Movement during Performance: A Hunt for Musical Structure in Postural Sway

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Introduction

- Watching a musician move in performance can give the audience insight into expression, sound level, and tempo (Davidson, 2007; Godoy, 2010; Dahl & Friberg, 2007).
- **Might it matter where we watch a performer move?**
  - Not for expression (Dahl & Friberg, 2007).
    - *This suggests that the movements are all a connected (dynamical?) system.*
- **Do movements provide information about the musical structure?**
  - ***Sound → Movement:*** **Yes**
    - Leman, Desmet, and Styns (2008) showed people can move their arms in similar velocity patterns when listening to musician.
  - ***Sight → Structure:*** **No, but should (Godoy, 2010; Shove & Repp, 1995)**
    - Davidson (2007) found that movements of the musician tend to look different each time the performer plays the same piece.
      - *Maybe a methodical problem? Researcher typically have used one-dimensional data, assume stationarity, and measured dimensions are independent.*
- **Unraveling a connected dynamical system**
  - By using phase-space reconstruction (PSR) the entire system of movements during performances can be reconstructed from information recorded in only one-dimension (Takens, 1981).
  - Once the complete system has been reconstructed, a recurrence quantification analysis (RQA) can be used to locate self-similarities within a performance.
  - RQA can provide visual and quantitative evidence of both the amount and location of recurrence in the movements as they unfold over the course of the performance.

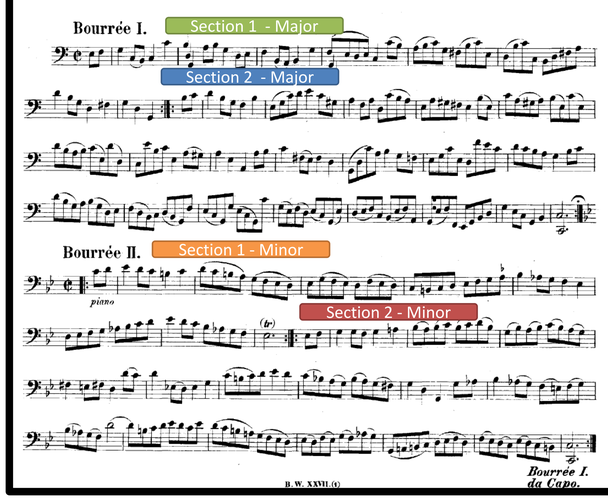
Method

Participant
- Professional Trombonist (third author)

Materials
- Wii Balance Board, WiiMote Toolbox, Psychopsychics toolbox, CRP toolbox.

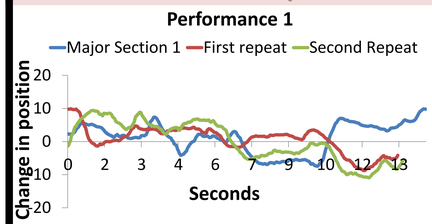
Procedure
- 3 performances with the score during the middle of the learning process were measured at 34 Hz in the x-axis.

Music
- J.S. Bach's Bourree I & II, all repeats, 3rd Cello suite.



Linear Analysis

Example of Movement from X-axis



- Movement from the Section 1 - Major with subsequent repeats are different within performances.
- The difficulty for analysis is that the time between sections, within and between performances, are not the same.

Correlations Within Performances

- In order to compare movements within a common temporal framework, we averaged position and velocity within each musical beat. This allows comparison without disrupting the integrity of the system dynamics, albeit at the cost of the fine grain structure within beats.
- The correlation matrices below compare repetitions of musical themes **within** each performance for position (left panel) and velocity (right panel).

	Mean Position per Beat		
Performance	Perf 1	Perf 2	Perf 3
Major 1 vs 1st Repeat	-0.21	0.11	0.29
Major 1 vs 2nd Repeat	0.03	0.33	0.48
Major 1: 1st R vs 2nd R	0.73	0.77	0.07
Major 2 vs 1st Repeat	0.50	0.26	-0.18
Major 2 vs 2nd Repeat	0.32	0.06	0.43
Major 2: 1st R vs 2nd R	0.58	0.28	0.18
Minor 1 vs 1st Repeat	-0.81	0.19	-0.23
Minor 2 vs 1st Repeat	0.61	-0.16	0.35

	Mean Velocity per Beat		
Performance	Perf 1	Perf 2	Perf 3
Major 1 vs 1st Repeat	0.42	0.39	0.47
Major 1 vs 2nd Repeat	0.31	0.45	0.03
Major 1: 1st R vs 2nd R	-0.09	0.62	0.06
Major 2 vs 1st Repeat	0.40	-0.04	0.06
Major 2 vs 2nd Repeat	0.50	0.06	0.30
Major 2: 1st R vs 2nd R	0.48	-0.35	-0.20
Minor 1 vs 1st Repeat	-0.61	-0.14	0.03
Minor 2 vs 1st Repeat	0.64	0.08	0.42

- Sometimes movements between sections are the same and sometimes not.

Correlations Between Performances

- The correlation matrices below compare repetitions of musical themes **between** each performance for position (left panel) and velocity (right panel).

	Mean Position per Beat		
Performance	1 vs 2	1 vs 3	2 vs 3
Major Section 1	-0.21	-0.13	0.73
Repeat	0.71	0.21	0.07
Major Section 2	0.25	0.47	0.28
Repeat	0.24	-0.01	-0.03
Minor Section 1	-0.94	0.14	-0.03
Repeat	0.17	0.00	-0.61
Minor Section 2	-0.15	0.62	-0.19
Repeat	-0.01	0.62	-0.30
Major Section 1	0.89	0.80	0.86
Major Section 2	-0.51	-0.16	0.62

	Mean Velocity per Beat		
Performance	1 vs 2	1 vs 3	2 vs 3
Major Section 1	0.48	0.37	0.53
Repeat	0.04	-0.05	0.39
Major Section 2	0.43	0.74	0.51
Repeat	0.08	-0.12	0.06
Minor Section 1	-0.83	0.39	-0.11
Repeat	0.06	-0.13	-0.32
Minor Section 2	0.33	0.69	0.34
Repeat	0.18	0.54	0.09
Major Section 1	0.78	0.44	0.50
Major Section 2	-0.30	0.09	0.47

- Between performances, some sections are similar (dark green), but many are not.

Discussion

The unreliable nature of movement patterns is supported by a traditional data analysis.

Examining the movements as they exist in one-dimension does not provide a complete picture as how the movements of the performer may embody musical structure.

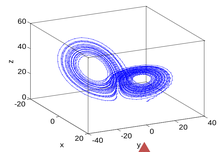
Using phase-space reconstructions we can unwrap the hidden layers of the movements that give rise to the complete performance. Further, we do not need to standardize the movements to the beat. Each performance can be examined as it was recorded and performed.

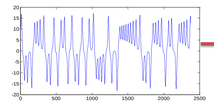
Lastly, apriori locations for examination with RQA do not need to be set. The movements of the entire performance can be compared.

Non-Linear Dynamical Systems Analysis

Step 1: Phase-Space Reconstruction (PSR)

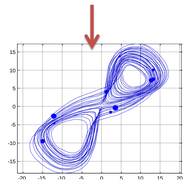
Example: a Known System, Lorenz Attractor





Extracted X-dimension

Missing dimensions reconstructed using time-lagged copies of the extracted dimension (Takens, 1981).



The reconstructed phase space will have the same topology as the original dynamical system, in that it will preserve the invariant aspects of the sequence of the points (Abarbanel, 1996).

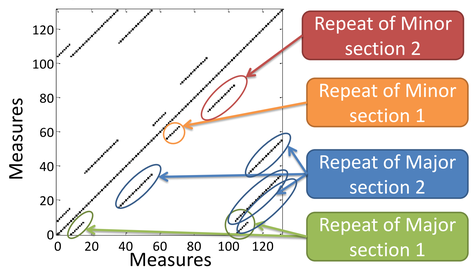
Step 2: Recurrence Quantification Analysis

- RQA takes the reconstructed system and tests for where the system 'nearly' recurs in phase-space.
- A radius is set for each data point. Any other data point within the radius counts as a recurrent point.
- This process is repeated for each data point.
- The result is a matrix of recurrent points (Marwan, et al., 2007)

RQA Hypothesis Based on Musical Structure

Based on the repetitions of sections, we can predict as to the where movements could recur.

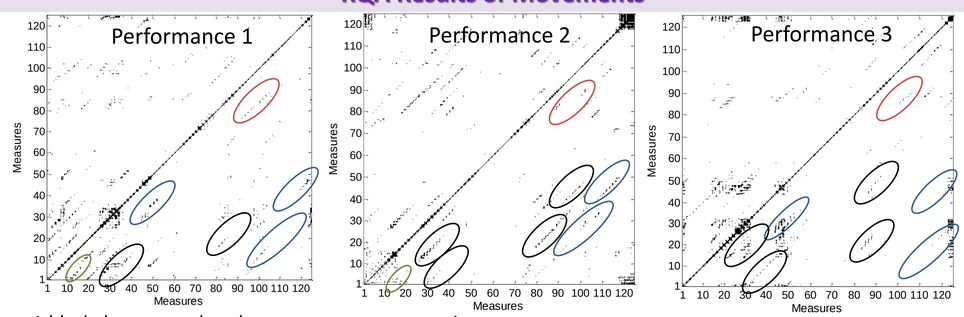
RQA Plot based on recurrence of measures



PSR and RQA for Movements

1) The movements of each of performance was converted to Zscores.
2) The movements of each performance underwent a phase-space reconstruction, using
   - a time lag of 83 (determined by an Average Mutual Index)
   - 7 embedding dimensions (determined by False Nearest Neighbors analysis)
3) Each reconstructed performance underwent RQA (using a radius of .9 Zscores) to look for recurrence in the movements in high dimensional reconstructed space.

RQA Results of Movements



- A black dot means that the movements are recurring.
- A diagonal line means that the recurrence is occurring for an extended time.
- Colored circles show places where the recurrence matches the predictions. However, the diagonal lines are often partial, suggesting that the movements are on-and-off again similar.
- Black circles represent somewhat reliable places with recurrence, not predicted solely by the recurrence of measures. For example, the second half of major section 2 and second half of minor section 2.

Discussion

PSR and RQA provide evidence for the intuition that movements do embody musical structure.

These techniques reveal a more complex structure of recurrence in the movements that could not be see with traditional analysis techniques.

The next step is examine the RQA plots of performances across learning to see how the embodiment of musical structure evolves.