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Perception of Rhythmic Similarity in Reich's *Clapping Music*: Factors and Models

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Background

An essential aspect of music is that it unfolds over time. Thus, understanding the perception and processing of the temporal organization of musical events (rhythm and metre) is critical to understanding music cognition and perception. The perception of similarity has been used as a measure of the underlying processing of categories of stimuli. There are various approaches and theories accounting for the perception of similarity including feature-based (Tversky, 1977), geometric (Shepard, 1987), and transformational (Chater and Vitanyi, 2003). Regarding music cognition, the perception of similarity has been used in research on the perception of melody (Eerola, et al., 2001) and computational approaches (Müllensiefen and Frieler, 2004), however very little work has investigated the perception of rhythmic similarity specifically.

Information theoretic approaches to music cognition can use computational models of the statistical properties of music to predict perception and neural responses to music (e.g. Pearce, et al., 2010), and provide information-processing models of the perceptual similarity between objects, based on how predictable an event is given the statistical properties of other events, or the information required to transform one stimulus configuration to another. These are consistent with an approach to music cognition that gives the statistical properties of musical events a central role, along with their effects on expectation, predictability, and emotional responses (e.g. Huron, 2006).

Aims

This study investigates influences on rhythm perception as measured by ratings of the perceived similarity of rhythmic figures from Reich's *Clapping Music* (1972).

Musical training has been robustly shown to change the way auditory information is processed, influencing perception, cognition, and physiology (Gaser and Schlaug, 2003). Thus we expect differences between musicians and non-musicians to be apparent in ratings of rhythmic similarity.

Performed music generally exhibits variations in timing, timbre, intensity, and other auditory properties, and these are continuously variable in natural performance, compared to the discrete nature of musical notation. We expect that natural, expressively performed versions of rhythms will provide greater information by which to distinguish rhythms than MIDI versions, influencing ratings of rhythmic similarity.

Clapping Music is a standard piece in the minimalist repertoire, and its composer wrote of his intention of perceptible processes in his work (Reich, 1974). By comparing perceived similarity of rhythms heard either in or out of the context of the piece's transformational process, we can explore the influence of the process, and reflect on its perceptibility.

Different approaches to similarity can either account for (i.e. Tversky, 1977), or ignore (i.e. Shepard, 1987), the possibility of asymmetrical perception, when the similarity between two stimuli depends on the order in which they are presented.

Method

In 2 experiments, 40 participants (20 musicians and 20 non-musicians) took part, listening to rhythms from 2 versions (MIDI and performed recording) of *Clapping Music*. This piece involves two performers clapping a rhythm through a transformation process that produces 12 distinct rhythmic figures. The MIDI version was created with samples of clapping sounds from the performed version, but arranged such that there was no natural variation in precise timing, timbre, or intensity. For isolated trials (Experiment 1), individual iterations (2.25s) of each rhythmic figure were used, and for contextual trials (Experiment 2), rhythms were repeated 4 times and heard in progressively longer excerpts of the piece in the intended order of rhythmic figures.

In Experiment 1, participants completed trials consisting of listening to two rhythms and then making a rating on a 7 point scale for perceived similarity of the rhythms (1 being very dissimilar, 7 very similar). Each participant heard each possible rhythm pair, in one order and in one version (MIDI or performed). Rhythm-pair trials were randomized for each participant, and balanced across musicians and non-musicians.

In Experiment 2, participants heard progressively longer excerpts of *Clapping Music* with four repetitions of each rhythmic figure. First, the first 2 figures were heard, then the first 3, up to the entire piece from the first figure to the last. After each excerpt, participants made ratings for the rhythmic similarity between the last rhythmic figure heard in the excerpt and each of the preceding figures in that excerpt, thus giving a rating of similarity between each pair of rhythms.

Analyses of variance (ANOVA) were performed on similarity ratings, investigating differences due to *musical training* (musicians vs. non-musicians), *expressive performance* (MIDI vs. performed version), and *musical context* (Experiment 1 vs. Experiment 2). Separate analysis looked at the effect of presentation order on pairwise similarity ratings (from Experiment 1 only).

Finally, measures were derived from 3 models representing quantitative relationships between individual rhythms. These were the Information Dynamics of Music model (Pearce, 2005, in prep.), Earth Mover's Distance in Conceptual Space model (Forth, in prep.) and a simple measure of edit distance between rhythms.

Results

Table 1 shows results of the main 2x2x2 ANOVA, revealing effects and interactions of musical training, expressive performance, and musical context. Table 2 shows mean ratings and standard deviations across all conditions.

Table 1. Statistics for Effects and Interactions of Factors

	F	*p*
Musical Training	9.13	.003
Expressive Performance	7.24	.008
Musical Context	16.14	<.001
Training x Performance	.71	.40
Training x Context	14.42	<.001
Performance x Context	30.43	<.001
Training x Performance x Context	3.80	.052

Table 2. Ratings of Perceived Rhythmic Similarity by Musicians and Non-Musicians Across both Experiments and Version

	Pairwise Presentation				*Contextual Presentation*			
	MIDI		*Performed*		*MIDI*		*Performed*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Mus	3.88	1.2	3.74	1.1	3.55	.62	3.67	.72
Non	4.26	1.0	3.77	1.0	3.90	.53	3.91	.45

For individual rhythms presented in pairwise fashion in Experiment 1, we analyze ratings of perceived rhythmic similarity for the influence of order, in that rhythms could be either in the order they appeared in the original composition, or in the reverse order. A paired *t* test for intended vs. reverse order of presentation shows that rhythm pairs are perceived as more similar when presented in the intended order ($t(263)=2.73$, $p=.007$). To explore the possible underlying causes of order-based differences, we also tested for the influence of rhythm structure on order-based differences in perception of rhythmic similarity. Since all rhythms contain 0, 1, 2, or 4 rests, we can consider all rhythms as having either an extreme number of rests (0 or 4) or a non-extreme number of rests (1 or 2). Rhythm pairs consisting of one rhythm with an extreme number of rests and one with a non-extreme number of rests, may substantially differ from rhythm pairs that consist of rhythms that both have either an extreme or non-extreme number of rests. We considered 'extreme-rest congruence' as a factor in a 2x2x2 ANOVA, with musical training and performance version, on order-based differences in mean similarity ratings for each rhythm pair.

Results of this test show a significant main effect of 'extreme-rest congruence' on order-based differences in perceived rhythmic similarity, where incongruent pairs have greater order-based difference than congruent pairs ($F(1,262)=3.91$, $p=.049$). No other effects or interactions are found.

Finally, correlations were examined between the similarity predicted for each pair of rhythms by each of the 3 models and similarity ratings from Experiment 1 using Spearman's ρ. Models' predictions correlate with similarity ratings ($\rho > .62$, $p < .01$) but with little differences between models.

Conclusions

Our results show that musical training, expressive performance, and musical context all influence rhythm perception as measured by ratings of perceived rhythmic similarity. We take lower mean similarity ratings (i.e. greater perceived dissimilarity) to reflect greater ease of making cognitive and perceptual distinctions between stimuli, thus facilitating cognitive processing.

Expressively performed rhythms provide greater information in the form of continuously variable timbre, intensity, and precise timing, and this added information leads to lower similarity ratings. However, this effect disappears when rhythmic figures are heard in the context of the musical process, suggesting that the information contained in the process itself is more important in distinguishing rhythms than that of expressive performance. Also, the advantage in processing rhythmic information afforded by expressive performance is significantly less for musicians than non-musicians. This is likely due to the experience musicians have in listening to, processing, and distinguishing rhythms as conceptual objects, rather than as purely auditory objects. That is, musical training provides an advantage in extracting specifically rhythmic information from an auditory sequence.

The surprising finding of asymmetrical rhythm perception also reflects an information-processing basis of rhythm perception. When a rhythm with an extreme number of rests is heard after a rhythm with a non-extreme number, the pair is rated as less similar than when heard in the opposite order. We interpret this effect by considering that rhythms with an extreme number of rests are less common, and lie on the extremes of the range of possible numbers of rests. Thus these rhythms have higher information content than rhythms with a non-extreme number of rests, and are less likely. High information content events are likely to be more salient, and the salience coming at the end of a pairwise trial may be confused with greater dissimilarity influencing the pattern of results we found.

Overall, this study reflects influences on rhythm perception, and supports information theoretic approaches to music.

Keywords

Rhythm perception; Similarity; Information theory.

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