Newcastle University

Parallel Assemblies Plot

a visualization tool to explore categorical and quantitative data:
application to digital mobility outcomes

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From Newcastle. For the world.

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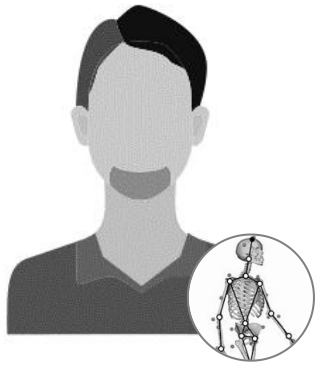
Context

Mobilise-D Project

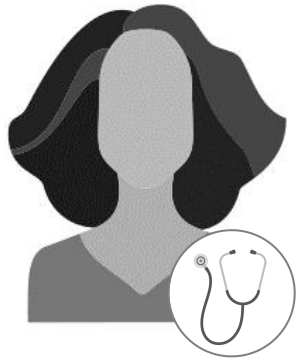
The Mobilise-D project aim at developing a system to evaluate people's gait based on **digital technologies** to monitor the following heath condition:

- Multiple Sclerosis
- Chronic Obtrusive Pulmonary Disease
- Parkinson's Disease
- Chronic Heart Failure
- Periprosthetic Femoral Fracture

More than **300 professionals** from **34 participating universities**, **hospitals**, and **industry**, representing **11 countries**, with the necessary technical, clinical, and regulatory expertise are working together over a five-year period.



Biomechanics



Clinicians

Data Scientists

Patient representatives

Pharmaceutics

Effect on mobility

Multiple Sclerosis (MS)

- **limit walking endurance**
- cause **weakness, poor balance, numbness,** or **spasticity**

Chronic Obstructive Pulmonary Disease (COPD)

- increase **duration between steps**
- increase **step duration variability**

Parkinson's Disease (PD)

- gait **slowness**
- increased **step variability**
- **poor postural control**

Chronic Heart Failure (CHF)

- can reduce **walking capacity**

Periprosthetic Femoral Fracture (PFF)

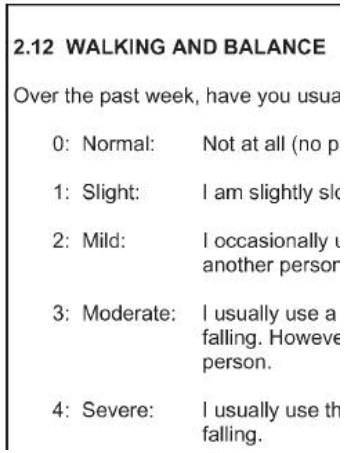
- affect **gait** and **balance** functions

Evaluating mobility in clinical context

CURRENTLY

Medical questionnaires

- ✖ Imprecise: Health status ranked on small scale (e.g. 0 to 5)
- ✖ Subjective: Depend on the context (different clinicians, relative to the previous patient, …)



2.12 WALKING AND BALANCE

Over the past week, have you usua

0:	Normal:	Not at all (no p
1:	Slight:	I am slightly slo
2:	Mild:	I occasionally u another persor
3:	Moderate:	I usually use a falling. Howeve person.
4:	Severe:	I usually use th falling.

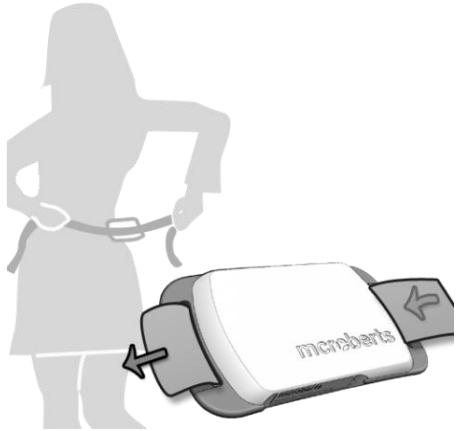
In-lab evaluation

- ✖ Not convenient: require patient to come to the lab for a long period of time
- ✖ Not ecologically valid: Snap shot rather than continuous change

WITH ACCELEROMETRY SENSORS

Real-life mobility tracking

- ✔ Precise: provides quantitative metrics on how people walk
- ✔ Objective: rely on accelerometry recording
- ✔ Convenient: easy to equip
- ✔ Ecologically valid: can be wear at all time



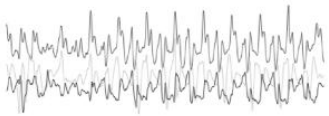
Project overview

TVS – Technical Validation Study

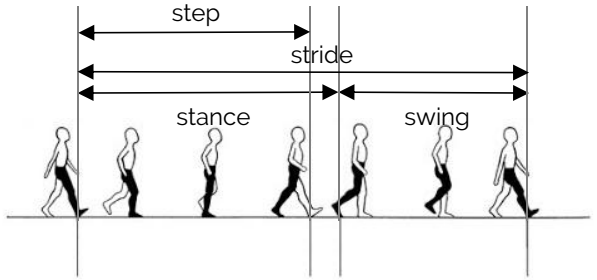
from **sensor data** to **mobility outcomes**

CVS - Clinical Validation Study

from **mobility outcomes** to **health status**



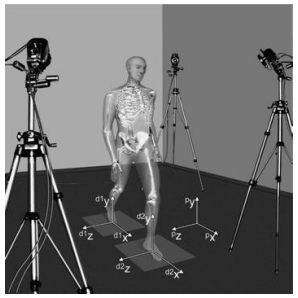
Sensor data



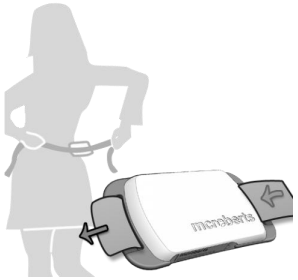
Digital Mobility Outcomes (DMO)

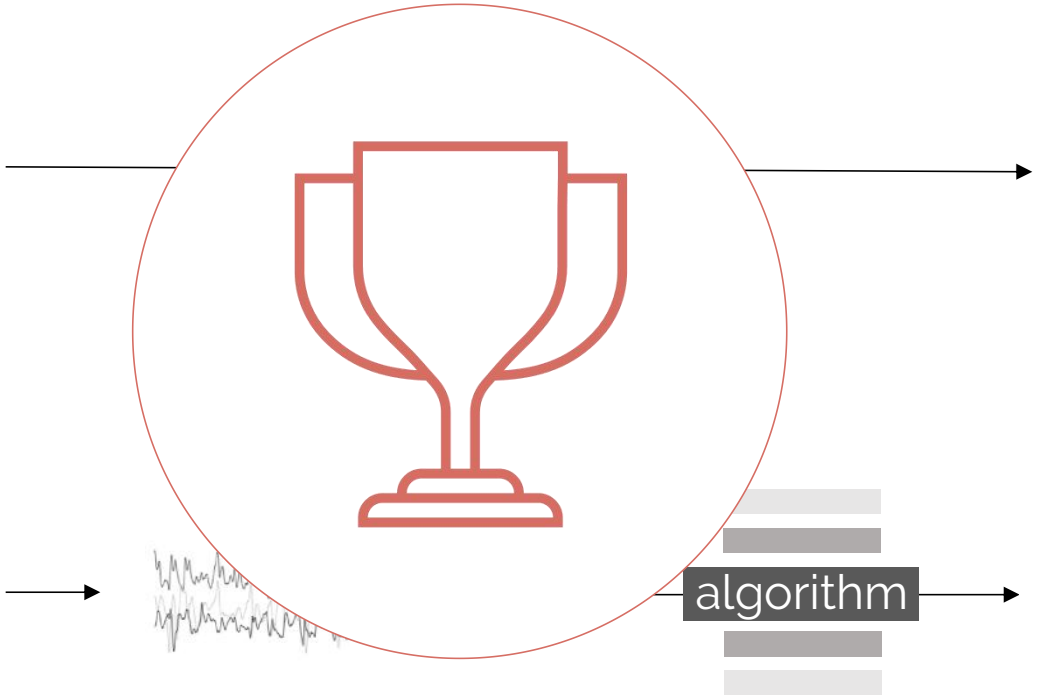
Health status

TVS Methodology

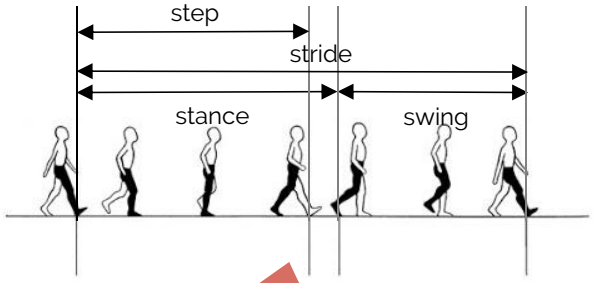


and

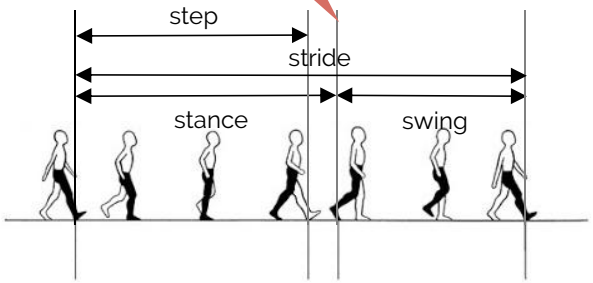




Reference DMOs

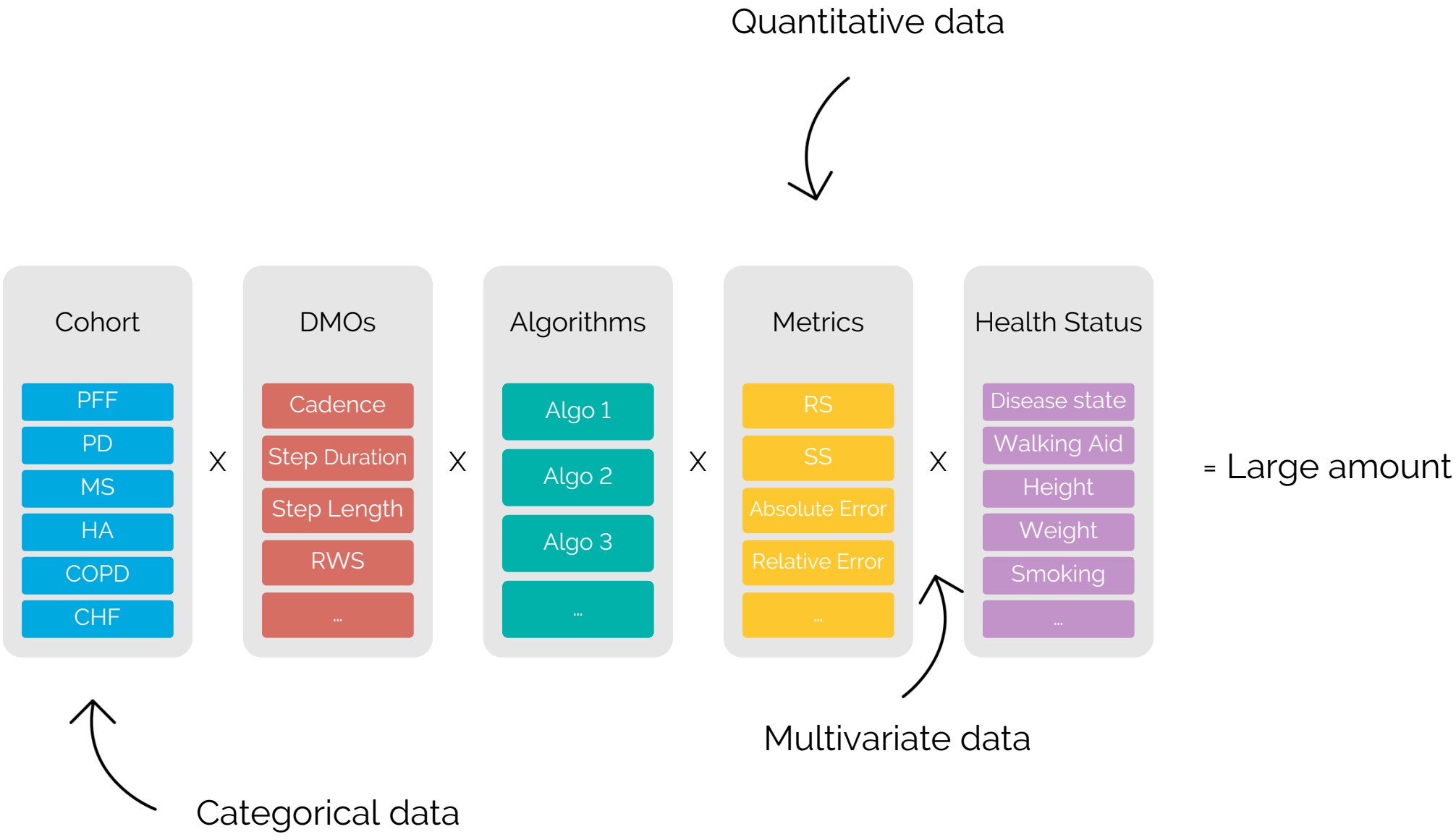


VS

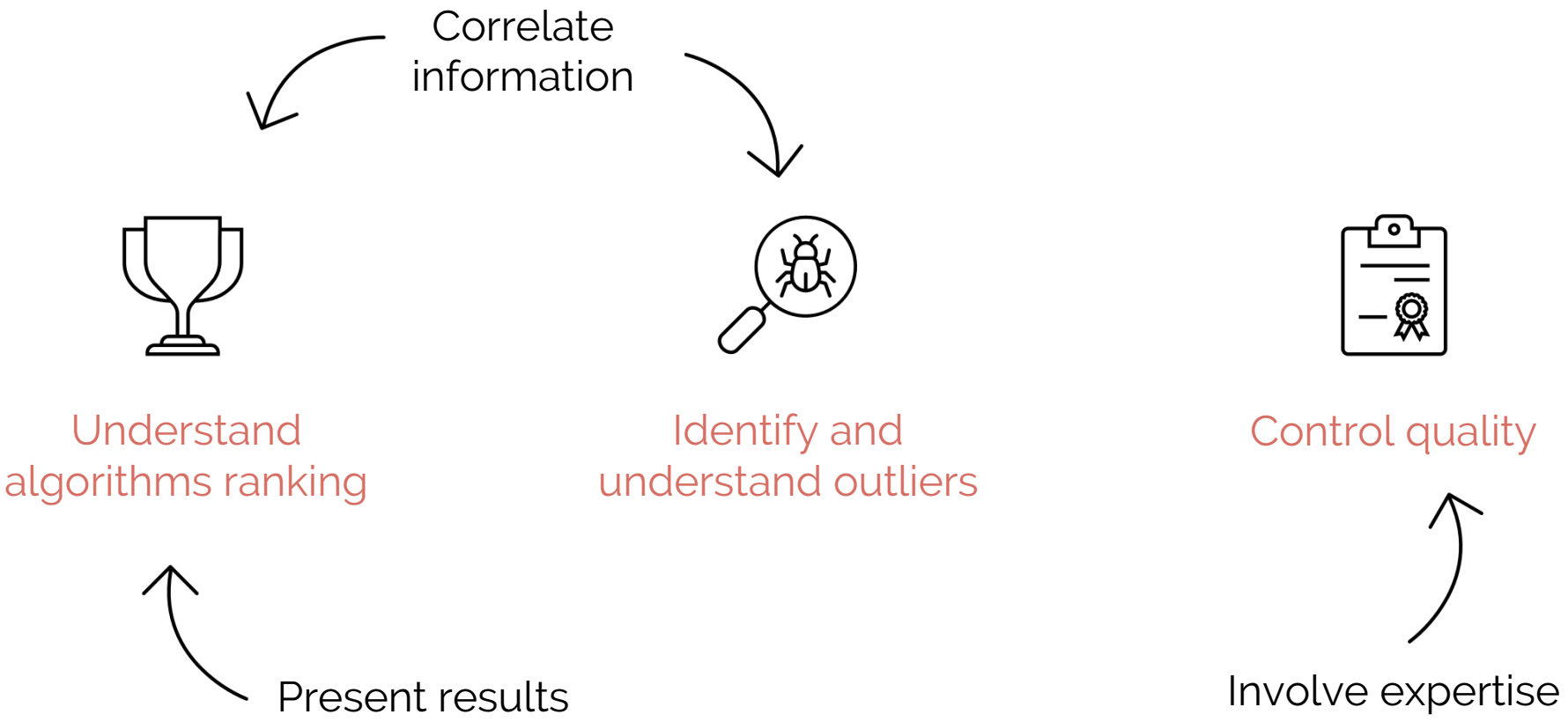


Algorithm Outcome DMOs

Data

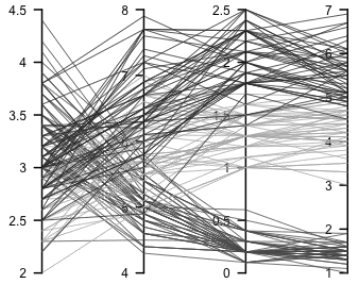

Quantitative data
Cohort
PFF
PD
MS
HA
COPD
CHF
X
DMOs
Cadence
Step Duration
Step Length
RWS
...
X
Algorithms
Algo 1
Algo 2
Algo 3
...
X
Metrics
RS
SS
Absolute Error
Relative Error
...
X
Health Status
Disease state
Walking Aid
Height
Weight
Smoking
...
= Large amount
Multivariate data
Categorical data

Tasks

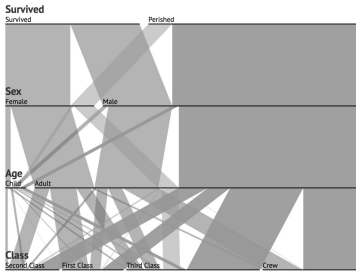

Correlate information
Understand algorithms ranking
Identify and understand outliers
Control quality
Present results
Involve expertise

Visualization

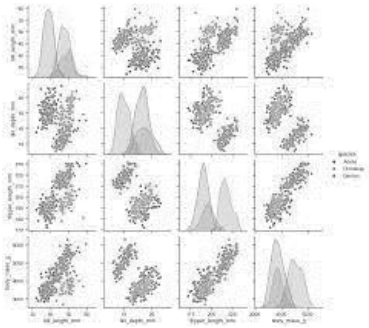
Existing work



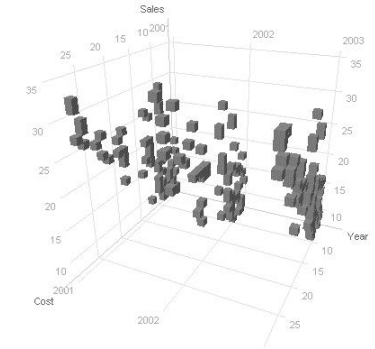
Parallel Coordinates



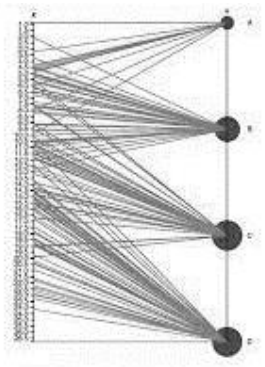
Parallel Sets



Scatterplots matrix



3D Scatterplot



Parallel Bubble

...

Limits

No categorial and quantitative data combined
or Loss of frequency information
or Loss of precision
or Limited correlation

Our solution for heterogeneous data

Splitting ribbons into polylines

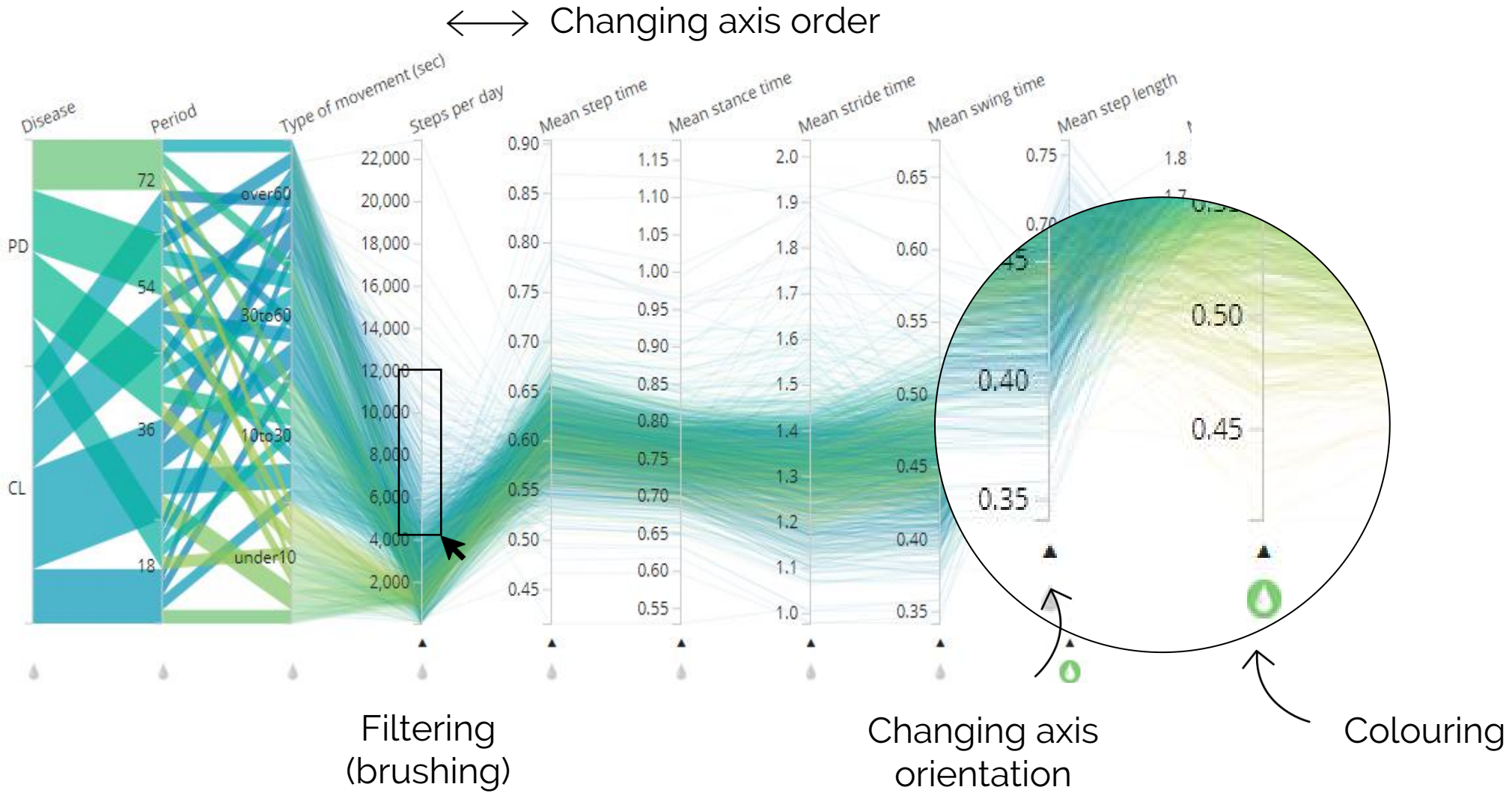
Maintain the hierarchy among ribbons

Color ribbons according to the average values of the category

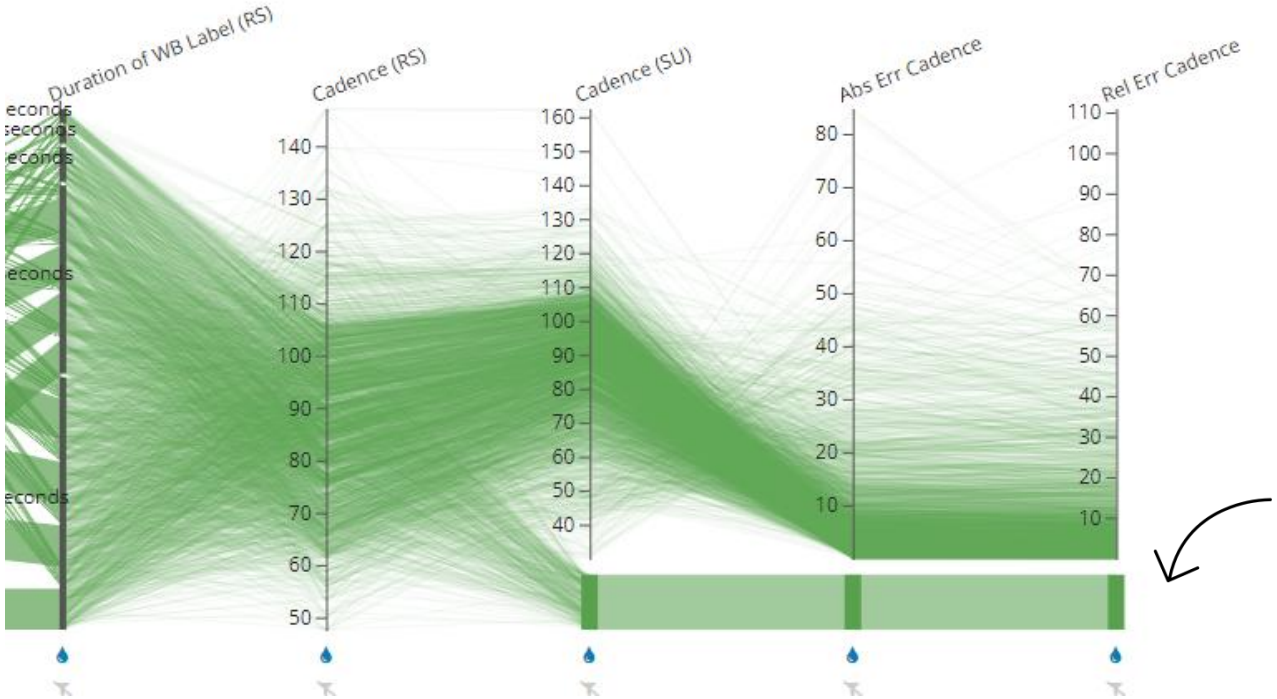
Categorical data

Quantitative data

Parallel axis features



Missing values



Colouring the missing ribbon with mean value

Relying on a ribbon to display frequency

TVS Data Explorer: CAD_Matrix.csv

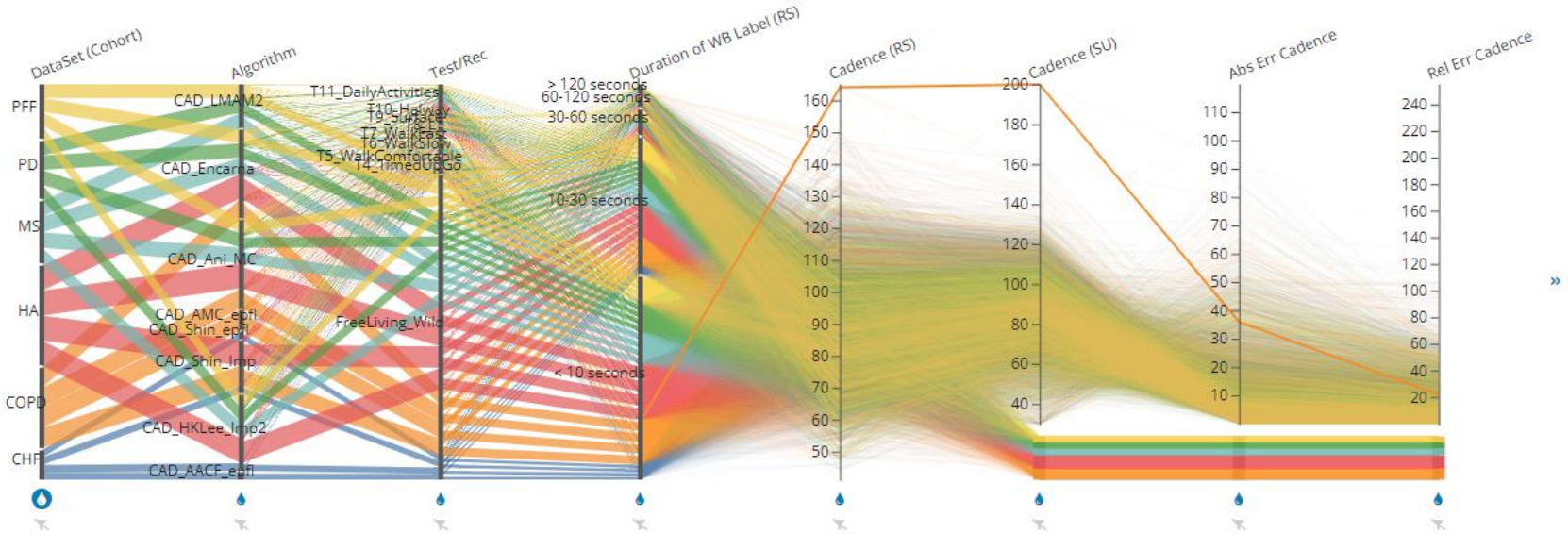
TVS – Visualization tool

Legend

Coloration:

Visible data: 25968 / 25968

Overview



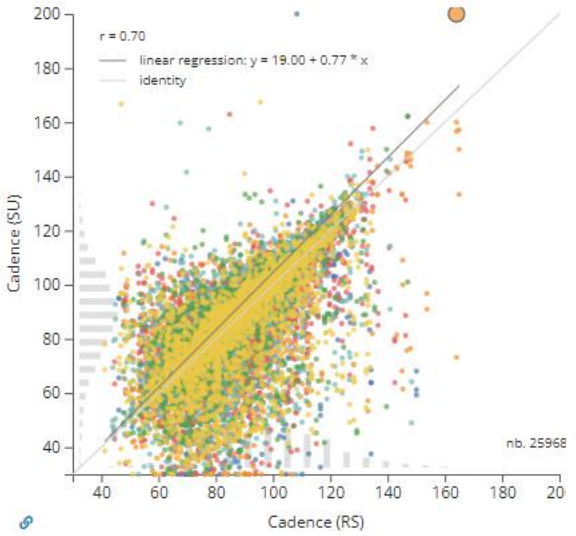
Visible Variables

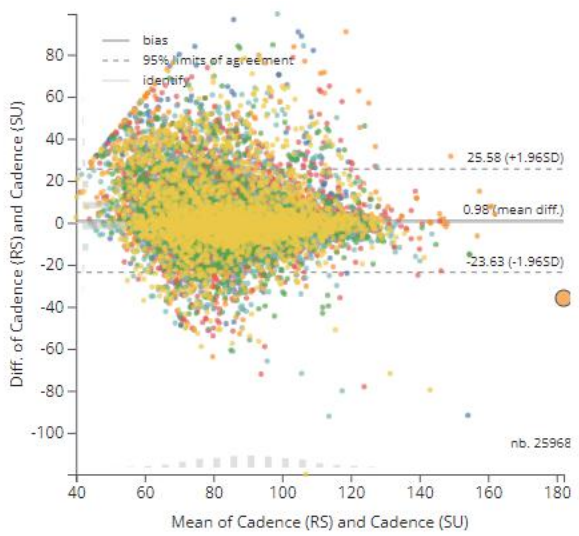
- [ ] % Perform WB (Algo)
- [ ] % Perform Subjects (Algo)
- [ ] Ranking (per Cohort)
- [x] Algorithm
- [ ] Subject ID
- [x] DataSet (Cohort)
- [ ] Location
- [ ] Reference System
- [x] Test/Rec
- [ ] Trial
- [ ] Height
- [ ] Weight
- [ ] Sensor Height
- [ ] Handedness
- [ ] Foot Size
- [ ] Walking Aid (0/1)
- [ ] Walking Aid Side
- [ ] Walking Aid Type
- [ ] Participant
- [ ] Cohort
- [ ] Site
- [ ] Age

Summary

Metrics	Mean	95% CI
Cadence (RS)	87.49	[87.31, 87.68]
Cadence (SU)	86.67	[86.45, 86.88]
Abs Err Cadence	7.36	[7.23, 7.49]
Rel Err Cadence	8.92	[8.75, 9.08]

Export





Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Location:	Laborato
Reference System:	Stereoph
Test/Rec:	T7_Walk
Trial:	Trial1
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

Evaluation

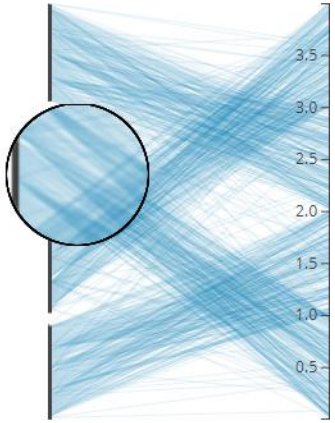
Qualitative study

Are experts able to better perform their tasks?

-> identification of pipeline errors
-> identification of outliers
-> identification of correlation

Quantitative evaluation

Is the junction between ribbons and polyline extend the correlation properties of existing work?



-> some identifications are faster
-> some identifications are more accurate
-> it allows to correlate more dimensions

Additional Information

Technology

- JavaScript d3.js
- Two data access versions
  - CSV loading
  - Link to data base with Flask

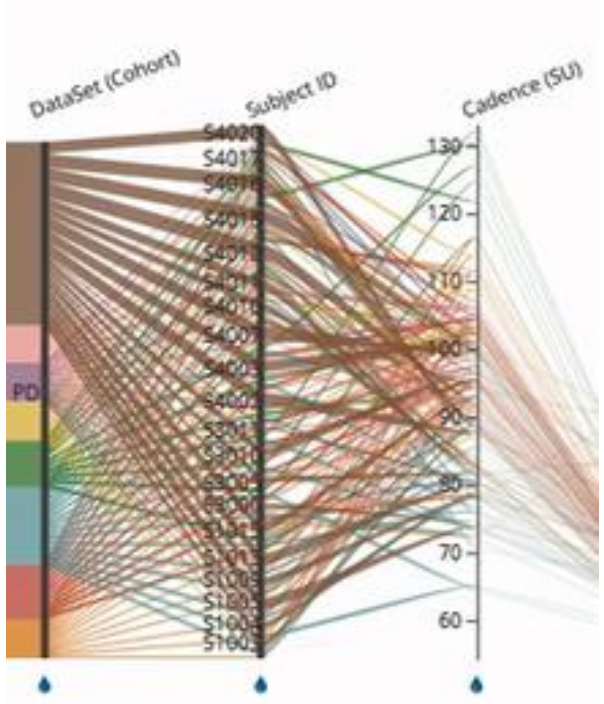
Fully data-dynamic

- Any data can be loaded as long as categorical and quantitative data are identified
- Currently working on
  - community behaviour analysis results
  - network flow analysis

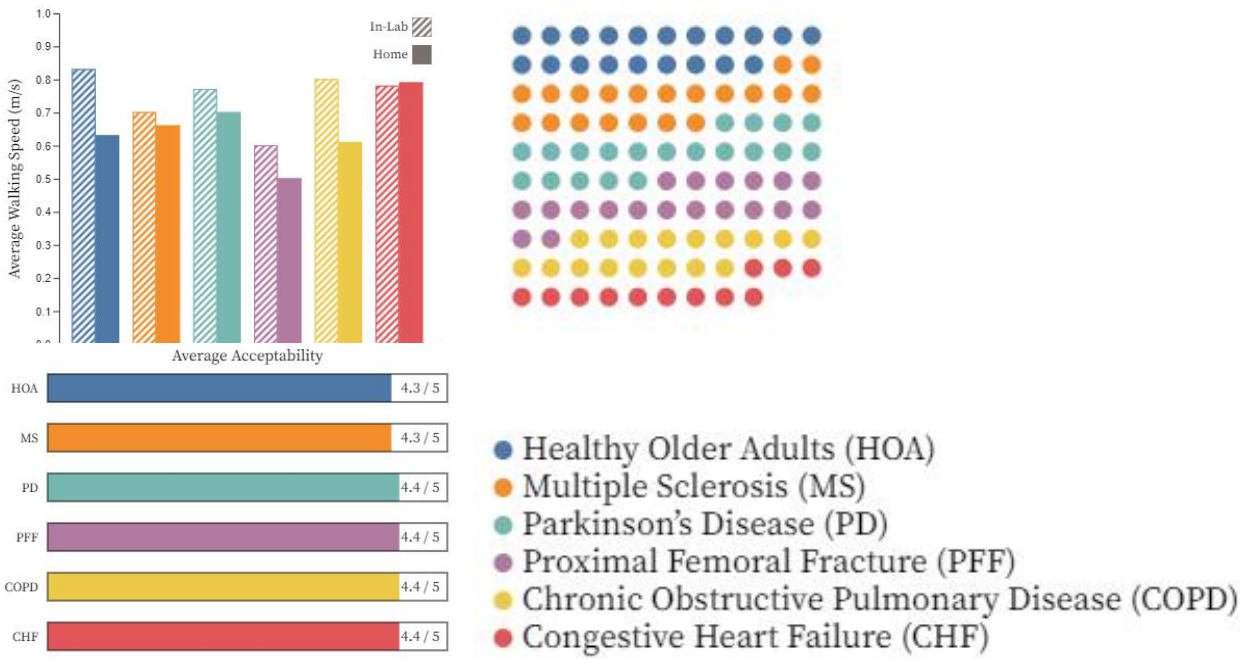
Not available on git hub yet

- will be available at the end of the project
- some features are still under publication process
- contact me if you want to access older version: alma.cantu@newcastle.ac.uk

Future work



Aggregation technique

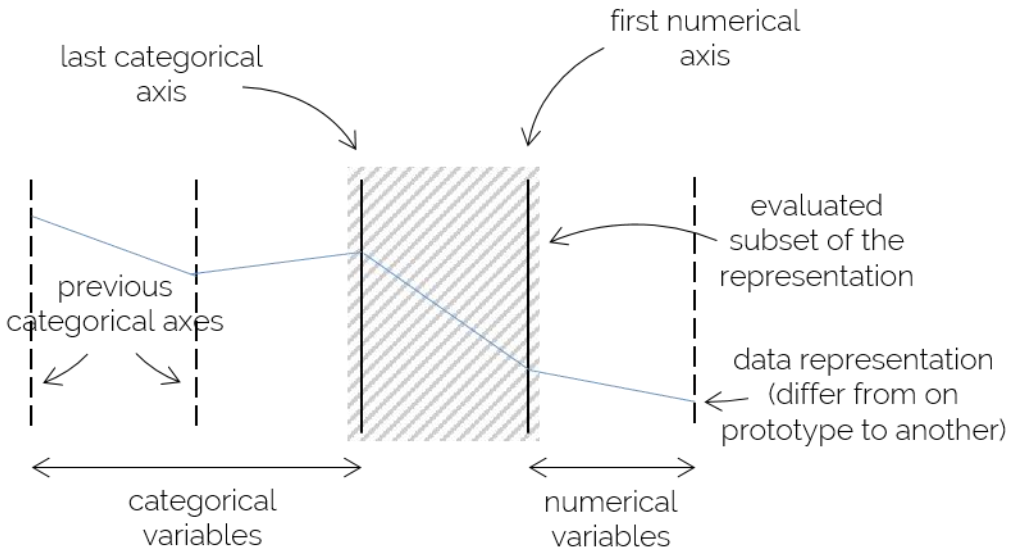


Visualization for patients

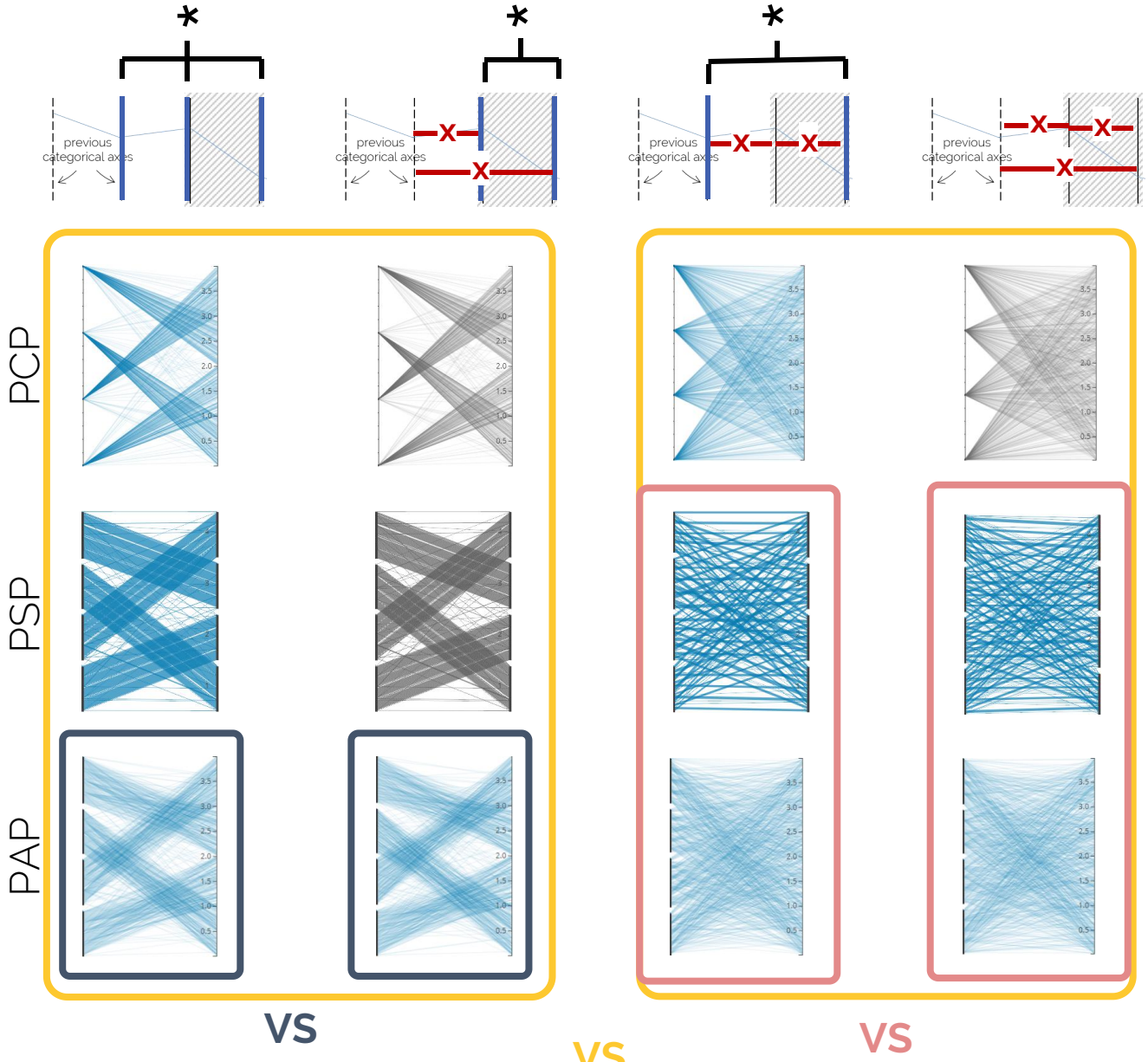
Thank you for your attention

Learn more on research.ncl.ac.uk/nova/projects/

Evaluation



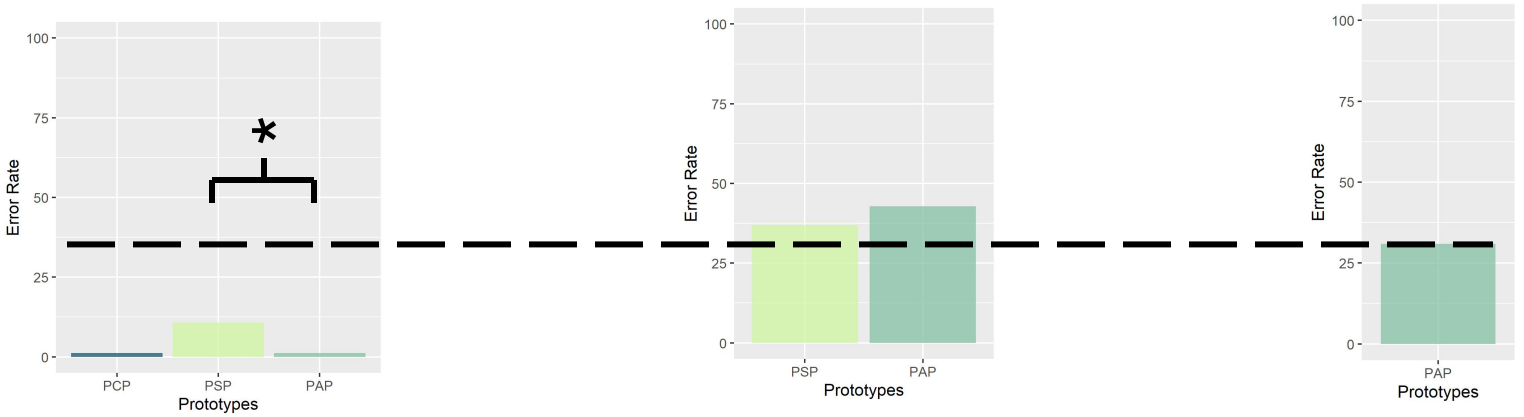
- Task 1: correlation vs no corelation
- Task 2: correlation uniquely with previous variable vs no correlation
- Task 3: full correlation or simple correlation



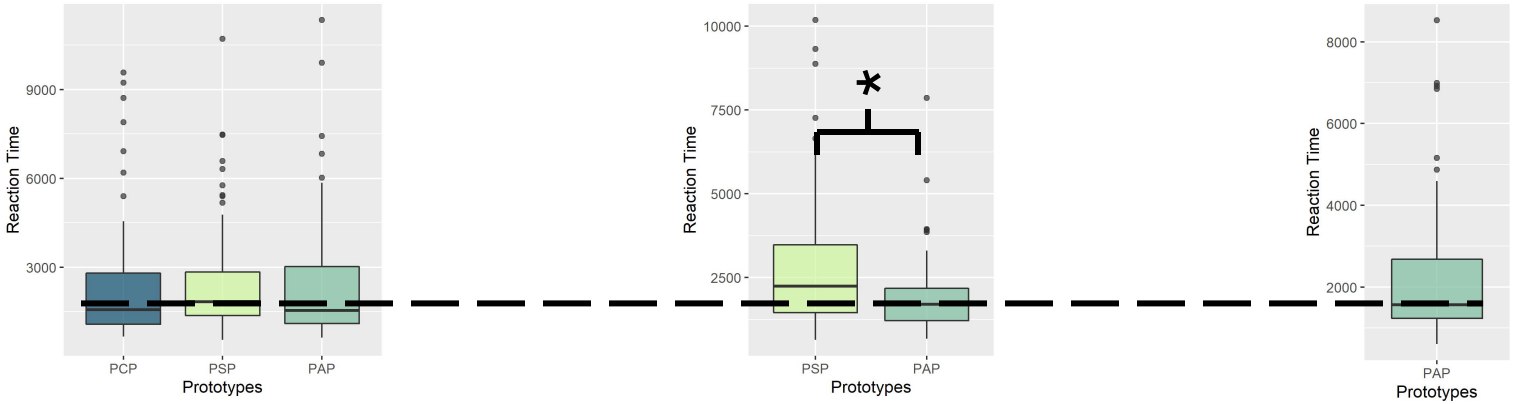
Results

Task 1 | Task 2 | Task 3

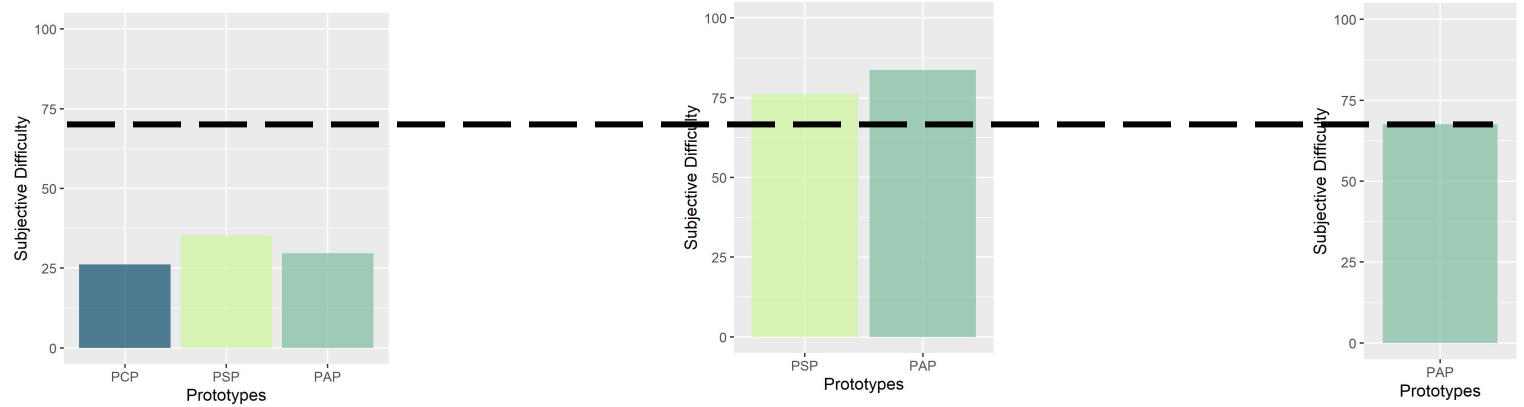
Error rate



Reaction time



Subjective difficulty



TVS – Visualization tool

Measurements are represented by lines and grouped in ribbons

Legend

Algorithms

Types of walking bouts

Cadence SS

Rel. error

Cohorts

Types of test

Cadence PS

Abs. error

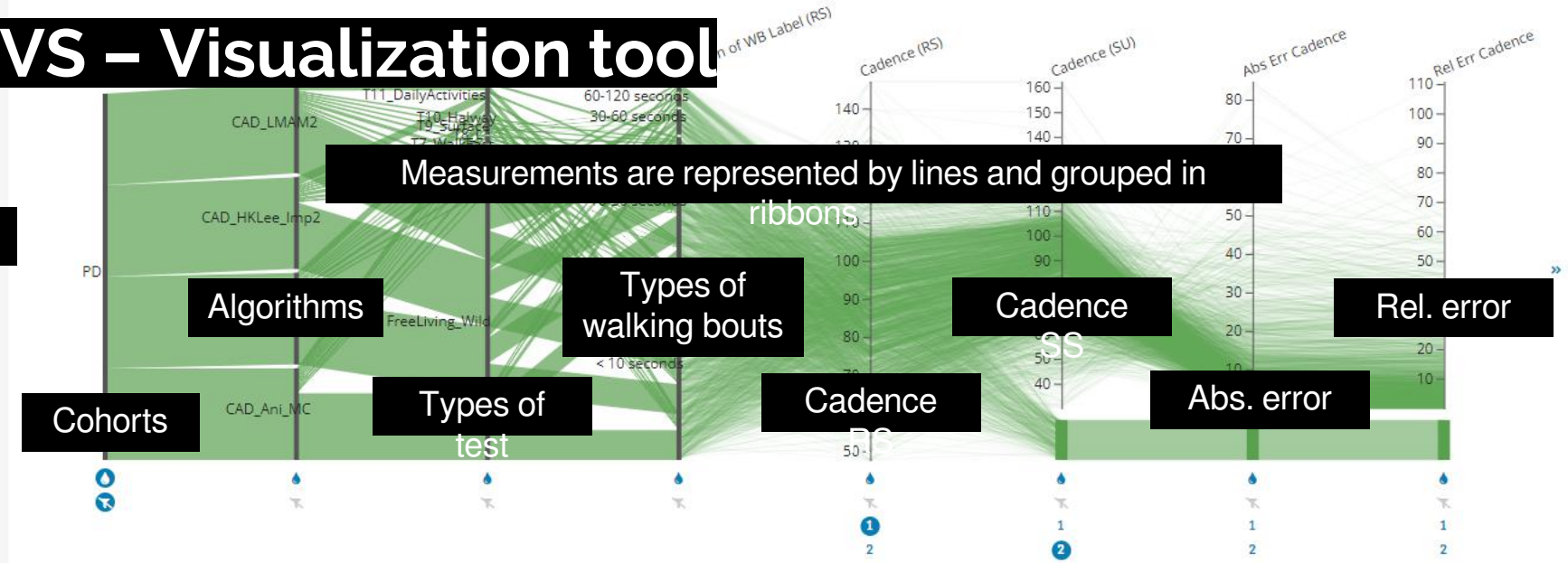
Possibility to access all the variables contained

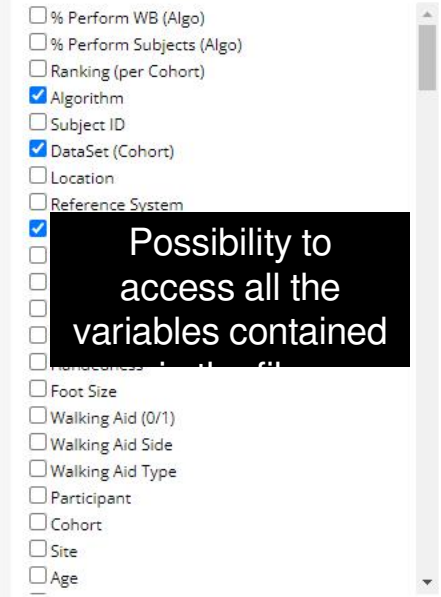
Summary of the displayed

Correlation plot on demand

Bland-Altman plot on demand

Access to detail on

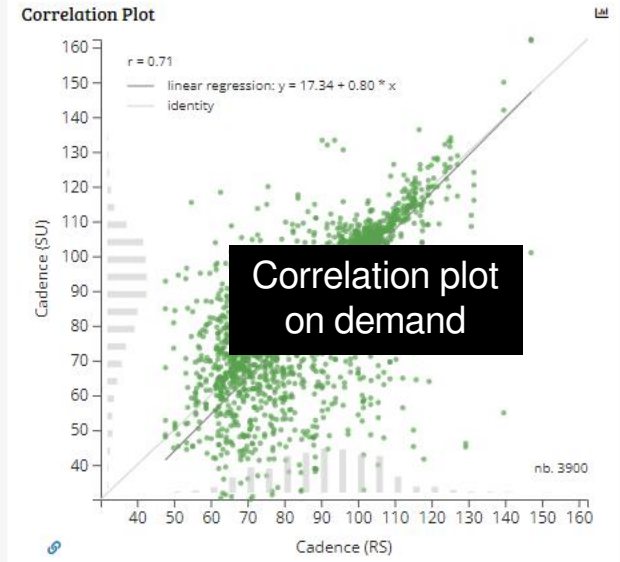


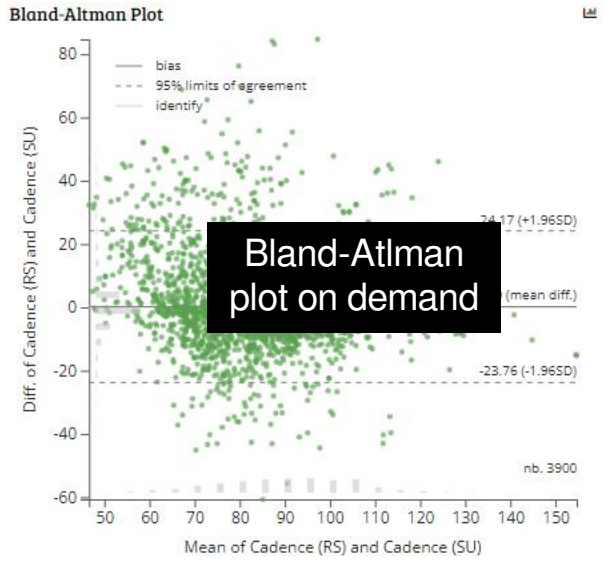


Summary

Metrics	Mean	95% CI
Cadence (RS)	87.21	[86.74, 87.68]
Cadence (SU)	87.18	[86.62, 87.74]
Abs Err Cadence	7.24	[6.91, 7.57]
Rel Err Cadence	8.87	[8.47, 9.27]

Export





Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

TVS Data Explorer: CAD_Matrix.csv

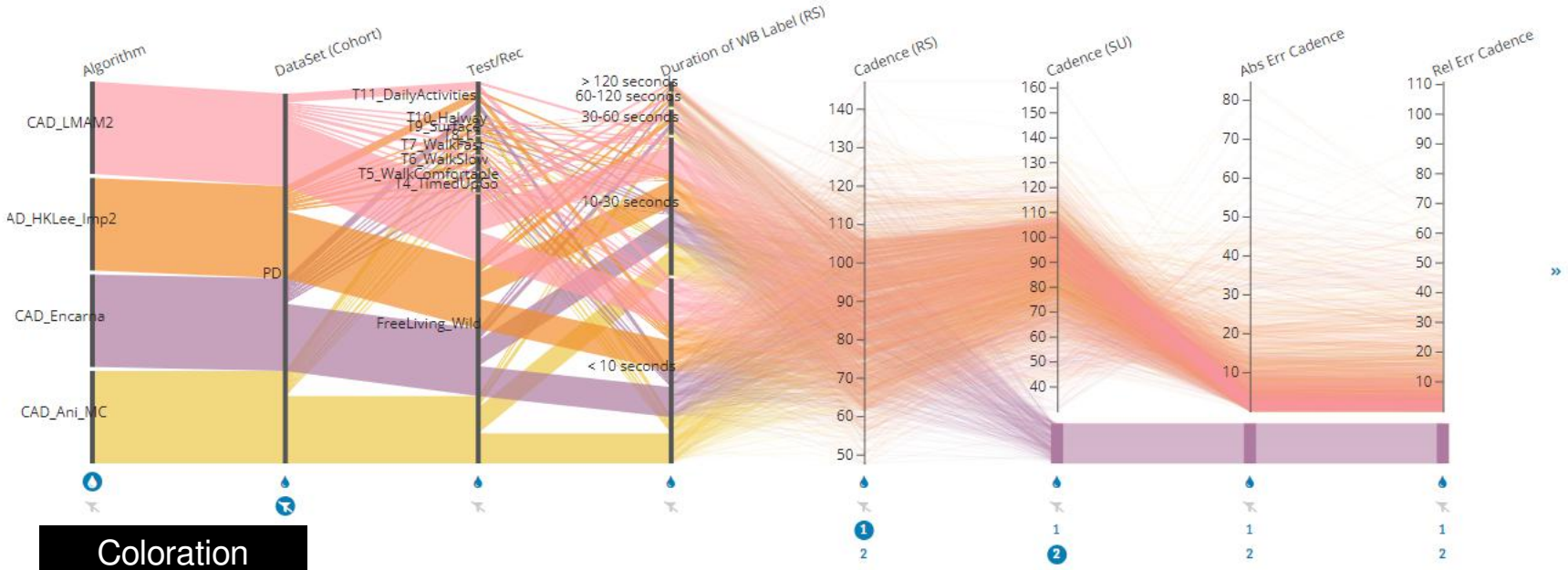
Newcastle University Mobilise-D

Legend

Coloration:

Visible data: 3900 / 25981

Overview



Coloration according to algorithms

Visible Variables

- [ ] % Perform WB (Algo)
- [ ] % Perform Subjects (Algo)
- [ ] Ranking (per Cohort)
- [x] Algorithm
- [ ] Subject ID
- [x] DataSet (Cohort)
- [ ] Location
- [ ] Reference System
- [x] Test/Rec
- [ ] Trial
- [ ] Height
- [ ] Weight
- [ ] Sensor Height
- [ ] Handedness
- [ ] Foot Size
- [ ] Walking Aid (0/1)
- [ ] Walking Aid Side
- [ ] Walking Aid Type
- [ ] Participant
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- [ ] Age

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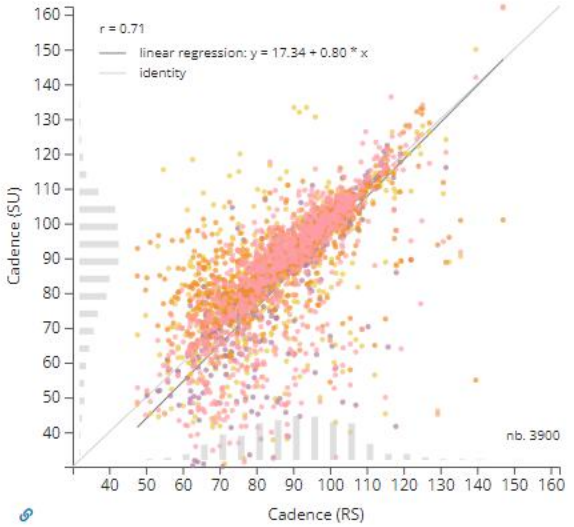
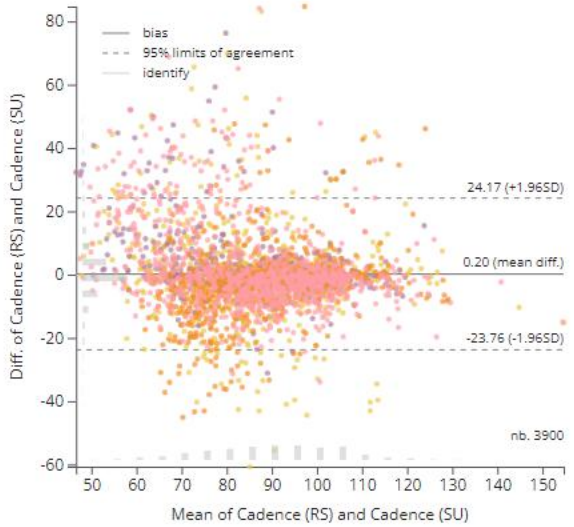
Cadence (SU)	87.18	[86.62, 87.74]
Abs Err Cadence	7.24	[6.91, 7.57]
Rel Err Cadence	8.87	[8.47, 9.27]

Export

Correlation Plot



Bland-Altman Plot



Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Location:	Laborato
Reference System:	Stereoph
Test/Rec:	T7_Walk
Trial:	Trial1
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

TVS Data Explorer: CAD_Matrix.csv

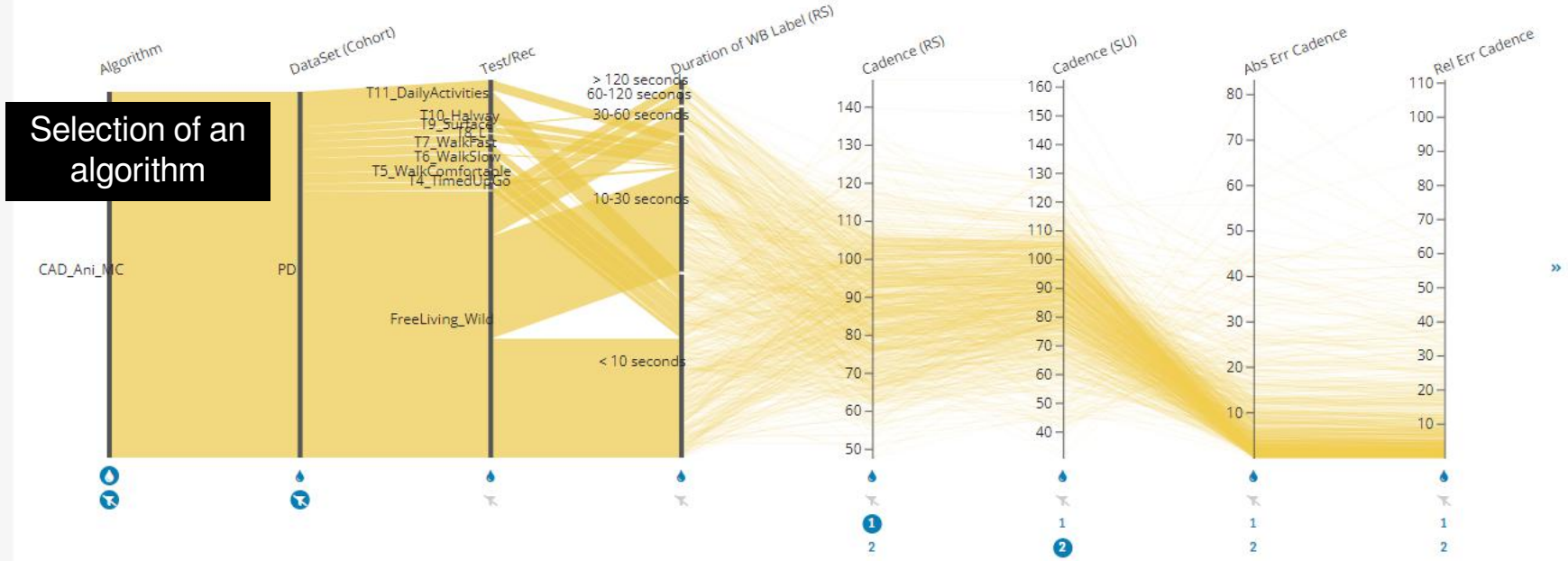
Newcastle University Mobilise-D

Legend

Coloration:

Visible data: 97 / 45985

Overview



Visible Variables

- [ ] % Perform WB (Algo)
- [ ] % Perform Subjects (Algo)
- [ ] Ranking (per Cohort)
- [x] Algorithm
- [ ] Subject ID
- [x] DataSet (Cohort)
- [ ] Location
- [ ] Reference System
- [x] Test/Rec
- [ ] Trial
- [ ] Height
- [ ] Weight
- [ ] Sensor Height
- [ ] Handedness
- [ ] Foot Size
- [ ] Walking Aid (0/1)
- [ ] Walking Aid Side
- [ ] Walking Aid Type
- [ ] Participant
- [ ] Cohort
- [ ] Site
- [ ] Age

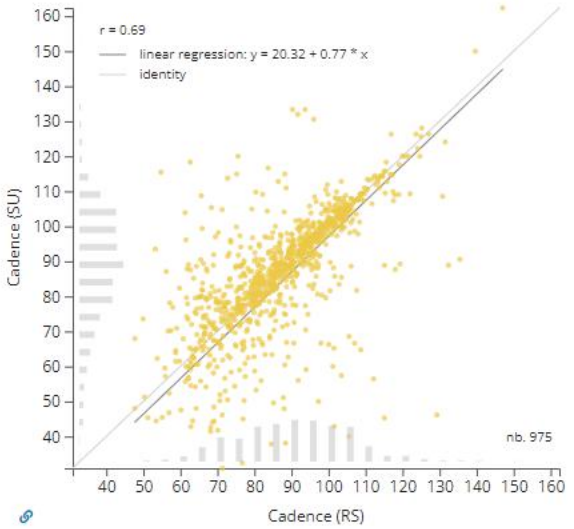
Summary

All

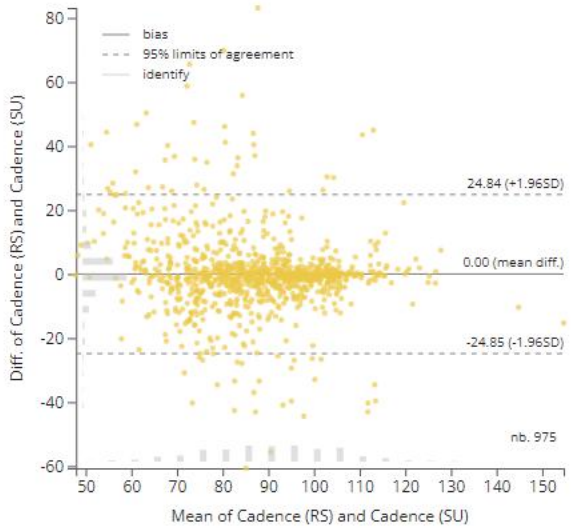
Per color	CAD_Ani_MC	
Metrics	Mean	95% CI
Cadence (RS)	87.21	[86.27, 88.15]
Cadence (SU)	87.21	[86.16, 88.26]
Abs Err Cadence	7.37	[6.73, 8.02]
Rel Err Cadence	9.11	[8.30, 9.92]

Export

Correlation Plot



Bland-Altman Plot



Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Location:	Laborato
Reference System:	Stereoph
Test/Rec:	T7_Walk
Trial:	Trial1
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

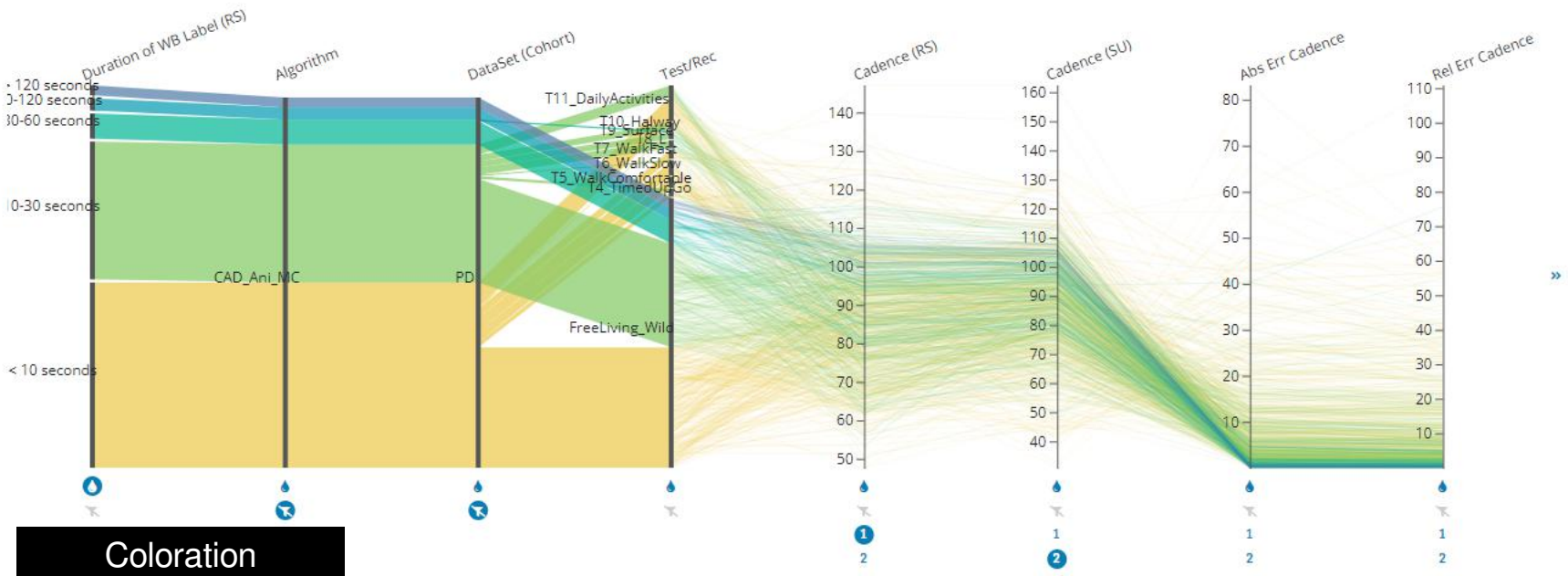
TVS Data Explorer: CAD_Matrix.csv

Newcastle University Mobilise-D

Legend

Coloration: Visible data:

Overview



Coloration according to types of walking bouts

Visible Variables

- [ ] % Perform WB (Algo)
- [ ] % Perform Subjects (Algo)
- [ ] Ranking (per Cohort)
- [x] Algorithm
- [ ] Subject ID
- [x] DataSet (Cohort)
- [ ] Location
- [ ] Reference System
- [x] Test/Rec
- [ ] Trial
- [ ] Height
- [ ] Weight
- [ ] Sensor Height
- [ ] Handedness
- [ ] Foot Size
- [ ] Walking Aid (0/1)
- [ ] Walking Aid Side
- [ ] Walking Aid Type
- [ ] Participant
- [ ] Cohort
- [ ] Site
- [ ] Age

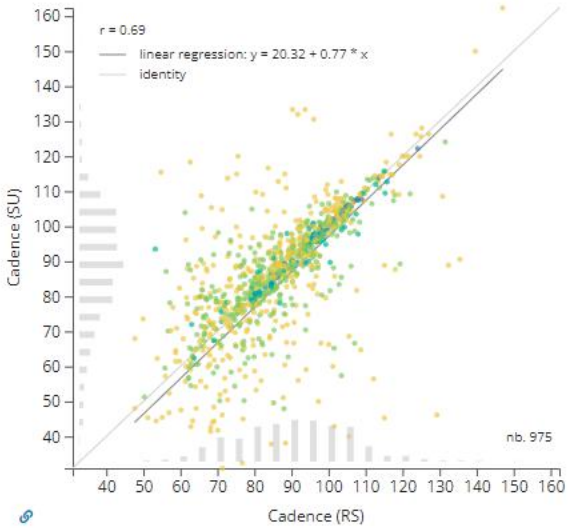
Summary

All

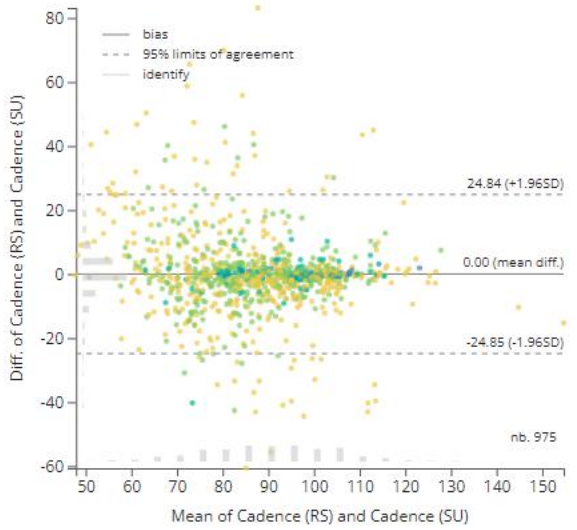
Per color	< 10 seconds		10-30 seconds		30-60 seconds		60-120 seconds		> 120 seconds	
Metrics	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Cadence (RS)	85.54	[84.12, 86.95]	86.60	[85.19, 88.00]	92.53	[89.29, 95.77]	94.80	[91.94, 97.67]	104.27	[101.83, 106.71]
Cadence (SU)	85.47	[83.77, 87.17]	86.61	[85.19, 88.04]	92.95	[90.16, 95.73]	94.82	[91.92, 97.72]	104.36	[102.00, 106.73]
Abs Err Cadence	9.74	[8.65, 10.84]	6.05	[5.27, 6.83]	2.92	[1.62, 4.22]	0.96	[0.55, 1.36]	0.47	[0.31, 0.63]
Rel Err Cadence	12.04	[10.70, 13.37]	7.48	[6.48, 8.49]	3.75	[1.45, 6.04]	1.00	[0.58, 1.41]	0.45	[0.30, 0.59]

Export

Correlation Plot



Bland-Altman Plot



Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Location:	Laborato
Reference System:	Stereoph
Test/Rec:	T7_Walk
Trial:	Trial1
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

TVS Data Explorer: CAD_Matrix.csv

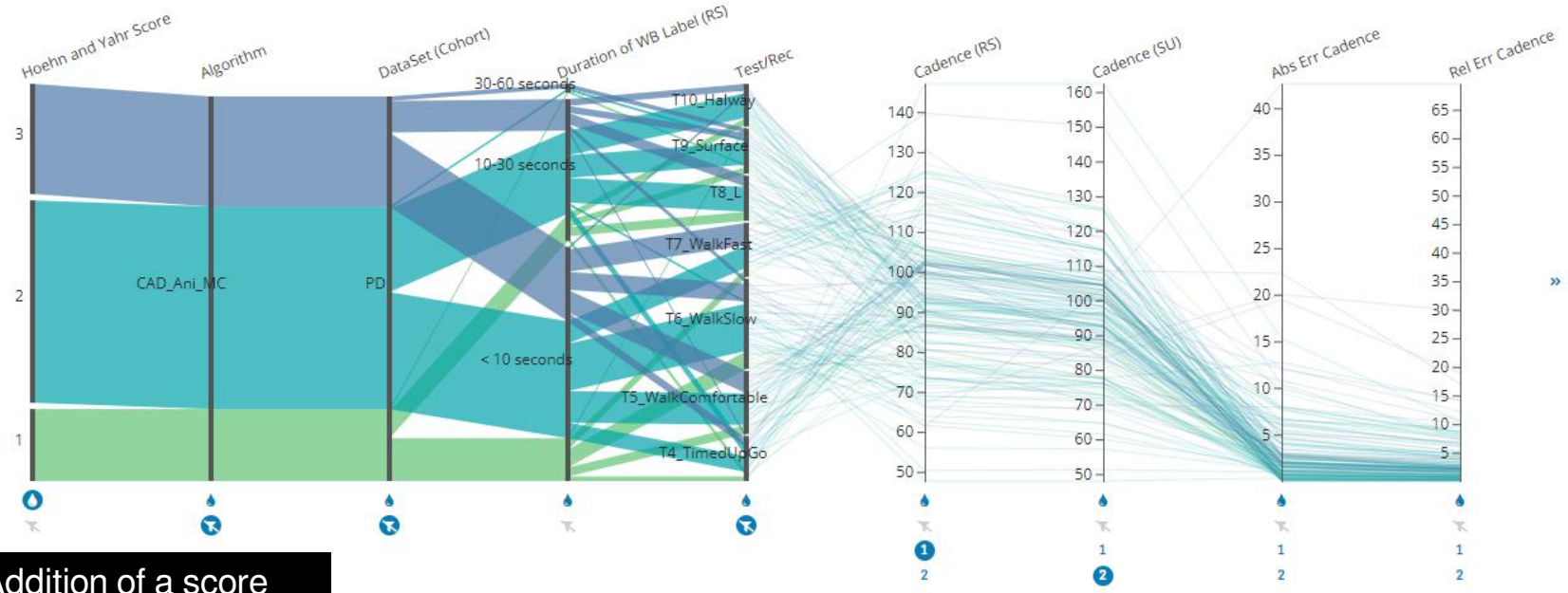
Newcastle University Mobilise-D

Legend

Coloration:

Visible data:

Overview



Addition of a score related to PD diagnose

Visible Variables

- [ ] Falls
- [ ] Medications
- [ ] Walking Aids Yes/No
- [ ] General Pain
- [ ] Walking Pain
- [x] Hoehn and Yahr Score
- [ ] SPPB Score
- [ ] CAT Score
- [ ] FEV1
- [ ] FVC
- [ ] 6MWT Distance
- [ ] KCCQ 12 Score
- [ ] EDSS Step
- [ ] Clinical Condition
- [ ] Cadence Ref. (RS)
- [ ] Duration Ref. (RS)
- [x] Duration of WB Label (RS)
- [ ] Walking Speed Ref. (RS)
- [ ] Av. Stride Length (RS)
- [ ] Num Strides WB (RS)
- [ ] Num Strides WB Label (RS)
- [ ] Av. Stride Speed (RS)

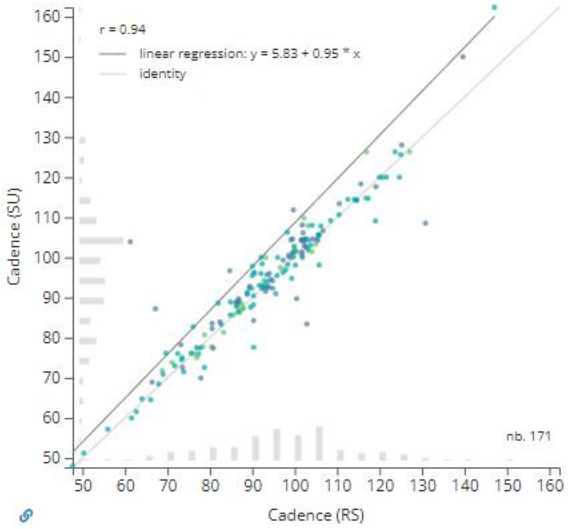
Summary

All

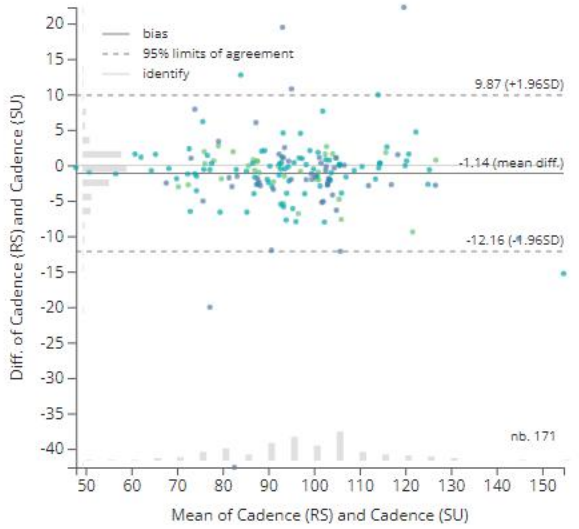
Per color	1		2		3	
Metrics	Mean	95% CI	Mean	95% CI	Mean	95% CI
Cadence (RS)	92.98	[88.29, 97.66]	93.10	[89.41, 96.79]	95.83	[91.49, 100.17]
Cadence (SU)	94.06	[89.14, 98.98]	93.88	[90.12, 97.65]	97.68	[93.56, 101.79]
Abs Err Cadence	2.26	[1.48, 3.03]	2.51	[1.92, 3.10]	5.13	[3.03, 7.22]
Rel Err Cadence	2.40	[1.64, 3.16]	2.71	[2.12, 3.30]	5.93	[2.90, 8.97]

Export

Correlation Plot



Bland-Altman Plot



Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Location:	Laborato
Reference System:	Stereoph
Test/Rec:	T7_Walk
Trial:	Trial1
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

TVS Data Explorer: CAD_Matrix.csv

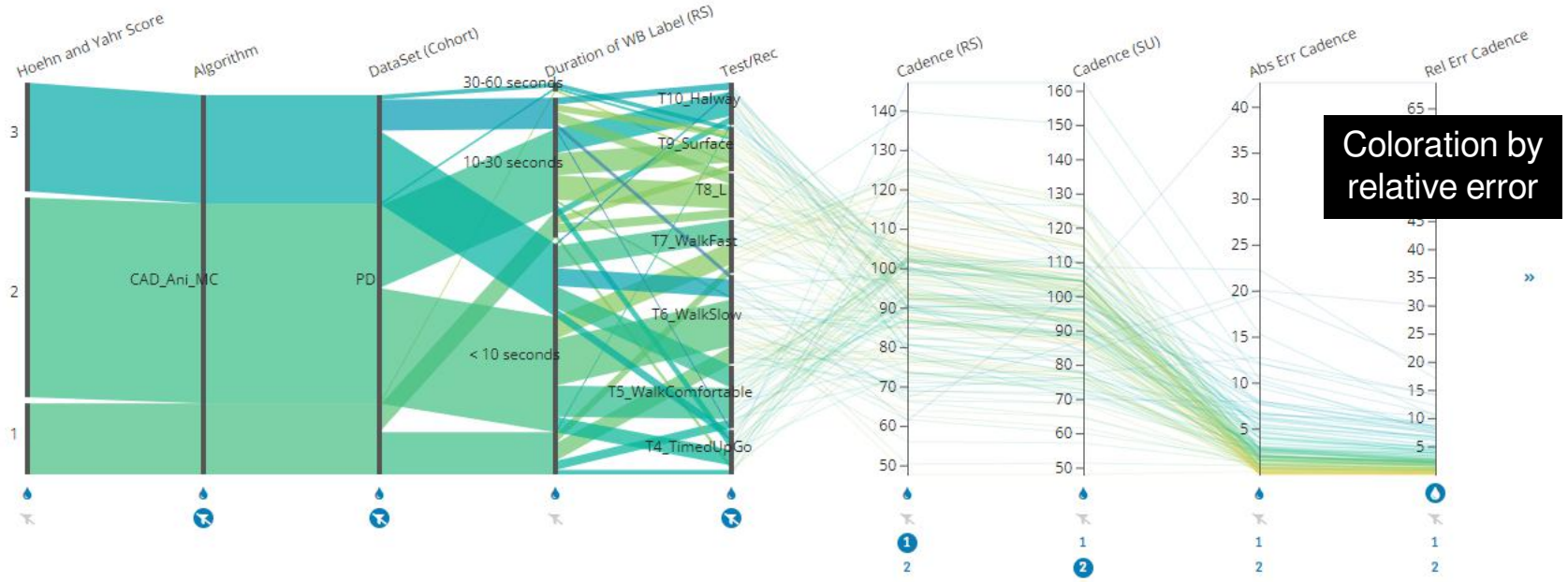
Newcastle University Mobilise-D

Legend

Coloration: 0.01 – 69.2

Visible data: 1 / 75968

Overview



Visible Variables

- [ ] Falls
- [ ] Medications
- [ ] Walking Aids Yes/No
- [ ] General Pain
- [ ] Walking Pain
- [x] Hoehn and Yahr Score
- [ ] SPPB Score
- [ ] CAT Score
- [ ] FEV1
- [ ] FVC
- [ ] 6MWT Distance
- [ ] KCCQ 12 Score
- [ ] EDSS Step
- [ ] Clinical Condition
- [ ] Cadence Ref. (RS)
- [ ] Duration Ref. (RS)
- [x] Duration of WB Label (RS)
- [ ] Walking Speed Ref. (RS)
- [ ] Av. Stride Length (RS)
- [ ] Num Strides WB (RS)
- [ ] Num Strides WB Label (RS)
- [ ] Av. Stride Speed (RS)

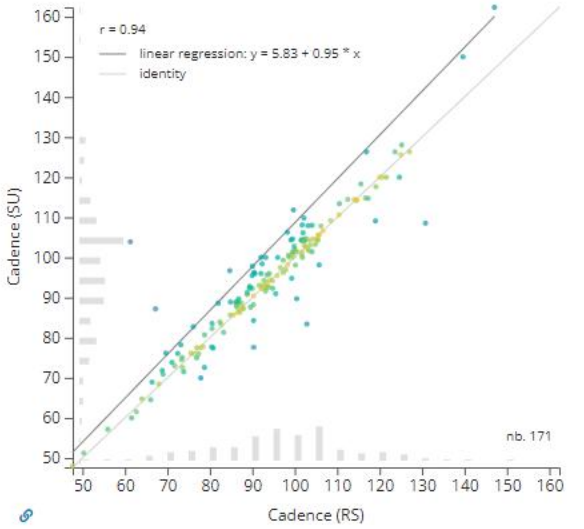
Summary

All

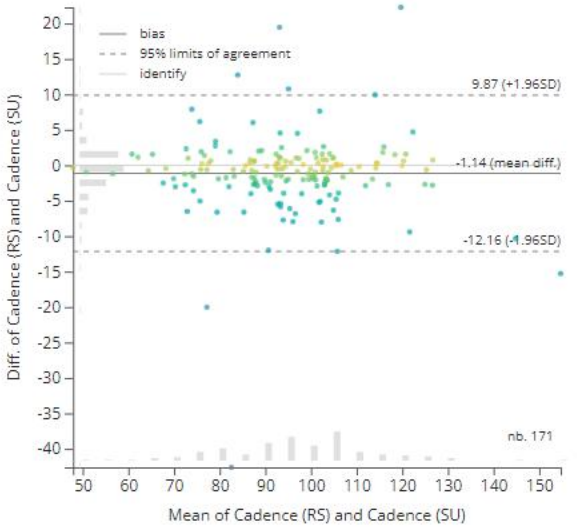
Metrics	Mean	95% CI
Cadence (RS)	93.86	[91.40, 96.32]
Cadence (SU)	95.00	[92.52, 97.49]
Abs Err Cadence	3.21	[2.50, 3.92]
Rel Err Cadence	3.58	[2.62, 4.53]

Export

Correlation Plot



Bland-Altman Plot



Selected Datum

% Perform WB (Algo):	100.00
% Perform Subjects (Algo):	100.00
Ranking (per Cohort):	23
Algorithm:	CAD_Enc
Subject ID:	S1020
DataSet (Cohort):	COPD
Location:	Laborato
Reference System:	Stereoph
Test/Rec:	T7_Walk
Trial:	Trial1
Height:	157.00
Weight:	60.00
Sensor Height:	96.20
Handedness:	R
Foot Size:	24.70
Walking Aid (0/1):	0
Walking Aid Side:	none
Walking Aid Type:	none

TVS Data Explorer: CAD_Matrix.csv

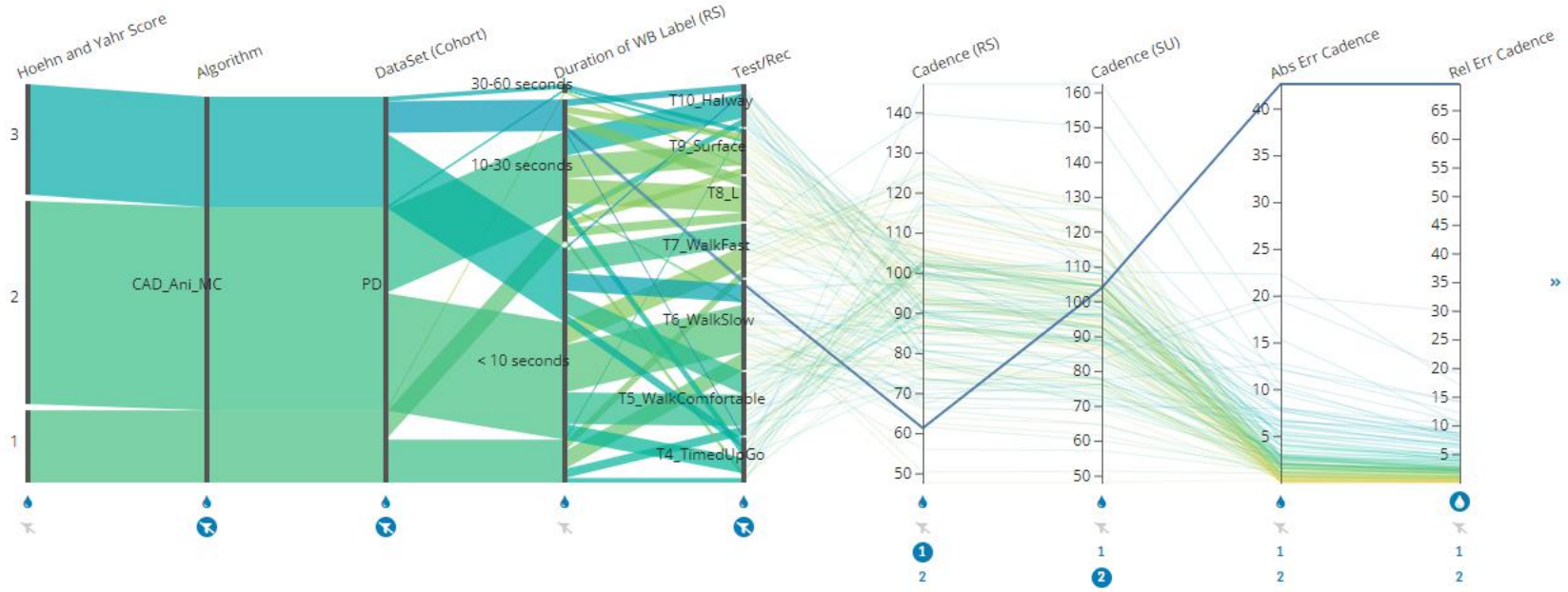
Newcastle University Mobilise-D

Legend

Coloration: 69.2 0.01

Visible data: 171 / 2598

Overview



Visible Variables

- [ ] Walking Aid (0/1)
- [ ] Walking Aid Side
- [ ] Walking Aid Type
- [ ] Participant
- [ ] Cohort
- [ ] Site
- [ ] Age
- [ ] Gender
- [ ] MOCA Score
- [ ] Residence
- [ ] Falls
- [ ] Medications
- [ ] Walking Aids Yes/No
- [ ] General Pain
- [ ] Walking Pain
- [x] Hoehn and Yahr Score
- [ ] SPPB Score
- [ ] CAT Score
- [ ] FEV1
- [ ] FVC
- [ ] 6MWT Distance
- [ ] KCCQ 12 Score

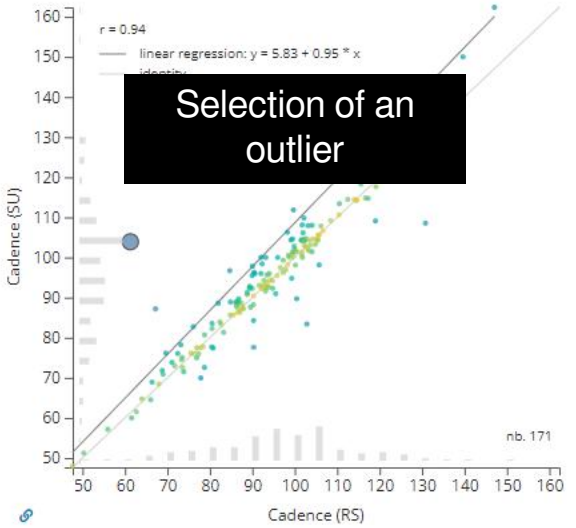
Summary

All

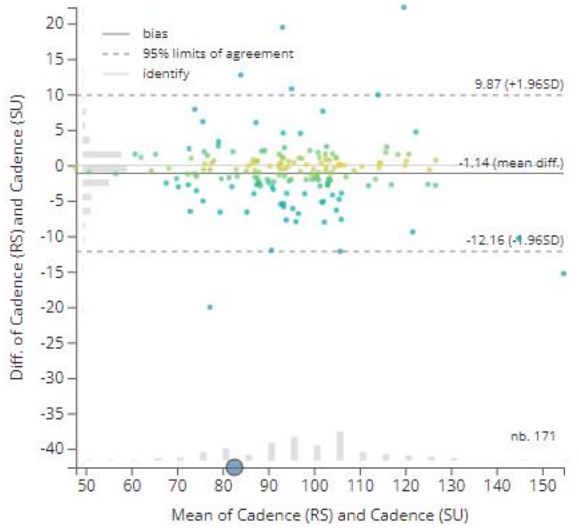
Metrics	Mean	95% CI
Cadence (RS)	93.86	[91.40, 96.32]
Cadence (SU)	95.00	[92.52, 97.49]
Abs Err Cadence	3.21	[2.50, 3.92]
Rel Err Cadence	3.58	[2.62, 4.53]

Export

Correlation Plot



Bland-Altman Plot



Selected Datum

Trial:	Trial1
Height:	156.00
Weight:	83.00
Sensor Height:	98.90
Handedness:	R
Foot Size:	27.00
Walking Aid (0/1):	1
Walking Aid Side:	Bilateral
Walking Aid Type:	Rollator
Participant:	4017
Cohort:	PD
Site:	CAU
Age:	70.00
Gender:	Female
MOCA Score:	20.00
Residence:	Nursing
Falls:	10.00
Medications:	Dridase,
Walking Aids Yes/No:	Y
General Pain:	22.00