conclusions

We confirmed our main hypothesis that alignment of metric strong-beats with phrase boundaries supports sentence comprehension. This was shown in:

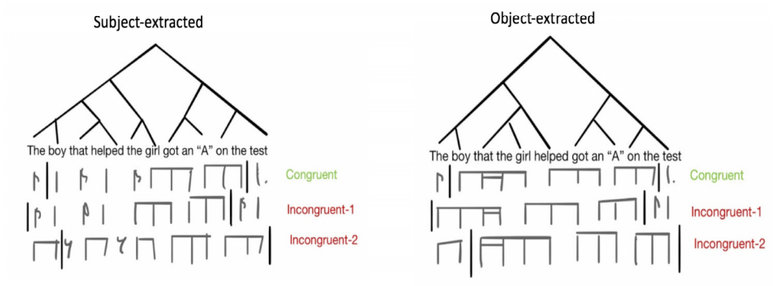
- Comprehension accuracy
- Tapping variability
- ~Response times (not significant, but consistently in right direction)

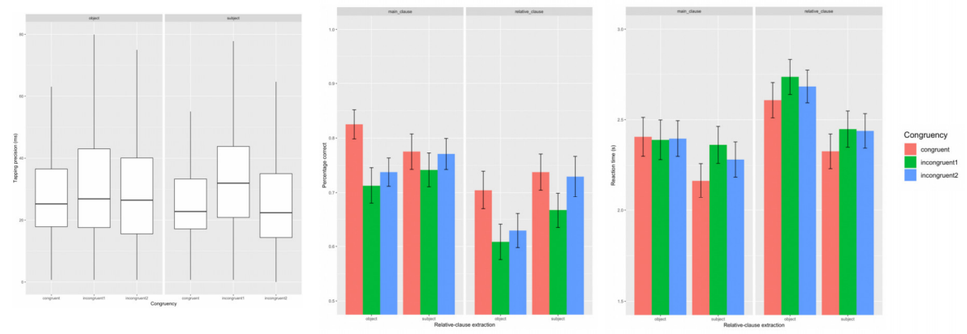
Although not significantly different from incongruent-2, incongruent-1 seemed to be the most incongruent beat alignment. Our hypothesis for this was based on the assumption of an underlying delta oscillation, where the advantage of incongruent-2 is because merge happens while attentional resources are rising rather than falling:



Further research will be required to pick-apart and test these theories, but in general, our data support the idea that syntactic structure-building is dependent on temporal prediction.

Experiment 2





Differences from Experiment 1:

- Now three levels of congruency (congruent, incongruent-1, incongruent-2)
- Sentences presented as auditory speech (rendered in a Python script using Google TTS and some preprocessing).
- Participants asked to tap the strong-beats on a MIDI drum-pad while listening to the speech.
- 24 more sentences and probes
- We also have 2 new hypotheses: tapping would be most consistent in congruent conditions. And incongruent-1 would be the most incongruent metric alignment (see Conclusions for why)

Results and Analysis: Logistic (Accuracy) and linear (RTs) mixed effects models were used to analyze the data:

- **Accuracy:** congruency (incongruent1: χ^2 = 13.23, p = <.001, incongruent2: χ^2 = 8.30, p = .004), syntactic complexity (χ^2 = 0.101, p = .750), clause-probed (χ^2 = 24.641, p = <.001).
- **RTs:** congruency (incongruent-1: χ^2 = 1.371, p = 0.242, incongruent-2: χ^2 = 0.837, p = 0.360) syntactic complexity (χ^2= 19.900, p = <.001) clause-probed (χ^2= 49.801, p = <.001)
- **Tapping:** congruency (incongruent-1: χ^2= 10.27, p = .001; incongruent-2: (χ^2= 3.25, p = .071)

References

Kotz, S. A., & Schmidt-Kassow, M. (2015). Basal ganglia contribution to rule expectancy and temporal predictability in speech. *Cortex*, *68*, 48–60.
Lakatos, P., Karmos, G., Mehta, A. D., Ulbert, I., & Schroeder, C. E. (2008). Entrainment of neuronal oscillations as a mechanism of attentional selection. *Science (New York, N.Y.)*, *320*(5872), 110–113.
Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition*, *106*(3), 1126–1177.
Meyer, L., & Gumbert, M. (2018). Synchronization of Electrophysiological Responses with Speech Benefits Syntactic Information Processing. *Journal of Cognitive Neuroscience*.
Nelson, M. J., El Karoui, I., Giber, K., Yang, X., Cohen, L., Koopman, H., … Dehaene, S. (2017). Neurophysiological dynamics of phrase-structure building during sentence processing. *Proceedings of the National Academy of Sciences*, *114*(18), 3669–3678.
Nozaradan, S., Peretz, I., Missal, M., & Mouraux, A. (2011). Tagging the neuronal entrainment to beat and meter. *The Journal of Neuroscience*, *31*(28), 10234–10240.