UPPER LIMITS OF AUDITORY MOTION PERCEPTION WITH PERCUSSION SOUNDS

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1 Introduction

Since the 16th century, composers have used spatialization in their compositions. Iannis Xenakis, for instance, wrote *Persephassa* for six percussionists, with up to six streams of instruments, rotating clockwise and counterclockwise around the audience [1]. And with technological progress and the emergence of electroacoustic music, composers are increasingly interested in moving sounds in space.

Yet, little is known about human auditory perception of rotation. Féron, Frissen, Boissinot, and Guastavino [2] have measured the upper limit of auditory motion perception; that is, the highest velocity beyond which participants can not perceive if sounds are rotating around them. They found that the average upper limits were up to 2.8 rot/s. Moreover, the upper limited decreased as the stimuli contained increasingly less low-frequency content, suggesting a particular importance for interaural time differences in tracking auditory motion.

The little work available is based on the use of synthetic sounds and manipulations in the spectral domain. This study is the first to investigate upper limits with recordings of percussive sounds which contain both spectral and temporal complexity.

2 Experiment 1

2.1 Method

Participants

Twenty-one participants (11 women) with reported normal hearing, of average age 25.4 years (SD = 4.3), and musically trained (minimum: 1 year; average: M = 11.9 years, SD = 6.2), were recruited via emails sent to the school of music at McGill University and the CIRMMT news list.

Setup and stimuli

The experimental setup was reproduced from Féron et al. [2]. It consisted of a horizontal circular array of 16 speakers with a diameter of 3.7 m centered on the participant's head. The rendering system takes into account motion-dependent propagation and reflections [3].

The stimuli were obtained from isolated recordings of each of the six players in *Persephassa* [4]. We created brief (0.6 to 3.7 s), clean, and looping excerpts of two instruments from each family of percussions (skin, metal, wood) used in the piece. We also added a condition with pink noise to serve as a control and to allow comparison with previous studies. All stimuli were normalized in amplitude to -20 dB (in RMS or peak levels) and then equalized in loudness.

Procedure

We had seven conditions, tested separately in seven sessions presented in randomized order: one high tom, one snare drum, one cymbal, one metallic *simantra*, two wooden *simantras*, and a pink noise. The first *Simantra* was played in a sort of slow single stroke four way and the second *Simantra* was played faster, like a stroke roll.

Upper limits were estimated with a two-alternative forced choice 2-up, 1-down staircase procedure, with a starting velocity of 1.3 rot/s. The task was to indicate the direction of rotation (clockwise or counter-clockwise) of the sound stimulus. A total of four staircases, two in each direction, were intertwined in each session to make sure the participants did not realize the type of procedure being used. Each staircase stopped after either 12 reversals or 60 trials, whichever came first.

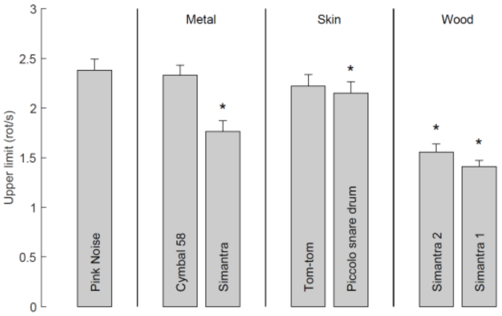

Figure 1: Upper limits for each condition of experiment 1 (N = 21). The asterisks denote a significant difference compared to the pink noise ($p < .01$)

Analyses

The analyses were conducted in MATLAB® (R2015b). For each staircase, the mean of the last four reversals was calculated. And for each condition, the means of the four staircases were averaged.

2.2 Results and discussion

The main results are shown in Figure 1. The upper limits for the three simantras (metal: $t(20)=7.14$, $p < .001$; wood 1: $t(20)=8.12$, $p < .001$; wood 2: $t(20)=9.95$, $p < .001$) and the piccolo snare drum ($t(20)=3.62$, $p < .01$) are significantly lower than for pink noise. The upper limits for the two metal

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instruments (simantra and cymbal) are also significantly (t(20)=5.89, p < .001) different from each other.

The upper limit for the pink noise was 2.4 rot/s, similar to the one for white noise from Féron et al. [2]. Among the set of stimuli, the upper limits for the three simantras are markedly lower. This reduction could be a due to differences in the temporal and spectral domain. That is, acoustic analysis revealed that the Simantra stimuli had a relatively lower event density and were less noise-like.

3 Experiment 2

3.1 Method

To explore the contribution of event density, and the noise-like quality of the signal, we conducted additional testing with the wooden *Simantra 1*, which is the condition with the lowest upper limit, and the most clearly discrete strokes. Specifically, we manipulated event density by controlling the beat frequency and we manipulated the noise-like character of the stimulus by superimposing levels of pink noise. After a small pilot to determine the signal-to-noise ratios (SNR) to use, we reproduced the same procedure.

Participants

Ten new participants (4 women) with reported normal hearing, of average age 27.0 years (SD = 5.9), and with sound-related knowledge and/or musical training (min.: 6 months; average: M = 10.1 years, SD = 7.6) were recruited from the same populations.

Stimuli

New stimuli were created by doubling the beat frequency and adding pink noise (in Audacity®) to the condition *Simantra 1* from the previous experiment.

We had seven conditions: the same pink noise as in experiment 1, as well as the same *Simantra 1* with no noise, 0.02, or 0.1 of added noise, and the same three *simantra* conditions with the beat density doubled. Table 1 lists the stimuli's signal-to-noise ratios.

Table 1: Signal-to-noise ratios (SNR) for the new conditions

		Beat frequency	
		x1	x2
SNR	0.02	+0.2 dB	-2.0 dB
	0.1	-0.7 dB	-2.6 dB

3.2 Results and discussion

The upper limits for the two no-noise conditions are significantly lower than those for the pink noise (original: t(9)=8.93, p < .001; doubled beat: t(9)=7.04, p < .001), and the added-noise conditions (original 0.02: t(9)=5.34, p < .001; original 0.1: t(9)=6.77, p < .001; double beat 0.02: t(9)=6.95, p < .001; double beat 0.1: t(9)=9.61, p < .001; Figure 2). The upper limits between noise conditions are similar within the groups of same beat frequency. The upper limits for each of the two no-noise conditions are significantly different (t(9)=3.10, p < .05).

An additional repeated measures ANOVA, with beat frequency and SNR as factors, shows a main effect of beat frequency (F(1, 9) = 29.845, p < .001) and SNR (F(2, 18) = 99.573, p < .001), with no interaction. The pairwise comparisons for SNR confirm that the upper limits for the no-noise stimuli are significantly lower than for the added-noise stimuli (p < .001).

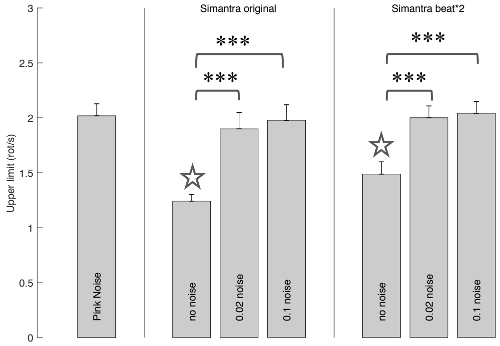

Figure 2: Upper limits for each condition of experiment 2 (N = 10). The stars denote a significant (p < .001) difference compared to the pink noise. ***, p < .001.

The upper limit improves sharply with the addition of noise, and mildly with the increase in beat frequency. This indicates that both spectral and temporal factors contribute to the upper limit, though in different proportions.

4 Conclusion

This was the first study to explore the influence of temporal and spectral complexity on the auditory perception of rotation. Overall, the upper limits we have estimated for real musical sounds are similar to the upper limits previously estimated for synthetic sounds. However, we need to disentangle the effects of temporal and spectral content. A further step will look into it with stimuli blending noise and percussive sounds, with the same temporal envelope.

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