Nonlinear analysis to quantify human movement variability from time-series data

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@neuromatch #nmc3

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Contents

Why Movement Variability?

Few challenges when quantifying movement variability

Theoretical challenges

- Modelling human movement (tasks, environments, agent, perception, action)
- Modelling human variability (complexity vs predictability)
- ?

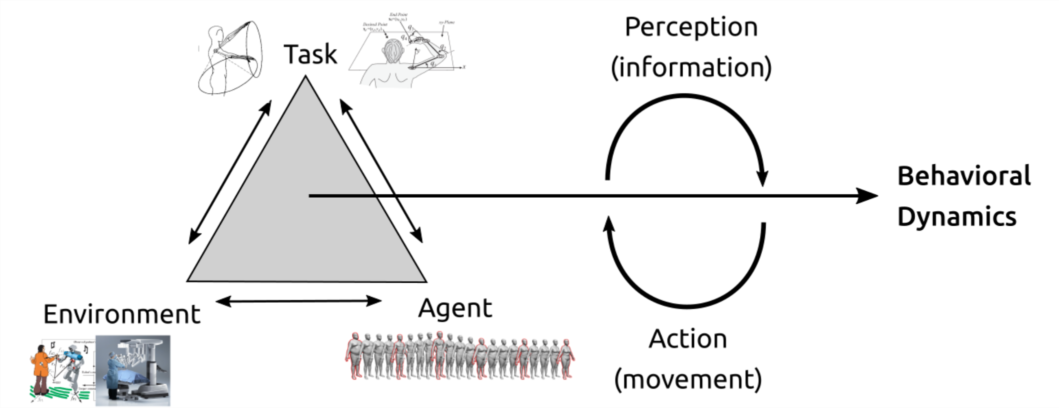
Choosing the right tools

- Time-based domain,
- Frequency-based domain
- Nonlinear dynamics
- ?

Technical challenges

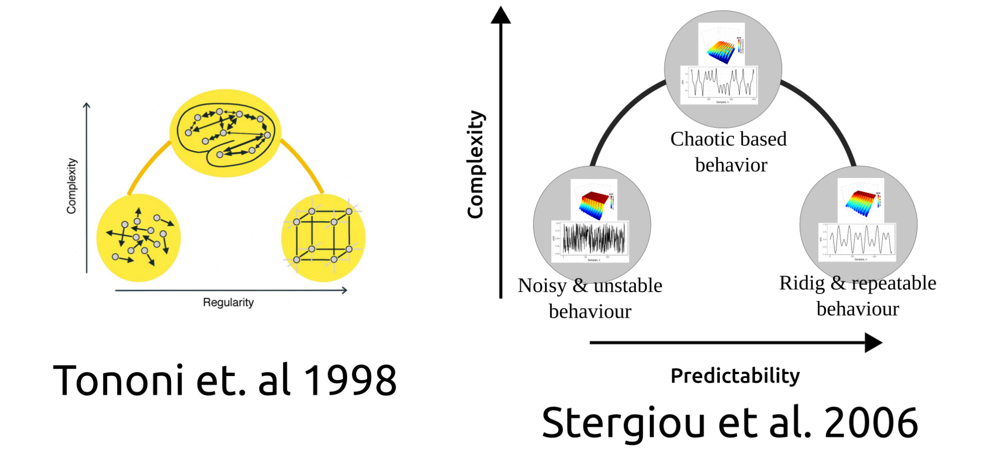
- non-stationarity,
- non-linearity,
- data length,
- sensor source,
- noise,
- ?

Modeling Human Movement



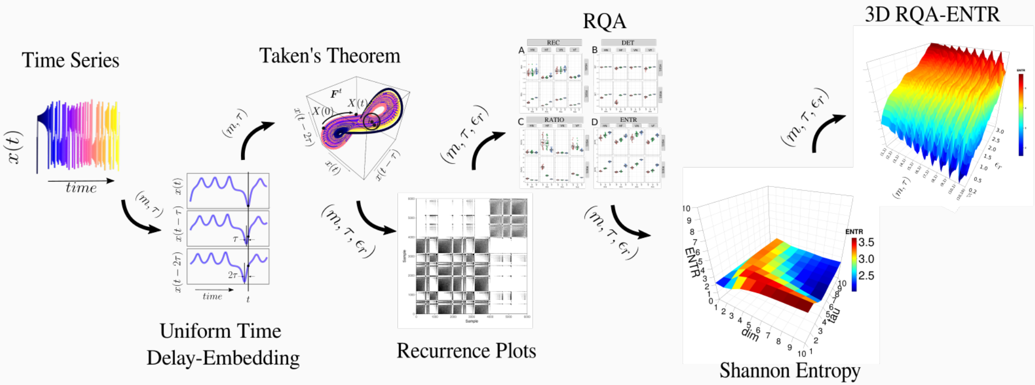
(Bernstein 1967 in **The co-ordination and regulation of movements**; Newell and Vaillancourt 2001 in **Hum Mov Sci**; Davids et al. 2003 in **Sport Medicine**; Warren 2006 in **Psychological Review**)

Modelling Movement Variability



(Stergiou et al. 2006 in **Neurologic Physical Therapy**; Stergiou and Decker 2011 in **Human Movement Science**; Tononi et al. 1998 in **Trends in Cognitive Sciences**)

Nonlinear Methods

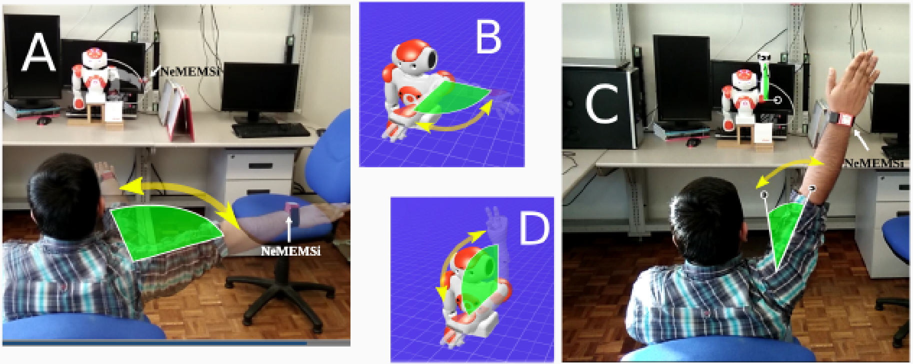


Time Series
$x(t)$
time
(m, τ)
Uniform Time Delay-Embedding
Taken's Theorem
(m, τ, ϵ_r)
Recurrence Plots
RQA
REC
DET
RATIO
ENTR
Shannon Entropy
3D RQA-ENTR

Experiment

Human-Humanoid Imitation Activities

20 participants with mean and standard deviation (SD) age of mean=19.8 (SD=1.39) years, being four females and sixteen males.

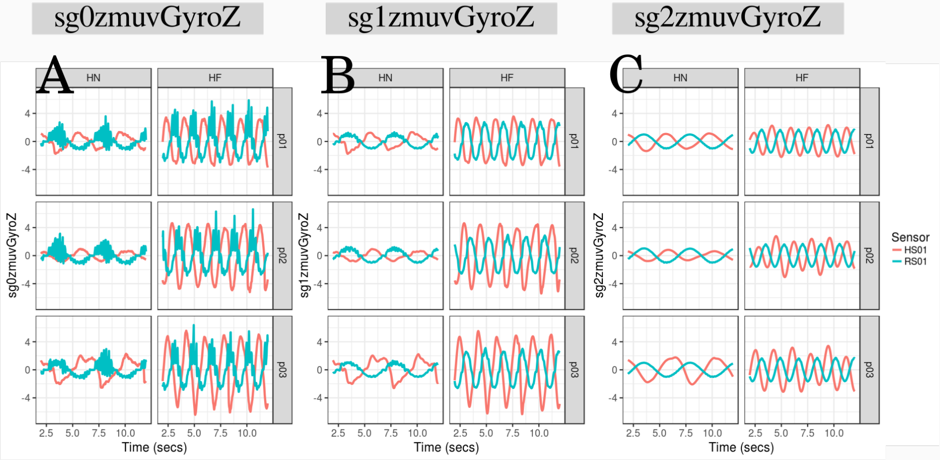


(A/C) Front-to-Front Human-Humanoid Imitation Activities of Horizontal/Vertical Movements, (B/D) NAO, humanoid robot, performing Horizontal/Vertical arm movements.

(Xochicale 2019 in **PhD thesis**)

Results

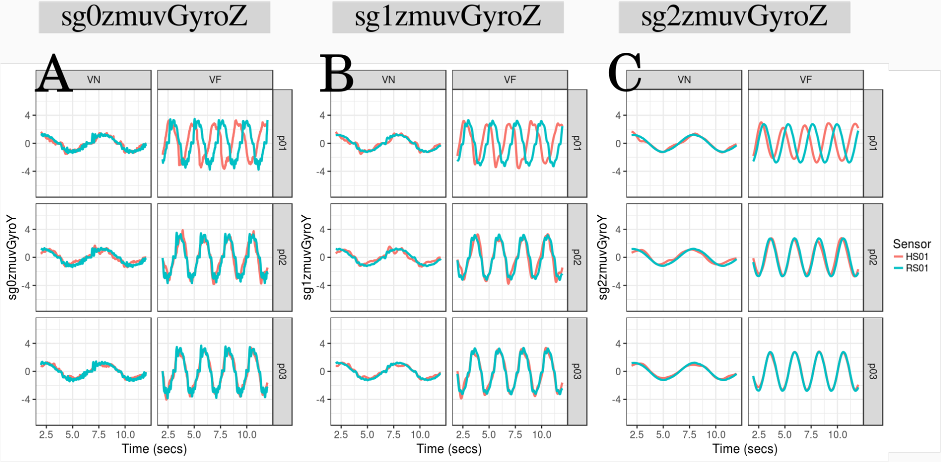
From Raw to Smoothed Time Series



Time-series of horizontal movements for (A) normalised, (B) ***`sgolay(p=5,n=25)`****, and (C)* ***`sgolay(p=5,n=159)`****.*

(Xochicale 2019 in **PhD Thesis**)

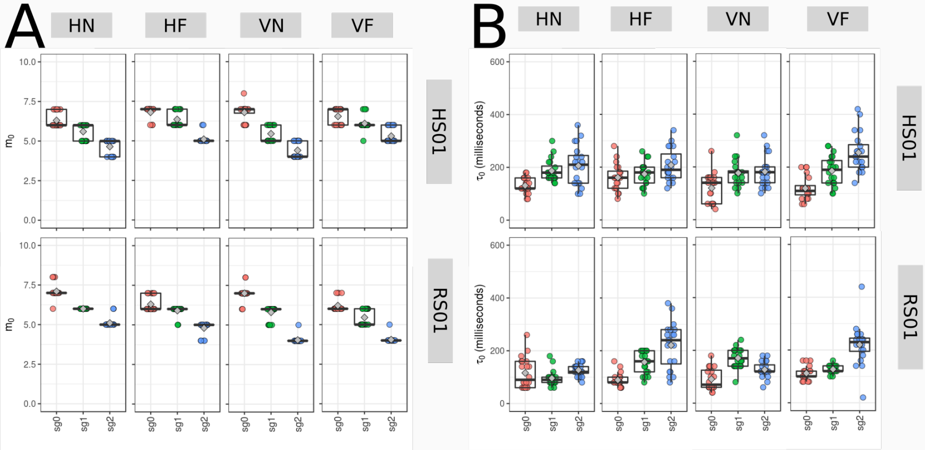
From Raw to Smoothed Time Series



Time-series of vertical movements for (A) normalised, (B) ***`sgolay(p=5,n=25)`****, and (C)* ***`sgolay(p=5,n=159)`****.*

(Xochicale 2019 in PhD Thesis)

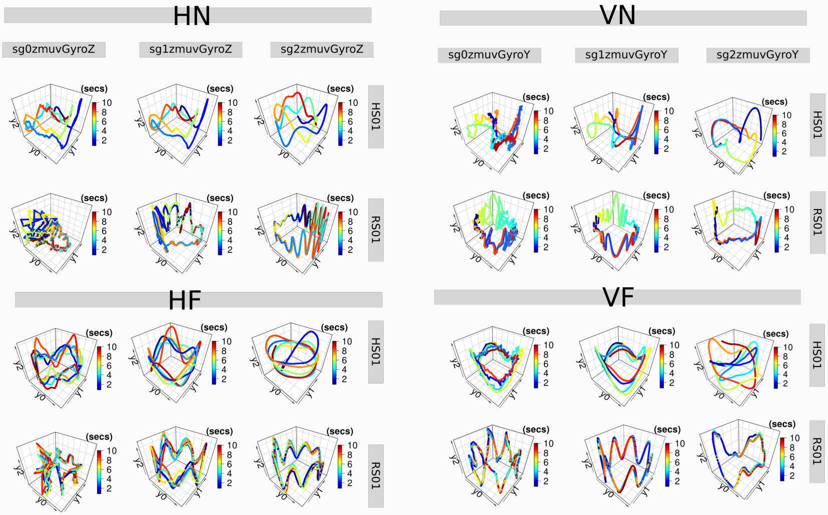
Minimum Embedding Parameters



(A) Minimum Embedding Dimension (B) First Minimum AMI

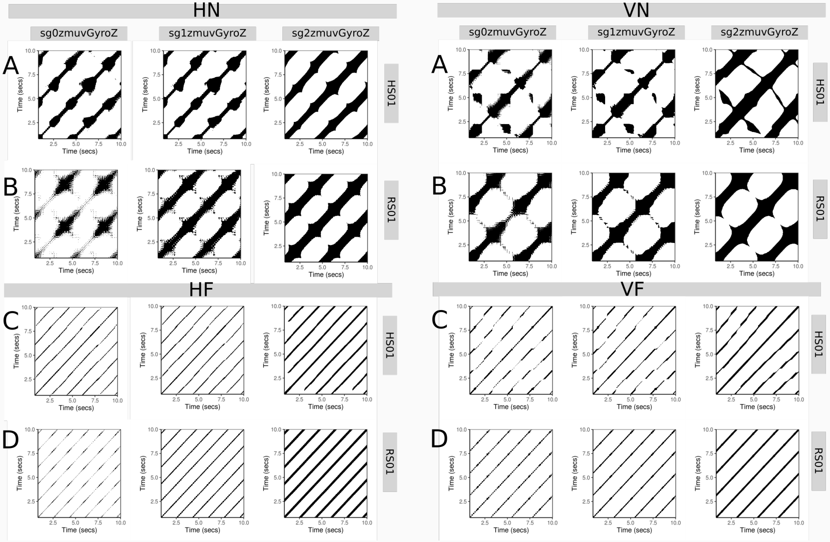
(Xochicale 2019 in **PhD Thesis**)

Reconstructed State Spaces



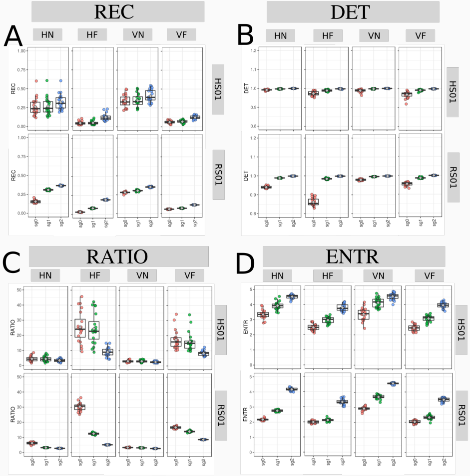
RSS for participant 01 computed with ($m = 6$, $\tau = 8$) for different activities, signals and source of time-series data.

Recurrence Plots



RP for participant 01 computed with ($m = 6$, $\tau = 8$, $\epsilon = 1$) for different activities, signals and source of time-series data.

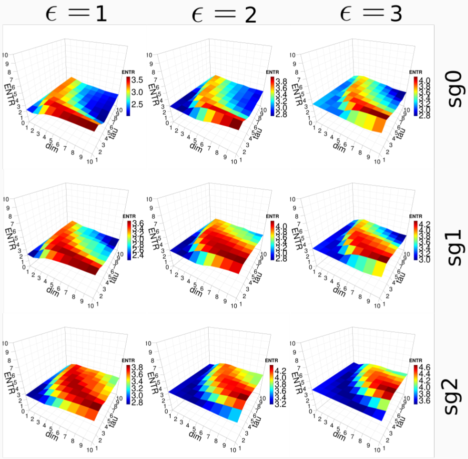
Recurrence Quantification Analysis



Box values of RQA computed with ($m = 7$, $\tau = 5$, $\epsilon = 1$). These values are for 20 participants.

(Xochicale 2019 in **PhD Thesis**)

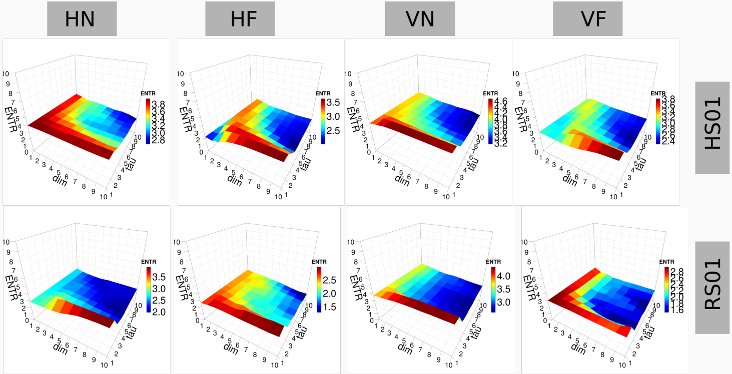
RQA ENTR for ϵ thresholds & smoothness



RQA ENTR values are for $p03$, sensor $HS01$, of a window size of 10-secs (500 samples).

(Xochicale 2019 in **PhD Thesis**)

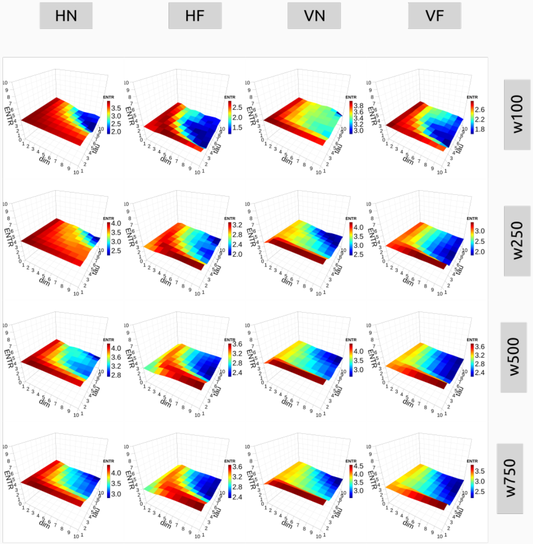
RQA ENTR for sensors and activities



RQA ENTR values are for $p03$, $sg0$ and window size of 10-secs (500 samples).

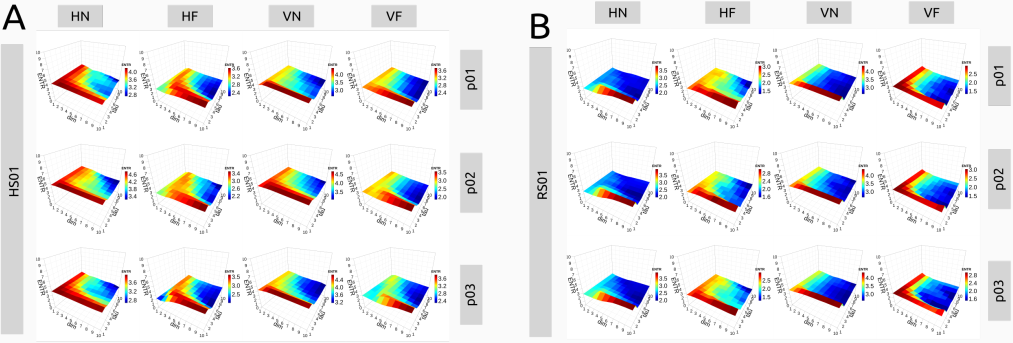
(Xochicale 2019 in **PhD Thesis**)

Window size lengths



(Xochicale 2019 in **PhD Thesis**)

Participants



Participants differences of 3D surface plots of RQA.

Conclusions

Conclusions and future work

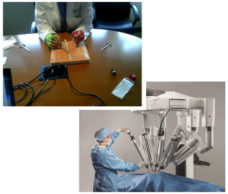
Take away messages

- Nonlinear analysis tools can quantify different data time-series.
- Shannon entropy with 3D plot surfaces of RQA appear to be robust for real-word data (i.e. different time series structures, window length size and levels of smoothness).
- Therefore, Shannon entropy would be a potential good tool to quantify complexity of movement.

Investigate

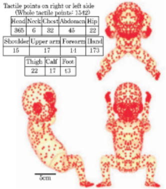
- other methodologies for state space reconstruction,
- the robustness of Entropy measurements with RQA, and
- variability in perception of velocity.

Quantification of skill learning



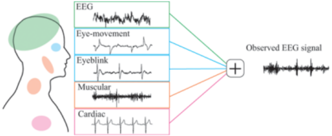
* Surgical Skills Assessment
* Robot-Assisted Surgery

Fetal behavioral development



* General movements
* Arm/Legs Movs
* Hand/Face Contacts

Nonlinear Biomedical Signal Processing



* EEG time series
* Heart rate variability
* Eye Movements

(Zia et al., 2017 in Computer Assisted Radiology and Surgery; Mori 2012 in Development and Learning and Epigenetic Robotics; Mitsukura et al., 2017 in Electroencephalography; Marwan et al. 2019 in http://recurrence-plot.tk/)

References

Xochicale Miguel
Nonlinear methods to quantify Movement Variability in Human-Humanoid Interaction Activities
Submission in progress to Scientific Reports
https://arxiv.org/abs/1810.09249

Thanks!!! Questions?

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`https://github.com/mxochicale/nmc3`

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