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The influence of eye movements on perceived tone frequency: exploring pitch-space associations through psychophysics

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1 INTRODUCTION

Saccade execution, via presaccadic attention shifts, is known to influence the perception of various visual features, such as size, space or contrast¹⁻². In action-perception studies, ocular saccades, which are simple, reproducible, and effortless movements, enable repeated testing and calculation of psychometric functions (PFs).

This contrasts with the more complex actions examined in previous studies investigating the impact of action on pitch perception³⁻⁴. For example, it has been found that pitch was overestimated in participants' verbal reports of tone frequency when they were walking upstairs and underestimated when they were walking downstairs³.

However, these results can be explained by the mere activation of spatial representations⁵⁻⁶ ('high' vs. 'low' pitch) or by other response biases such as verbal labeling. In the example cited above, simply standing upstairs might be sufficient to cause pitch overestimation.

To examine the specific influence of movement on pitch perception, we used a psychophysical method to compare the perceived frequency of pure tones when participants made saccades vs. when they fixated a point on a screen.

2 METHODS

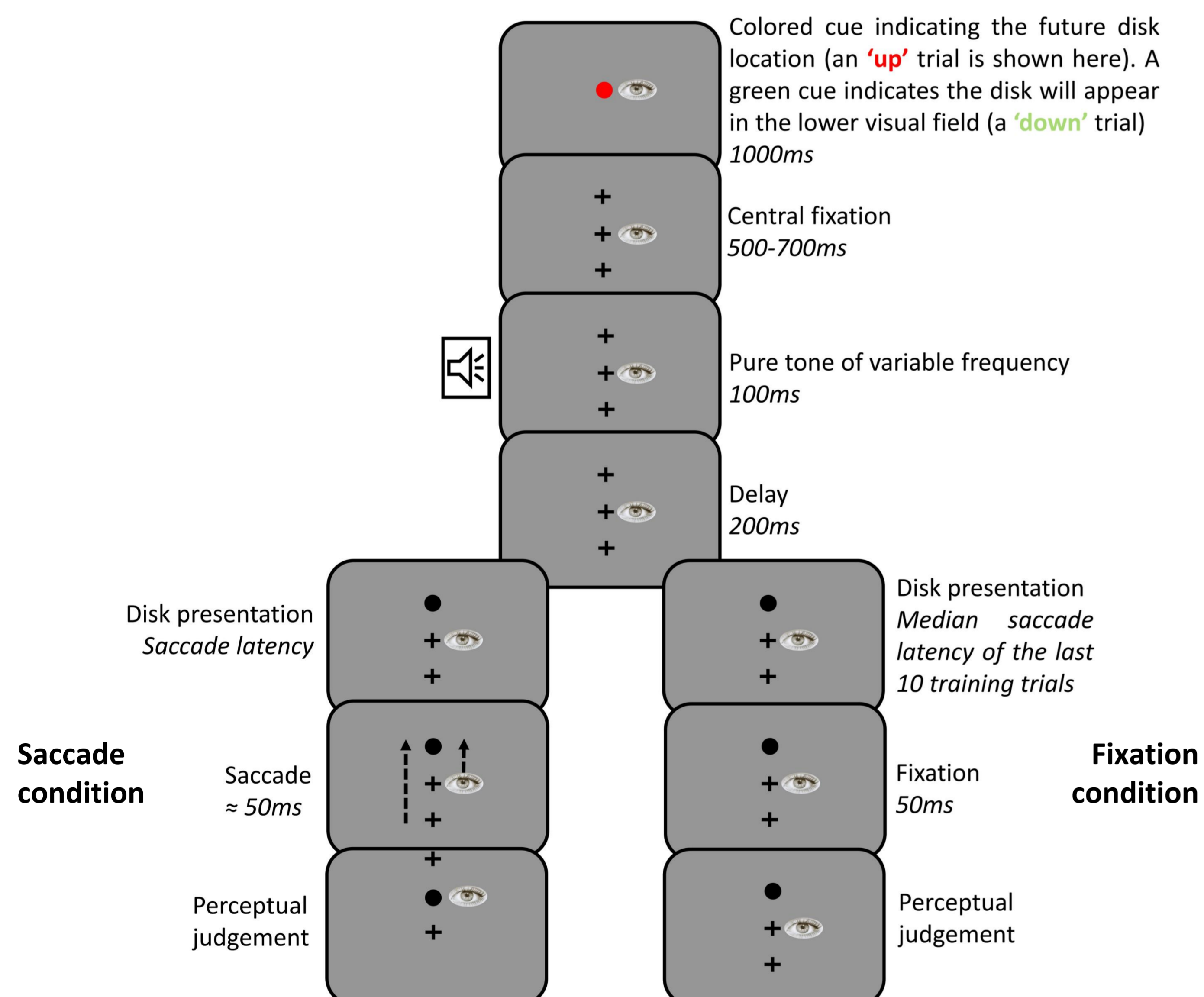
Participants

28 participants (22 females) aged 18 to 34 years ($M = 20.21$ years, $SD = 3.71$) were enrolled; 4 were excluded as outliers.

Procedure

- Preliminary threshold task** : A parametric staircase procedure (64 QUEST+⁷⁻⁸ trials) was used to individually adjust the frequency of the tones used in the main experiment.
- Training** : 32 trials of the Saccade condition (see below) were carried out with feedback on tone judgments and saccade latencies.
- Saccade (182 trials) & Fixation conditions (182 trials)** : Participants compared a variable tone frequency to an implicit standard frequency, which was the stored representation of the average of previously heard stimuli (Method of Single Stimuli⁹). The condition order was counterbalanced across participants. 'Up' and 'Down' trials were interleaved in each condition.

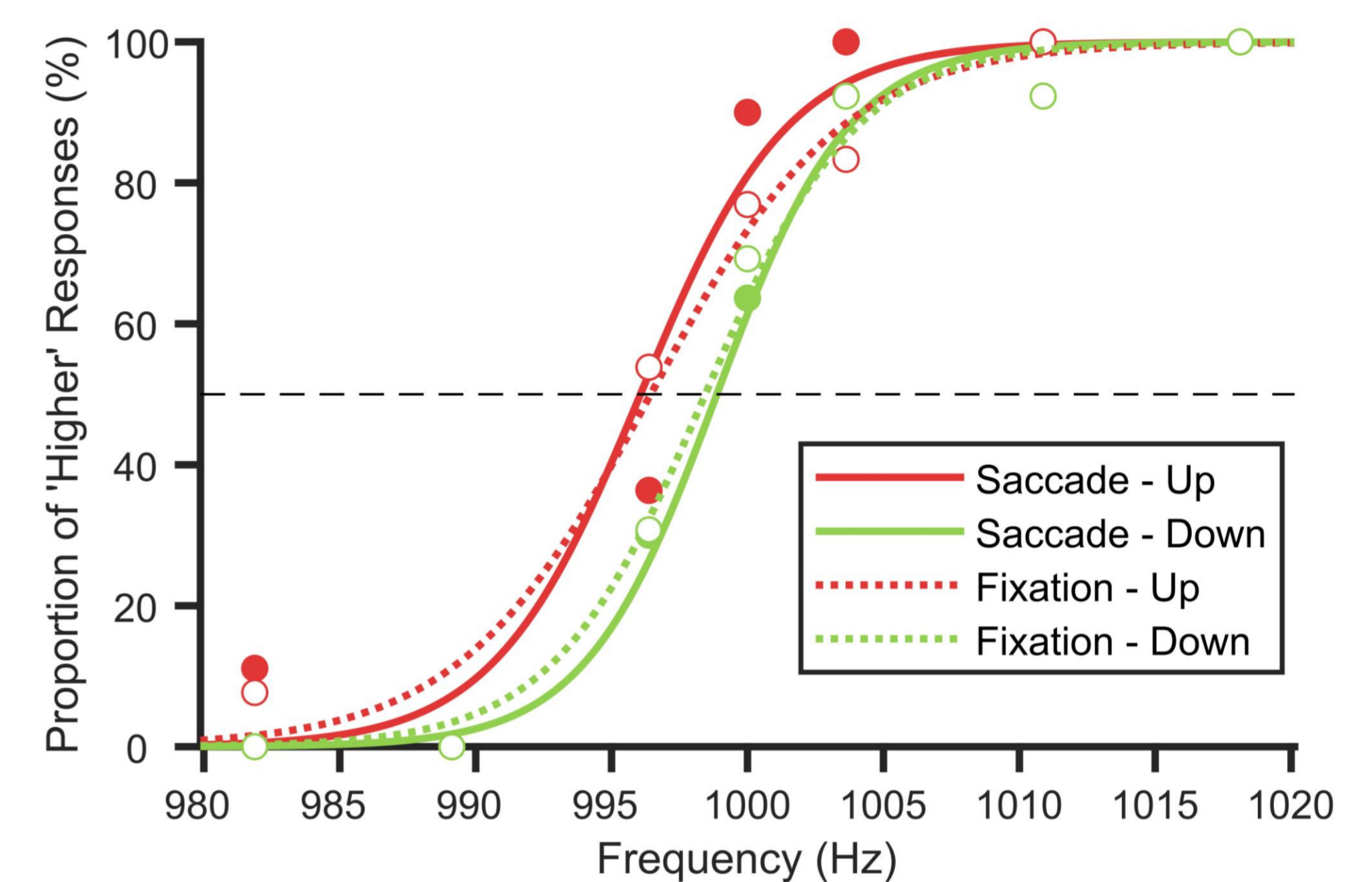
Structure of an 'up' trial : Pitch comparison to the representation of the average tone frequency



Hypotheses

- If spatial representations or other response biases are sufficient to bias pitch perception → PSEs should be lower when the disk was displayed in the upper visual field than in the lower visual field, in both the Saccade and Fixation conditions. This suggests that pitch was overestimated in the 'up' condition compared to the 'down' condition.
- If presaccadic attention facilitates pitch perception (similarly to other visuospatial dimensions²) → JNDs should be lower in the Saccade condition than in the Fixation condition, indicating better discrimination sensitivity.

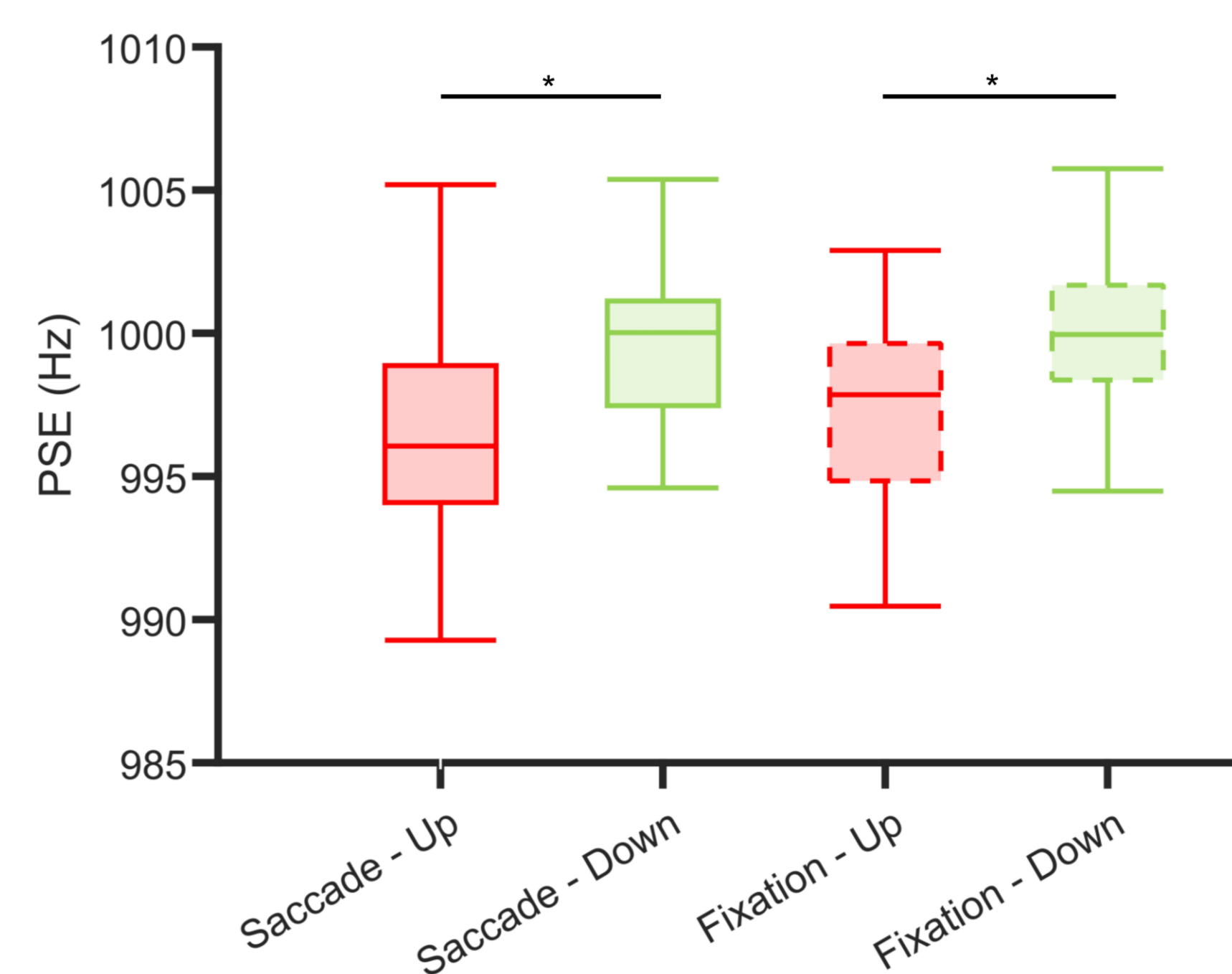
3 RESULTS



Examples of individual psychometric functions (PFs) for each condition

This representative participant judged tone frequencies to be higher than the implicit reference more often when the disk appeared in the upper visual field (red curves) than in the lower visual field (green curves). This resulted in a shift of the PFs, leading to lower PSEs in the 'up' condition than in the 'down' condition.

PSE Analyses

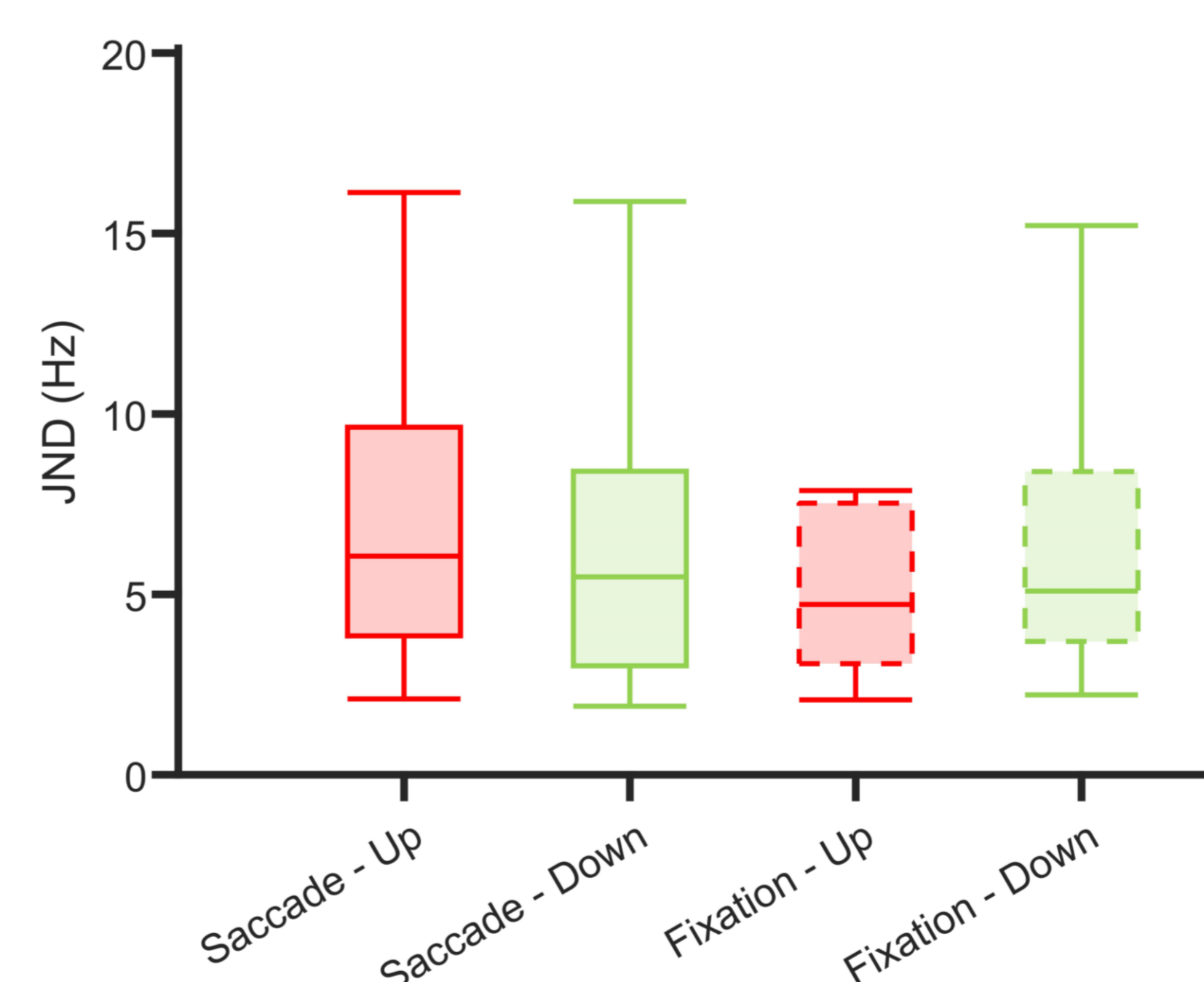


PSEs were significantly lower when the disk appeared in the upper visual field than in the lower visual field, $F(1,23) = 12.23$, $p = .002$, $\eta_p^2 = .35$; $BF_{10} = 21.30$.

The other statistical comparisons did not reach significance :

- Movement : 'Saccade' vs. 'Fixation', $F(1,23) = 1.85$, $p = .19$; $BF_{10} = 0.49$.
- 'Disk Location' x 'Movement', $F(1,23) = 0.49$, $p = .49$; $BF_{incl} = 0.52$.

JND Analyses



None of the effects tested reached significance :

- Disk Location : 'Up' vs. 'Down', $F(1,23) = 0.73$, $p = .40$; $BF_{10} = 0.38$.
- Movement : 'Saccade' vs. 'Fixation', $F(1,23) = 0.20$, $p = .66$; $BF_{10} = 0.34$.
- 'Disk Location' x 'Movement', $F(1,23) = 0.95$, $p = .34$; $BF_{incl} = 0.48$.

Statistical conclusions did not change when we included outliers, excluded musicians, or removed trials with anticipatory saccades (i.e., whose latency <100ms).

4 CONCLUSION

Pitch estimation was influenced by the disk location: pitch was perceived as higher when the stimulus appeared in the upper visual field compared to the lower visual field. We found no evidence that saccade execution affected this bias or discrimination sensitivity.

→ This study, which introduced a fixation condition, replicates previous findings indicating that representations or other response biases can influence tone frequency estimation⁵⁻⁶, and in addition, shows that this effect is independent of movement execution.

¹ Binda, P., & Morrone, M. C. (2018). Vision During Saccadic Eye Movements. *Annual Review of Vision Science*, 4(1), 193-213.

² Li, H.-H., Hanning, N. M., & Carrasco, M. (2021). To look or not to look : Dissociating presaccadic and covert spatial attention. *Trends in neurosciences*, 44(8), 669-686.

³ Hostetter, A. B., Dandar, C. M., Shimko, G., & Grogan, C. (2019). Reaching for the high note : Judgments of auditory pitch are affected by kinesthetic position. *Cognitive Processing*, 20(4), 495-506.

⁴ Repp, B. H., & Knoblich, G. (2009). Performed or observed keyboard actions affect pianists' judgements of relative pitch. *Quarterly Journal of Experimental Psychology*, 62(11), 2156-2170.

⁵ Connell, L., Cai, Z. G., & Holler, J. (2013). Do you see what I'm singing? Visuospatial movement biases pitch perception. *Brain and Cognition*, 81(1), 124-130.

⁶ Dolscheid, S., Shayan, S., Majid, A., & Casasanto, D. (2013). The Thickness of Musical Pitch : Psychophysical Evidence for Linguistic Relativity. *Psychological Science*, 24(5), 613-621.

⁷ Watson, A. B. (2017). QUEST+ : A general multidimensional Bayesian adaptive psychometric method. *Journal of Vision*, 17(3), 10.

⁸ Paire, A., Hillairet de Boisferon, A., & Paeye, C. (2022). Empirical validation of QUEST+ in PSE and JND estimations in visual discrimination tasks. *Behavior Research Methods*.

⁹ Morgan, M. J., Watamaniuk, S. N. J., & McKee, S. P. (2000). The use of an implicit standard for measuring discrimination thresholds. *Vision Research*, 40(17), 2341-2349.