Single and multiscale entropy - Regularity and complexity of human movement

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Content

- Relative input parameter consistency
- Discrete vs. continuous data
- m – vector length
- r – tolerance limit
- N – number of data points
- Recommended reading

Sample entropy – relative input parameter consistency

- Many (if not all) nonlinear mathematical tools have input parameters.
- Changing the input parameters affects the outcome of the calculation.
- Any observed biological phenomenon should remain the same when changing input parameters (within a range) to be considered valid.
  - Differences between tasks
  - Differences between groups
  - Differences before/after intervention

Always test and report the relative input parameter consistency of your data!

- For sample entropy: m, r and N

Sample entropy – input parameters

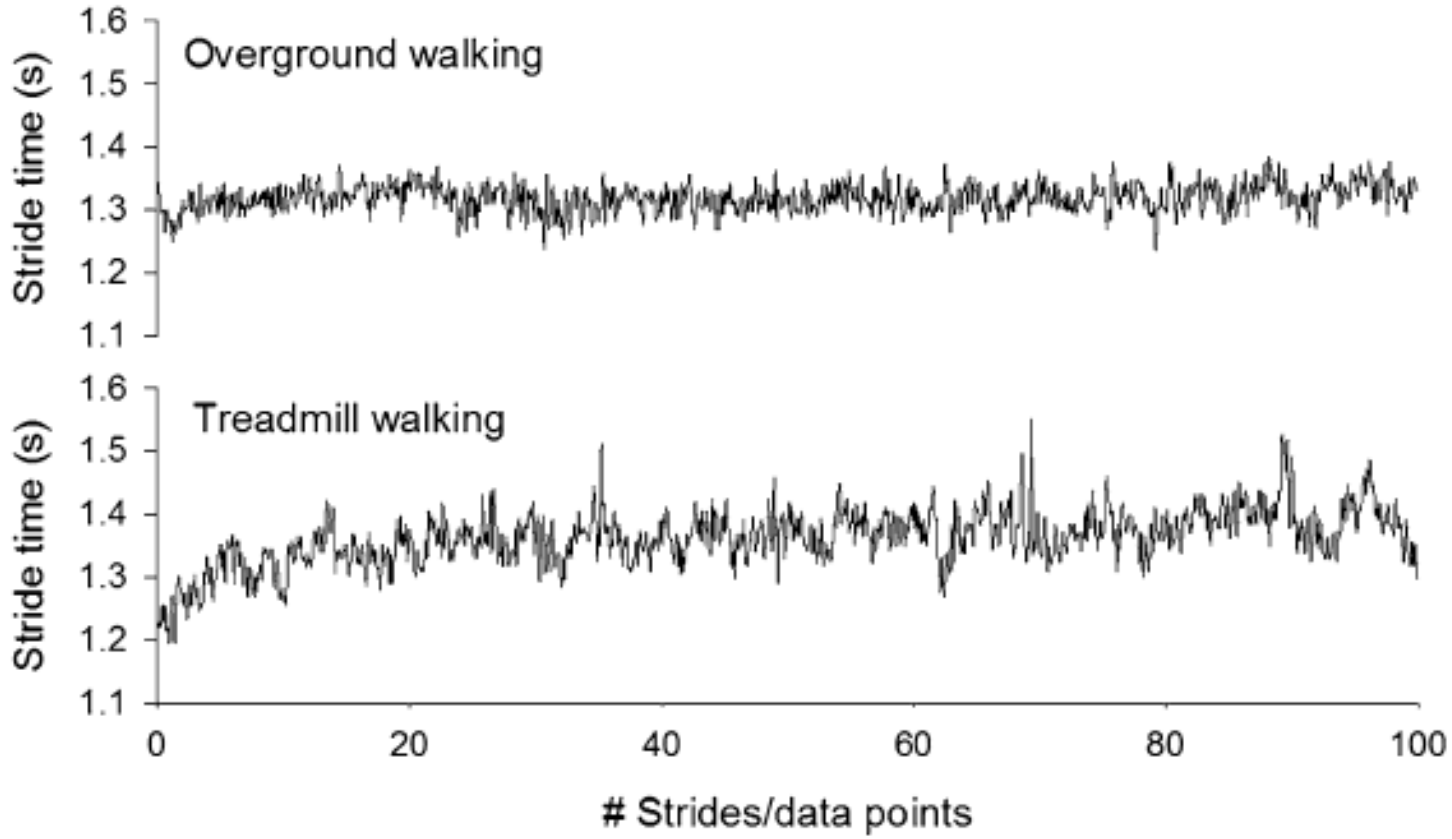
Three studies:

- Yentes et al. 2012 (discrete data)
  - Treadmill walking of young adults for 3 minutes.
  - Motion capture quantified step time, step width and step length.
  - Comparisons of ApEn and SaEn with different input parameters.
- Yentes et al. 2018 (discrete data)
  - Overground and treadmill walking in young adults for one hour.
  - Step time quantified using heel switches.
  - Comparisons of ApEn and SaEn with different input parameters.
- Raffalt et al. 2023 (continuous data)
  - Isometric submaximal force in young adults for 180 seconds.
  - Investigate relative input parameter consistency of r, m, and N.

Sample entropy – input parameters

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

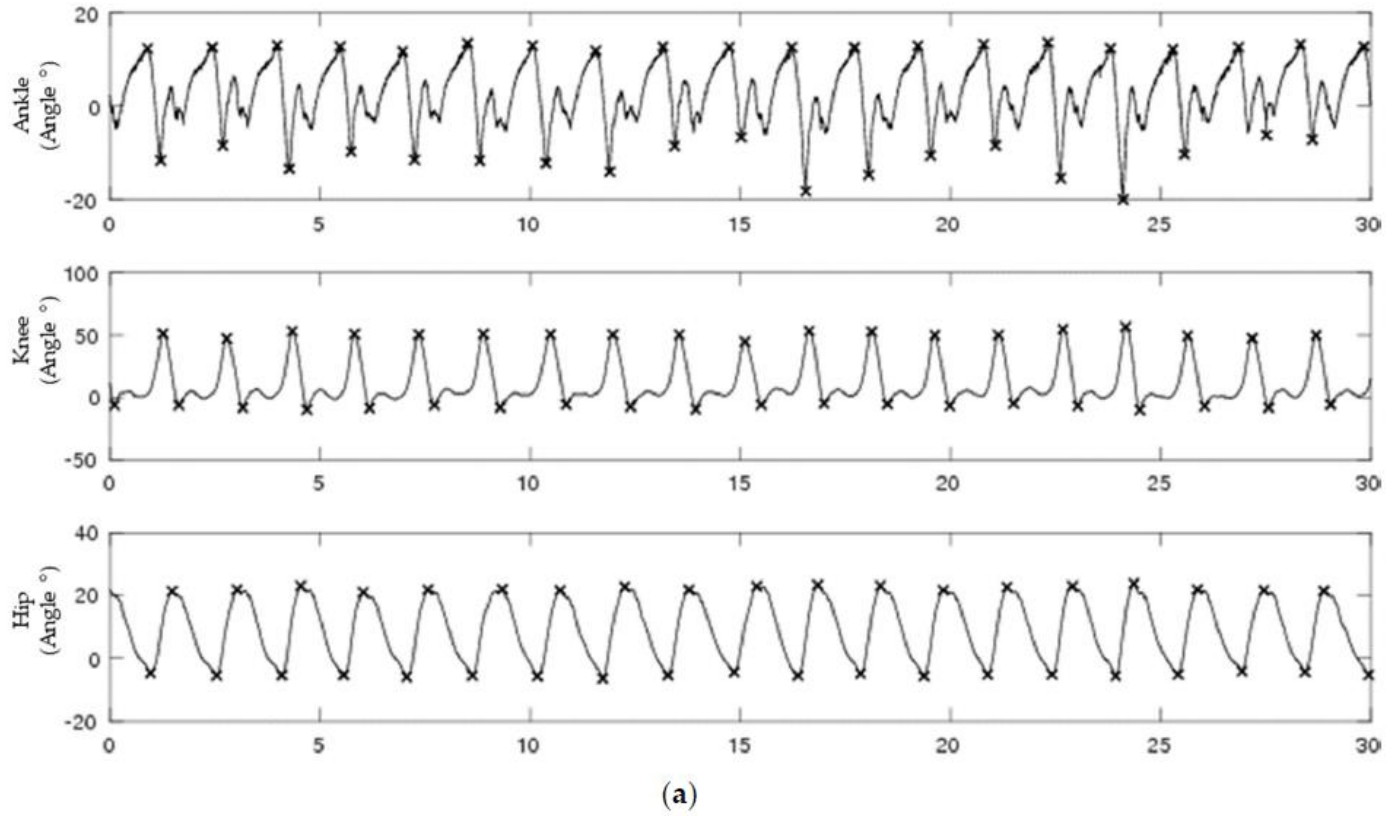
- **Discrete** vs continuous data – N is the number of observations of a particular event e.g., strides/steps



Sample entropy – input parameters

$$SaEn(m, r, N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- Discrete vs **continuous** data – N is the number of data points given by the observation time and the sampling frequency



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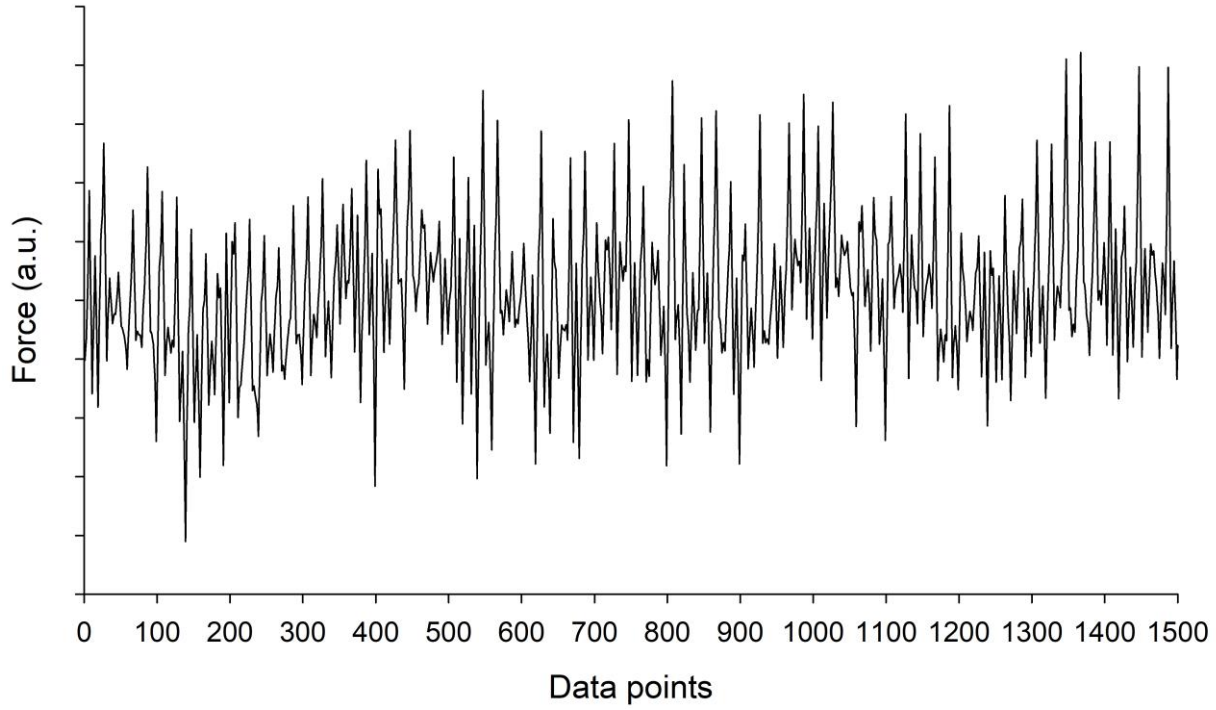
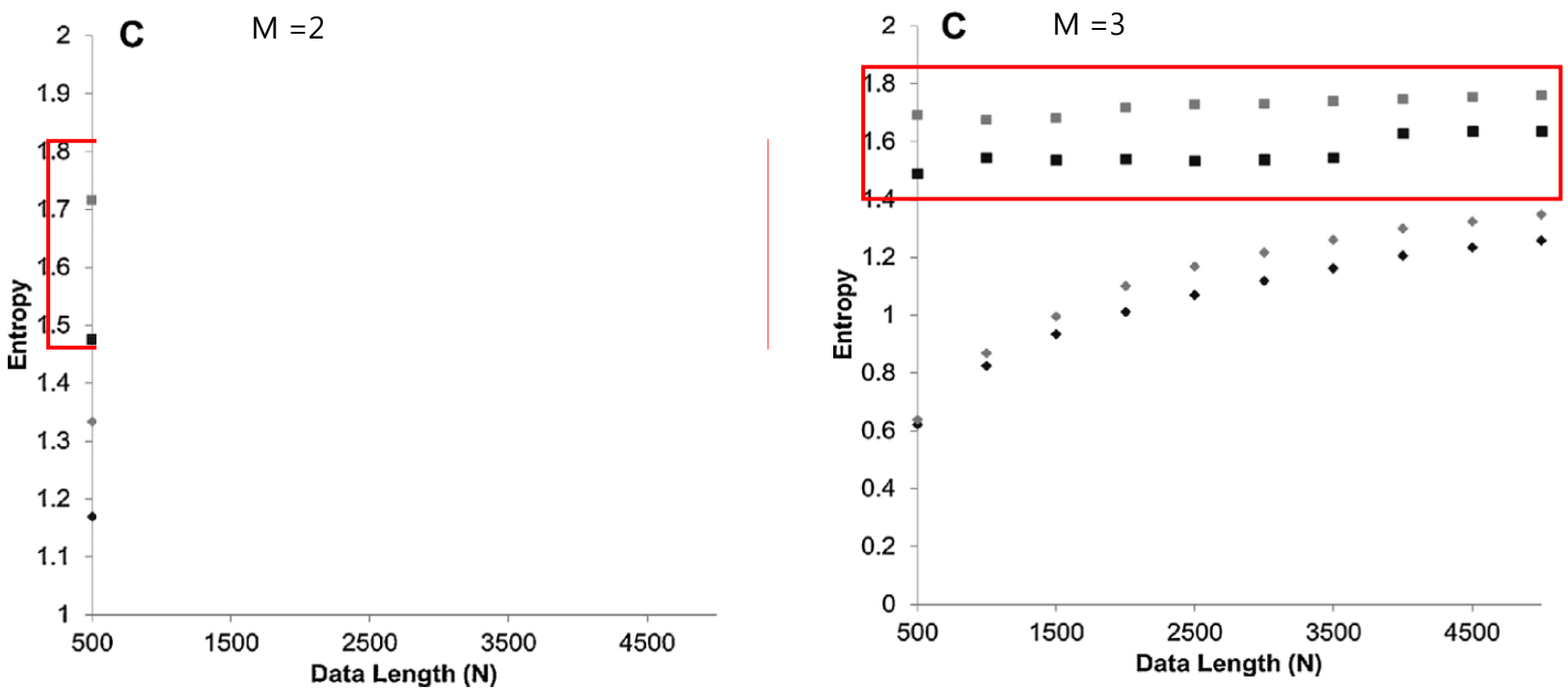


Sample entropy – input parameter m

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- m is the vector length
- ApEn vs SaEn across different N (from 500 to 5000) with r=0.25 and m=2 or 3.

Gray: overground walking
Black: treadmill walking
ApEn: diamond
SaEn: square

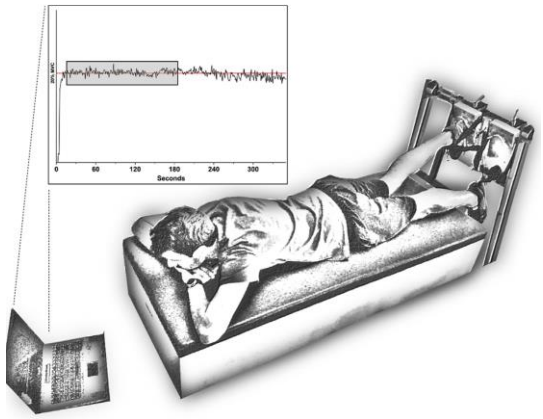


Yentes et al. 2018

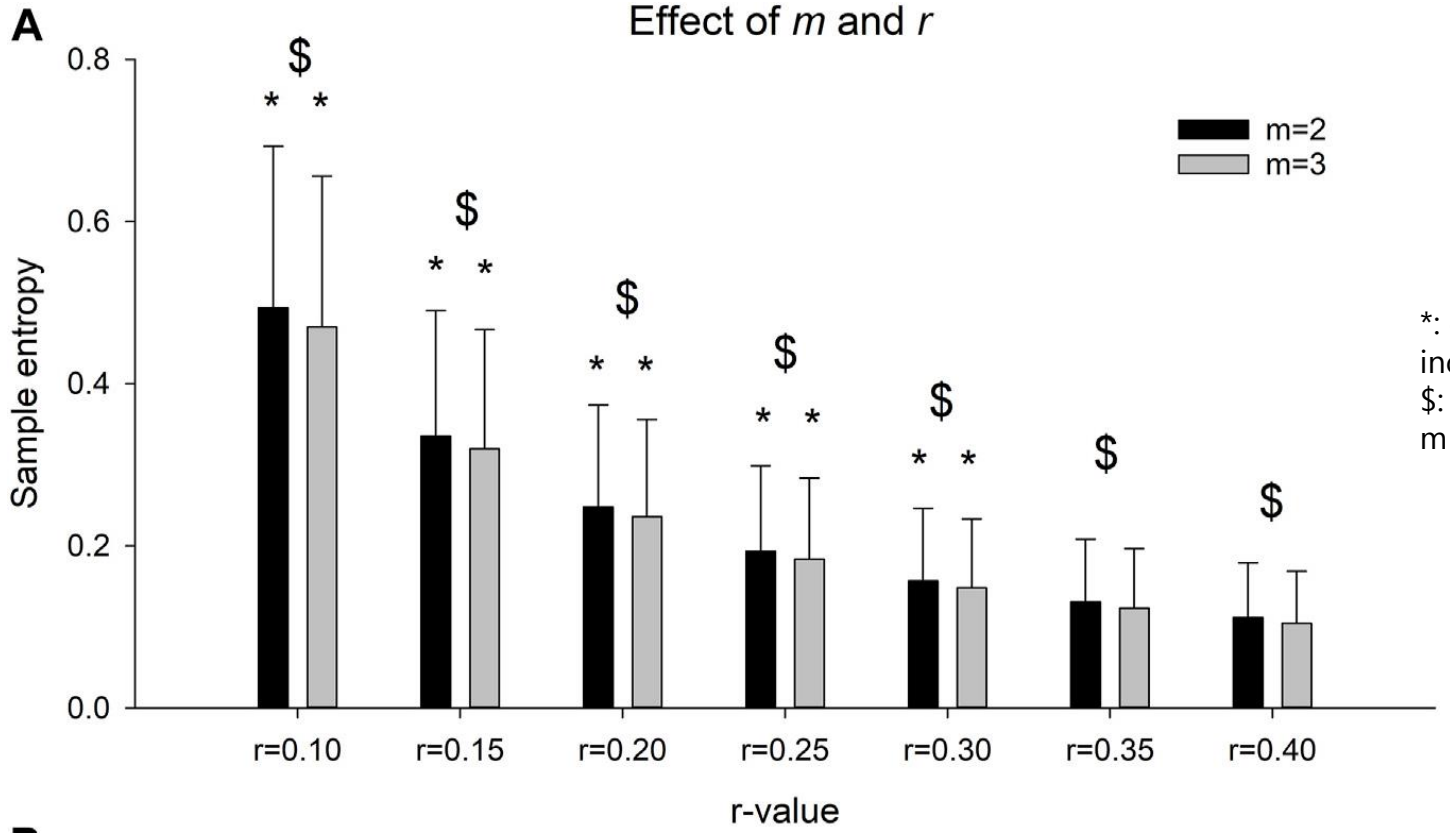
Sample entropy – input parameter m

$$SaEn(m, r, N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- m is the vector length
- SaEn across different r with m=2 and 3, sampling frequency=100Hz and observation time = 180s



Raffalt et al. 2023

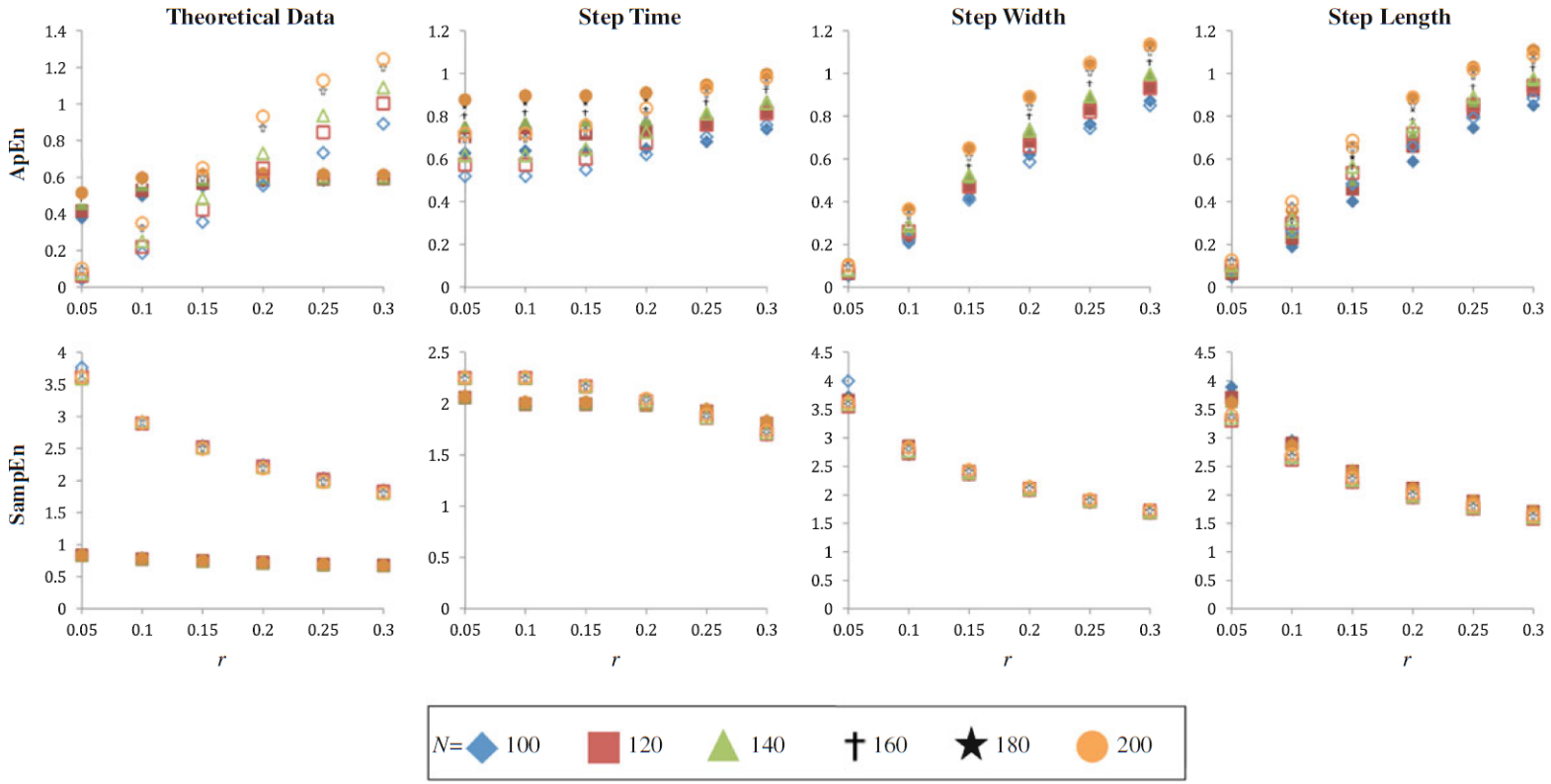


*: decrease in SaEn with increase in r.
$: difference in SaEn between m for a given r

Sample entropy – input parameter r

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- R is the tolerance limit (r x SD)
- ApEn vs SaEn across different N (from 100 to 200) and different r (from 0.05 to 0.3) and m=2.



Yentes et al. 2012

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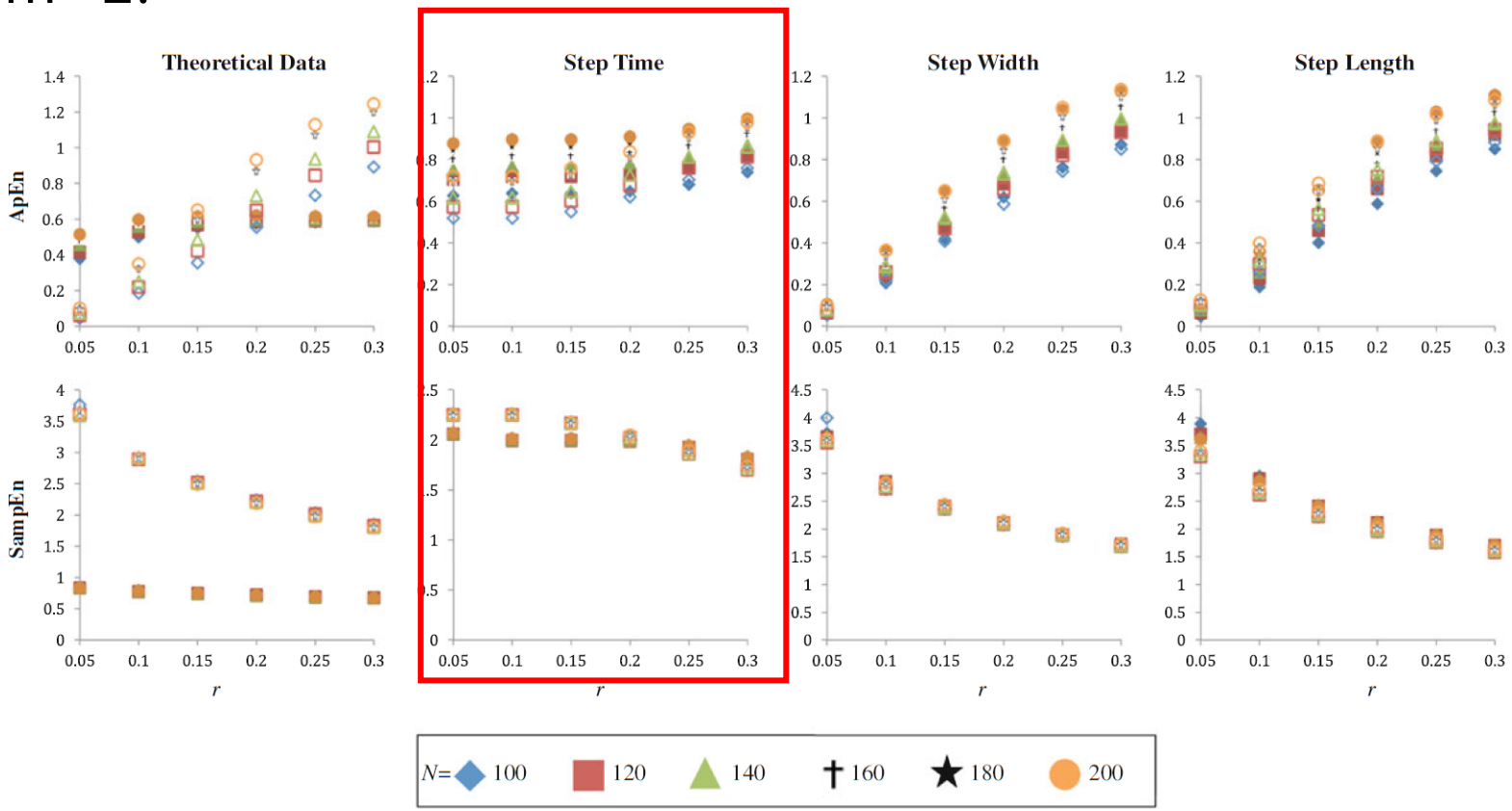

Yentes et al. 2012

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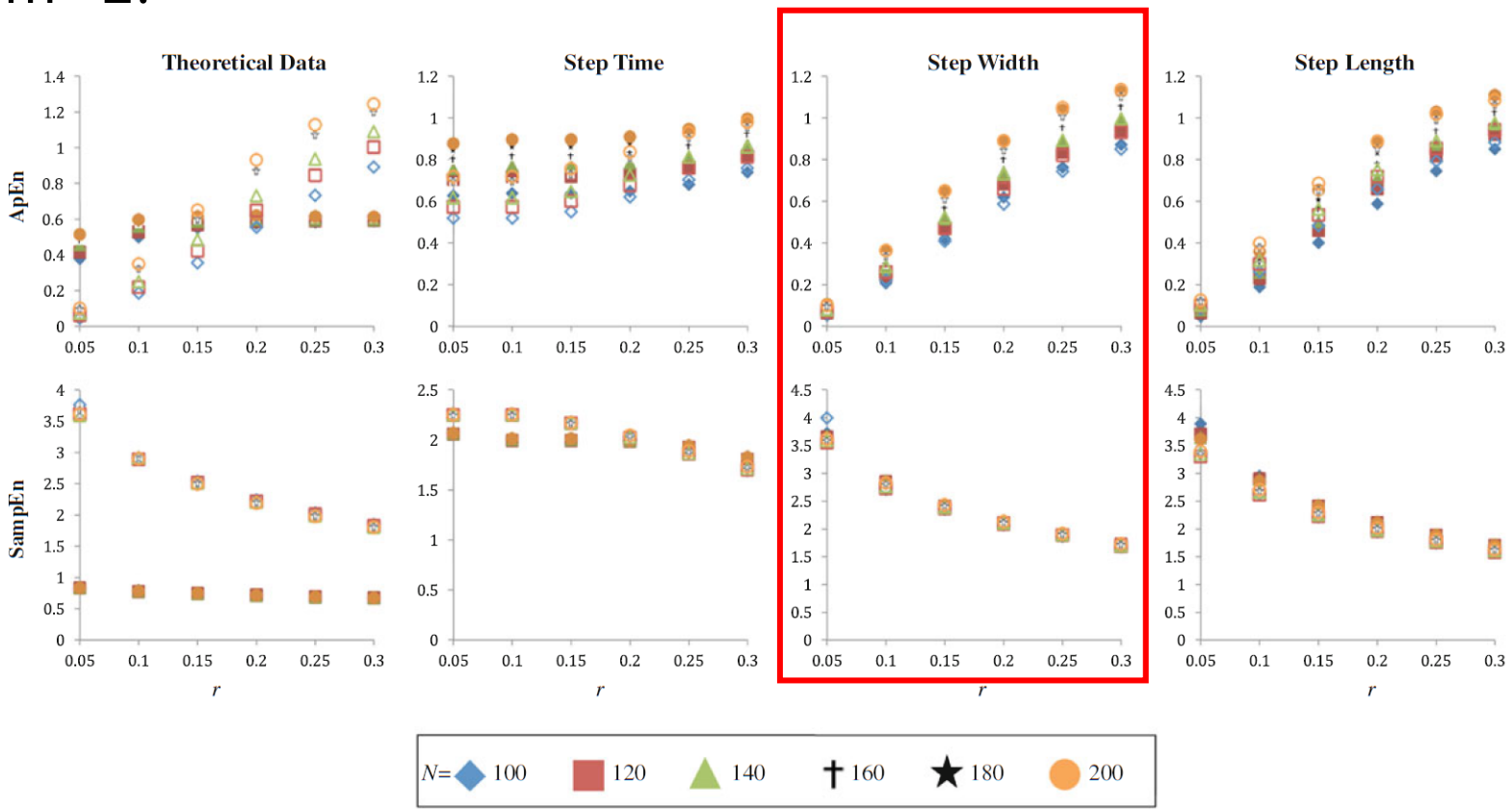

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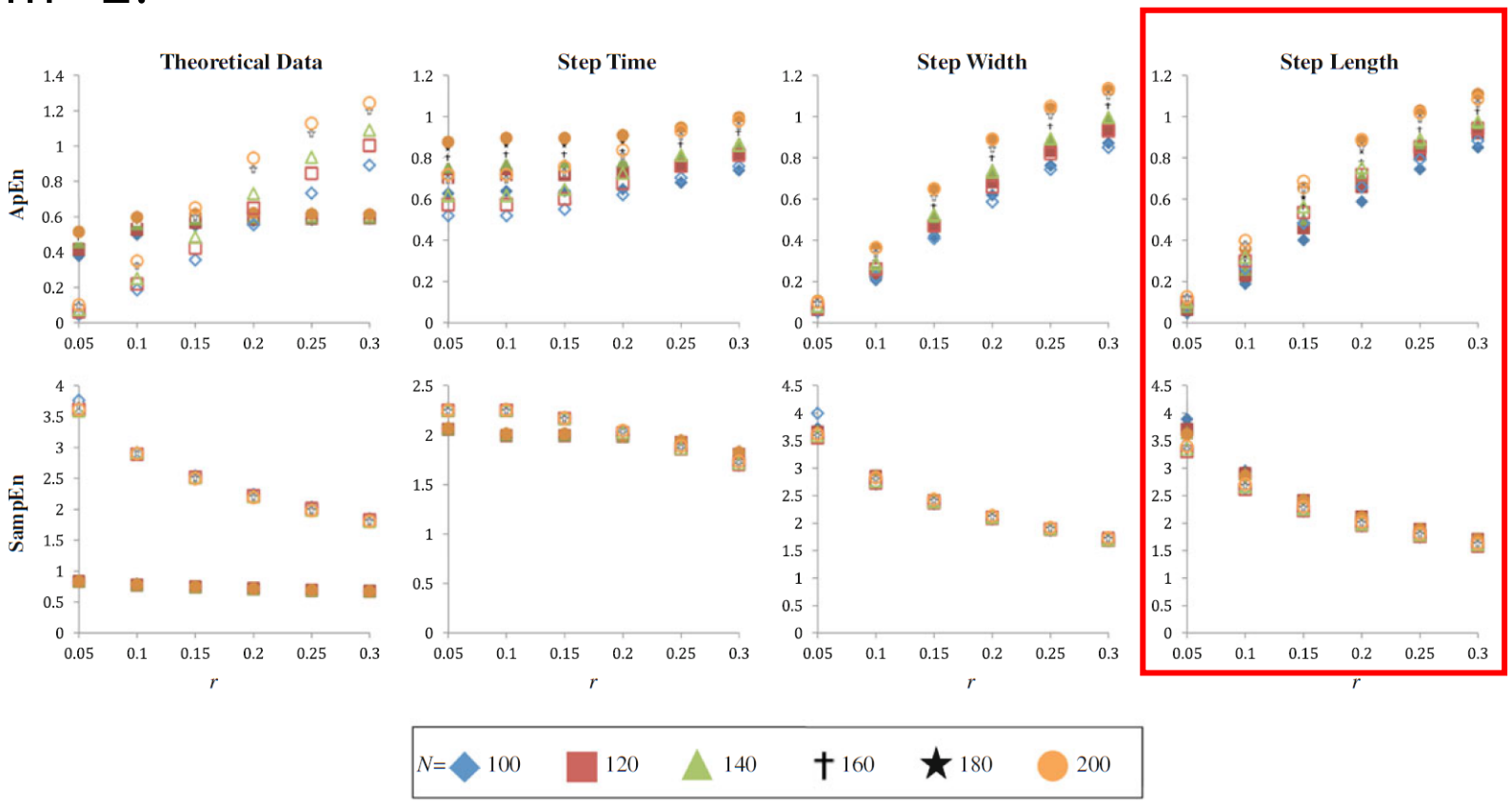
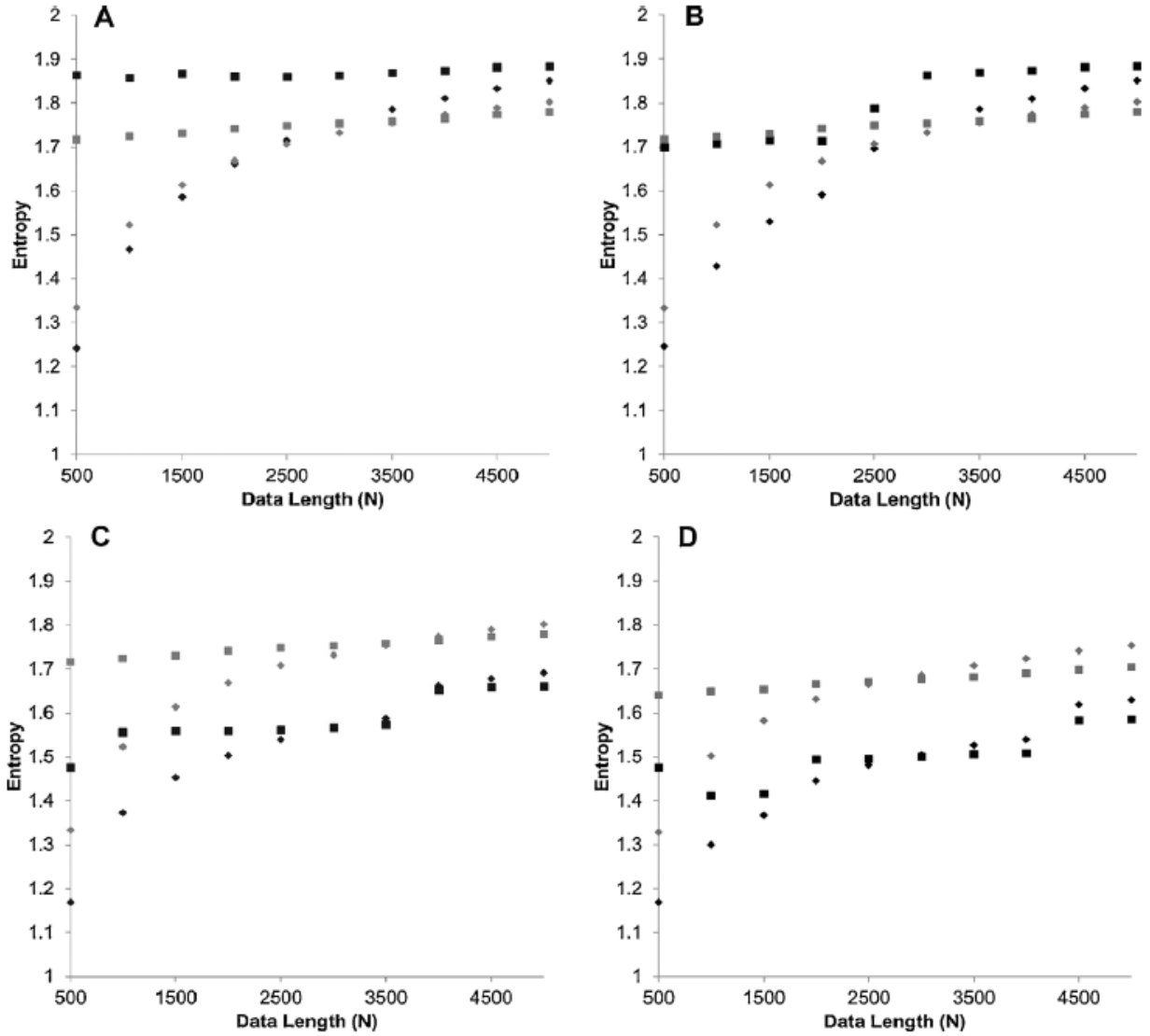


Yentes et al. 2012

Sample entropy – input parameter r

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- R is the tolerance limit (r x SD)
- ApEn vs SaEn across different N (from 500 to 5000)
- r=0.15 (A), r=0.2 (B), r=0.25 (C) and r=0.3 (D)
- m=2



Gray: overground walking
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Yentes et al. 2018

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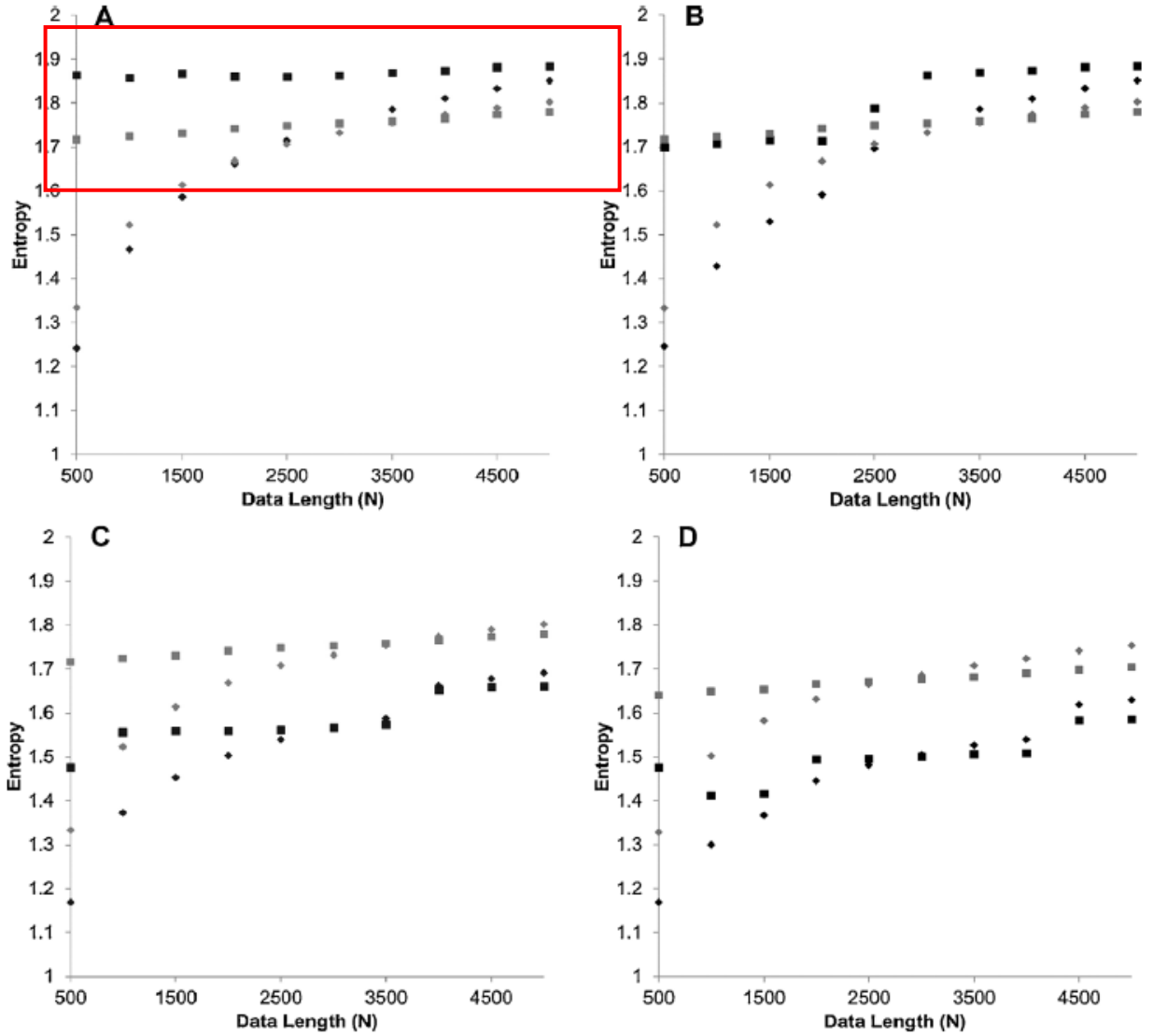

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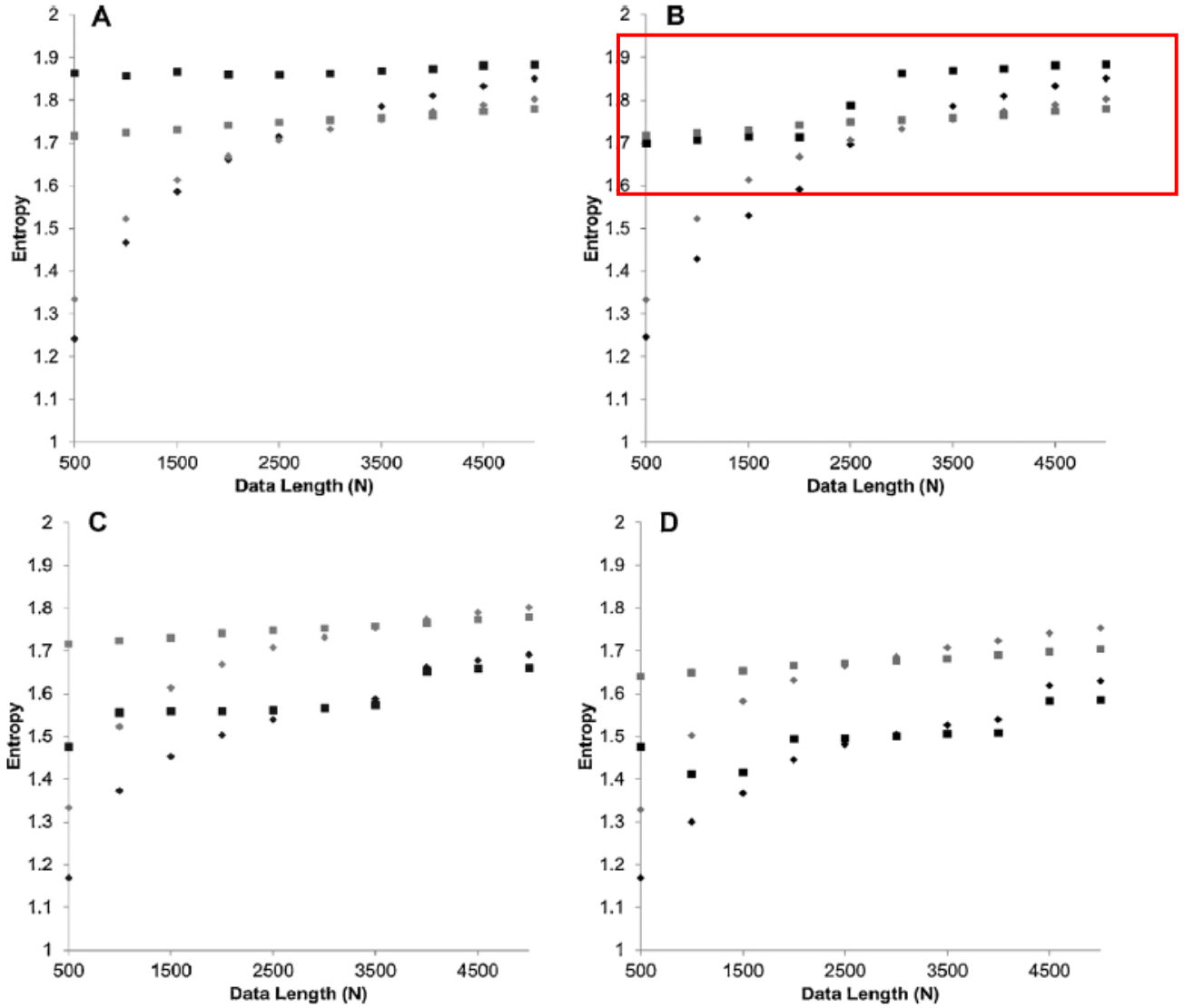

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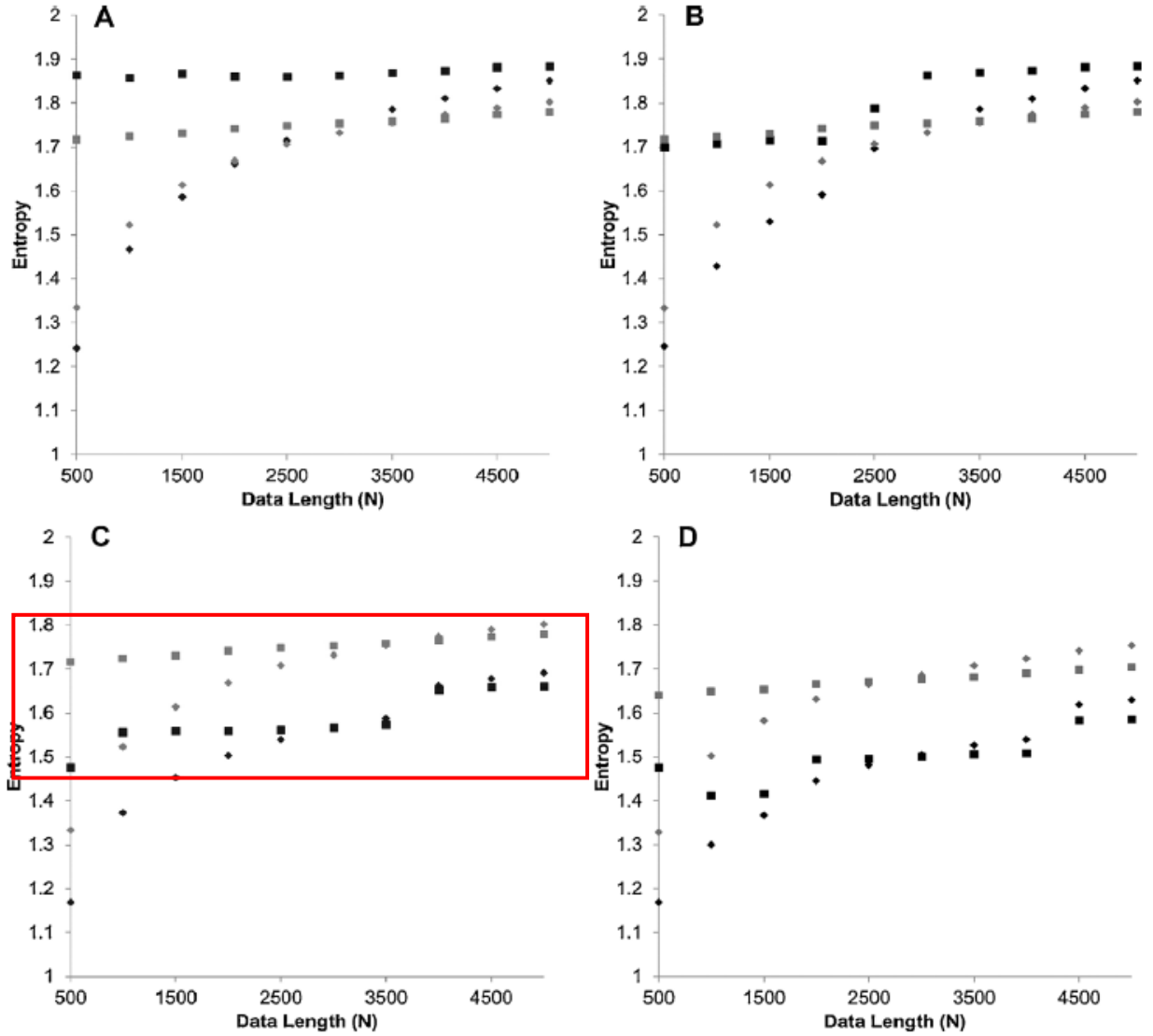

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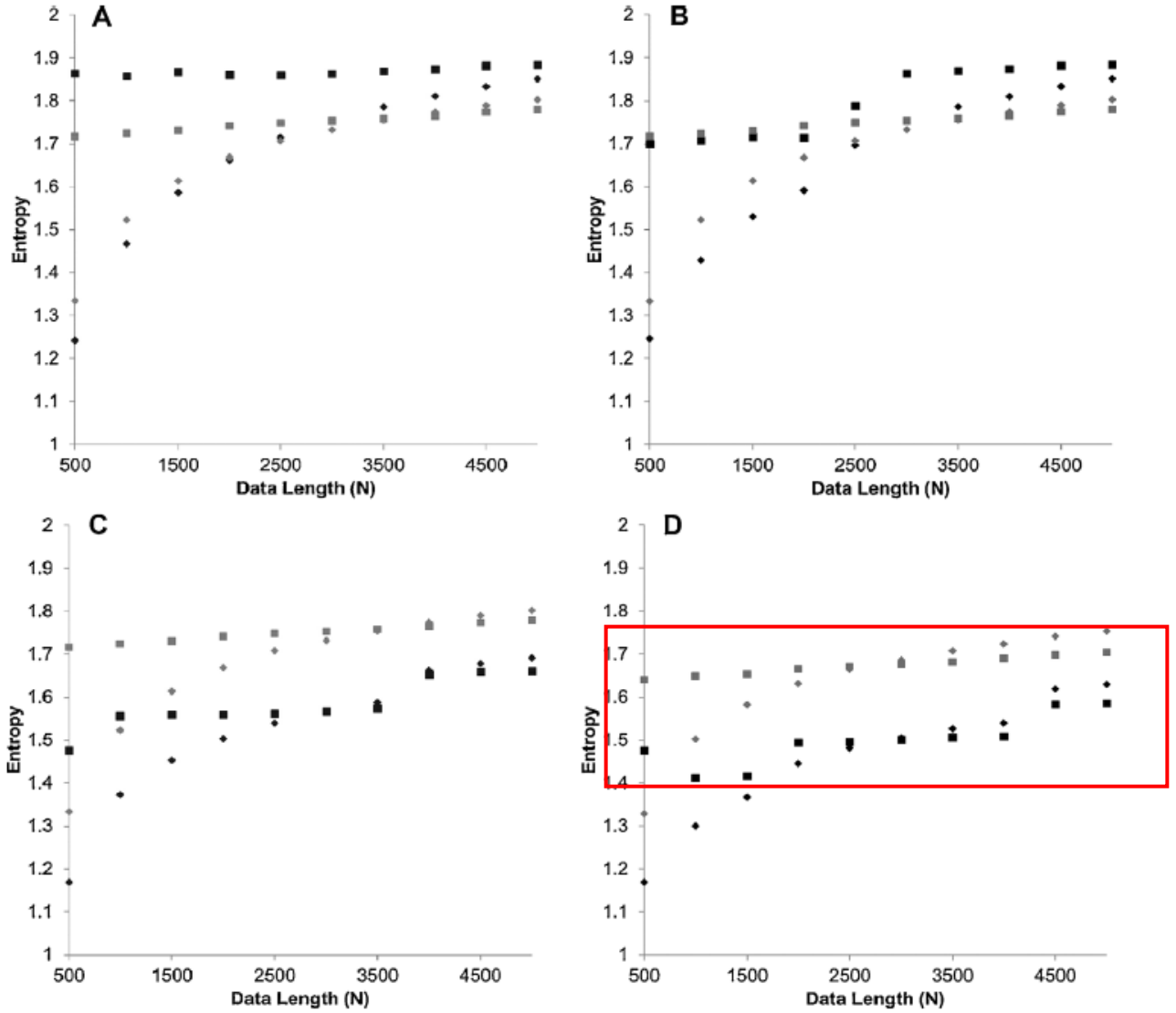

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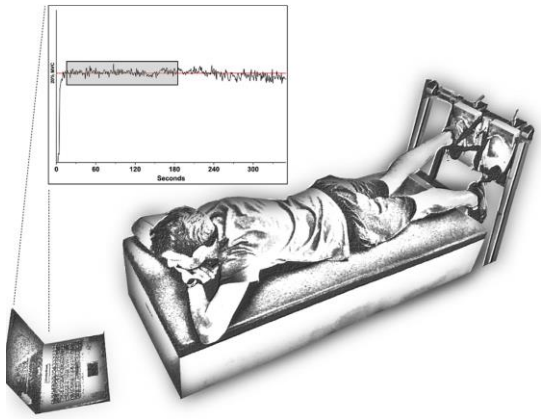
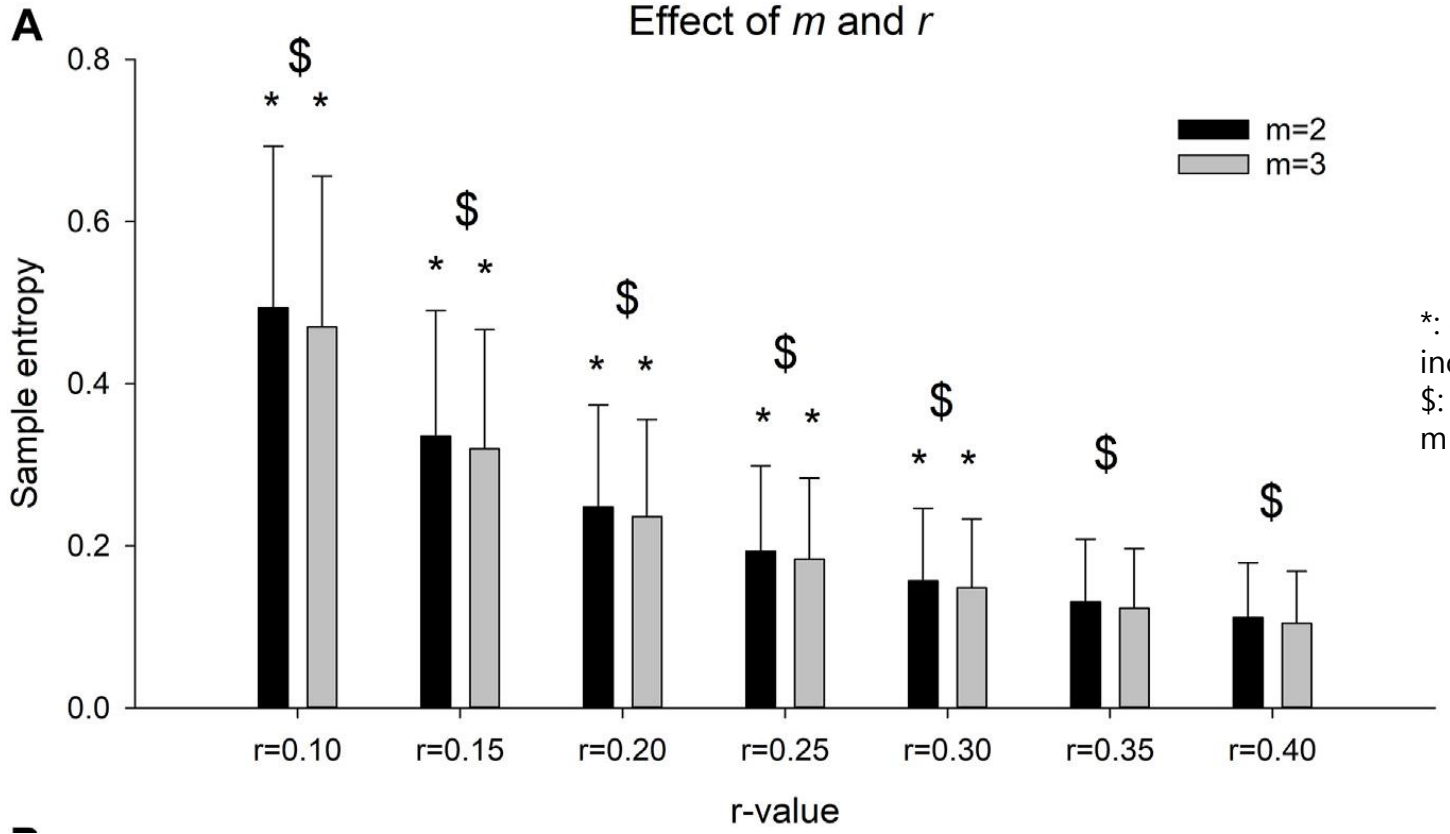


Raffalt et al. 2023



*: decrease in SaEn with increase in r.
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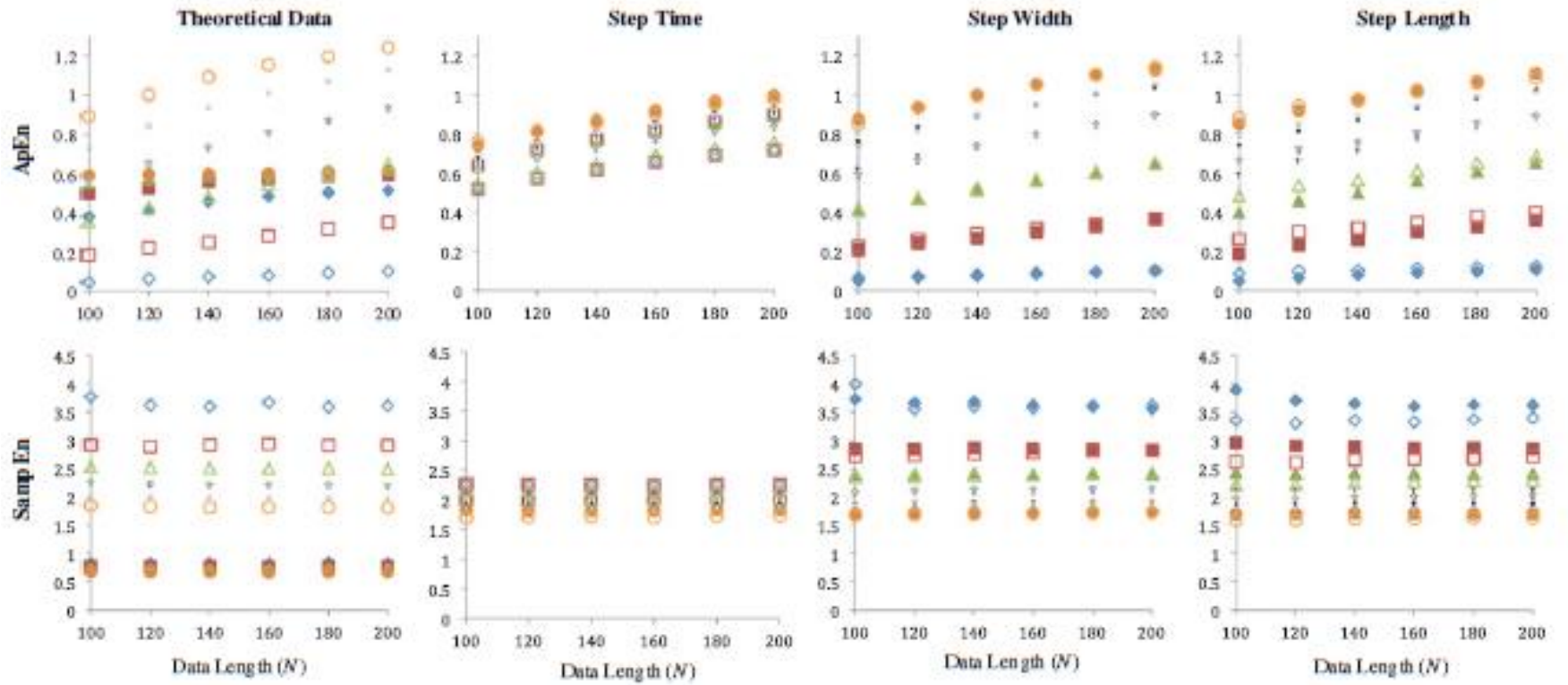
Sample entropy – input parameter N

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- When N is the number of walking steps
- ApEn vs SaEn across different N (from 100 to 200), different rxSD and m=2



Filled symbols: young adults
Open symbols: older adults

Yentes et al. 2012

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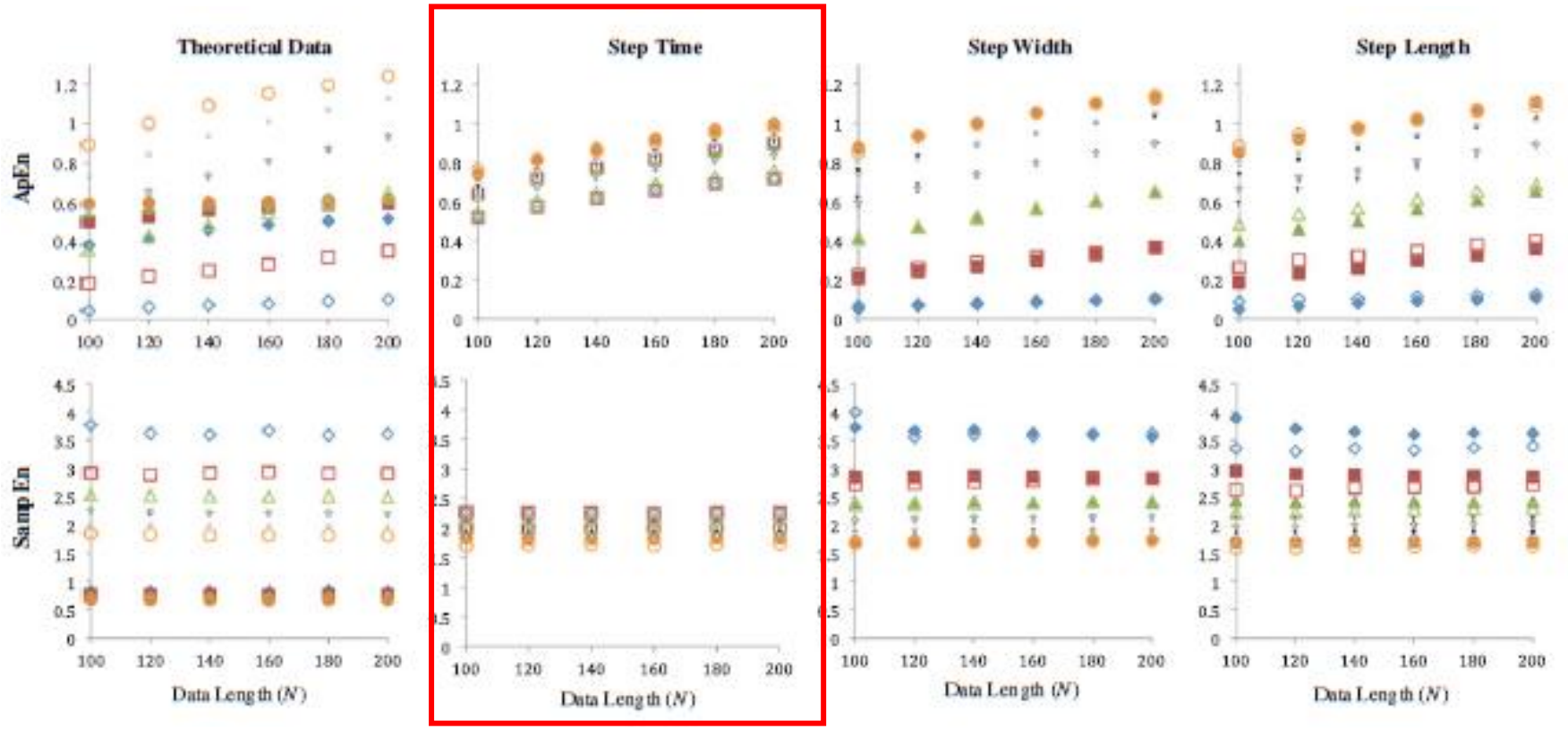

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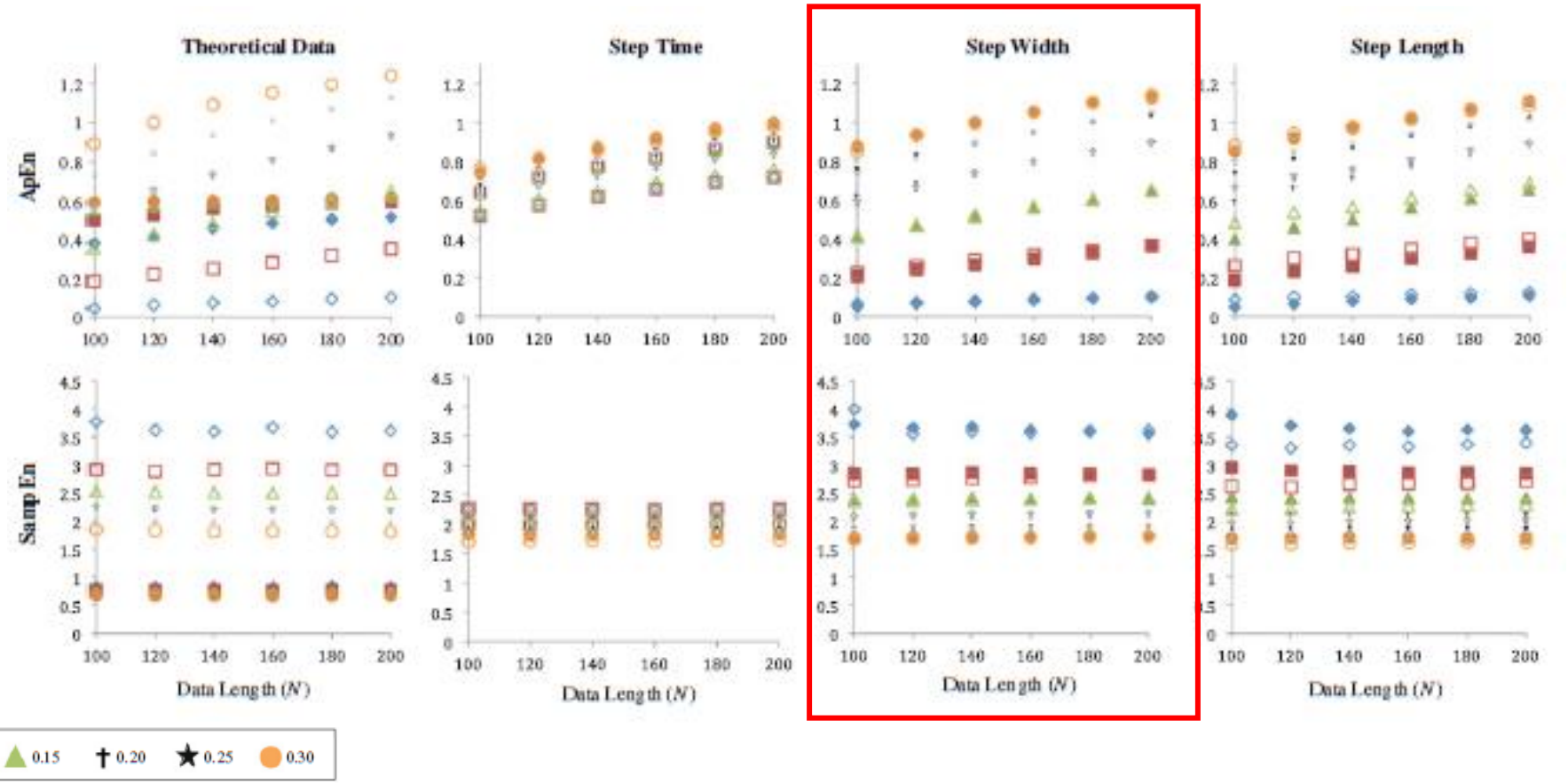

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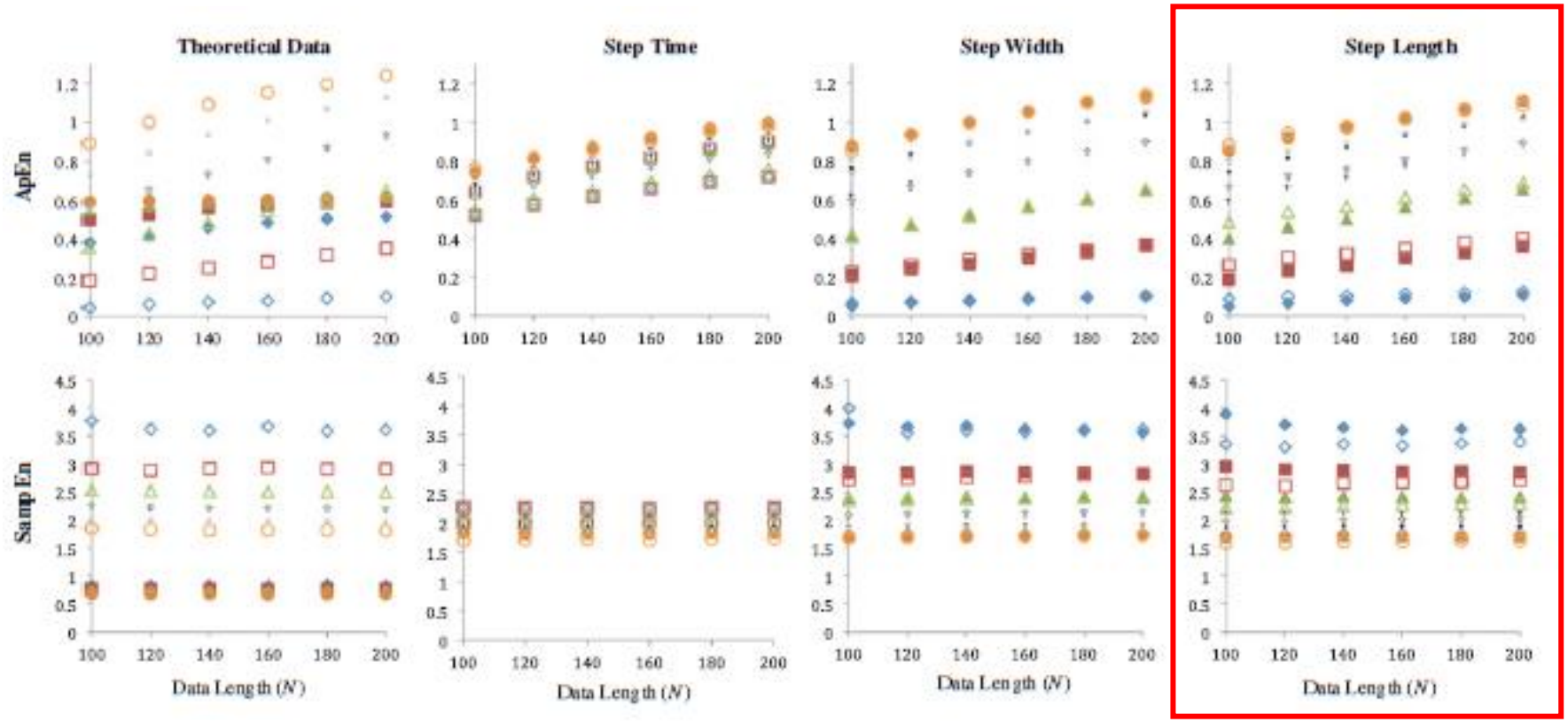

Filled symbols: young adults
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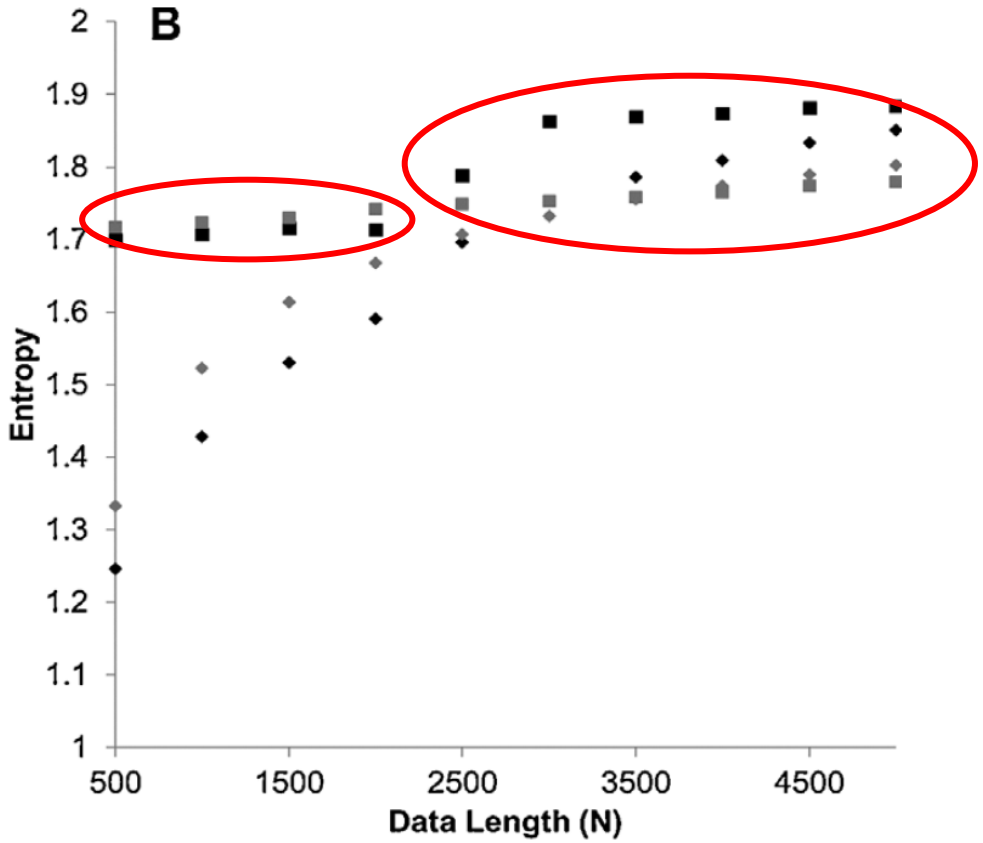
Yentes et al. 2012

Sample entropy – input parameter N

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- When N is the number of walking steps
- ApEn vs SaEn across different N (from 500 to 5000) for r=**0.2**xSD and m=2

Gray: overground walking
Black: treadmill walking
ApEn: diamond
SaEn: square



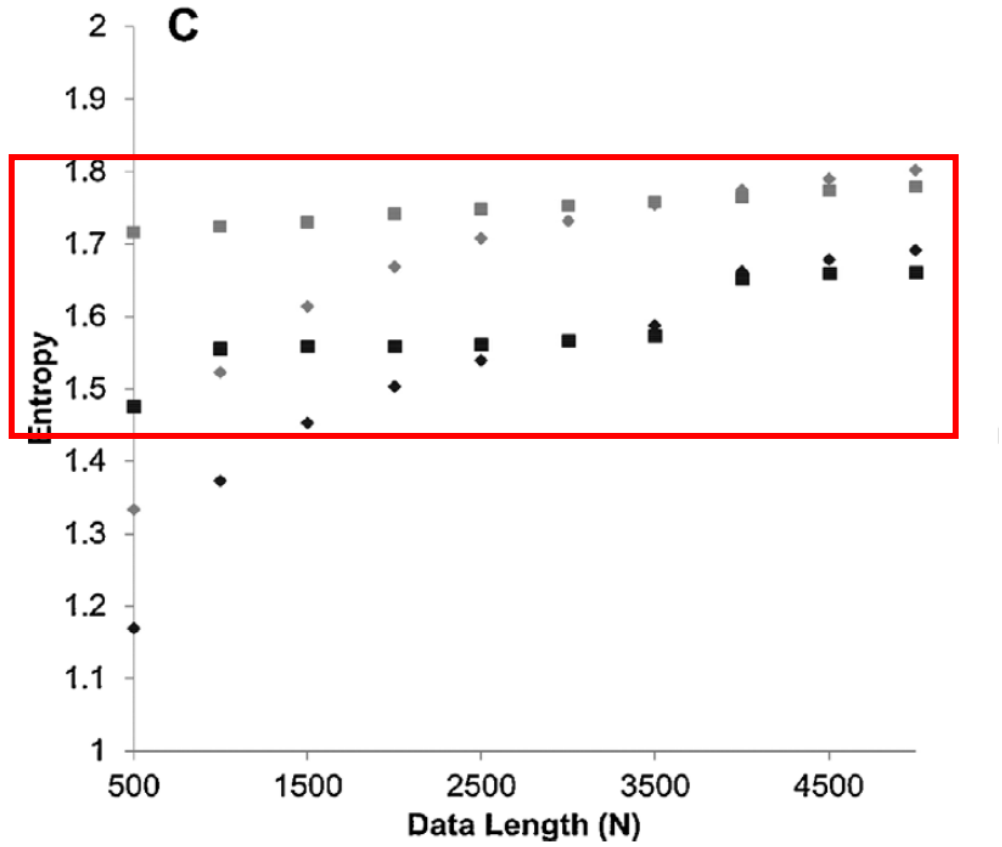
Yentes et al. 2018

Sample entropy – input parameter N

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- When N is the number of walking steps
- ApEn vs SaEn across different N (from 500 to 5000) for r=**0.25**xSD and m=2

Gray: overground walking
Black: treadmill walking
ApEn: diamond
SaEn: square

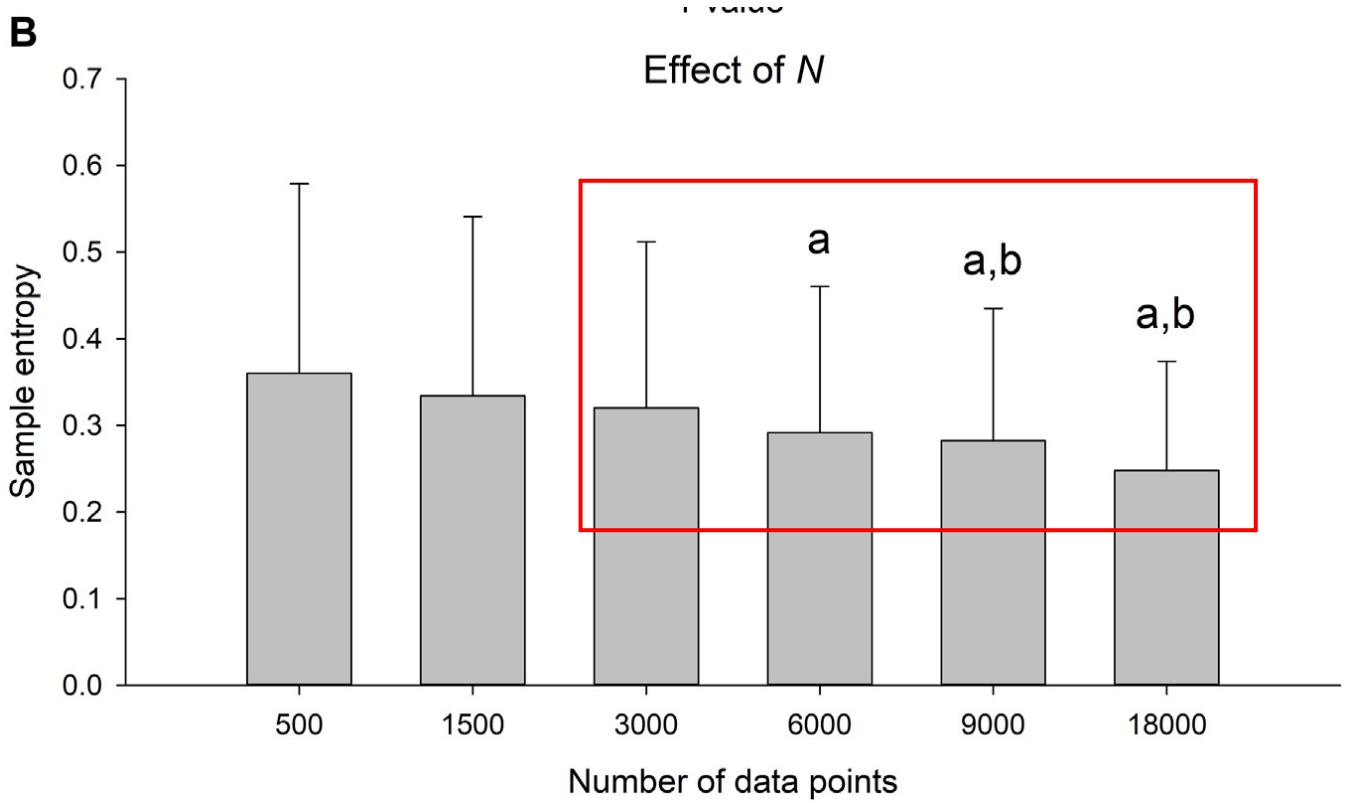


Yentes et al. 2018

Sample entropy – input parameter N

$$SaEn(m,r,N) = -\ln\left[\frac{A^{m+1}(r)}{B^{m}(r)}\right]$$

- When N is the length of the force time series
- SaEn across different N (from 500 to 18000) for r=0.2xSD, m=2 and sampling frequency = 100Hz



A: different from SaEn of 500 data points.
B: different from SaEn of 1500 data points

Raffalt et al. 2023

Sample entropy – input parameter N with discrete data

- N is the number of observations of a particular event e.g., strides/steps.
- The used N should provide relative input parameter consistency.
- Changing the sampling frequency affects the binning of vectors in SaEn calculation. McCamley et al. 2018
- A high sampling frequency enables accurate detection of events.

- To capture the temporal evolution of any given biological phenomenon through **discrete** data requires *sufficient observations* and *adequate observation frequency* for the detailed dynamics of the phenomenon to unfold.

Sample entropy – input parameter N with continuous data

- N is the number of data points.
- The used N should provide relative input parameter consistency.
- N = sampling time x sampling frequency.
- Choose sampling frequency based on:
  - A priori power spectral analysis
  - The neuromuscular system operates on a millisecond level

- To capture the temporal evolution of any given biological phenomenon through **continuous** data requires *sufficient observation time* and *adequate observation frequency* for the detailed dynamics of the phenomenon to unfold.

Methodological recommendations

Annals of Biomedical Engineering (© 2021)
https://doi.org/10.1007/s10439-020-02616-8

BMES BIOMEDICAL ENGINEERING SOCIETY

Check for updates

Review

Entropy Analysis in Gait Research: Methodological Considerations and Recommendations

JENNIFER M. YENTES[1] and PETER C. RAFFALT[2,3]

[1]Center for Research in Human Movement Variability, University of Nebraska at Omaha, 6160 University Drive South, Omaha, NE 68182-0860, USA; [2]Department of Physical Performance, Norwegian School of Sport Sciences, Sognsveien 220, 0806 Oslo, Norway; and [3]Department of Biomedical Sciences, University of Copenhagen, Blegdamsvej 3B, 2200 Copenhagen N, Denmark

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European Journal of Applied Physiology
https://doi.org/10.1007/s00421-021-04684-7

LETTER TO THE EDITOR

Check for updates

Methodological considerations for a non-linear analysis of running in the heavy and severe intensity domains

Jennifer M. Yentes[1] · Peter C. Raffalt[2] · João R. Vaz[3]

Received: 7 March 2021 / Accepted: 8 April 2021

Frontiers in Physiology

TYPE Original Research
PUBLISHED 01 June 2023
DOI 10.3389/fphys.2023.1173702

Calculating sample entropy from isometric torque signals: methodological considerations and recommendations

Peter C. Raffalt[1,2], Jennifer M. Yentes[3], Sandro R. Freitas[4] and João R. Vaz[5]*

[1]Department of Biology, University of Southern Denmark, Odense, Denmark, [2]Department of Nutrition, Exercise and Sports, University of Copenhagen, Copenhagen, Denmark, [3]Department of Kinesiology & Sport Management, Texas A&M University, College Station, TX, United States, [4]Faculdade de Motricidade Humana, Universidade de Lisboa, Lisboa, Portugal, [5]Egas Moniz Center for Interdisciplinary Research (CiiEM), Egas Moniz School of Health & Science, Caparica, Almada, Portugal

Time for some Matlab!

- Try to implement sample entropy calculation to different time series
- Investigate the effect of filtering
- Investigate relative parameter consistency
- Try to implement multiscale entropy

- Two scripts
- Five data sets