Pupillary and eyeblink responses to auditory stimuli index attention and sensorimotor coupling

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Introduction

Behavioral, electrophysiological, and neuroimaging studies have all confirmed that attentional processing and motor output can become entrained to and enhanced by rhythmic auditory stimuli. However, most of these studies have used simple, isochronous stimuli and have rarely assessed auditory attention via eye-tracking. This study aims to 1) determine the effects of complex rhythmic stimuli on visual motor behavior 2) test the power of Tomic and Janata's (2008) oscillator model in predicting both perceptual thresholds and continuous attentional state (as indexed by pupil dilation).

Methods

Participants: *N* = 18; mean age: 26 +/- 8, all normal hearing; mixed levels of musical training.

Stimuli: Four multi-timbre percussive patterns (Figure 2), each played back as a continuous loop at 107 beats per minute. In each stimulus, a transient (200 ms) intensity increment could occur at four possible time points: two corresponding to moments of high, model-predicted attentional salience and two to low.

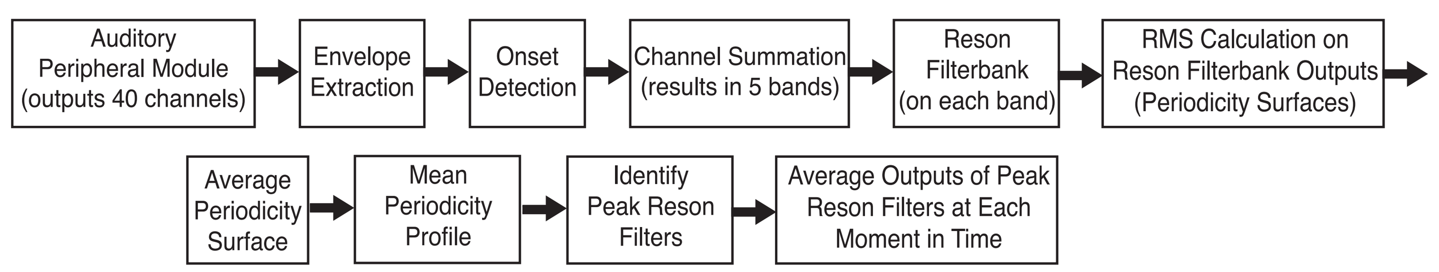


Figure 1. Processing stages of Tomic & Janata's (2008) Beyond-the-Beat model.

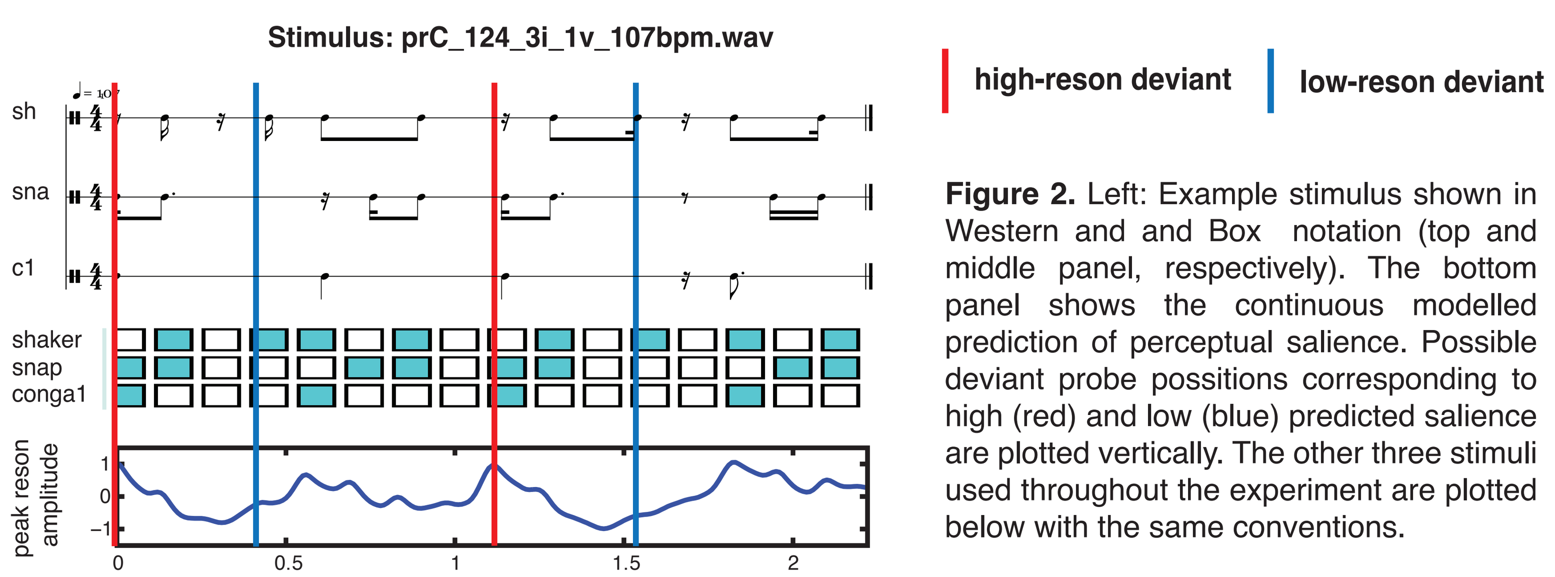
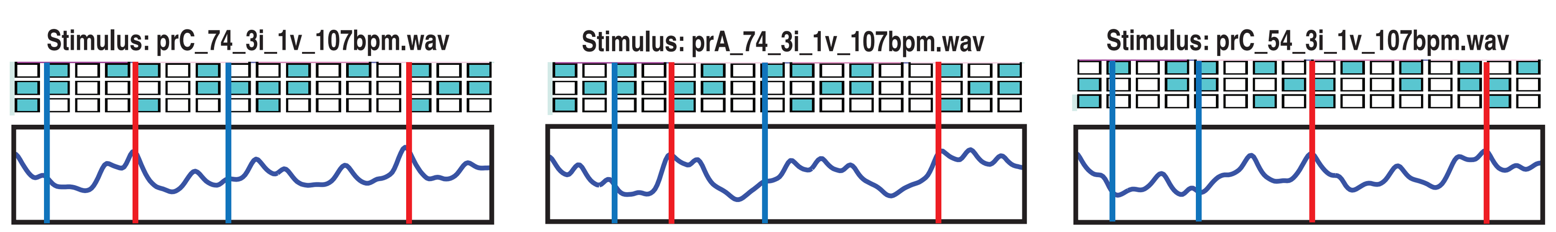


Figure 2. Left: Example stimulus shown in Western and and Box notation (top and middle panel, respectively). The bottom panel shows the continuous modelled prediction of perceptual salience. Possible deviant probe possitions corresponding to high (red) and low (blue) predicted salience are plotted vertically. The other three stimuli used throughout the experiment are plotted below with the same conventions.



Apparatus: An infrared eye-tracker (Eyelink 1000, sampling at 500Hz) was used to record eye movements. Stimuli were presented via MAX/MSP (Cycling '74).

Procedure: Participants were instructed to comfortably maintain their gaze on a fixation cross, attend to the rhythmic patterns, and press the spacebar any time they heard an increase in volume. Each of the four patterns looped for approximately 7 minutes; an adaptive thresholding algorithm adjusted the intensity of each subsequent deviant at each probe position.

Analysis

Adaptive threshold. We assessed participants' performance on the task using an adaptive threshold procedure: Zippy Estimation by Sequential Testing (ZEST) (Marvitet al., 2003). ZEST uses Bayes Theorem to adjust stimulus intensity and converge on a threshold based on the participant's performance. We tracked multiple thresholds concurrently, such that separate thresholds could be estimated for each deviant probe position. Lower deviance detection thresholds imply greater perceptual sensitivity, whereas higher thresholds imply less perceptual sensitivity.

Eyeblink Response. Eyeblinks were detected using the Eyelink parser blink detection algorithm. Runs containing blinks of a duration greater than 1000ms were discarded, as such a duration is typically considered a microsleep or occured due to missing data from the eye-tracker.

Pupillary Response. Pupil data was preprocessed using custom scripts and third party toolboxes in MATLAB (MathWorks, Inc., Natick, MA). Blinks were removed from the pupil data by the Eyelink parser blink detection algorithm, which identifies blinks as periods of loss in pupil data surrounded by saccade detection, presumed to occur based on the sweep of the eyelid during the closing and opening of the eye. Saccades were also removed. Any missing pupil data was linearly interpolated using Matlab's interp1 function. Runs requiring greater than 25% interpolation were discarded (Kang & Wheatley, 2015). Following this, the pupil data was high-pass filtered at .05Hz to remove any large-scale drift in the data. Pupil data for each run/each subject was normalized by subtracting the mean for that run and dividing by the standard deviation.

Results: Behavior

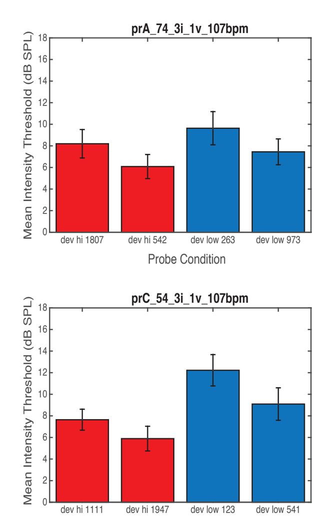
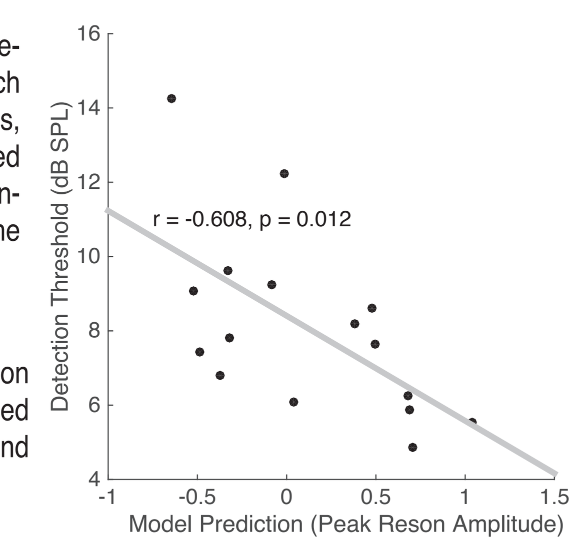


Figure 3 (left). Mean detection thresholds for each probe in each stimulus, across participants, treated categorically. Error bars indicate standard error of the mean.

Figure 4 (right). Correlation between model-predicted salience (continuous) and detection threshold.



Results: Eye-tracking

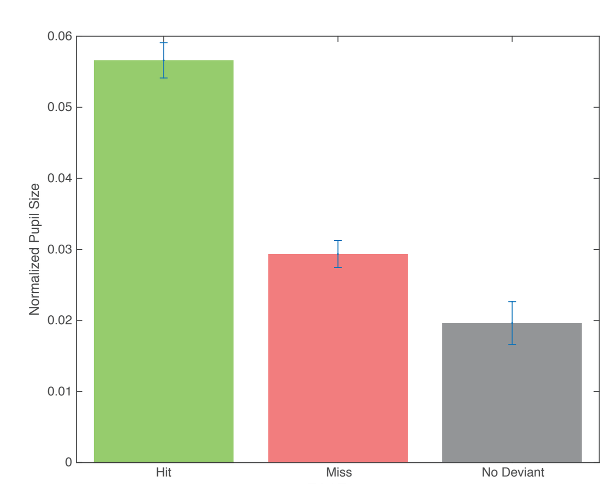
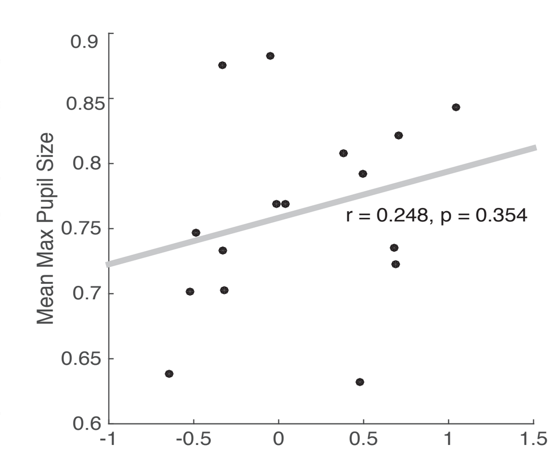


Figure 5 (left). Mean pupil size within a 1.5 s window following deviant or loop onset, across all stimuli and participants. Error bars indicate standard error of the mean.

Figure 6 (right). Correlation between model-predicted salience (continuous) and average max pupillary response to each deviant.



Results: Eye-tracking

Mean pupillary and blink responses to each probe in example stimuli, across participants

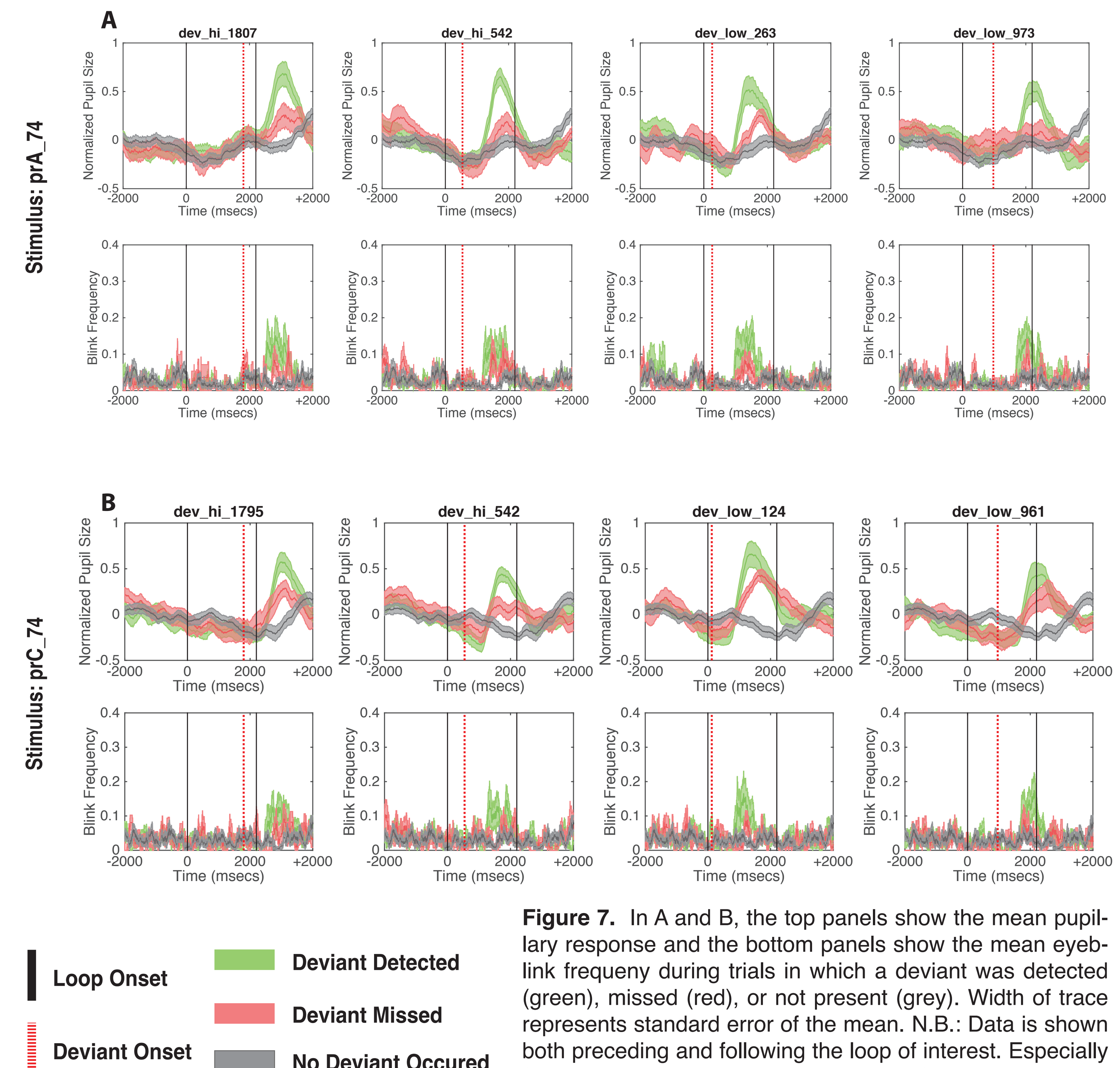


Figure 7. In A and B, the top panels show the mean pupillary response and the bottom panels show the mean eyeblink frequeny during trials in which a deviant was detected (green), missed (red), or not present (grey). Width of trace represents standard error of the mean. N.B.: Data is shown both preceding and following the loop of interest. Especially for deviants that occur towards the end of a loop, the pupil is still responding well into the subsequent loop.

Conclusion

These results confirm the utility of using eye-tracking to continuously index attention to auditory stimuli, as well as the promise of using output from Tomic and Janata's (2008) model to predict temporal attention to complex rhythmic stimuli.

References

Kang, O. & Wheatley, T. (2015). Pupil dilation patterns reflect the contents of consciousness. *Consciousness & Cognition, 35,* 128–135.

Marvit, P., Florentine, M. & Buus, S. (2003). A comparison of psychophysical procedures for level-descrimination thresholds. *J Acoust Soc Am., 113*(6), 3348-61.

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