Influences of Pitch and Spatial Trajectories on Relative Timing Judgments in Auditory Sequences

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Background

- Listeners integrate cues from acoustic features such as pitch and spatial location with onset timing to segregate multiple auditory objects.
- The *kappa effect* is a perceptual illusion which illustrates perceptual interactions between competing spectrotemporal cues.[1,2,3]
- *Auditory Kappa Effect:* timing judgments of auditory sequences are biased by changes in pitch, where larger pitch changes between sequential tones are perceived as longer time intervals. Two competing hypotheses are:
- **Auditory Motion Hypothesis:** individuals use pitch-time information ('pitch velocity') for tone sequences to predict *where* (in pitch space) and *when* an auditory event will occur.[4]
- **Auditory Grouping Hypothesis:** sequential events more similar in a task-irrelevant, non-temporal feature are grouped together as an auditory object, and thus perceived as occurring closer together in time.
- Aims: 1) test competing hypotheses and 2) test whether the kappa effect is generalizable to the spatial domain where changes in spatial location bias relative timing judgments among sequential auditory stimuli.

General Methods

Participants

- Participants had hearing thresholds <20dB HL at audiometric frequencies 0.25 - 8 kHz
- Experiment 1: n = 24 (age 18 - 31 yrs), Experiment 2: n = 23 (age 19 – 38 yrs), Experiment 3: n = 7 (age 19 – 36 yrs).

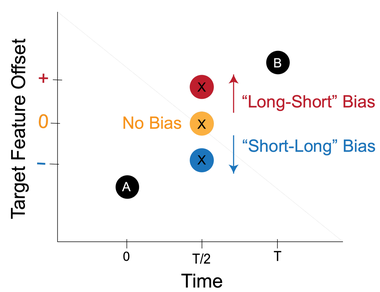
Kappa Task

- Heard sequences of 3 brief sounds (A-X-B paradigm)
- Judged whether the target sound ('X') was closer in time to sound 'A' or 'B' by responding 'Short-Long' or 'Long-Short' about the pattern of inter-onset intervals (IOI)

Stimuli

- A and B ('bounding sounds') had fixed timing *and* pitch separation (Exp 1 & 2) *or* spatial separation (Exp 3).
- Target timing varied trial to trial (Fig. 1)
- Target sound varied in pitch (Exp 1 & 2) or spatial location (Exp 3) with respect to pitch or spatial midpoint between bounding sounds (Fig. 2)

Fig 1. Kappa Effect illustration: Timing bias for target sounds that are shifted closer to 'A' or 'B' in a non-temporal stimulus feature. When target sound 'X' is more similar to 'A', there will be a bias to respond 'Short-Long.' When 'X' is more similar to 'B', there will be a bias to respond 'Long-Short.'



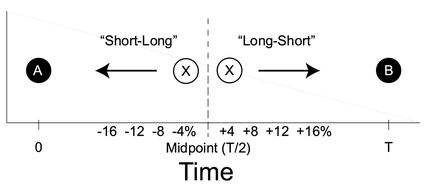
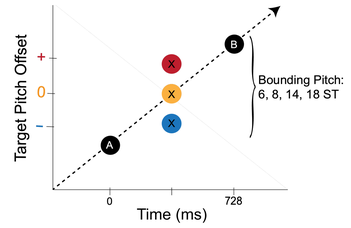


Fig 2. Target timing conditions: Targets ('X') were 4, 8, 12, 16% early or late with respect to temporal midpoint between bounding sounds ('A' and 'B'). Sequences with negative timing offsets are 'Short-Long' patterns and positive timing offsets are 'Long-Short'.

Experiment 1: Consistent Pitch Trajectory

Predictions: *Auditory motion hypothesis* - larger kappa effect for larger pitch intervals
Auditory grouping hypothesis - smaller kappa effect for larger pitch intervals

Fig 3. Exp 1 Stimuli: Bounding tones separated by 6, 8, 14, or 18 ST. Target pitch was either directly between bounding pitches (yellow) or 1 to 2 ST closer to 1st (blue) or 3rd (red) pitch.



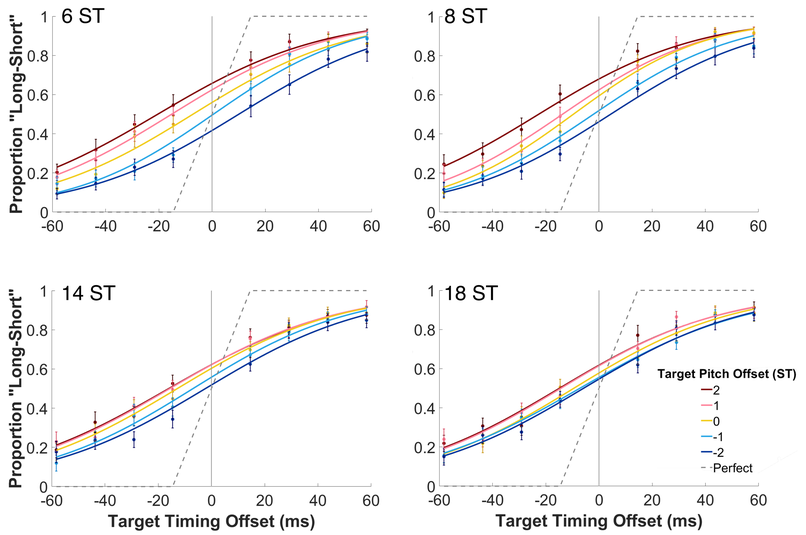


Fig 4. Exp 1 Results show a kappa effect. 'Long short' responses increased for target ('X') pitch shifted closer to tone 'B' (red lines). This effect diminished with greater pitch separation, indicating that large pitch leaps discouraged pitch-based tone grouping.

Experiment 3 – Spatial Trajectory

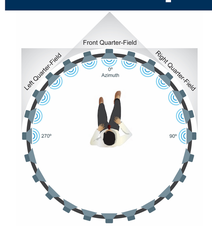
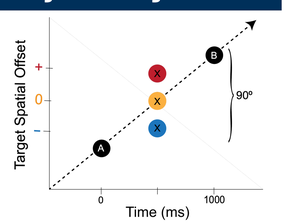


Fig 7. Left: Top-down view of 360° speaker array. Front, Left, and Right 90° quarter-fields were tested.

Right: Exp 3 stimuli schematic. Target spatial offset conditions mirrored the pitch offsets in Exp 1 and 2.



A) Front Quarter-Field B) Right Quarter-Field C) Left Quarter-Field

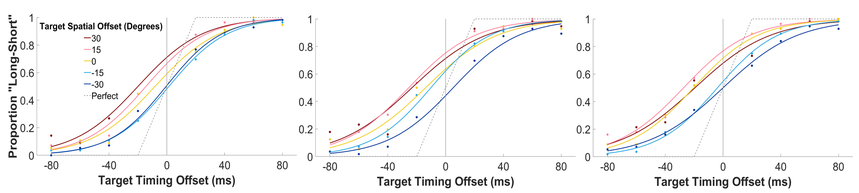
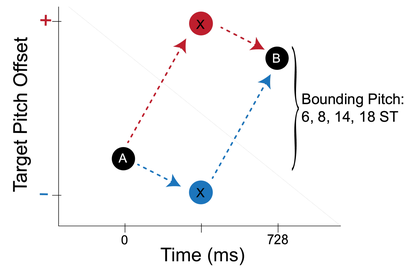


Fig 8. Exp 3 preliminary results show a spatial kappa effect. Participants respond 'Long-short' more when the target was closer in space to 3rd sound compared to when target was closer in space to 1st sound.

Experiment 2: Changing Pitch Trajectory

Predictions: *Auditory motion hypothesis* - no kappa effect for unpredictable pitch trajectories due to lack of stable pitch velocity referent.
Auditory grouping hypothesis - kappa effect will be present due to grouping by pitch proximity, regardless of pitch motion.

Fig 5. Exp 2 Stimuli. Target pitch was either 1 to 2 ST below 1st (blue) or above 3rd (red) pitch. Kappa effect is present if observe bias to report that two tones closer in pitch are closer in time.



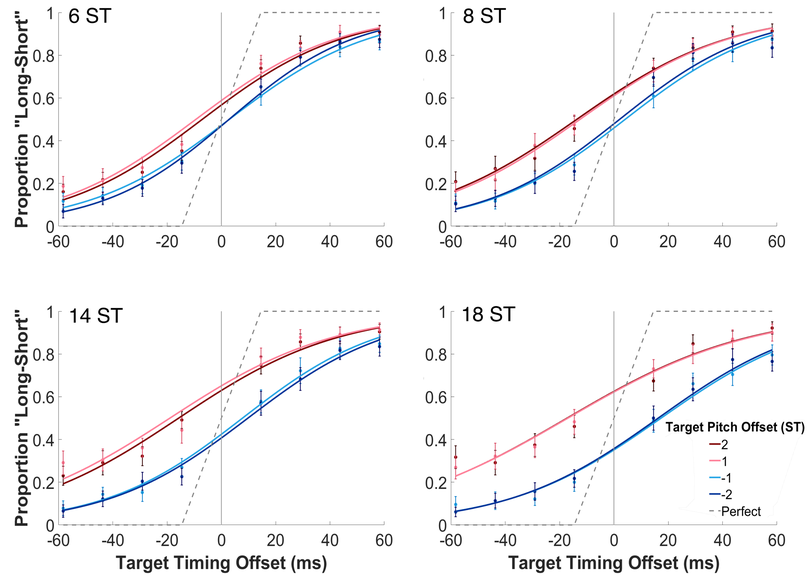


Fig 6. Exp 2 Results: Participants reported that two tones closer in pitch were also closer in time (kappa effect) regardless of changing motion trajectory, supporting the auditory grouping hypothesis. Proportion of 'long short' responses increased when target pitch offset was closer to 3rd pitch (red lines).

Discussion

- Results support the *auditory grouping hypothesis*: tones closer in pitch or space were perceived closer in time, regardless of auditory motion.
- Results support a generalizable kappa effect across feature domains.
- This study informs our understanding of auditory feature binding for streaming and object perception and is important for understanding how disruptions in pitch and spatial audition can affect time perception.
- Future experiments will examine kappa effects for other features (e.g., timbre, musical harmony) including combined features such as pitch *and* space, and will test the spatial kappa effect as a potential clinical measure of auditory spatial acuity in patients with unilateral deafness.

References

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Acknowledgments

- Funding: NIH T32-DC000011 (CK), UM funds (AHM)
- Research assistants: Zhiqing Yin, Deshaun Omane, Joscelyn Kooistra, Ilhan Onder, Deborah Fu, Mason Shields

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