



Effect of Network Latency on  
Interactive Musical Performance  
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## Overview

- ▶ What is latency in performance?
  - ▶ External
  - ▶ Internal
- ▶ Dimensions of musical interaction
  - ▶ Pacing
  - ▶ Regularity
  - ▶ Coordination
  - ▶ 'Musicality'
- ▶ Previous research
- ▶ Experimental procedure
- ▶ Results
- ▶ Discussions

## Latency in Musical Performance

- ▶ Aim – to find maximum tolerable external latency
- ▶ External latency
  - ▶ Delay due to physical constraints such as:
    - ▶ Distance
    - ▶ Human perception
- ▶ Internal latency
  - ▶ Delay due to the performer's expressive choices
    - ▶ Anticipation
    - ▶ Delay
    - ▶ Errors
    - ▶ Randomness
    - ▶ Accents



## Dimensions of musical interaction

- ▶ Pacing
  - ▶ Global ensemble tempo
  - ▶ Mean IOI (ms)
- ▶ Regularity
  - ▶ Timing *within* parts
  - ▶ Coefficient of Variability (CV) = Std. Dev./Mean
- ▶ Coordination
  - ▶ Timing *between* parts
  - ▶ Mean asynchrony (ms)
- ▶ Musicality
  - ▶ Subjective
  - ▶ Score from 1.0-5.0, at performer's discretion
  - ▶ 1 = "unmusical", "mechanical"
  - ▶ 5 = "musical", "interactive"



## Previous Research

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- ▶ Two notes detected as distinct, at >20ms (Hirsh 1936; Vernon, 1936)
  - ▶ Given isochrony, ear can be sensitive to deviations of a few ms (Clarke, 1989; Schuett, 2002)
  - ▶ When notes are lengthened, it is harder to perceive deviations (Repp, 1992)
  - ▶ Pianists may deliberately play asynchronously to separate voices (Palmer, 1989; Repp, 1994; Shaffer, 1984)
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## Audio Samples

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- ▶ Performance of k. 487 – duet #2 for violin and cello
    - ▶ <http://www.youtube.com/watch?v=4AakmnXCJel>
  - ▶ Performance of k. 487 – duet #2 for flutes
    - ▶ <http://www.youtube.com/watch?v=kbjf4rwAEOg>
  - ▶ K. 487 – duet #5 for clarinets
    - ▶ [http://www.youtube.com/watch?v=I I \\_TdavNSL0](http://www.youtube.com/watch?v=I I _TdavNSL0)
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### Duet #2

Musical score for Duet #2, measures 1-16. The score is written for two staves (treble and bass clef) in a 3/4 time signature with a key signature of one sharp (F#). The melody in the upper staff consists of quarter and eighth notes, while the bass line in the lower staff features a steady eighth-note accompaniment. The piece concludes with a double bar line and the word "Fine" written in the right margin.

Musical score for Duet #5, measures 25-32. The score is written for two staves (treble and bass clef) in a 3/4 time signature with a key signature of one sharp (F#). The upper staff contains a melodic line with some rests, and the lower staff provides a rhythmic accompaniment. The piece ends with a double bar line and the instruction "D.C. al Fine" written in the right margin.

Duet #5 on following slide



## Experimental Procedure

### Experiment 1

- ▶ Performer setup:
  - ▶ Isolated both visually and aurally
  - ▶ Given headphones, microphones
- ▶ Subjects instructed to perform with 'musical expression'
- ▶ Subjects' start time synchronized, but were not informed of latency level
- ▶ Latency levels used – 6, 26, 56, 106, 156, 206ms
- ▶ No practice with latency

### Experiment 2

- ▶ Setup identical
- ▶ Subjects practiced at each latency level
- ▶ Subject devised a strategy to compensate for latency in advance
- ▶ Latency levels used – 46, 86, 126ms

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## Results – Experiment 1

TABLE 1. Clarinetists' results for duet # 2

Latency	Pacing (mean IOI)	Regularity (CV)	Coordination (mean asynchrony)	Musicality (mean rating)
6 ms	198 ms	10.2	27 ms	3.0
26 ms	209 ms	10.4	30 ms	4.0
56 ms	254 ms	10.9	41 ms	3.0
106 ms	280 ms	17.4	50 ms	2.5
156 ms	384 ms	14.3	75 ms	3.0
206 ms				
Trial 1	646 ms	19.8	139 ms	2.0
Trial 2	380 ms	14.8	98 ms	2.0

TABLE 2. String players' results for duet #2

Latency	Pacing (mean IOI)	Regularity (CV)	Coordination (mean asynchrony)	Musicality (mean rating)
6 ms	254 ms	14.6	44 ms	3.5
26 ms	265 ms	14.7	51 ms	4.5
56 ms	298 ms	15.5	65 ms	4.5
106 ms	453 ms	31.8	129 ms	3.0
156 ms	476 ms	18.3	139 ms	4.0
206 ms	526 ms	27.0	177 ms	3.0



## Results – Experiment 2

TABLE 5. Clarinetists' results for Experiment #2

Latency	Pacing (mean IOI)	Regularity (CV)	Coordination (mean asynchrony)	Musicality (mean rating)
46 ms	231 ms	10.9	31 ms	4.0
86 ms				
Trial 1	230 ms	10.6	63 ms	2.5
Trial 2	229 ms	11.3	52 ms	3.25
126 ms				
Trial 1	288 ms	13.4	71 ms	2.25
Trial 2	244 ms	12.5	57 ms	2.0
Trial 3	313 ms	26.4	69 ms	1.5

TABLE 6. String players' results for Experiment #2

Latency	Pacing (mean IOI)	Regularity (CV)	Coordination (mean asynchrony)	Musicality (mean rating)
46 ms				
Trial 1	269 ms	14.8	63 ms	4.5
Trial 2	263 ms	12.4	57 ms	5.0
86 ms				
Trial 1	293 ms	13.2	79 ms	3.5
Trial 2	274 ms	13.6	74 ms	4.0
Trial 3	270 ms	13.3	66 ms	4.0
126 ms				
Trial 1	271 ms	13.8	94 ms	2.5
Trial 2	287 ms	16.9	64 ms	2.5



## Authors' Discussion

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- ▶ **Key latency threshold - 106ms**
  - ▶ Pacing, regularity jump beyond this level of latency
  - ▶ May indicate a threshold beyond which 'musical' performance is impossible
- ▶ **Here, 'musicality' is restricted to timing variation only**
  - ▶ Does not consider tone, pitch, dynamics etc.
- ▶ **Experienced musicians handle latency better than novices**



## Other Observations

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- ▶ **Note segmentation**
  - ▶ Done in MATLAB using dual-FFTs
  - ▶ Severely lacking context – need to justify method
  - ▶ Affects onset detection in measurements
- ▶ **Musicality**
  - ▶ Difficult to discern a trend of musicality over latency
  - ▶ Inadequate metric
  - ▶ Likely bias by only using performers' input

