Microsaccade Rate Increases Under High Visual Processing Load in Syncopated Rhythm Reading

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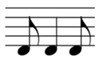
INTRODUCTION

Reading musical rhythms involves processing not only visual symbols but also their temporal arrangement. Here, two rhythm types contain the *same* visual elements, yet differ in how those elements are positioned within the metrical structure. This allows us to ask whether rhythmic patterns modulate visual processing. Syncopated rhythms have been shown to impose greater processing loads than non-syncopated rhythms (Kim & Kim, 2023). To examine whether such structural complexity is reflected in fine-grained fixational eye movements, we examined microsaccades, a direct indicator of visual attentional load (Martinez-Conde et al., 2006), and fixation stability during rhythm processing.

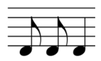
METHODS

Participants 21 participants (14 females, mean age: 24.5)

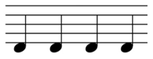
Stimuli



Syncopated Rhythm (S)
: note onsets shifted to off-beat positions
(high visual processing load)

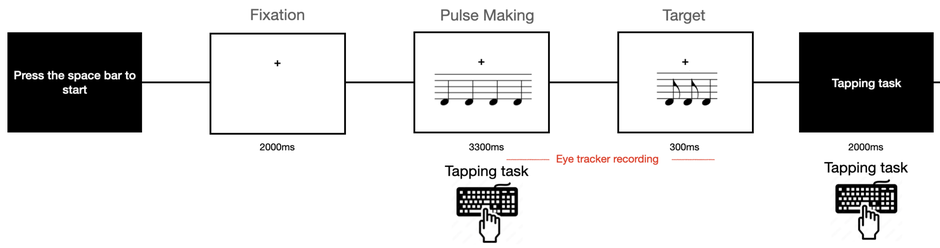


Non-Syncopated rhythm (NS)
: note onsets on strong beats
(low visual processing load



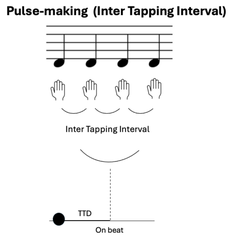
Pulse Making: four quarter notes

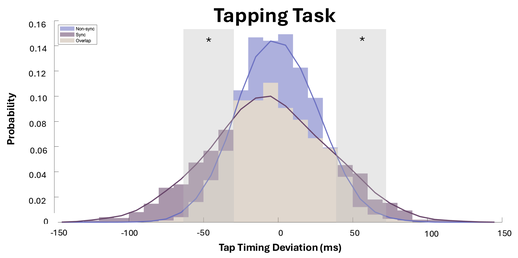
Procedure



- Pulse making: participants *tap* at a comfortable pace to establish their internal tempo within the stimulus duration
- Target: visual rhythm stimulus (**S** or **NS**) presented below the fixation cross
- *Eye movements recorded during pulse making and target presentation via Eyelink 1000 (1000 Hz)*
- Target tapping task: reproduce the rhythm by tapping the spacebar

ANALYSES





- In each trial, participants' tapping tempo was estimated from their pulse-making phase (*median Inter-Tap Interval*).
- This trial-specific ITI was used to generate expected beat times for that trial's target tapping (*Tapping Timing Deviation*).
- Tapping accuracy was computed as residual asynchrony (tap – expected beat) within each trial.

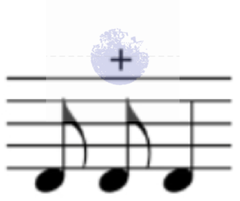
Most taps in both conditions were tapped near the expected beat, but the **S** condition showed a wider spread, indicating reduced temporal precision ($p<0.05$)

Fixation Stability (Bivariate Contour Ellipse Area)

- Fixations were defined within 1.5° of the fixation cross
- 68% confidence ellipse of the fixation distribution.

Microsaccade

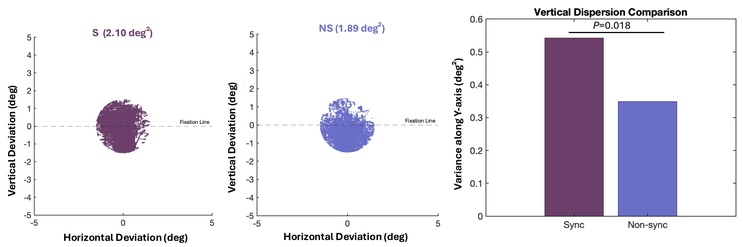
- Velocity-threshold algorithm (cf. Engbert & Kliegl, 2003)
- Gaussian smoothing (σ = 40 ms)
- fixation window ± 1°



Example of BCEA analysis

RESULTS

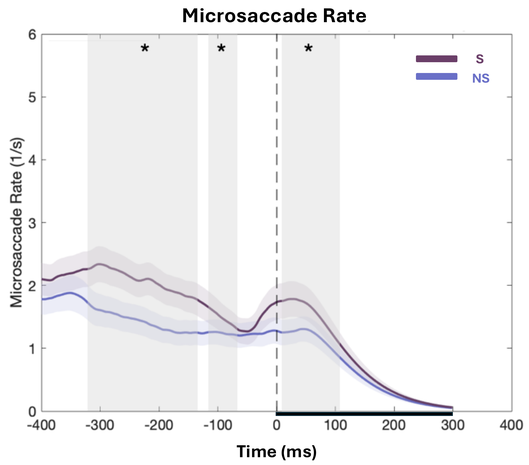
Fixation Stability



- Fixation area was larger in the **S** condition than the **NS** condition, indicating overall reduced fixation stability (p =0.006).
- Vertical variance was significantly higher in the **S** condition ($p = 0.018$), showing increased instability along the vertical axis.

Fixation stability was reduced under **S** condition, indicating that syncopated rhythm disrupts steady gaze and induce axis-specific instability.

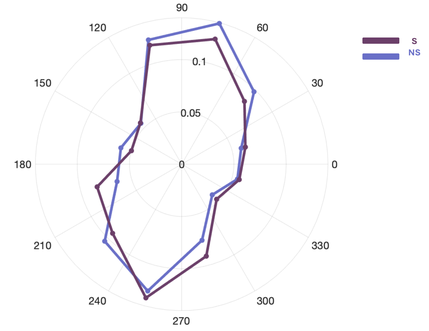
Microsaccade Rate



- Microsaccade rate was significantly higher in the **S** condition both before and after stimulus onset.
- Pre-onset (–307 to –128 ms; –120 to –67 ms) indicate weaker microsaccade inhibition prior to syncopated rhythm processing (p=0.008, 0.05).
- Post- onset (23–110 ms), the **S** condition showed a greater post-inhibition increase, revealing stronger modulation of microsaccade temporal dynamics under higher processing load (p<0.05)

Syncopated rhythm imposes greater demands on oculomotor control.

Microsaccade Direction



- Microsaccade direction showed no significant difference between **S** and **NS** conditions.

Despite higher temporal demands in syncopated rhythm reading, overall spatial distribution of microsaccades remained stable.

CONCLUSION

Different temporal ordering of visually identical notes creates distinct rhythmic structures (syncopated or non-syncopated rhythm) that increase visual processing load. Syncopated rhythm increases microsaccade rate and reduces fixation stability, indicating greater oculomotor demands with limited alteration of spatial viewing strategy

Engbert, R. (2006). Microsaccades: A microcosm for research on oculomotor control, attention, and visual perception. *Progress in brain research*, *154*, 177-192.
Kim, H. J., & Kim, C. Y. (2023). Processing load in pitch and rhythm notation reflects the discriminatory eye responses. *Journal of Vision*, *23*(9), 4760-4760.
Martinez-Conde, S., Macknik, S. L., & Hubel, D. H. (2006). The role of fixational eye movements in visual perception. *Nature Reviews Neuroscience*, *5*(3), 229–240.