



3rd workshop on Social Behaviour in Music
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Analysis of Leadership in a String Quartet

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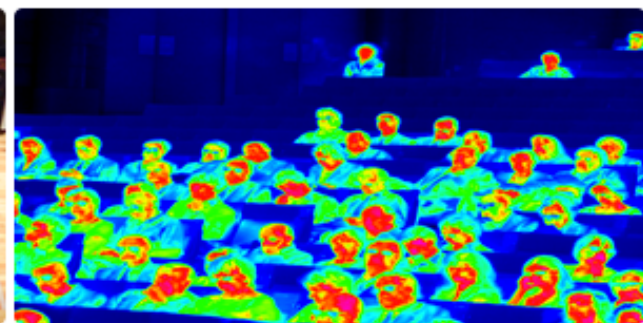
- **Research question:** how can we characterize leadership within a small group of individuals involved in a creative joint activity.
- **String Quartet (SQ) as test case**
 - Music perfect test-bed to study non-verbal communication
 - Dynamic hierarchy (“SQ as Self-Managed Team”)

Gilboa & Tal-Shmotkin 2010

Background :

EU-ICT FET **SIEMPRE** project scenario

- Research on social interactions within music ensemble address four types of scenario:
 - Performer– performer
 - Conductor – performer
 - Performer– audience
 - Mobile co-creativity and musical experience



Background : approaches

- Research on social interactions within music ensemble include two approaches:
 - Qualitative approach: self-report assessment, manual video coding [Davidson et al 2006](#), [King 2008](#)
 - Quantitative approach based on automatic analysis of non-verbal behavioral cues
 - Chronemics [Varni et al. 2010](#)
 - Entropy [Glowinski et al. 2010](#)
 - Granger Causality (Orchestra) [Ausilio et al. 2012](#)

Leadership in String Quartet (SQ)

- **Leadership:** person's capacity to guide people by means of his social and organizational skills
[Guastello, 1998](#)
- The regular presence of a leader may ensure group cohesion and facilitate the collaborative music-making process [Gilboa & Tal-Shmotkin 2010](#)
- **Leadership patterns:** Leadership is not always exerted by the same single musician as in an orchestra, different configurations exist [King 2006](#)

Leadership pattern in String Quartet (SQ)

- The SQ case actually exhibits a variety of “leadership patterns” that can occur at different levels:
 - (i) Social statute
 - (ii) Musical structure
 - (iii) Performance techniques of the ensemble

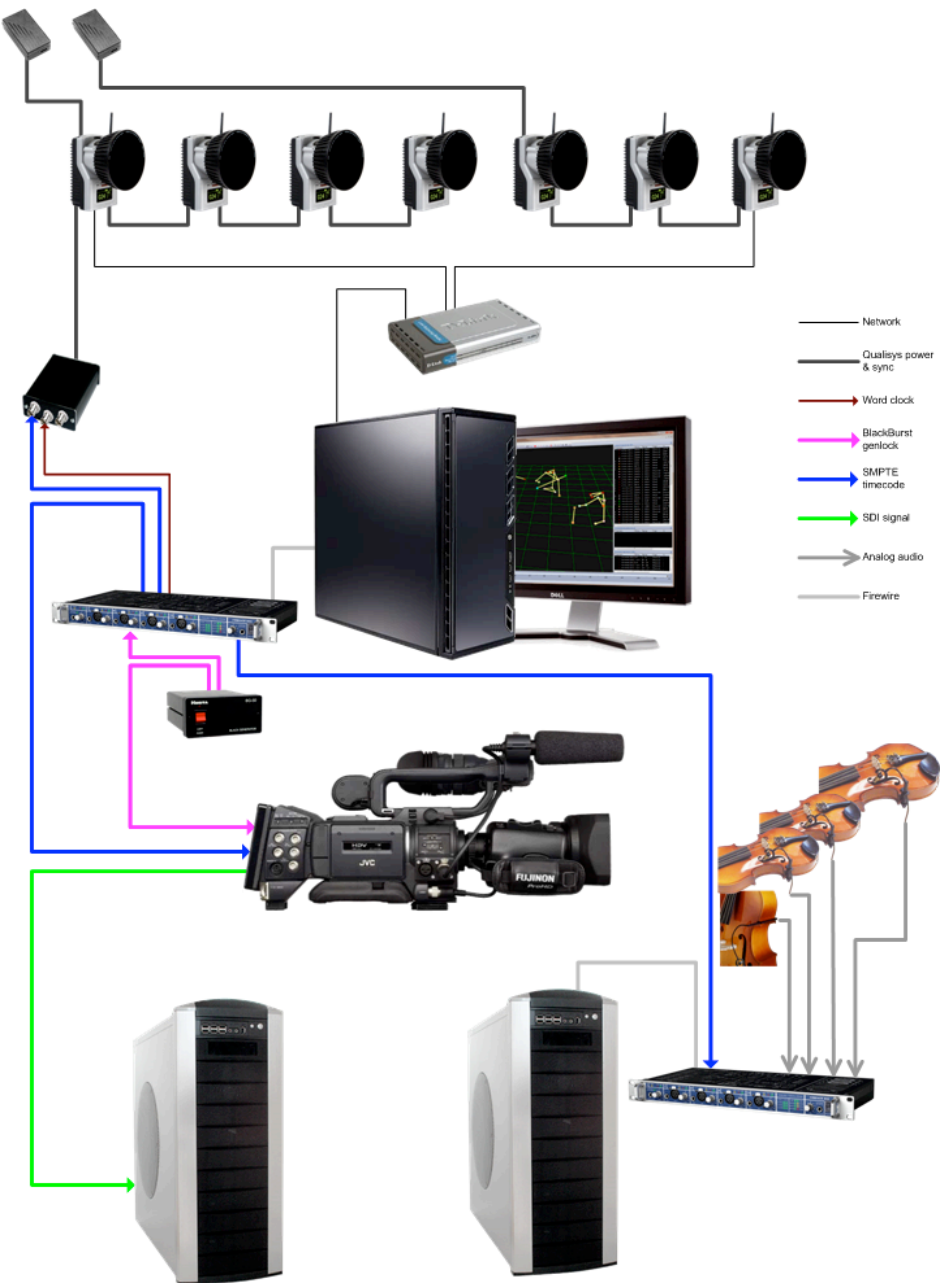
Setup and Method

- Multimodal recording of String Quartet “Quartetto di Cremona” at Casa Paganini hall
- Methods based on Granger causality to identify “main” leader(s) (through ***positive driving force***), ***leadership distributions***, and ***inter-musician communication***

Multimodal Setup

- SIEMPRE Software Platform for synchronous recording of multimodal data – [demo](#) -
 - Video, audio, MoCap and physiological data





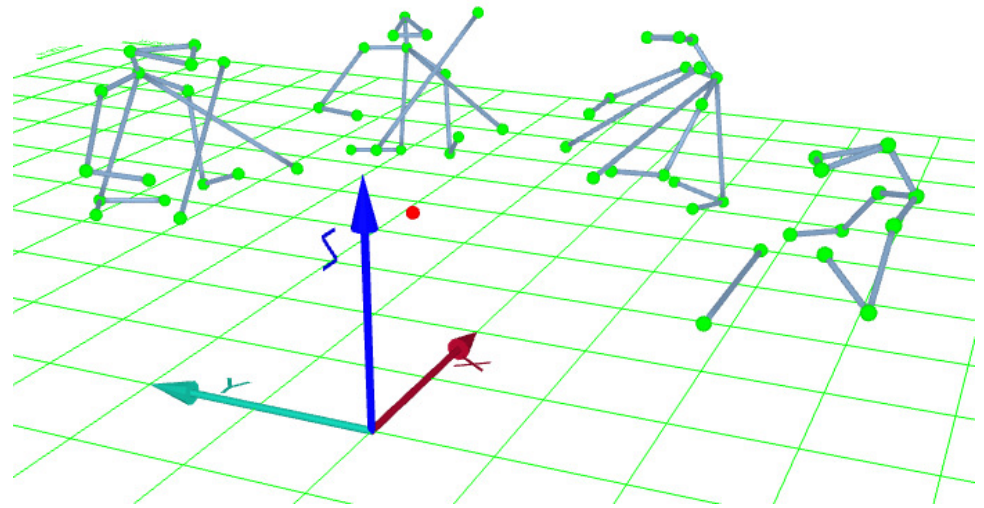
SIEMPRE Software
 Platform for
 synchronous recording
 of multimodal data
 based on EyesWeb
 platform
 (www.eyesweb.org)

Protocol and Stimuli

- **Protocol** : Cremona SQ were asked to play 5 times altogether the same 2 minutes length music segment without any break
- Post-performance questionnaires
- **Stimuli** : 5 musical phrases that setup specific interactions between musicians from Schubert piece *The Death and The Maiden*

Data

- Head distance variations with respect to the subjective center of the group (the “ear”)



Method: Granger Causality

Definition:

Given two time series x and y , x “G-causes” y if the past values of x contain information that helps predict y above and beyond the information contained in the past values of y

Assumptions:

- causality is based on temporal precedence
- the two time series are stationary and linear
- the prediction (on which Granger causality is based) is carried out by Auto-Regressive (AR) models

Mathematical formulation (1)

Reduced AR model:

$$x(t) = \sum_{j=1}^l a_{R,j} x(t-j) + \varepsilon_R(t)$$

$$y(t) = \sum_{j=1}^l d_{R,j} y(t-j) + \eta_R(t)$$

Complete model:

$$x(t) = \sum_{j=1}^l a_{U,j} x(t-j) + \sum_{j=1}^l b_{U,j} y(t-j) + \varepsilon_U(t)$$

$$y(t) = \sum_{j=1}^l c_{U,j} x(t-j) + \sum_{j=1}^l d_{U,j} y(t-j) + \eta_U(t)$$

Mathematical formulation (2)

G-causality values:

$$\mathcal{F}_{x \rightarrow y} = \ln \frac{H_R}{H_U} \qquad \mathcal{F}_{y \rightarrow x} = \ln \frac{E_R}{E_U}$$

where:

$$E_R = \text{var}(\varepsilon_R(t))$$

$$E_U = \text{var}(\varepsilon_U(t))$$

$$H_R = \text{var}(\eta_R(t))$$

$$H_U = \text{var}(\eta_U(t))$$

Driving force

- Two (out of three) measures we used to analyze the quartet data are based on the concept of Driving Force
- Definition of Driving Force

$$DF_{i \rightarrow j} = \frac{\sum_{k=1}^{N_w} S(\mathcal{F}_{M_{k,i} \rightarrow M_{k,j}}) - S(\mathcal{F}_{M_{k,j} \rightarrow M_{k,i}})}{N_w}$$

$$S(\mathcal{F}_{x \rightarrow y}) = \begin{cases} \mathcal{F}_{x \rightarrow y} & \text{if } \mathcal{F}_{x \rightarrow y} \text{ is significant} \\ 0 & \text{otherwise} \end{cases}$$

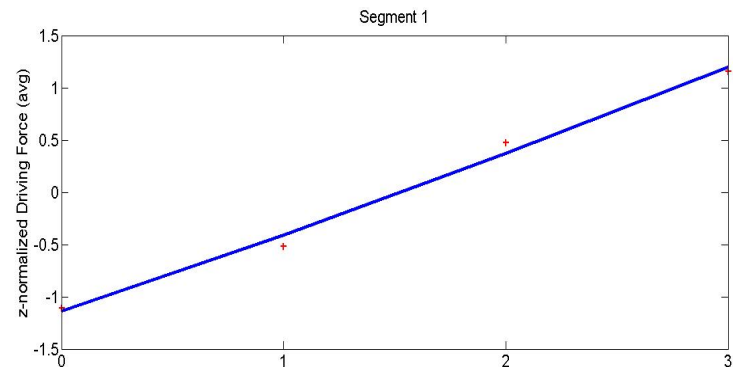
where

N_w = number of windows used to segment the distance time series

$M_{k,i}$ = slice of time series i in window k

3 measures

- **(1) Positive Driving Force** (of each musician): number of segment repetitions where a musician exerted a positive Driving Force
- **(2) Leadership Distribution** (in each segment): the average Driving Forces of the four musicians are sorted in ascending order and the four values fitted with a 2nd order polynomial



3 measures

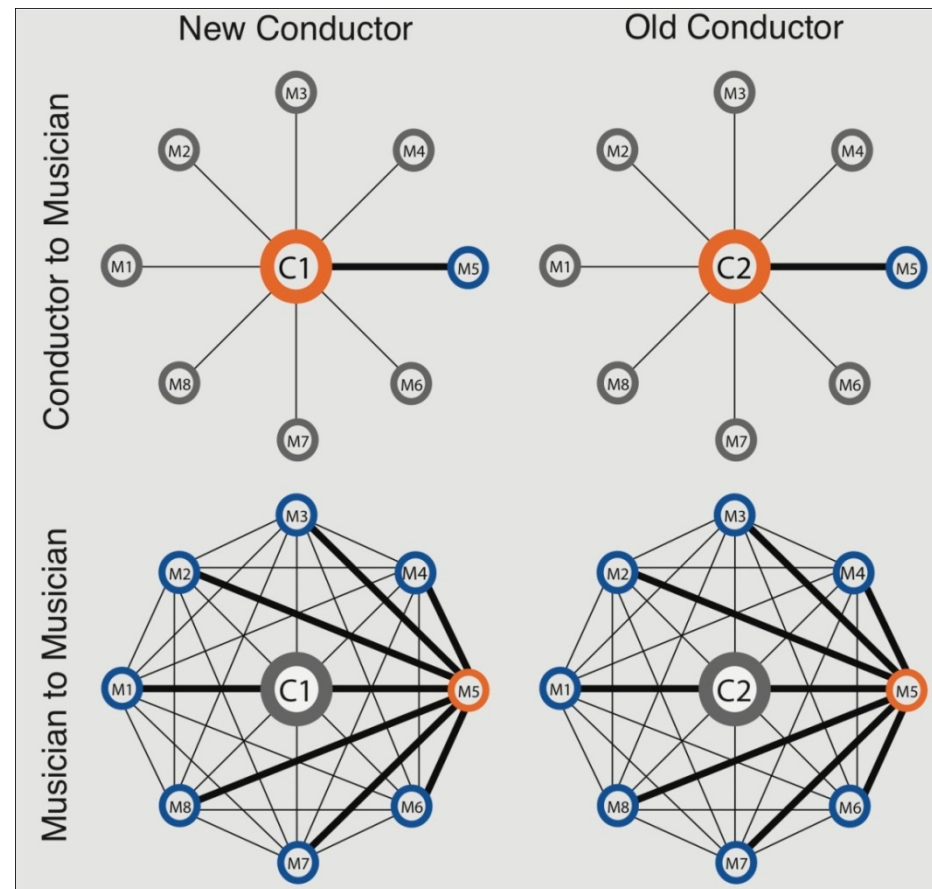
(3) Inter-musician communication (per each segment):
overall effective transfer of information within musicians.
It is based on Conditional Granger causality

$$\text{Inter-musician communication} = \sum_{i,j \neq i} S(F_{i \rightarrow j} | Q - \{i,j\})$$

Q = set of all 4 time series

Previous work: Analysis of causal relations in Orchestra

(on baton and bow accelerations)



D'Ausilio A., et al. (2012) Leadership in Orchestra Emerges from the Causal Relationships of Movement Kinematics. PLoS ONE 7(5)

Result : measure n°1

- Evaluating the **Total positive driving forces** within the quartet:

10

7

6

7



Results : measure n°1

- Evaluating the **Total positive driving forces**
 - **Highest** value of 1st violin
 - **Restricted** range of values.

10

7

6

7



Results : measure n°2

- Evaluating the **leadership distribution (LD)** within the quartet – **3 typical patterns** based on second order polynomial fit of driving forces distribution

1 

small values of 1st and 2nd coefficients
> Leadership **equally** distributed

2 

large positive value of 1st coefficients
> Leadership **concentrated** on one musician

3 

large negative value of 1st coefficients
> Leadership **shared** by more than one musician

Results : measure n°2

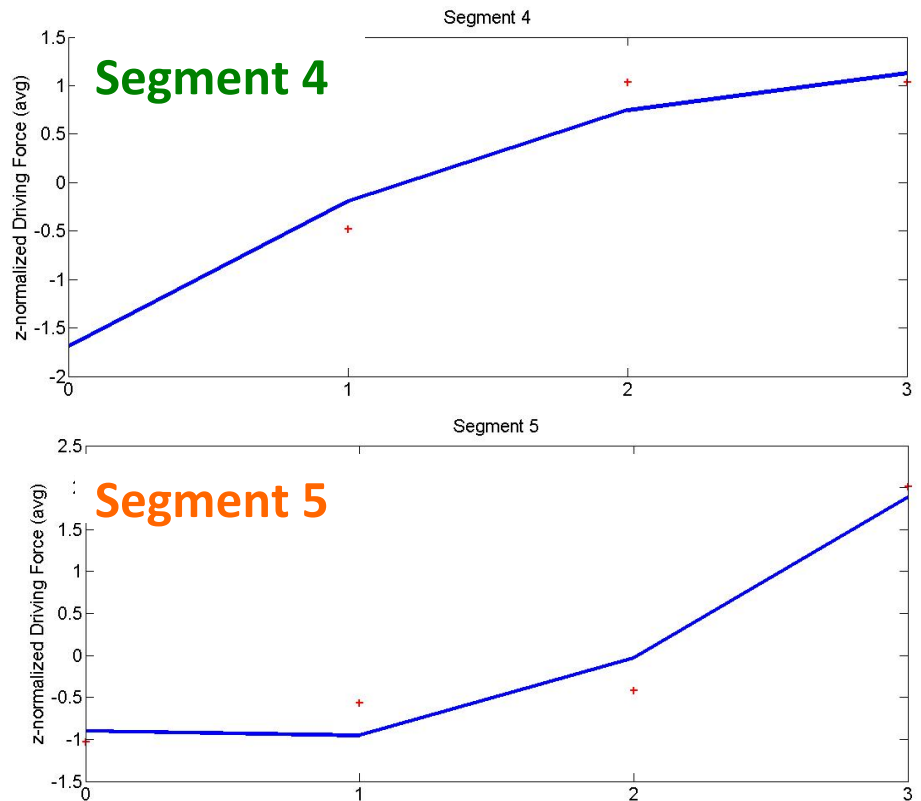
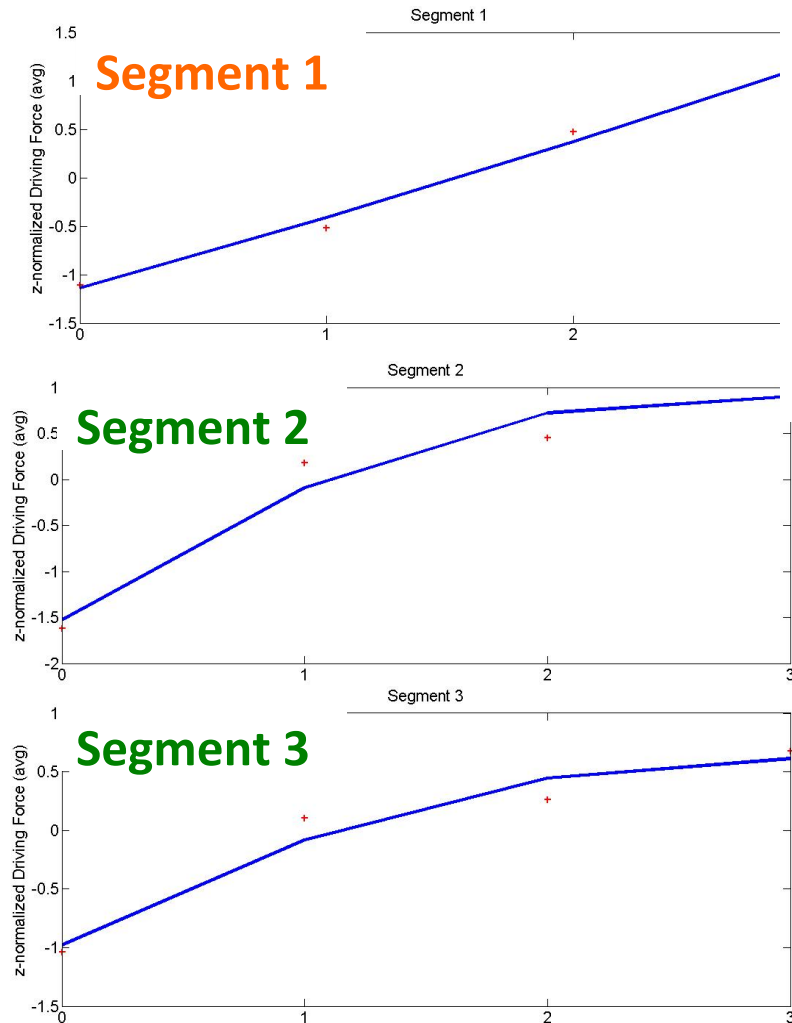
- Evaluating the **leadership distribution (LD)** within the quartet

	Leadership distribution	
	1-st coeff.	2nd coeff.
Segment 1	0.02	0.7
Segment 2	-0.31	1.75
Segment 3	-0.18	1.07
Segment 4	-0.29	1.78
Segment 5	0.49	-0.55

Results : measure n°2

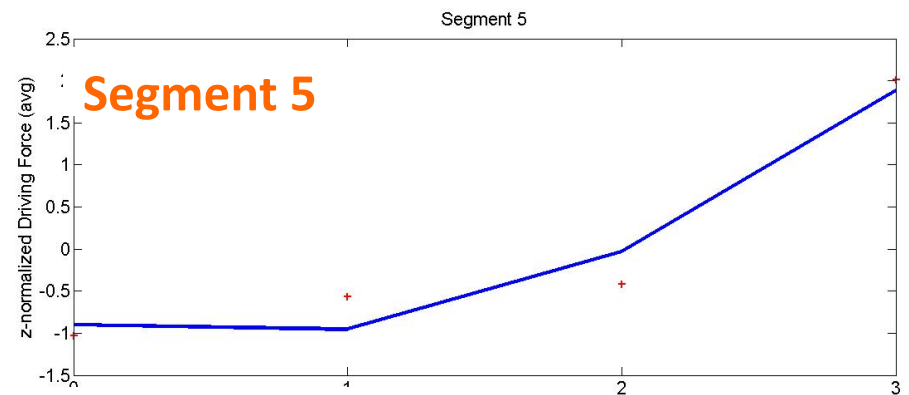
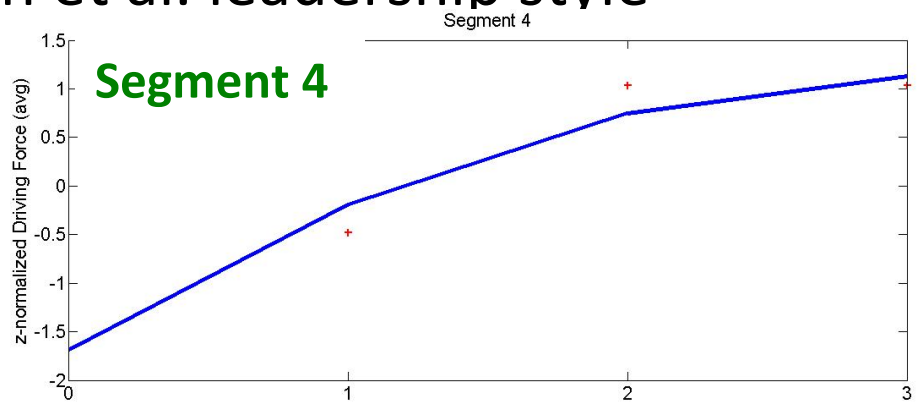
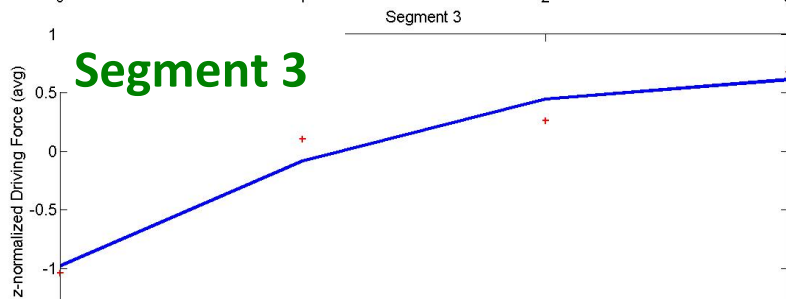
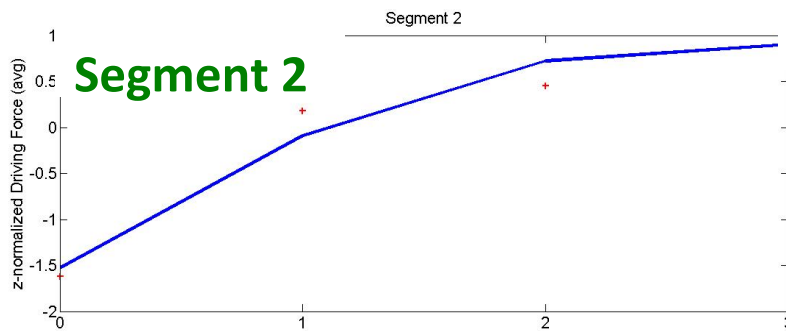
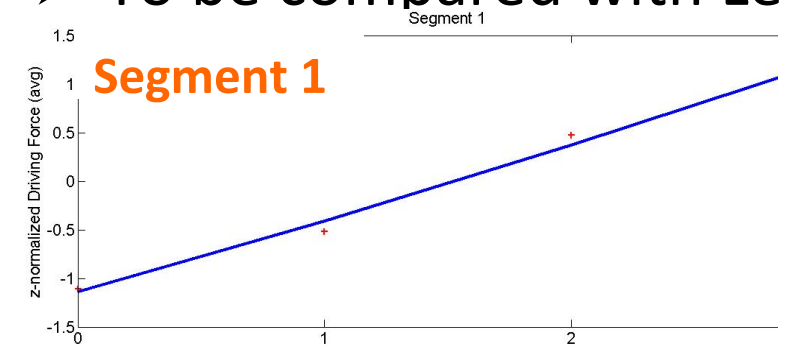
- Evaluating the leadership distribution (LD)

> two patterns emerged: **Unipolar** and **Bipolar**



Results : measure n°2

- LD may relate to behavioral strategies of musician for creative joint activity
- No strict relationship with music score
- To be compared with Lewin et al. leadership style



Unipolar

Bipolar

Results: measure n°3

- computing the **degree of inter-musician communication (MC)**

	Leadership distribution		Inter-musician communication
	1-st coeff.	2nd coeff.	
Segment 1	0.02	0.7	0.52
Segment 2	-0.31	1.75	0.13
Segment 3	-0.18	1.07	0.26
Segment 4	-0.29	1.78	0.37
Segment 5	0.49	-0.55	0.28

Results: measure n°3

- computing the **degree of inter-musician communication (MC)**
- > Does a specific leadership pattern facilitate the communication process between musician?

Unipolar

	Leadership distribution		Inter-musician communication
	1-st coeff.	2nd coeff.	
Segment 1	0.02	0.7	0.52
Segment 2	-0.31	1.75	0.13
Segment 3	-0.18	1.07	0.26
Segment 4	-0.29	1.78	0.37
Segment 5	0.49	-0.55	0.28

Results: measure n°3

- computing the **degree of inter-musician communication (MC)**
- > Does a specific leadership pattern facilitate the communication process between musician?

		Leadership distribution		Inter-musician communication
		1-st coeff.	2nd coeff.	
	Segment 1	0.02	0.7	0.52
Bipolar	Segment 2	-0.31	1.75	0.13
	Segment 3	-0.18	1.07	0.26
Bipolar	Segment 4	-0.29	1.78	0.37
	Segment 5	0.49	-0.55	0.28

Results: measure n°3

- computing the **degree of inter-musician communication (MC)**
 - > gives an additional information about the effective success of leadership strategy

Discussion:

3 measures on leadership

- **Total of positive driving force**
 - Gives an overview of each musician role among the ensemble revealing the relative prominence of the first violin
- **leadership distribution (LD)**
 - Identify leadership pattern, i.e. the behavioral strategies exerted by musicians to interpret the music as an ensemble
 - characterized two leadership patterns: Unipolar Vs Bipolar.
- **Inter-musician communication (MC)**
 - assessed the impact of leadership patterns on the communication within the ensemble

Conclusion

- SQ as a test-case to understand how leadership can emerge in a group where all participants stands theoretically as equal
- Leader identified by capacity to influence others' behavior
- Definition of 3 indexes based on Granger causality method

Future work

- (i) computing a set of non-verbal expressive cues to characterize individual performance characteristics (e.g., entropy) and hence giving an insight on why some musician succeed in causing other's behaviour
- (ii) applying our approach on other modalities such as audio (e.g., loudness variations from one musician to the other)
- (iii) Correlate results with perceptual assessment of group interactions