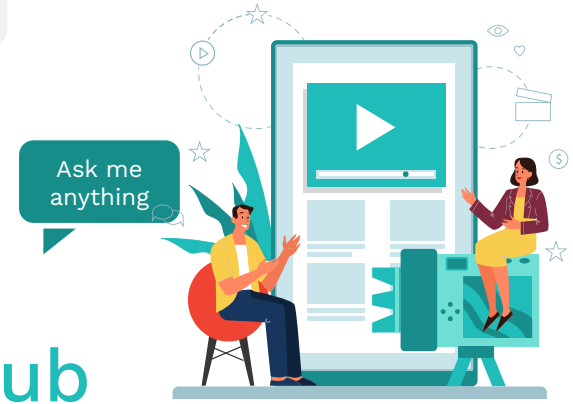
Virtual Journal club



Yiorgos Christakis, MSc
Pfizer Early Clinical Development
Digital Sciences & Translational Imaging Quantitative Sciences

SciKit Digital Health: Python Package for Streamlined Wearable Inertial Sensor Data Processing

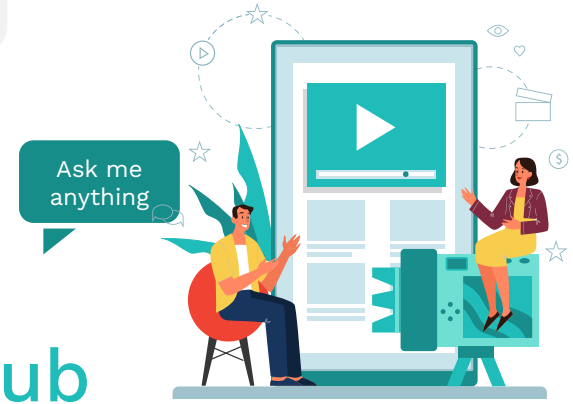
October 5, 2022 | 11am ET

Lukas Adamowicz, MSc
Pfizer Early Clinical Development
Digital Sciences & Translational Imaging Quantitative Sciences

But first, housekeeping

- Please note today's session is being recorded
- To ask a question for discussion during Q&A, please:
    - Either 'raise your hand' in the participant window and moderator will unmute you to ask your question live, or
    - Type your question into the chat box
- Slides and recording will be available after today's session

Virtual Journal club



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SciKit Digital Health

What does SKDH address?

Existing Solutions & Literature

- **Lots** of literature on gait, activity, sleep, etc
- **Lack** of existing **implementations** from literature
- **Lack of Open-Source** algorithms or implementations
- Packages do exist, but have drawbacks
  - GGIR: sleep & activity only, not easily extensible
  - GaitPy (Pfizer): gait only, harder to interface
- Many packages are one area only (e.g. activity only, or gait only, etc.)

Python Algorithms Package

- **Distributable** package in common language
- Open-Source
- Algorithms from literature & internal research
- Algorithms **validated** against ground truth
- Consolidate common algorithms into one package/repository
- Custom framework handles multiple pipeline variations
- Clean & well documented code

Scikit Digital Health – General Purpose Modules

IO

- Read common (binary) file types into memory for processing
  - GeneActiv
  - Axivity
  - APDM
  - Etc.
- Low-level language extensions for speed

Signal Features

- Suite of common signal features
- Common framework allows easy extension/custom features
  - Can be computed at same time as rest of built-in features
- Low-level language extensions for speed

Pre-Processing

- Pre-processing algorithms for multi-day accelerometer data
- Wear detection (van Hees 2013)
- Accelerometer calibration (van Hees 2014)

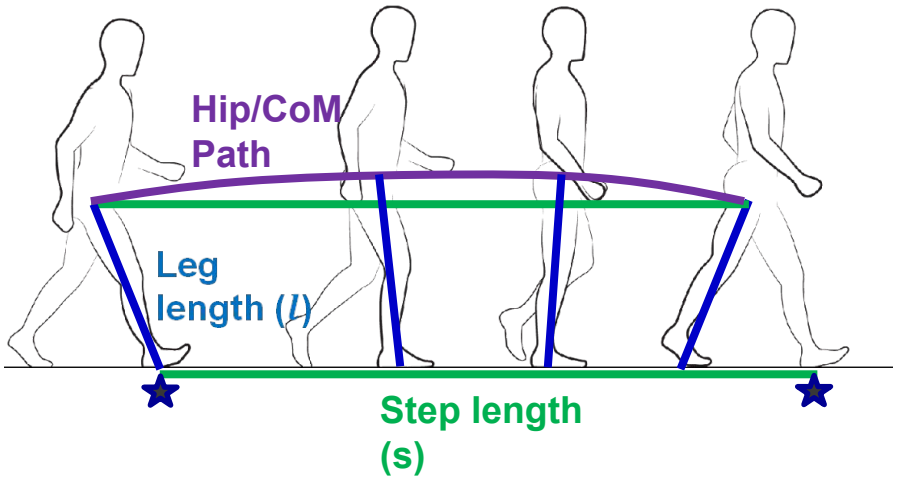
[1] *V. T. van Hees et al., "Separating Movement and Gravity Components in an Acceleration Signal and Implications for the Assessment of Human Daily Physical Activity," PLOS ONE, vol. 8, no. 4, p. e61691, Apr. 2013, doi: 10.1371/journal.pone.0061691.*
[2] *V. T. van Hees et al., "Autocalibration of accelerometer data for free-living physical activity assessment using local gravity and temperature: an evaluation on four continents," Journal of Applied Physiology, vol. 117, no. 7, pp. 738–744, Aug. 2014, doi: 10.1152/japplphysiol.00421.2014.*
[3] *L. Adamowicz et al. "SciKit Digital Health: Python Package for Streamlined Wearable Inertial Sensor Data Processing" JMIR Mhealth Uhealth 2022;10(4):e36762 doi: 10.2196/36762*

Scikit Digital Health – Gait Algorithm & Model

Algorithm Details

- **Lumbar accelerometer based**
- **Provides temporal (e.g. stride time) & spatial (e.g. stride length) gait metrics**
- Algorithm details:
  - Custom classifier detects gait bouts (3s windows)
  - Continuous wavelet transform (CWT) based initial/final contact detection (McCamley 2012)
  - Inverted pendulum model for spatial metrics (Zijlstra 2003)
  - Quality check per step/strides:
    1. Loading time less than P% of max. stride time (20%)
    2. Stance time less than half gait cycle + initial double support
    3. Maximum stride time not exceeded (2.25s)
  - Computes signal-based asymmetry endpoints

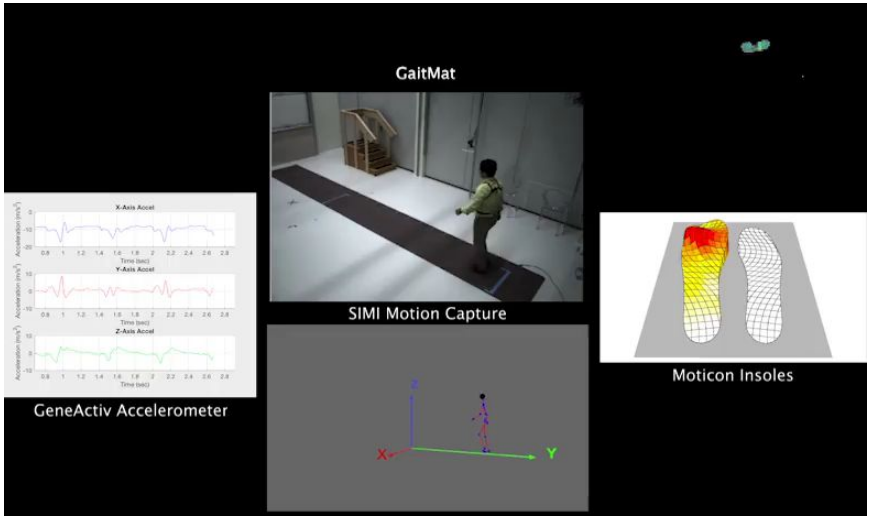
Step Length Estimation Diagram



[1] J. McCamley, M. Donati, E. Grimpampi, and C. Mazza, "An enhanced estimate of initial contact and final contact instants of time using lower trunk inertial sensor data," Gait & Posture, vol. 36, no. 2, pp. 316–318, Jun. 2012, doi: 10.1016/j.gaitpost.2012.02.019.
[2] W. Zijlstra and A. L. Hof, "Assessment of spatio-temporal gait parameters from trunk accelerations during human walking," Gait & Posture, vol. 18, no. 2, pp. 1–10, Oct. 2003, doi: 10.1016/S0966-6362(02)00190-X.

Scikit Digital Health – Gait Validation & Applications

Gait Validation



Example Applications

- Healthy Adults:
  - Showed good-excellent agreement with GaitRite mat
  - Significant differences between young (18-40) and old (65-80) groups at-home
  - Minimum monitoring durations of ~3-4 days
- Healthy Children:
  - Adjust expected step frequency (CWT IC/FC detection) and maximum stride time
  - Good-excellent agreement with GaitRite mat
- Children with Achondroplasia
- Adults with knee osteo-arthritis

[1] *J. McCamley, M. Donati, E. Grimpampi, and C. Mazzà, "An enhanced estimate of initial contact and final contact instants of time using lower trunk inertial sensor data," Gait & Posture, vol. 36, no. 2, pp. 316–318, Jun. 2012, doi: 10.1016/j.gaitpost.2012.02.019.*
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Scikit Digital Health - Activity

Algorithm

- **Wrist accelerometer based**
- **Computes MVPA, sedentary/light time, max accel. over time windows**
- Algorithm details:
  - Compute Euclidean Norm Minus One (ENMO) and window (default 5s)
  - Thresholds from previous literature for estimating activity level duration
  - Additionally computes other endpoints:
    - Intensity Gradient (Rowlands 2018)
    - Fragmentation endpoints (Di 2017)
  - Framework for adding other custom endpoints

Example Applications

- Healthy Adults:
  - [In-progress] Agreement with other open/closed source algorithms
    - ActiGraph, GeneActiv, & GGIR
  - [In-progress] Investigate group differences between younger (18-40) and older (65-80) participants at-home
- Cachexia
- Heart Failure
- etc

[1] A. V. Rowlands, et al., "Beyond Cut Points: Accelerometer Metrics that Capture the Physical Activity Profile," *Medicine & Science in Sports & Exercise*, vol. 50, no. 6, pp. 1323–1332, Jun. 2018, doi: 10.1249/MSS.0000000000001561.
[2] J. Di *et al.*, "Patterns of sedentary and active time accumulation are associated with mortality in US adults: The NHANES study," *bioRxiv*, p. 182337, Aug. 2017, doi: 10.1101/182337.
[3] J. H. Migueles *et al.*, "Comparability of accelerometer signal aggregation metrics across placements and dominant wrist cut points for the assessment of physical activity in adults," *Scientific Reports*, vol. 9, no. 1, Art. no. 1, Dec. 2019, doi: 10.1038/s41598-019-54267-y.

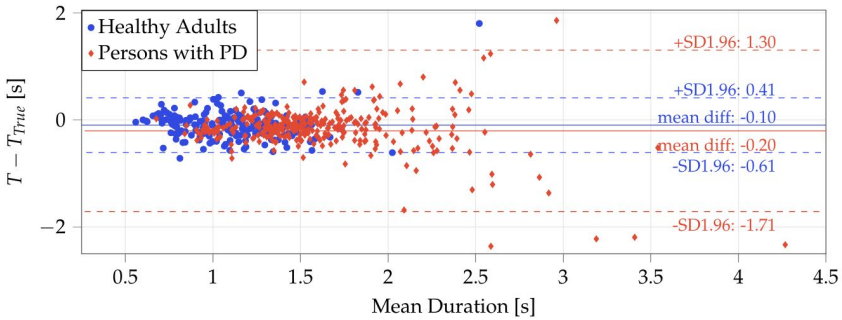
Scikit Digital Health – Sit-to-Stand

Algorithm

- **Lumbar based accelerometer-only**
- **Computes duration, STS dynamics, signal smoothness**
- Algorithm details:
  - Orientation independent
  - Heuristic algorithm uses CWT to detect potential sit-to-stand transfers
  - Each possible location is QC'ed to eliminate partial or false transfers

Validation & Application

- Validated in healthy and patients with Parkinson's Disease (Adamowicz 2020)
- Ongoing work in people with knee OA, cachexia



[1] L. Adamowicz *et al.*, "Assessment of Sit-to-Stand Transfers during Daily Life Using an Accelerometer on the Lower Back," *Sensors*, vol. 20, no. 22, Art. no. 22, Jan. 2020, doi: 10.3390/s20226618.
[2] Christakis et al., (2019). SleepPy: A python package for sleep analysis from accelerometer data. Journal of Open Source Software, 4(44), 1663, https://doi.org/10.21105/joss.01663

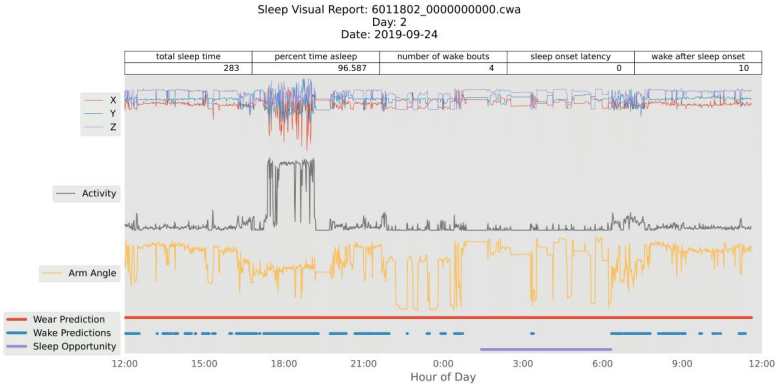
Scikit Digital Health – Sleep

Algorithm

- **Wrist accelerometer based**
- **Computes sleep duration, sleep fragmentation, awake time**
- Algorithm details:
  - Updated implementation of SleepPy (Christakis 2019)
  - Heuristic algorithms based on activity measures and estimated arm-angle

Application & Validation

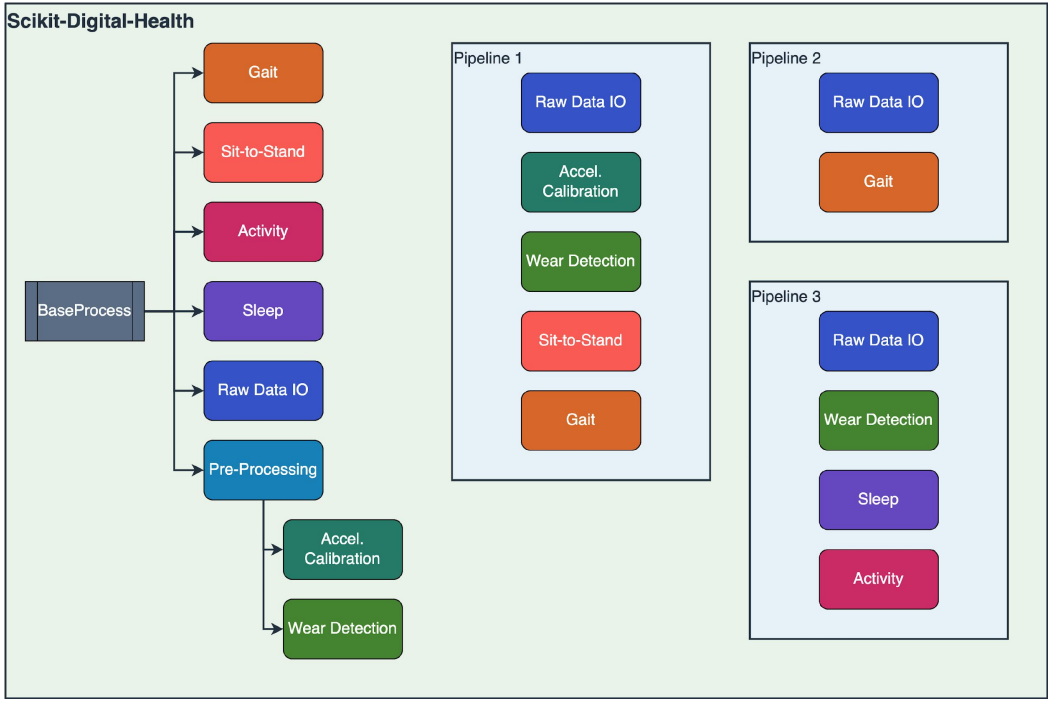
- Validation against PSG in people with Atopic Dermatitis (Mahadevan 2019)
- [In-progress] Healthy populations



[1] L. Adamowicz *et al.*, "Assessment of Sit-to-Stand Transfers during Daily Life Using an Accelerometer on the Lower Back," *Sensors*, vol. 20, no. 22, Art. no. 22, Jan. 2020, doi: 10.3390/s20226618.
[2] Christakis et al., (2019). SleepPy: A python package for sleep analysis from accelerometer data. Journal of Open Source Software, 4(44), 1663, https://doi.org/10.21105/joss.01663
[3] N. Mahadevan *et al.*, "Development of digital measures for nighttime scratch and sleep using wrist-worn wearable devices," *npj Digit. Med.*, vol. 4, no. 1, pp. 1–10, Mar. 2021, doi: 10.1038/s41746-021-00402-x.

Scikit Digital Health – Package Framework

- **Common input/output** → chain process modules
- **Pipeline structure** → simple expression of complex/arbitrarily-ordered processing steps
  - Pipeline: processing steps for generating DHEs
- User-adjustable algorithm parameters
- Pipelines can be saved & loaded for repeatability or documentation
- **Common structure** → extensible



Scikit Digital Health – Framework Example

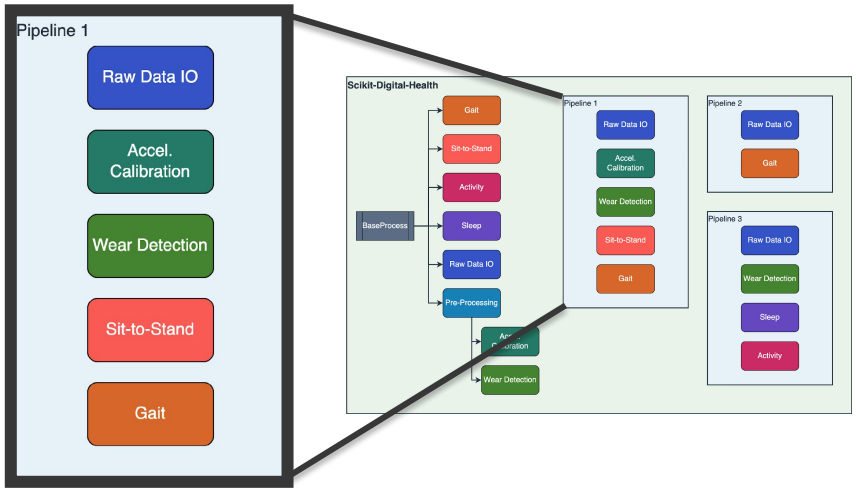
Creating a pipeline instance

```
import skdh

pipeline = skdh.Pipeline()
pipeline.add(skdh.io.ReadBin())
pipeline.add(skdh.preprocessing.CalibrateAccelerometer())
pipeline.add(skdh.preprocessing.DetectWear())
pipeline.add(skdh.sit2stand.Sit2stand())
pipeline.add(skdh.gait.Gait())

pipeline.run(file="example_geneactiv_file.bin")
```

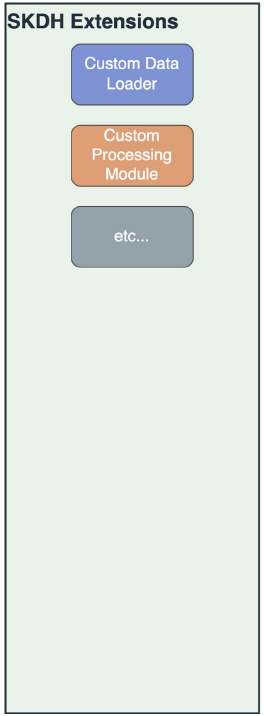
Pipeline Representation

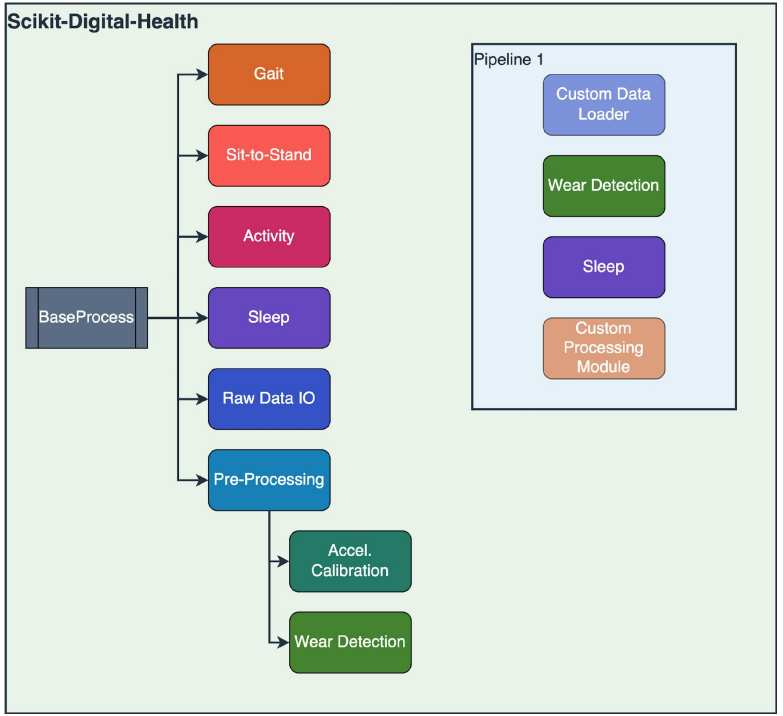


Scikit Digital Health – Extending

Ease of Extending

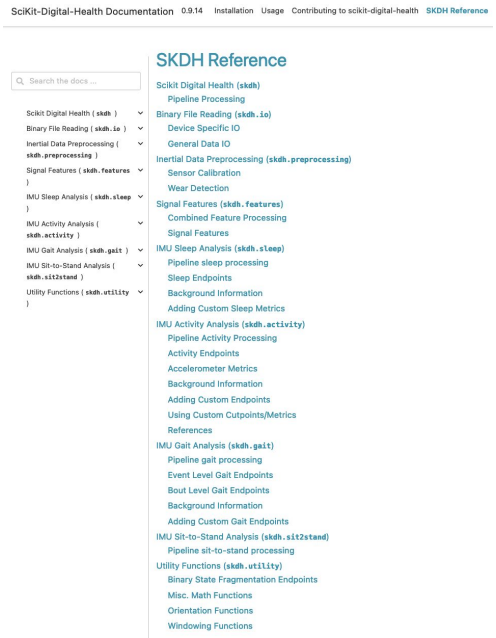
- Public base class
- Create custom/one-off extensions for niche cases
- Mix & match SKDH and extensions in pipelines

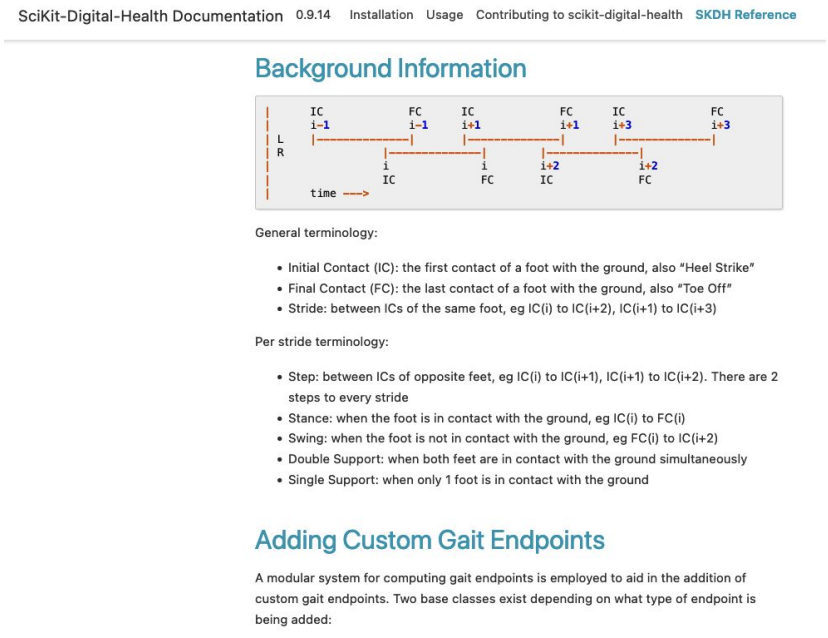




Scikit Digital Health – Documentation

https://scikit-digital-health.readthedocs.io/en/latest/





Scikit Digital Health - Accessing

https://github.com/PfizerRD/scikit-digital-health

https://pypi.org/project/scikit-digital-health/

https://anaconda.org/conda-forge/scikit-digital-health

THANK YOU

Yiorgos and Lukas!

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- Tomasz Adamusiak* (former Pfizer Employee)
- Matt Czech* (former Pfizer Employee)

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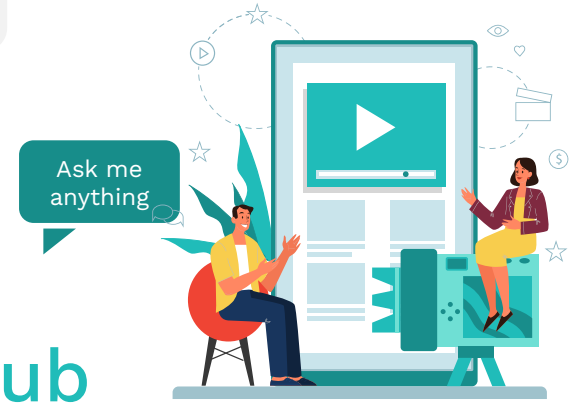


David A. Simon, Ph.D, J.D., LL.M.
Research Fellow, Petrie-Flom Center
Harvard Law School

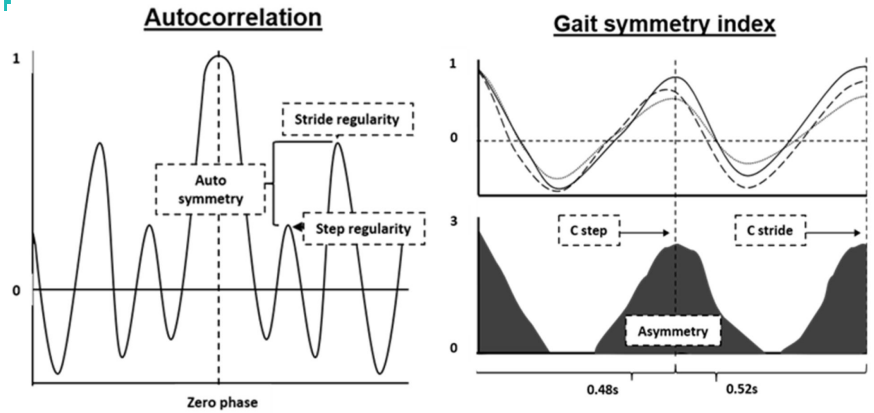
Moderator: Pip Griffiths, PhD
Digital Medicine Society

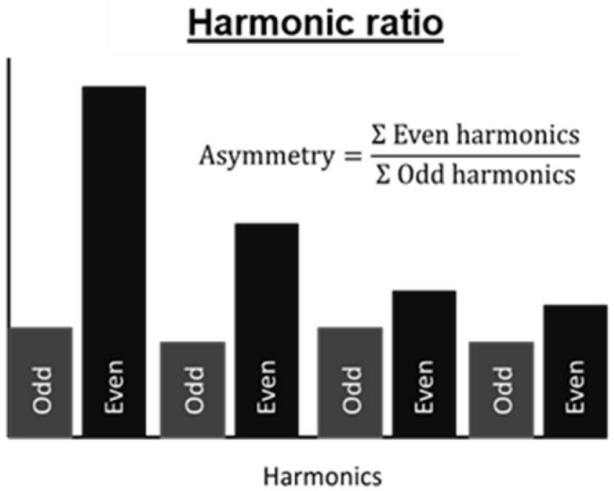
Should Alexa diagnose Alzheimer's?: Legal and ethical issues with at-home consumer devices

November 2nd 11am EST

Scikit Digital Health: Gait Endpoints

Metric	GaitPy [2]	SKDH
Stride/Step Time/Cadence	x	x
Stride Phases	x	x
Single/Double Support	x	x
Stride/Step length	x	x
Gait Speed	x	x
Basic Asymmetry	x	x
Intra-stride/step-covariance		x
Harmonic Ratio		x
Stride SPARC		x
Regularity Indices/GSI		x
Phase Coordination Index		x
Autocovariance Symmetry		x





https://doi.org/10.21105/joss.01778

Scikit Digital Health: Activity Endpoints

Metric	SKDH	GGIR	GENEActiv	Actigraph
Sed/Light/Mod/Vig Duration	x	x	x	x
Bouted activity level Duration	x	x		
MET estimates				x
Intensity Gradient (Rowlands 2018)	x	x		
Max. Accel. in windows	x		Computable	Computable
Avg. Duration	x	Future?		
State Transition Prob.	x	Future?		
Gini Index	x	Future?		
Avg. Hazard	x	Future?		
State Power Lab Dist.	x	Future?		

Scikit Digital Health: Sit-to-Stand Endpoints

Metric	SKDH
Duration	x
Vertical Displacement	x
Max. Acceleration	x
Min. Acceleration	x
Spectral Arc Length	x

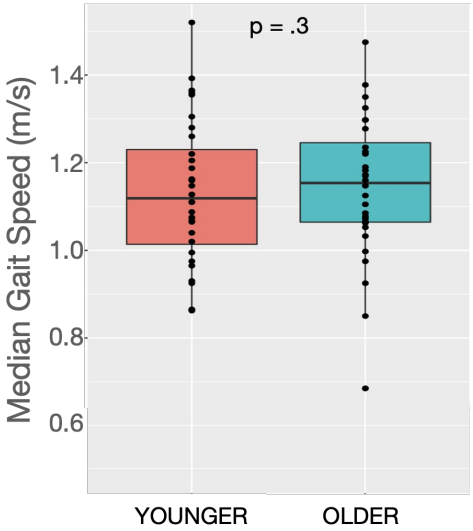
Scikit Digital Health: Sleep Endpoints

Metric	SKDH	SleepPy
Total Sleep Time	x	x
Percent Time Asleep (sleep efficiency)	x	x
Number of Wake Bouts	x	x
Sleep Onset Latency	x	x
Wake After Sleep Onset	x	x
Average Sleep Duration	x	
Average Wake Duration	x	
Sleep-Wake Transition Probability	x	
Wake-Sleep Transition Probability	x	
Sleep Gini Index	x	
Wake Gini Index	x	
Sleep Average Hazard	x	
Wake Average Hazard	x	
Sleep Power Law Distribution	x	
Wake Power Law Distribution	x	

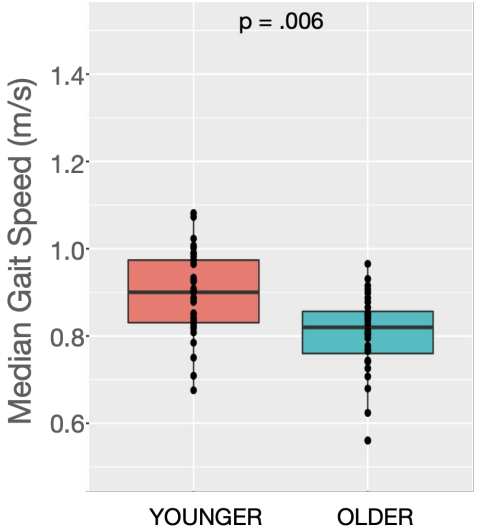
Scikit Digital Health – Gait Validation in Healthy Adults

Gait in Healthy Adults (23-39 & 65-85 years)

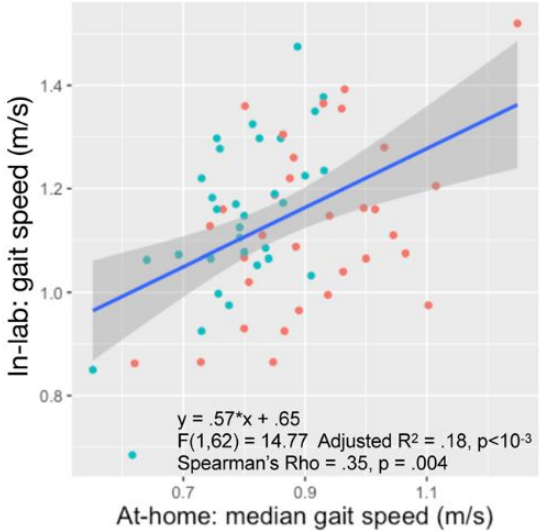
Gait Speed In Lab



Gait Speed At Home



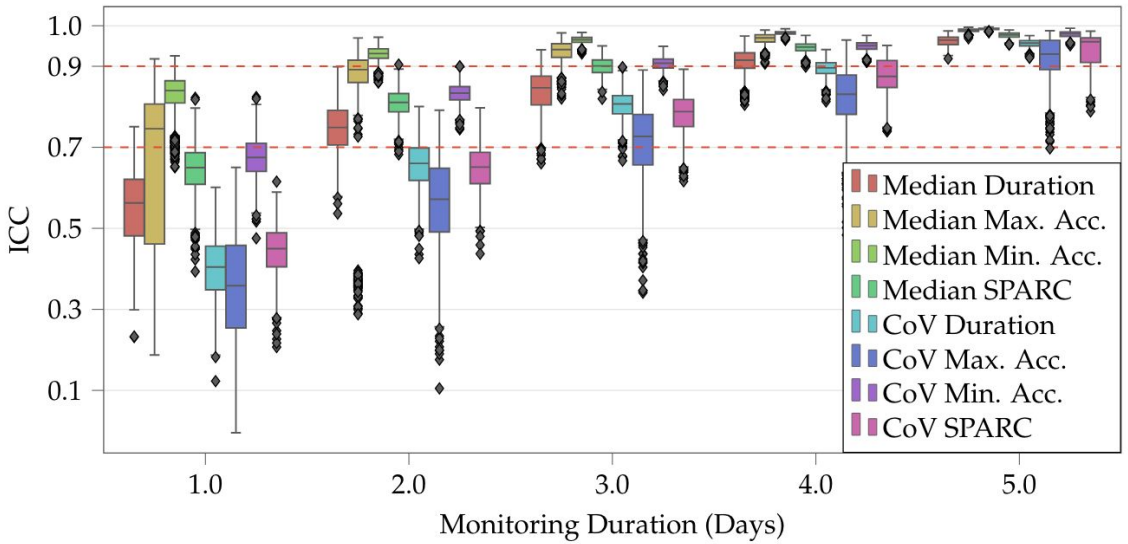
Gait Speed: Lab vs Home



[1] M. D. Czech *et al.*, "Age and environment-related differences in gait in healthy adults using wearables," *npj Digital Medicine*, vol. 3, no. 1, Art. no. 1, Sep. 2020, doi: 10.1038/s41746-020-00334-y.

Scikit Digital Health – Sit-to-Stand At-Home

Minimum monitoring duration for Sit-to-Stand transfer endpoints



Key Points

- After 2 days all median endpoints have median ICC > 0.7
- After 5 days all endpoints have median ICC > 0.9

[1] L. Adamowicz *et al.*, "Assessment of Sit-to-Stand Transfers during Daily Life Using an Accelerometer on the Lower Back," *Sensors*, vol. 20, no. 22, Art. no. 22, Jan. 2020, doi: 10.3390/s20226618.