

SpiroSmart

Using a Microphone to Measure Lung Function
on a Mobile Phone

Eric Larson, Mayank Goel,

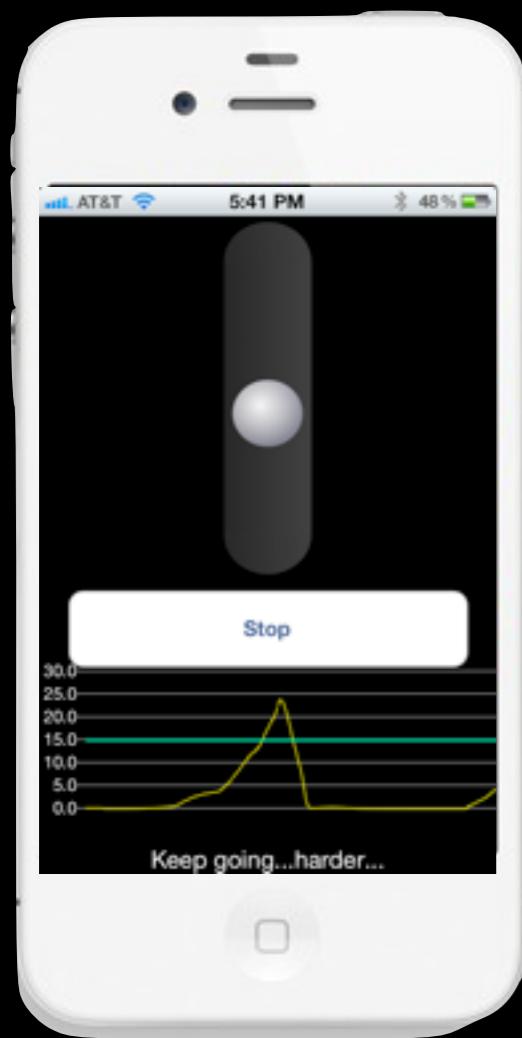
Gaetano Borriello, Sonya Heltshe, Margaret Rosenfeld, Shwetak Patel

University of Washington

UbiComp Lab

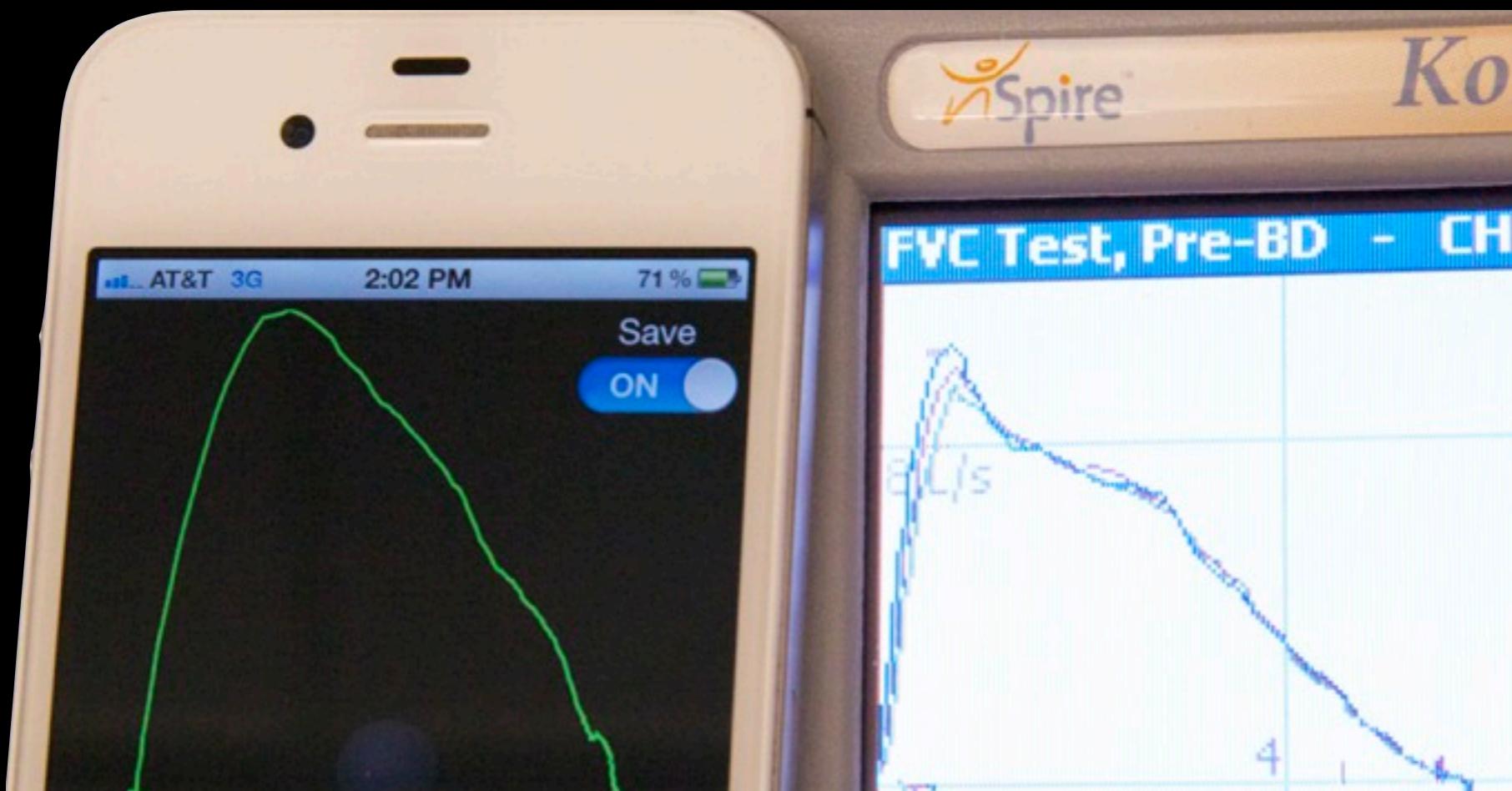


What is SpiroSmart?



A smartphone based spirometer that leverages on-device microphone to help you keep track of your lung function.

Performance

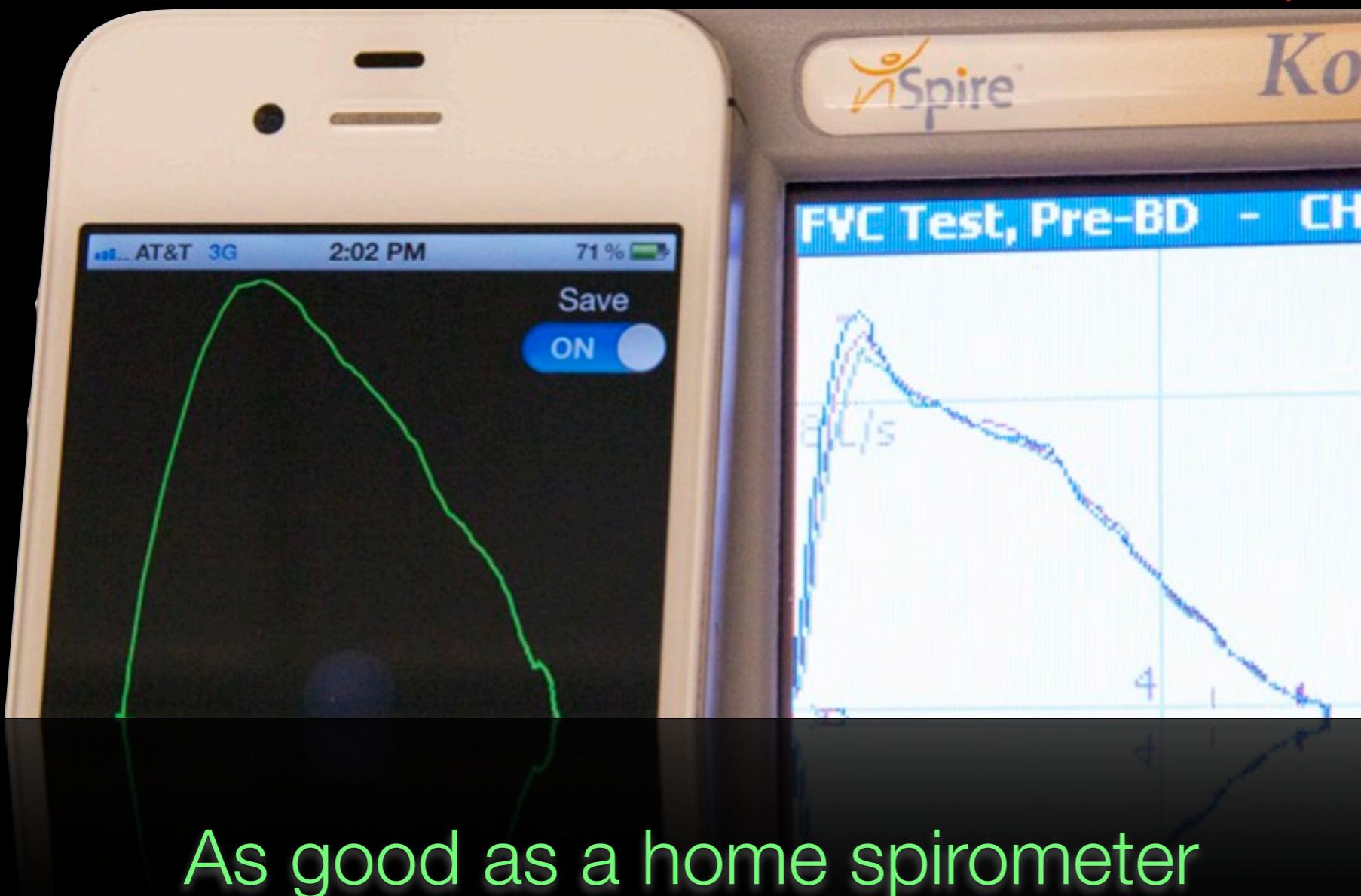


As good as a home spirometer

Error within 5.1% in a study with 52 participants

Performance

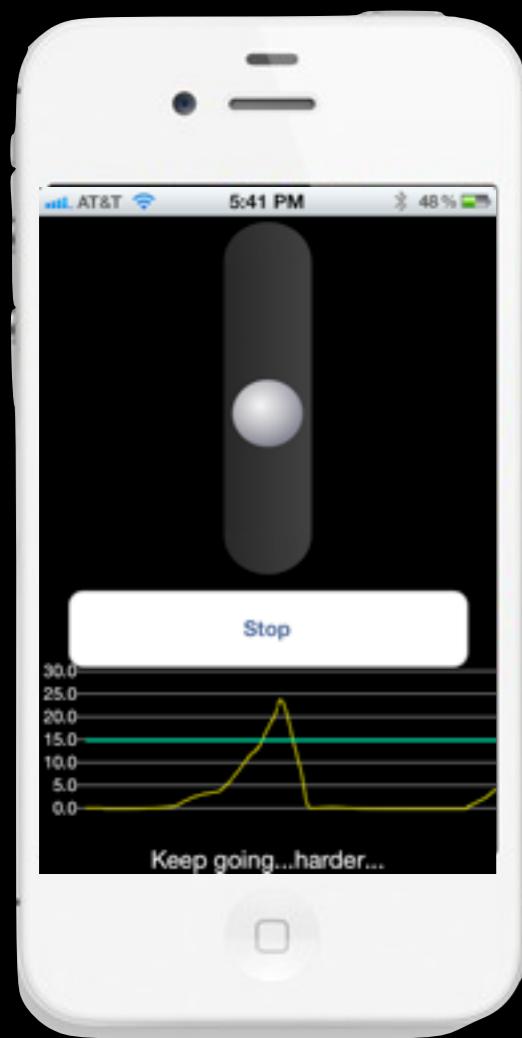
> \$2000



As good as a home spirometer

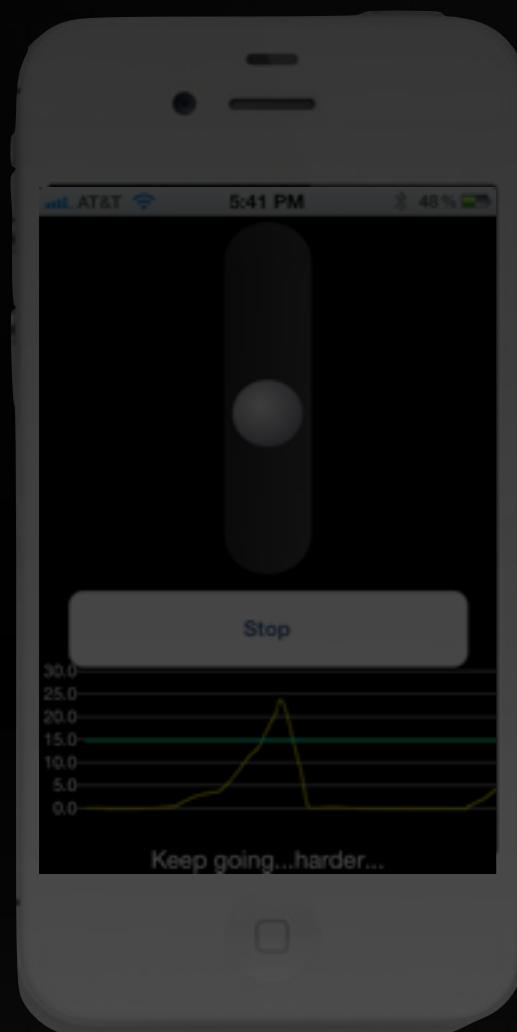
Error within 5.1% in a study with 52 participants

What is SpiroSmart?



A smartphone based spirometer
that helps you keep track of your
lung function.

What is SpiroSmart?



A smartphone based **spirometer** that helps you keep track of your lung function.

Spirometer?



Device that measures
amount of air inhaled and
exhaled.

Lung Function?



Evaluates severity of pulmonary impairments.

For example:

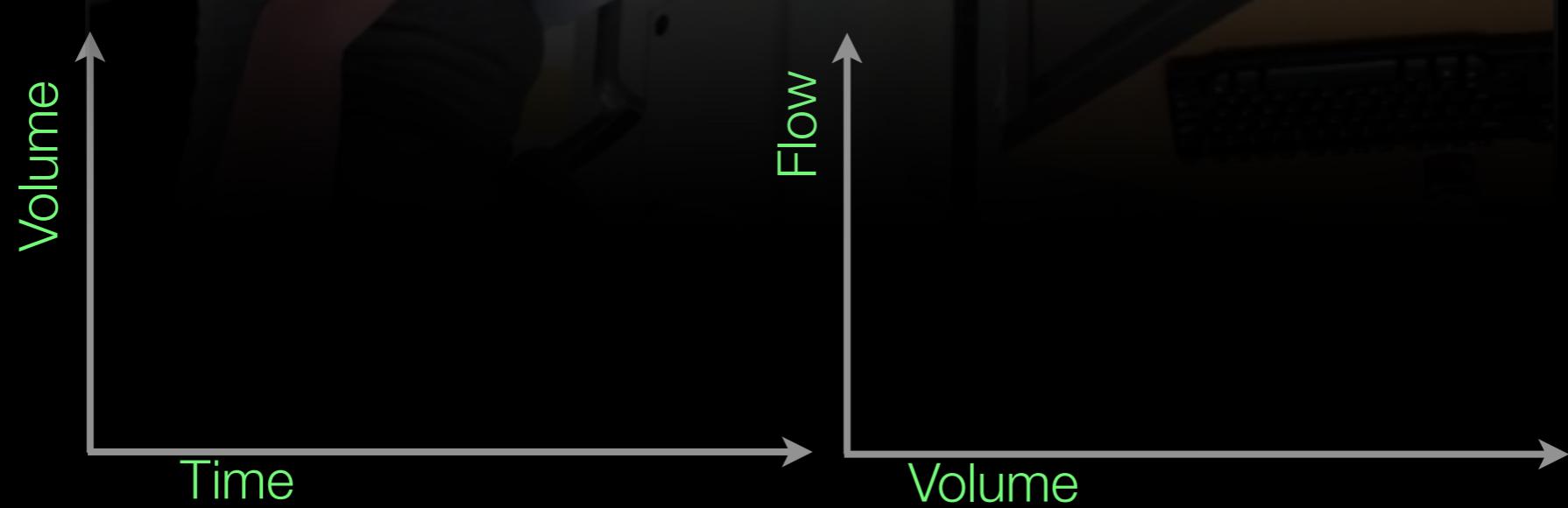
Asthma

COPD

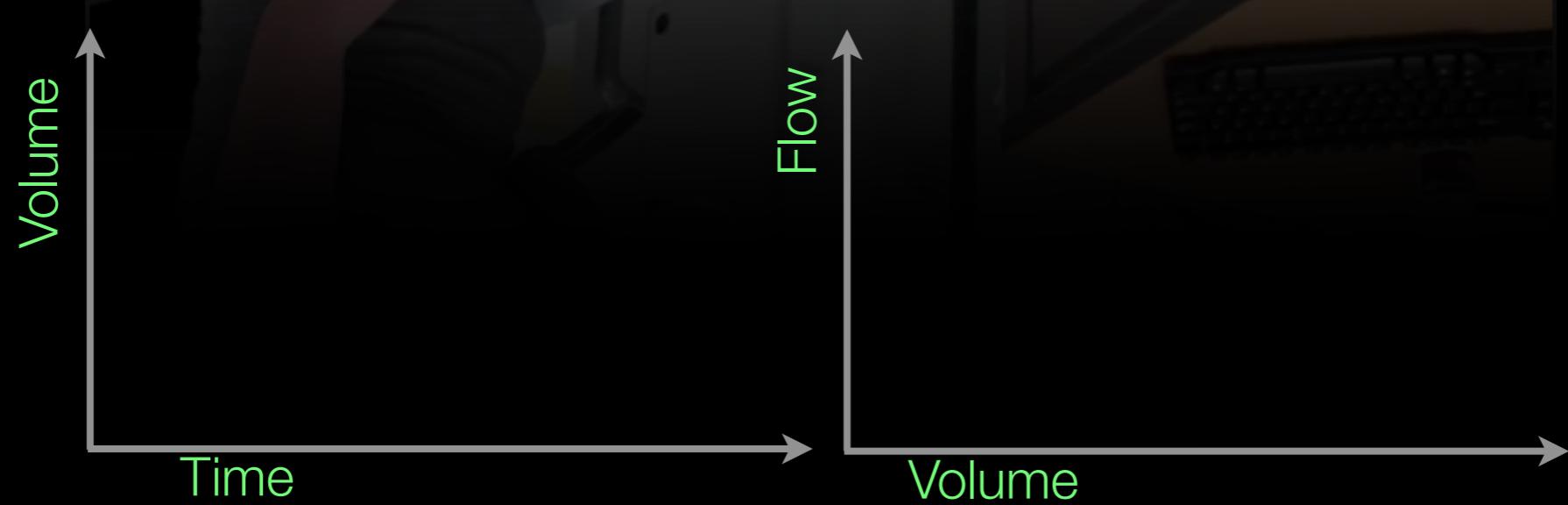
Cystic Fibrosis

Chronic Bronchitis

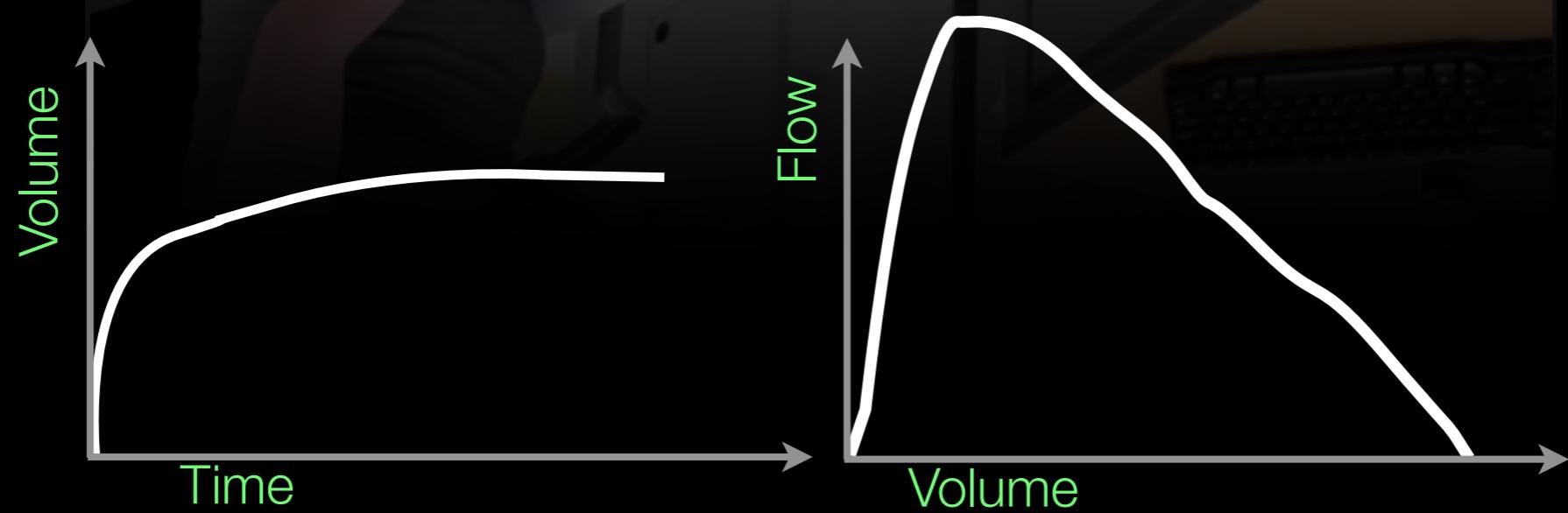
Using a spirometer



Using a spirometer



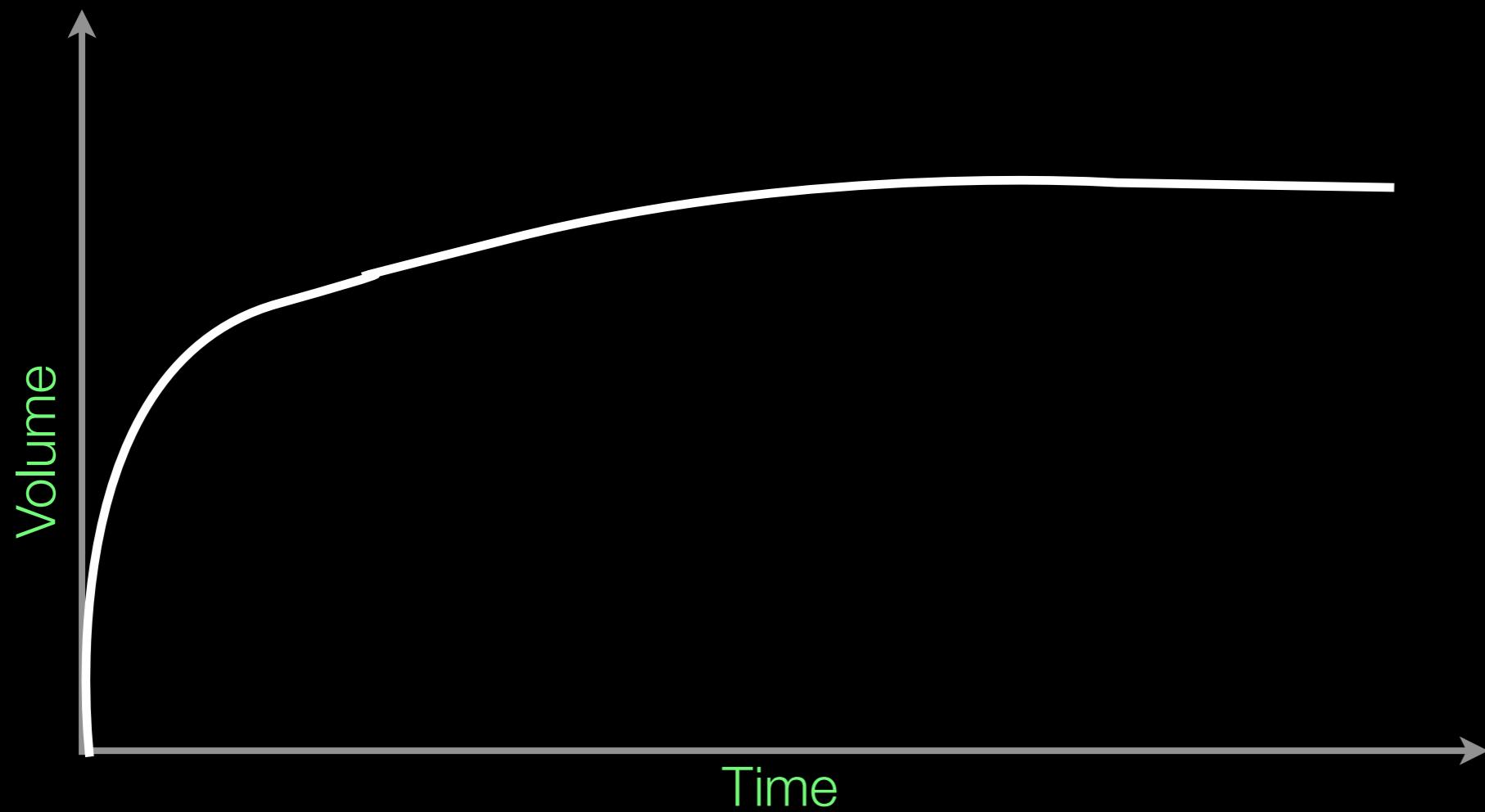
Using a spirometer



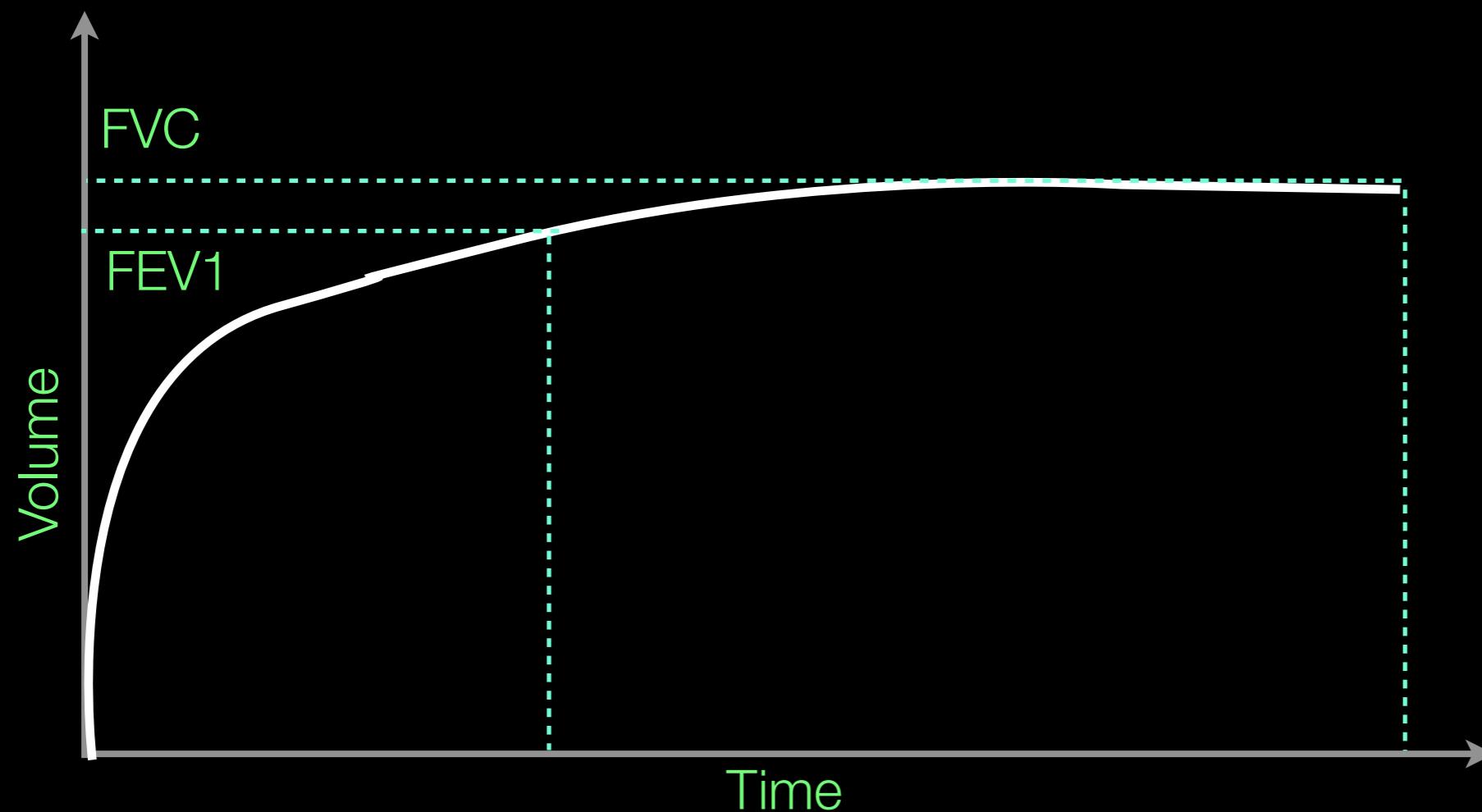
Volume-Time Graph



Volume-Time Graph

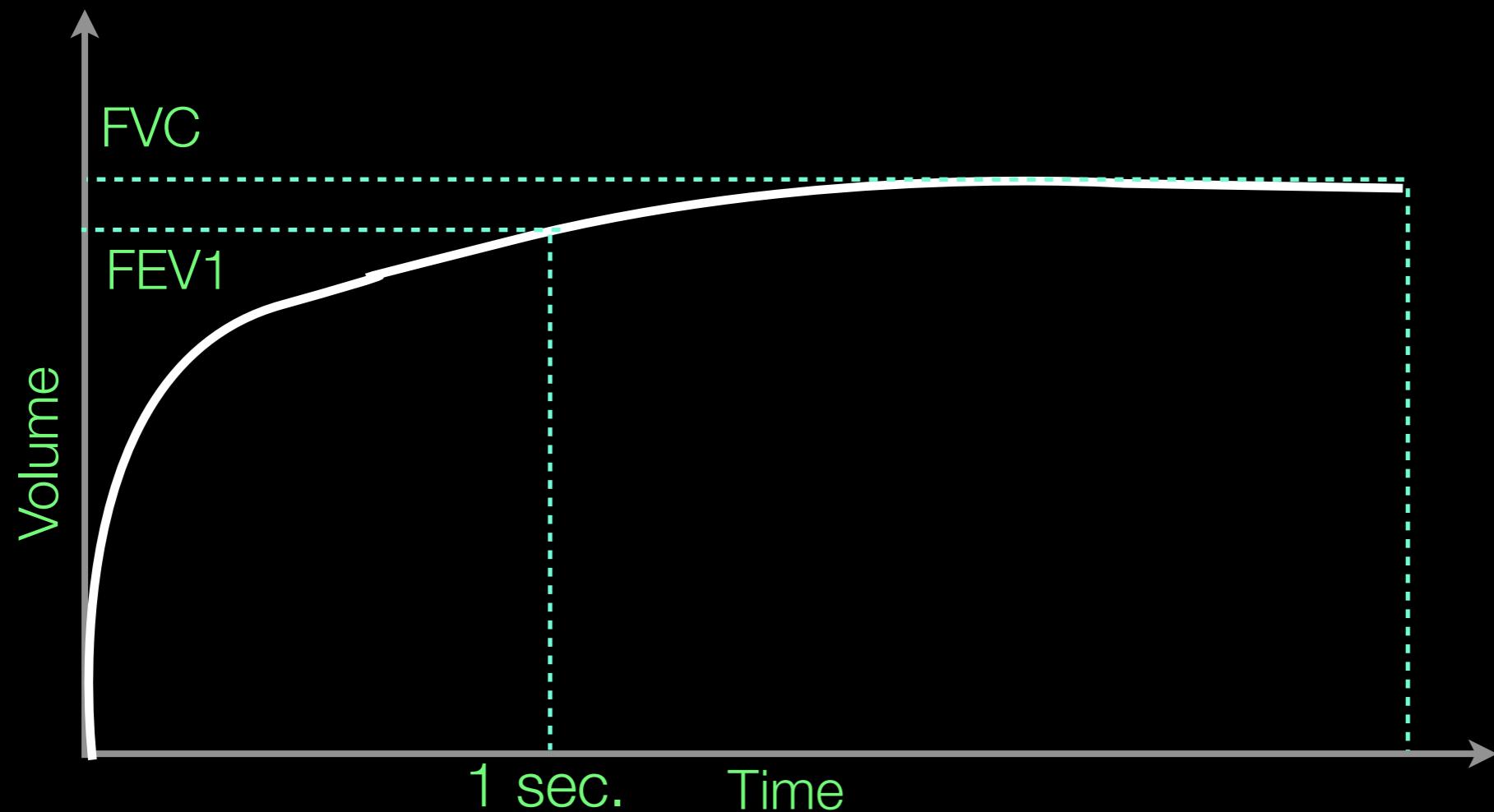


Volume-Time Graph



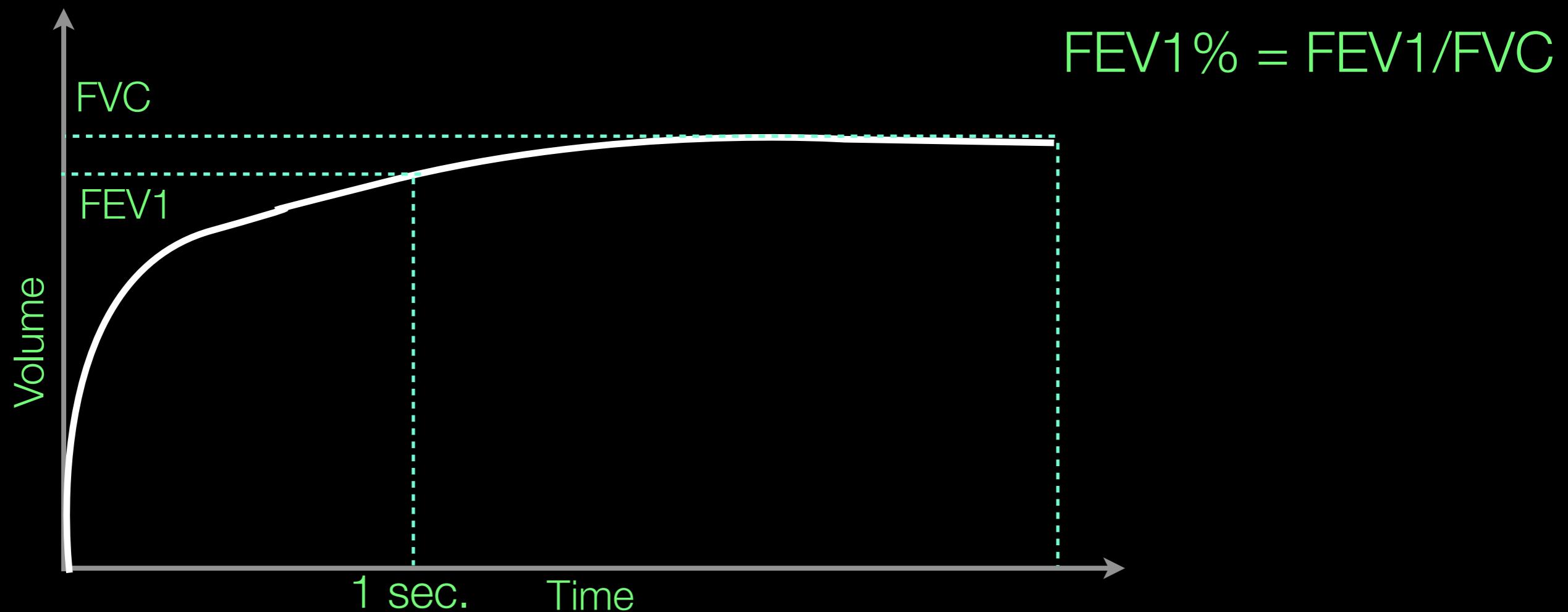
FEV1: Forced Expiratory Volume in 1 second
FVC: Forced Vital Capacity

Volume-Time Graph



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Volume-Time Graph



FEV1: Forced Expiratory Volume in 1 second
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Volume-Time Graph

$$\text{FEV1\%} = \text{FEV1/FVC}$$

FEV1: Forced Expiratory Volume in 1 second
FVC: Forced Vital Capacity

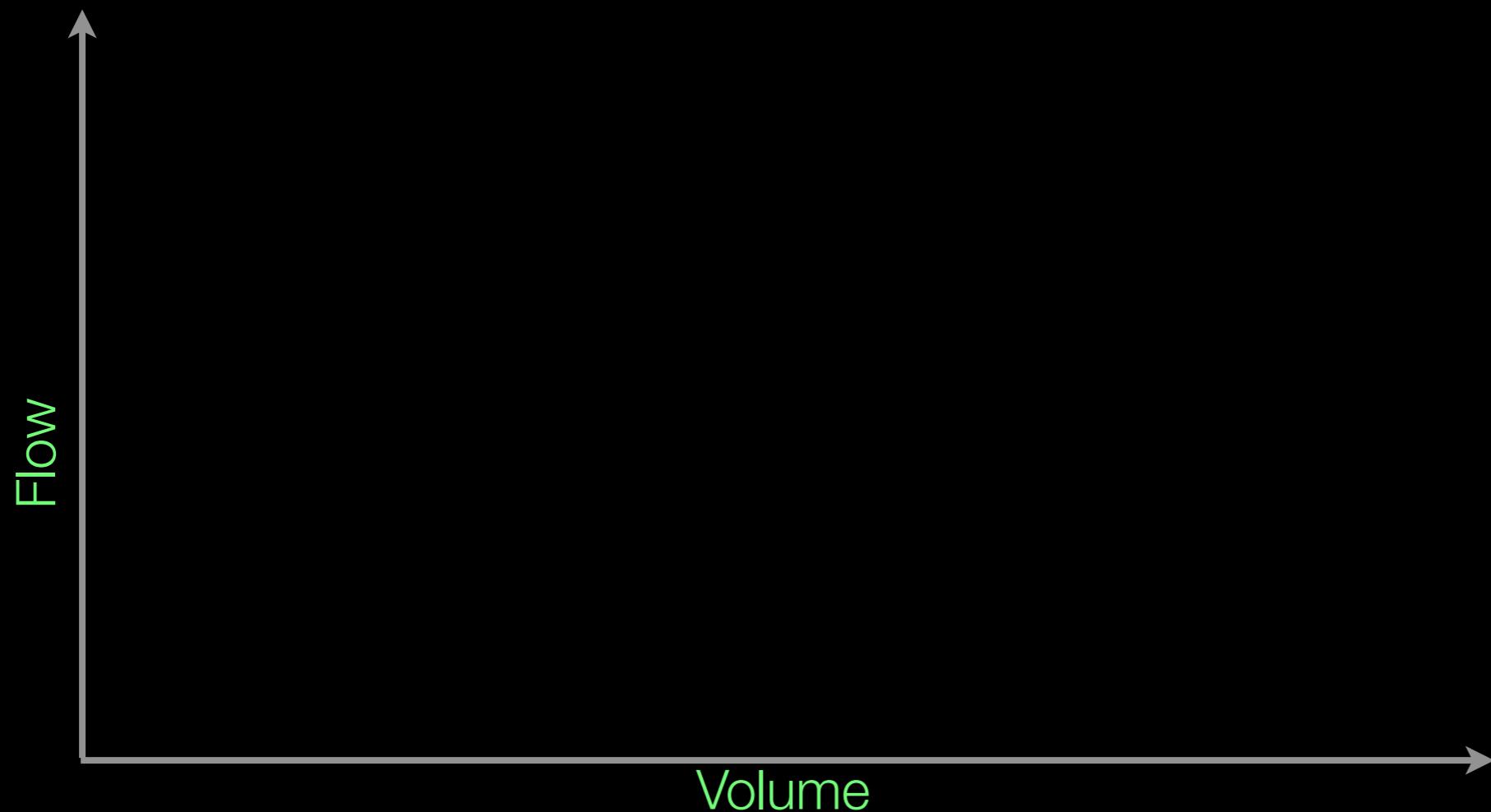
Volume-Time Graph

$$\text{FEV1\%} = \text{FEV1/FVC}$$

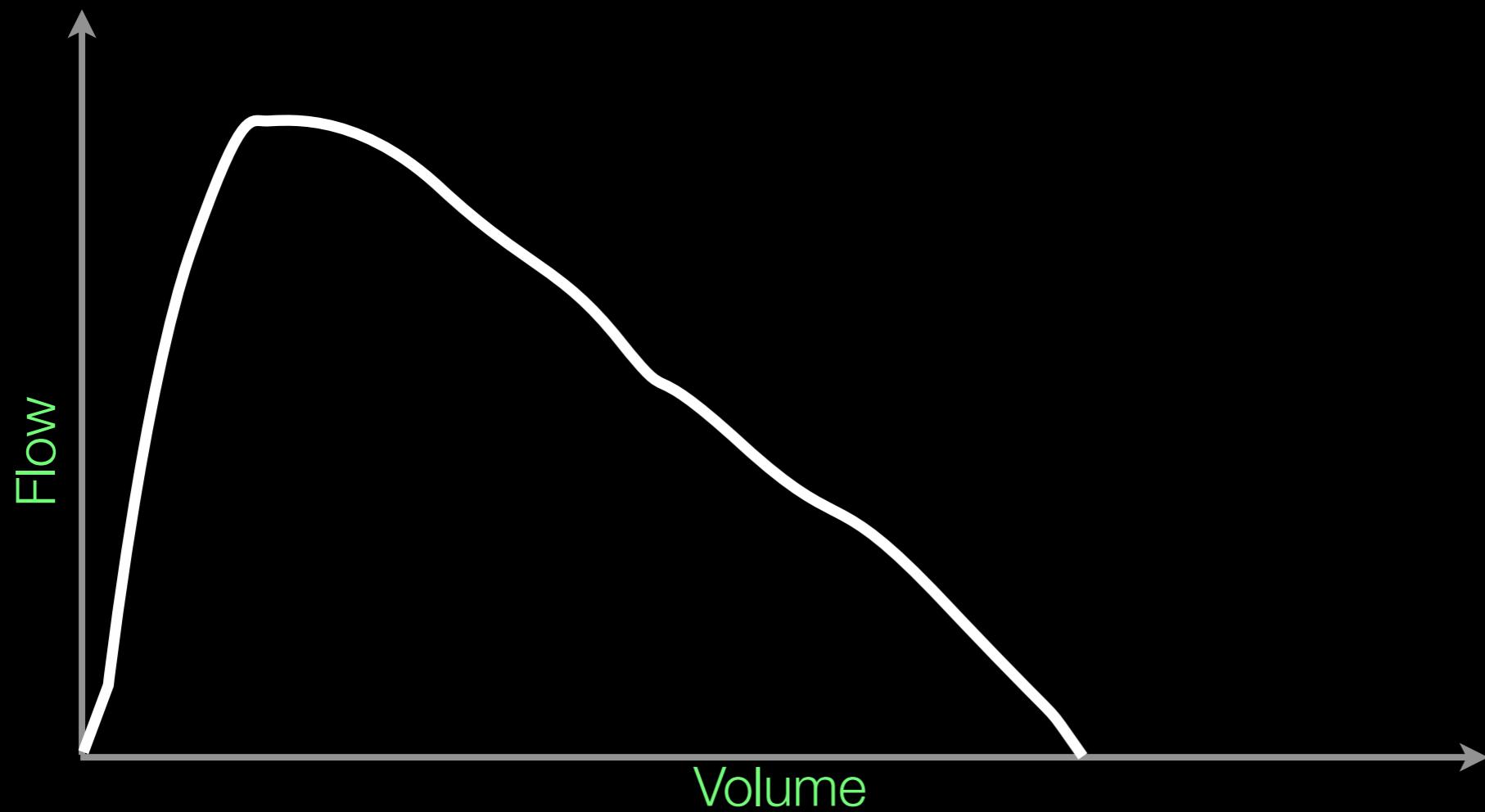
> 80%	Healthy
60 - 79%	Mild
40 - 59%	Moderate
< 40%	Severe

FEV1: Forced Expiratory Volume in 1 second
FVC: Forced Vital Capacity

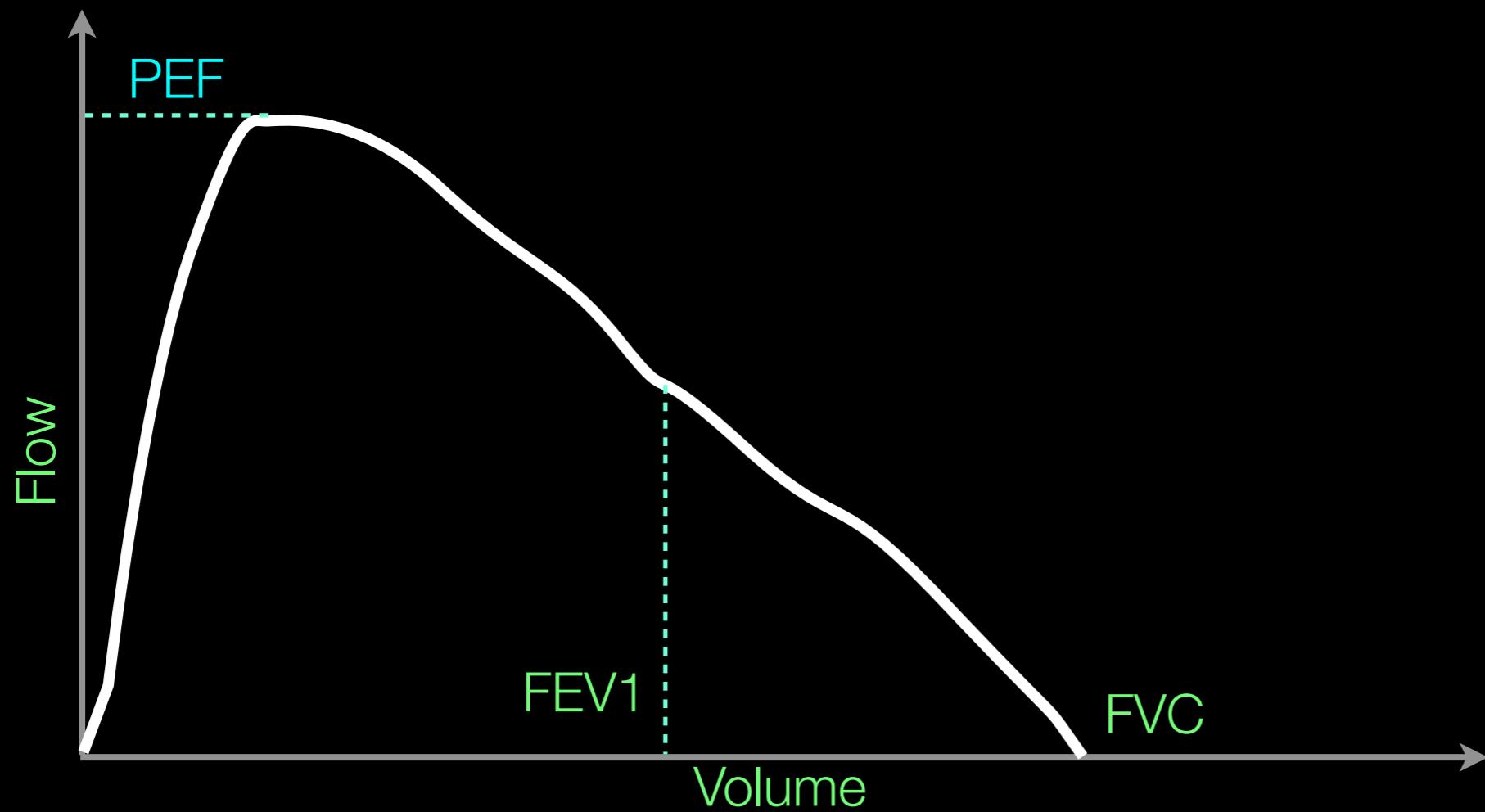
Flow-Volume Graph



Flow-Volume Graph



Flow-Volume Graph

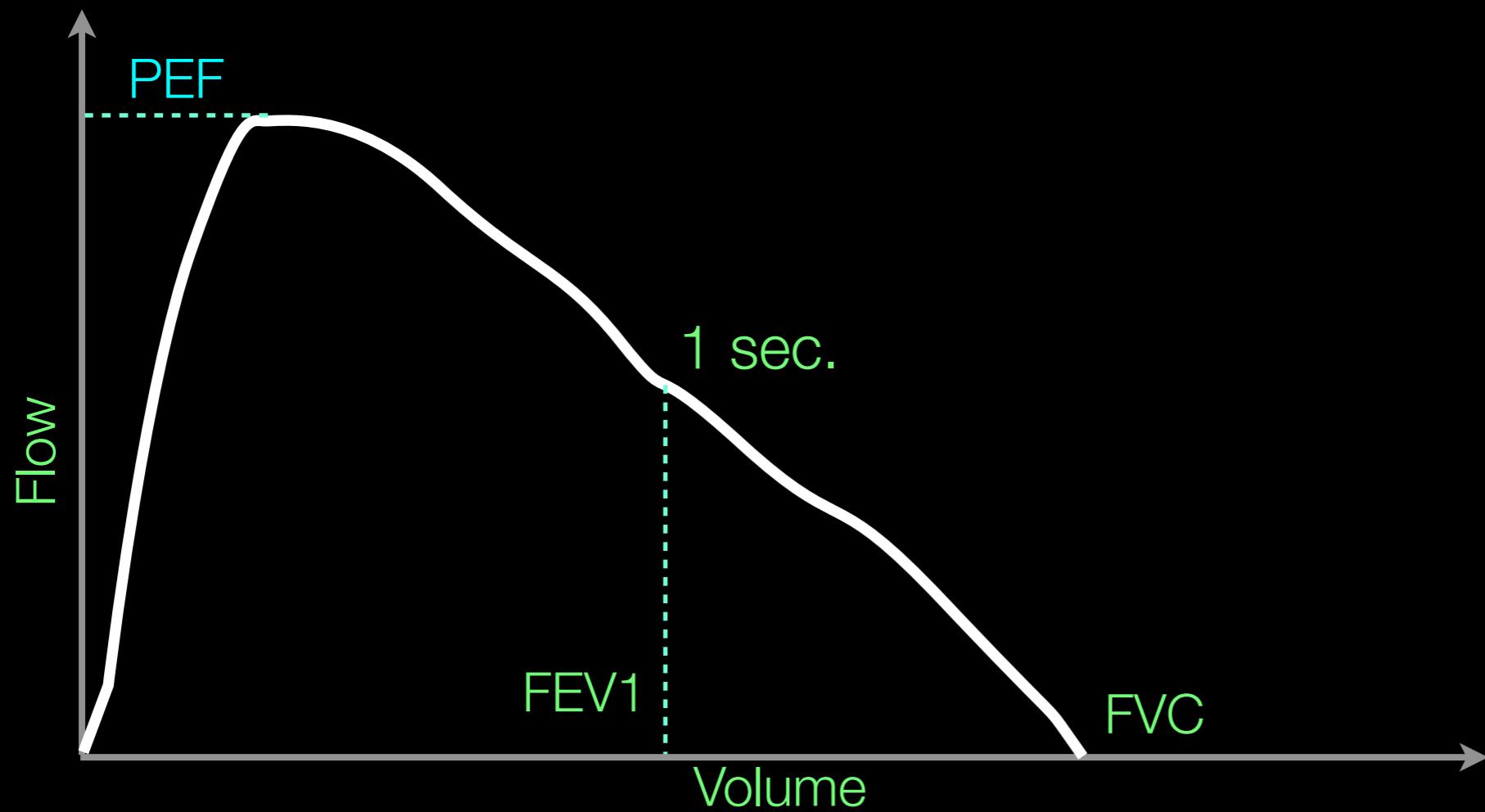


PEF: Peak Expiratory Flow

FEV1: Forced Expiratory Volume in 1 second

FVC: Forced Vital Capacity

Flow-Volume Graph

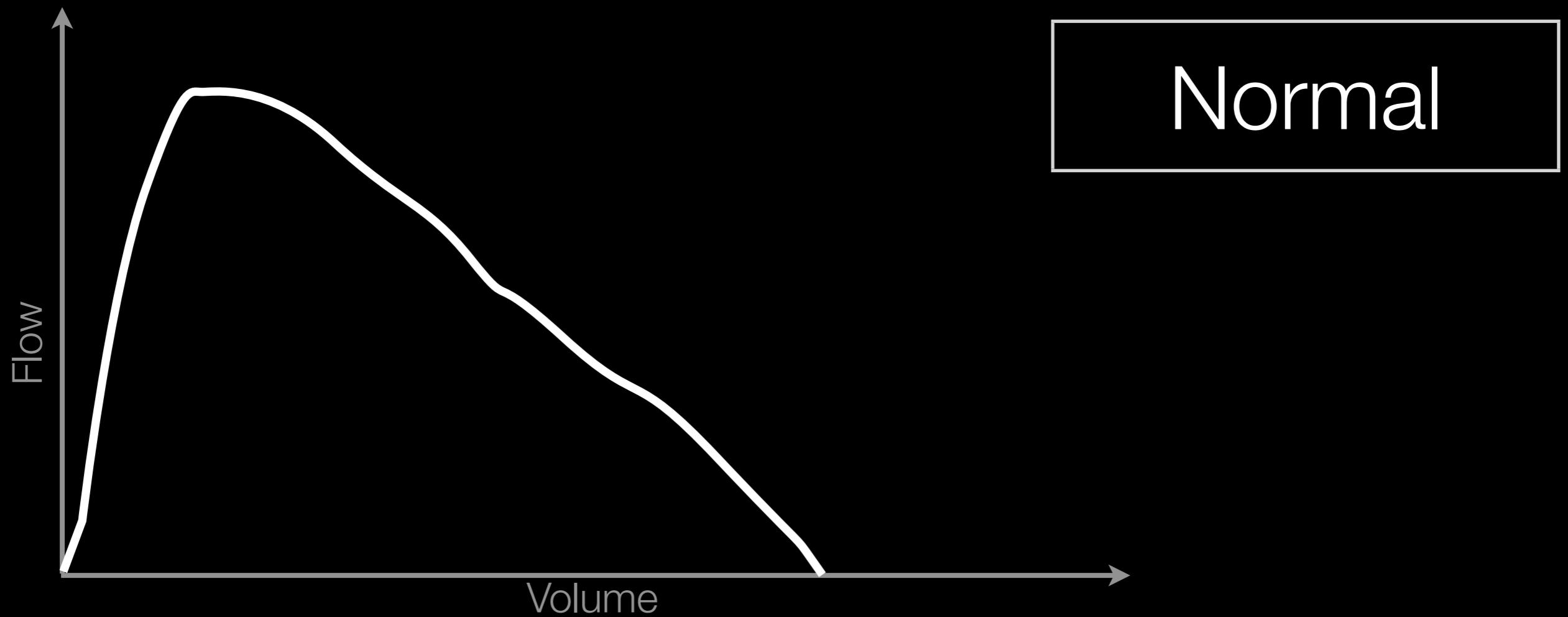


PEF: Peak Expiratory Flow

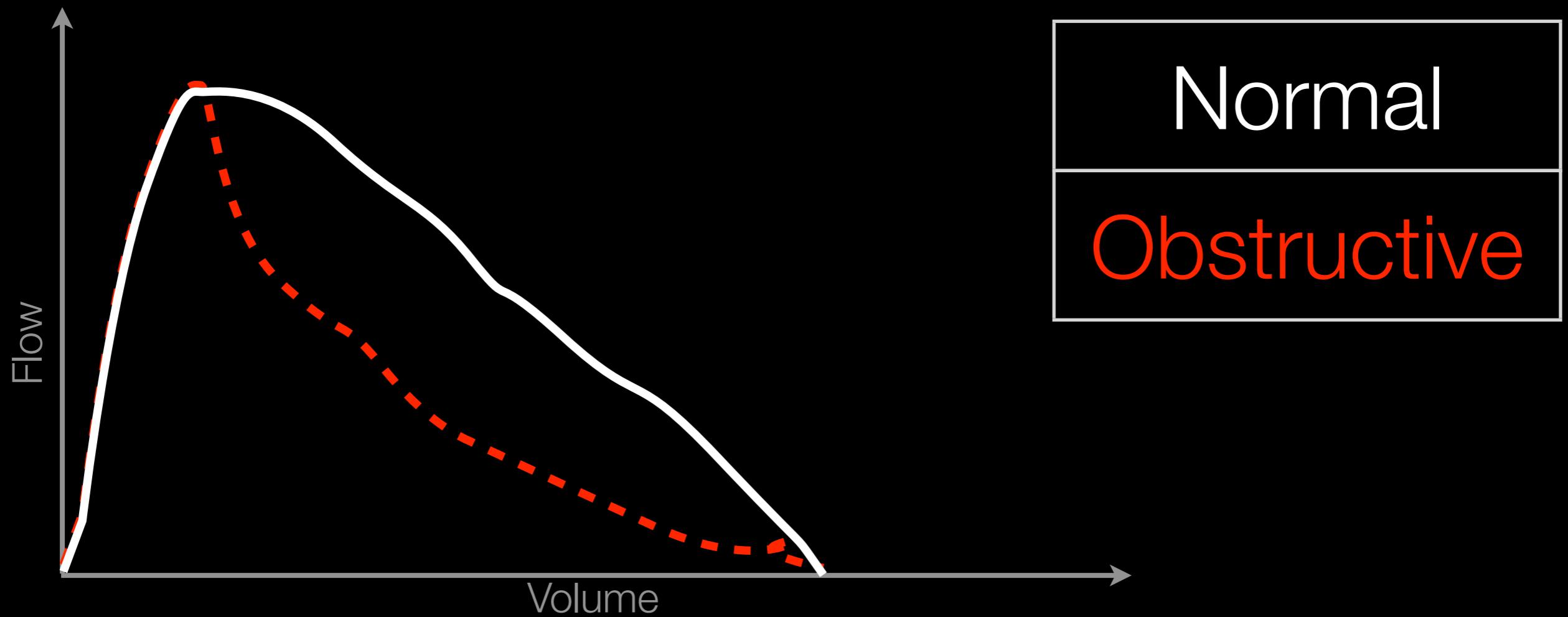
FEV1: Forced Expiratory Volume in 1 second

FVC: Forced Vital Capacity

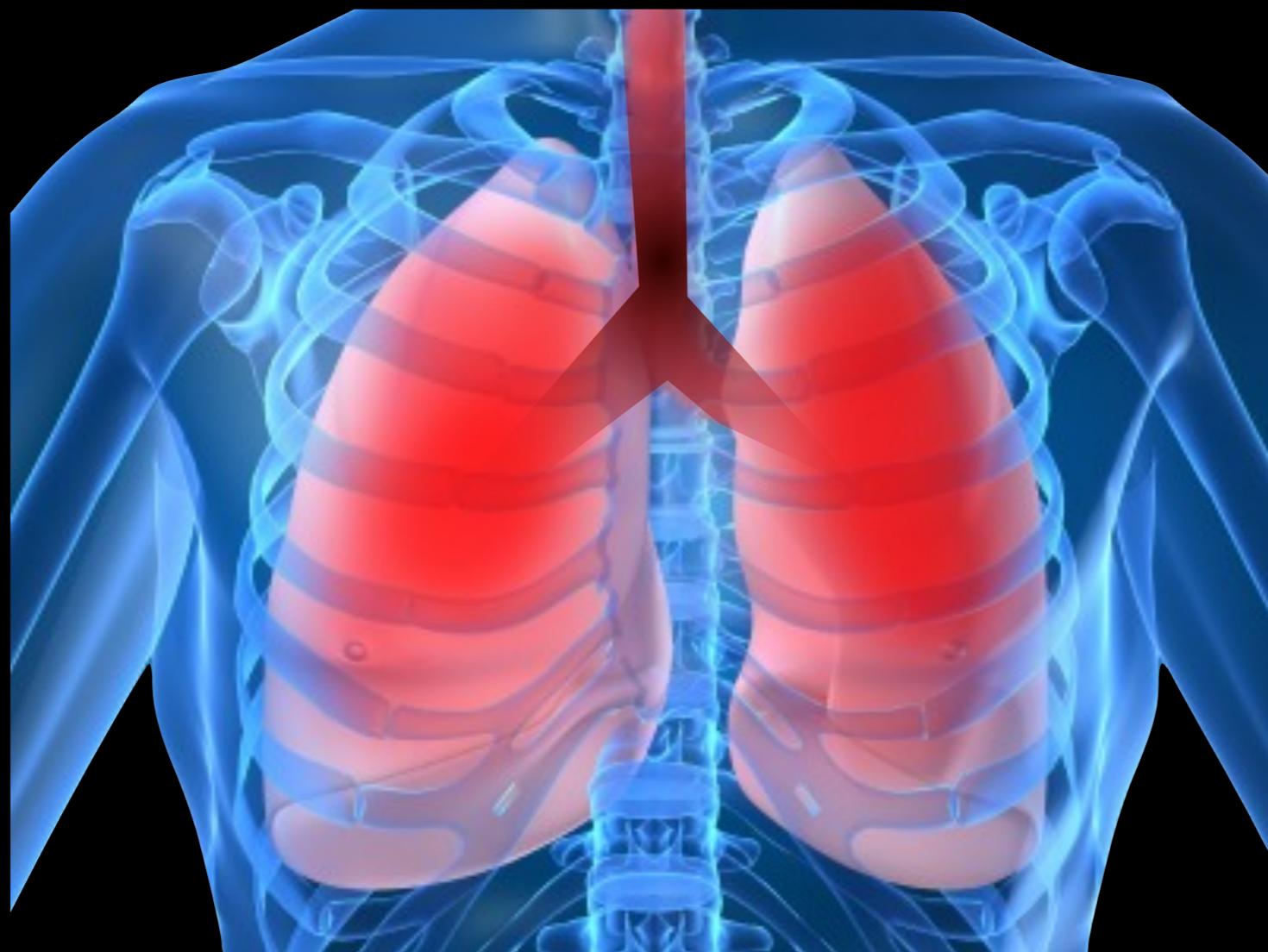
Flow-Volume Graph



Flow-Volume Graph

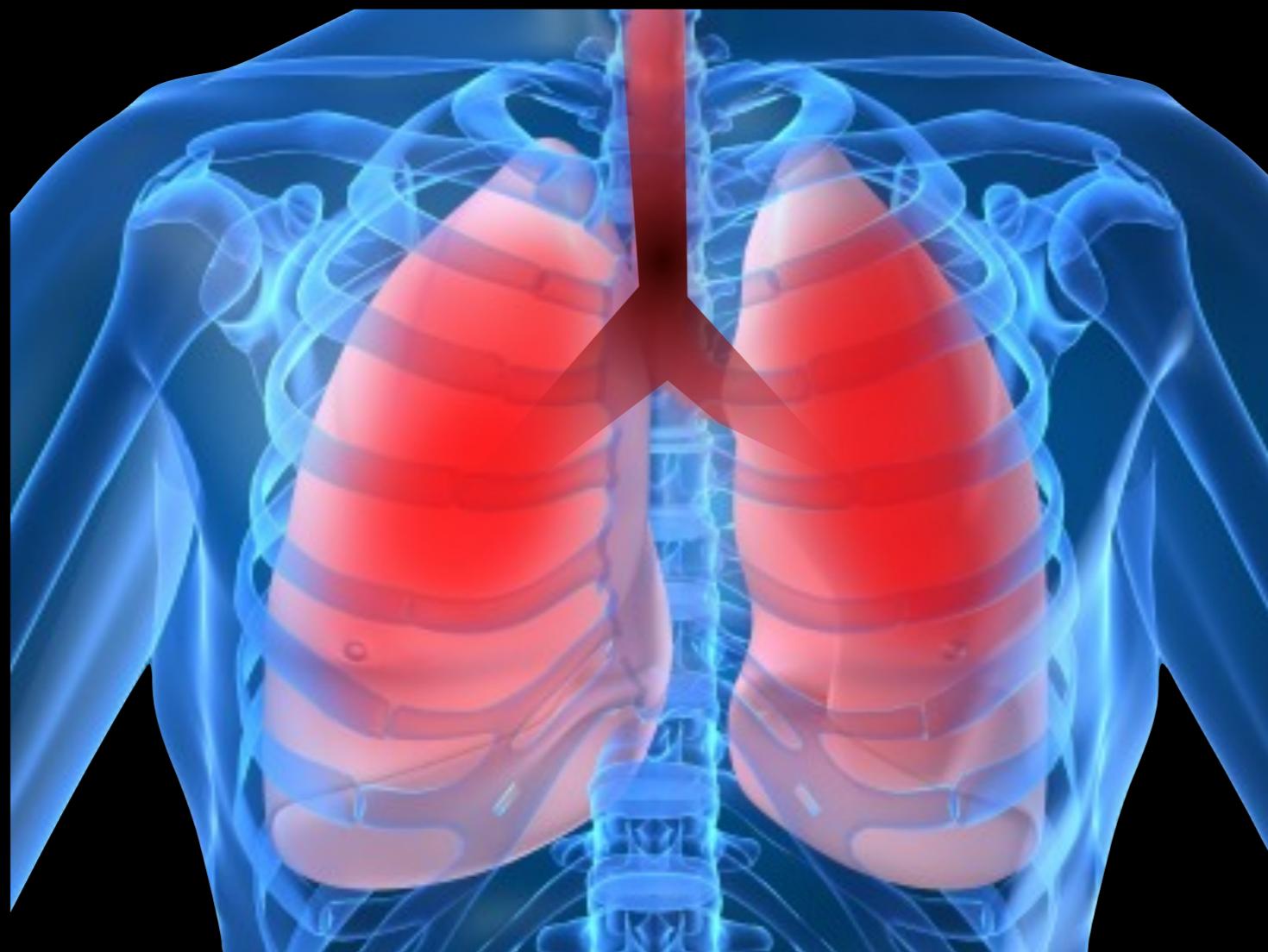


Obstructive Diseases



Resistance in air path leads to reduced air flow

Obstructive Diseases



Resistance in air path leads to reduced air flow

Restrictive Diseases



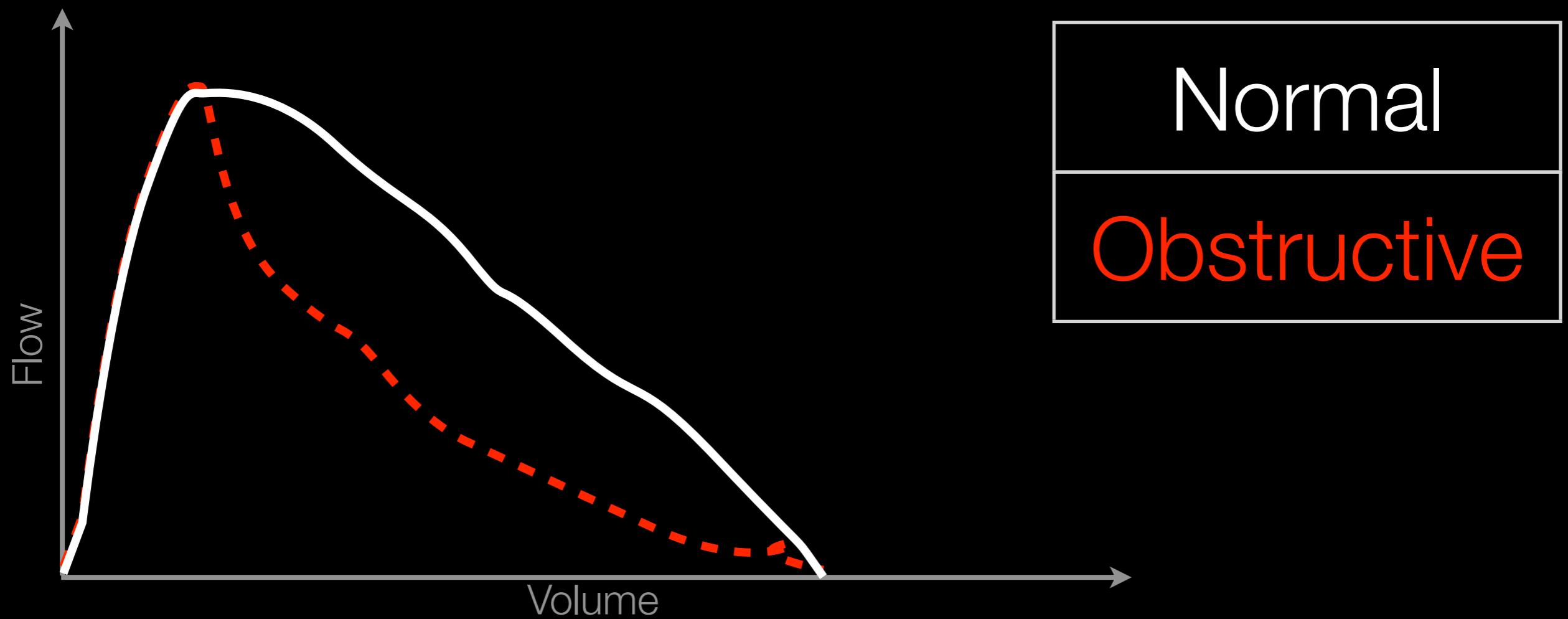
Lungs are unable to pump enough air and pressure

Restrictive Diseases

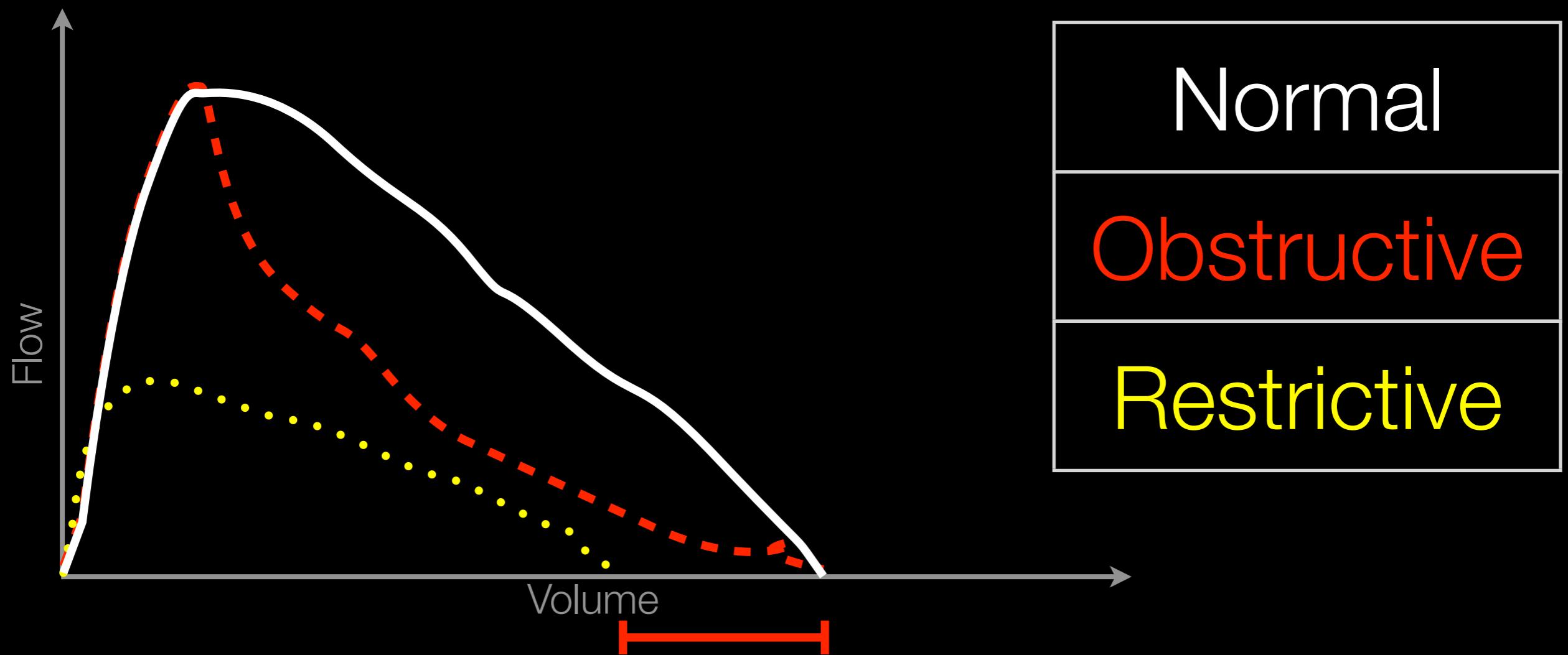


Lungs are unable to pump enough air and pressure

Flow-Volume Graph



Flow-Volume Graph



Normal

Obstructive

Restrictive

Clinical Spirometry



Home Spirometry



Home Spirometry



Faster detection

Rapid recovery

Challenges with Home Spirometry



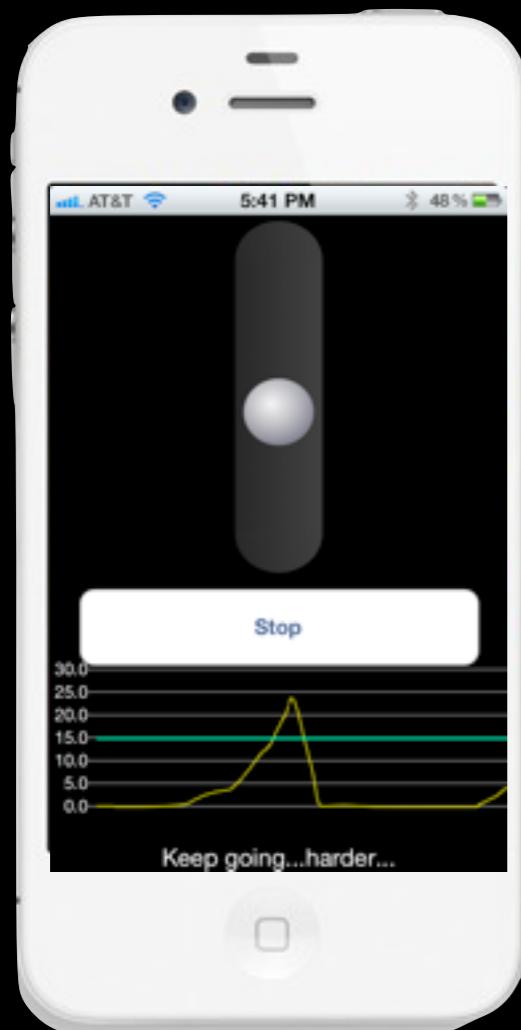
High cost barrier

Patient compliance

Less coaching

Limited feedback

SpiroSmart



Availability

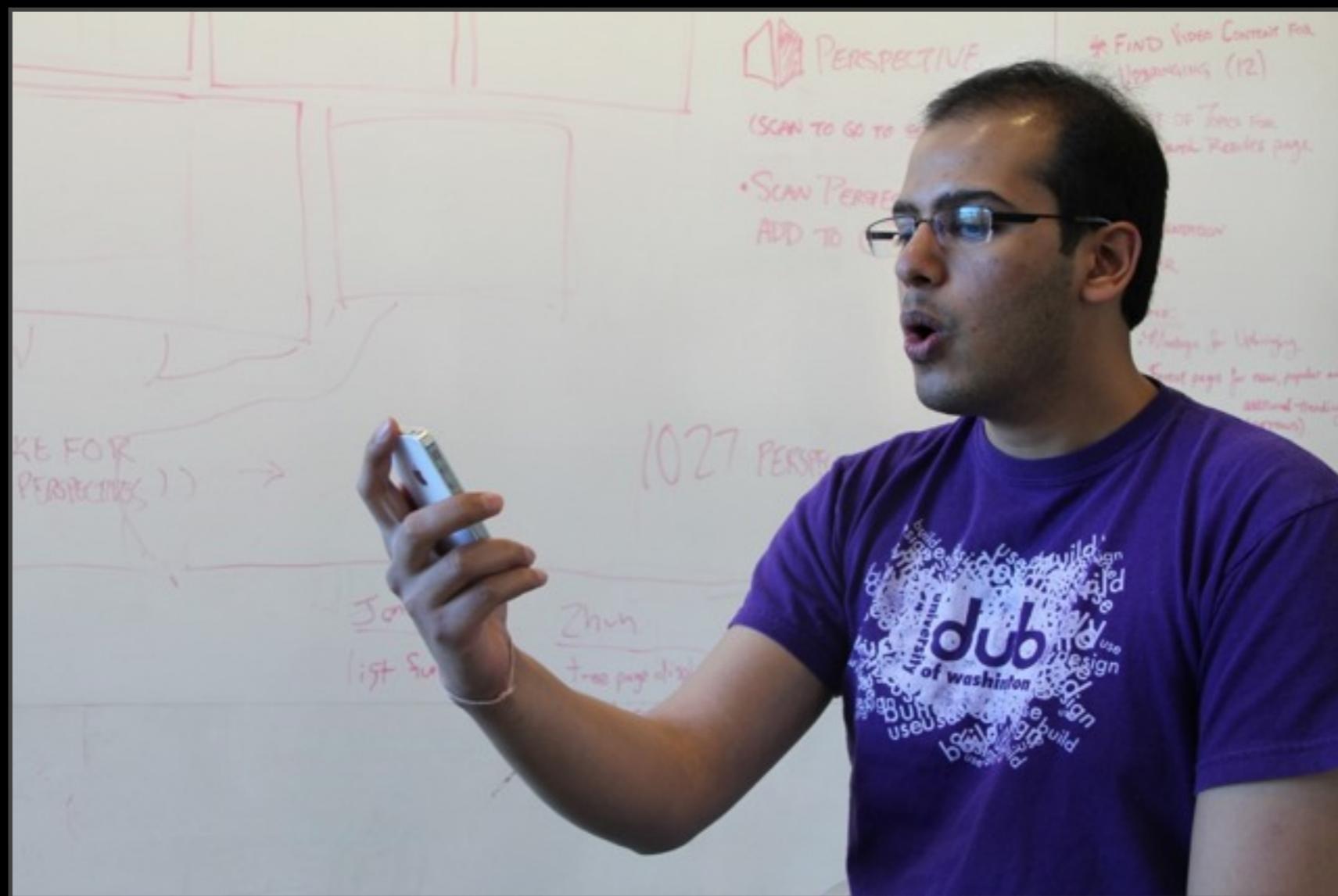
Cost

Portability

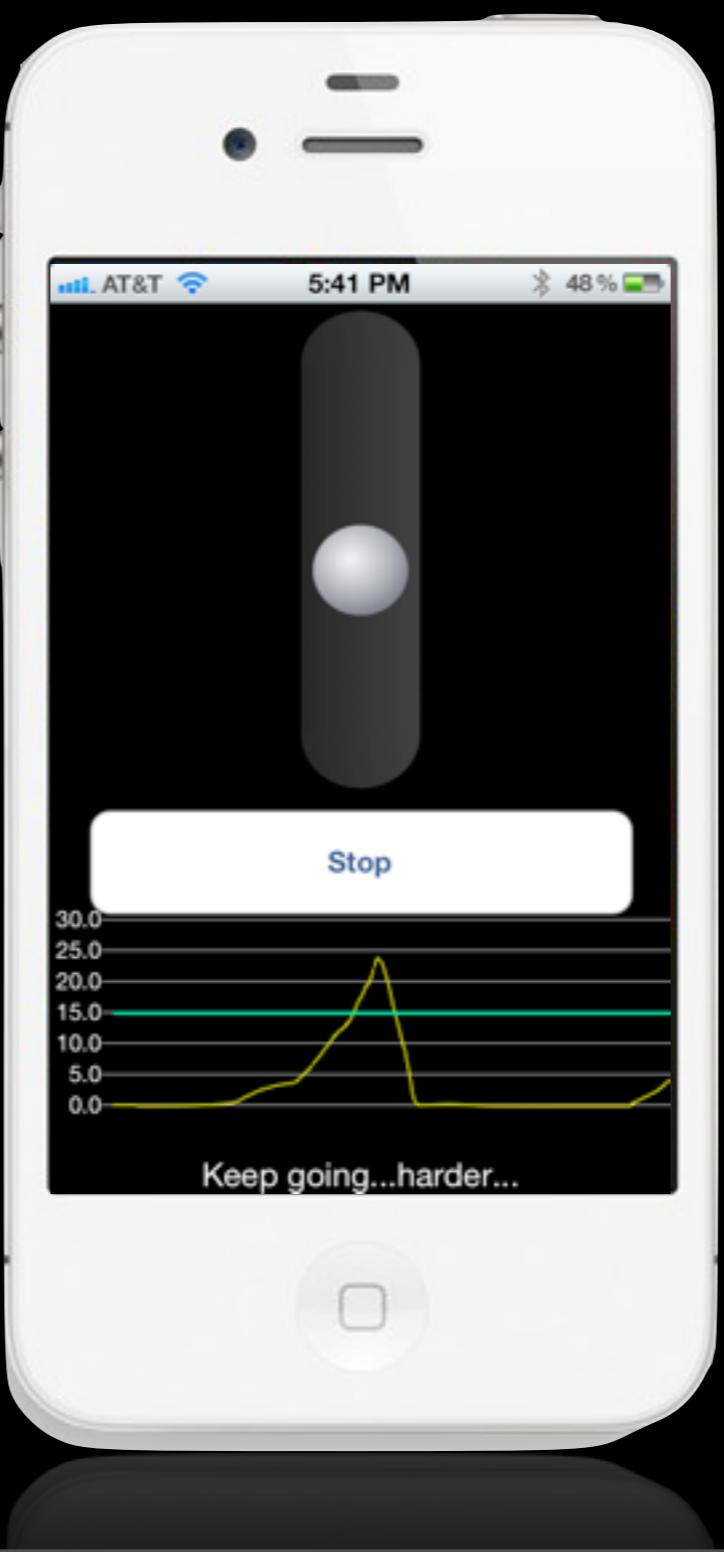
More effective coaching interface

Integrated uploading

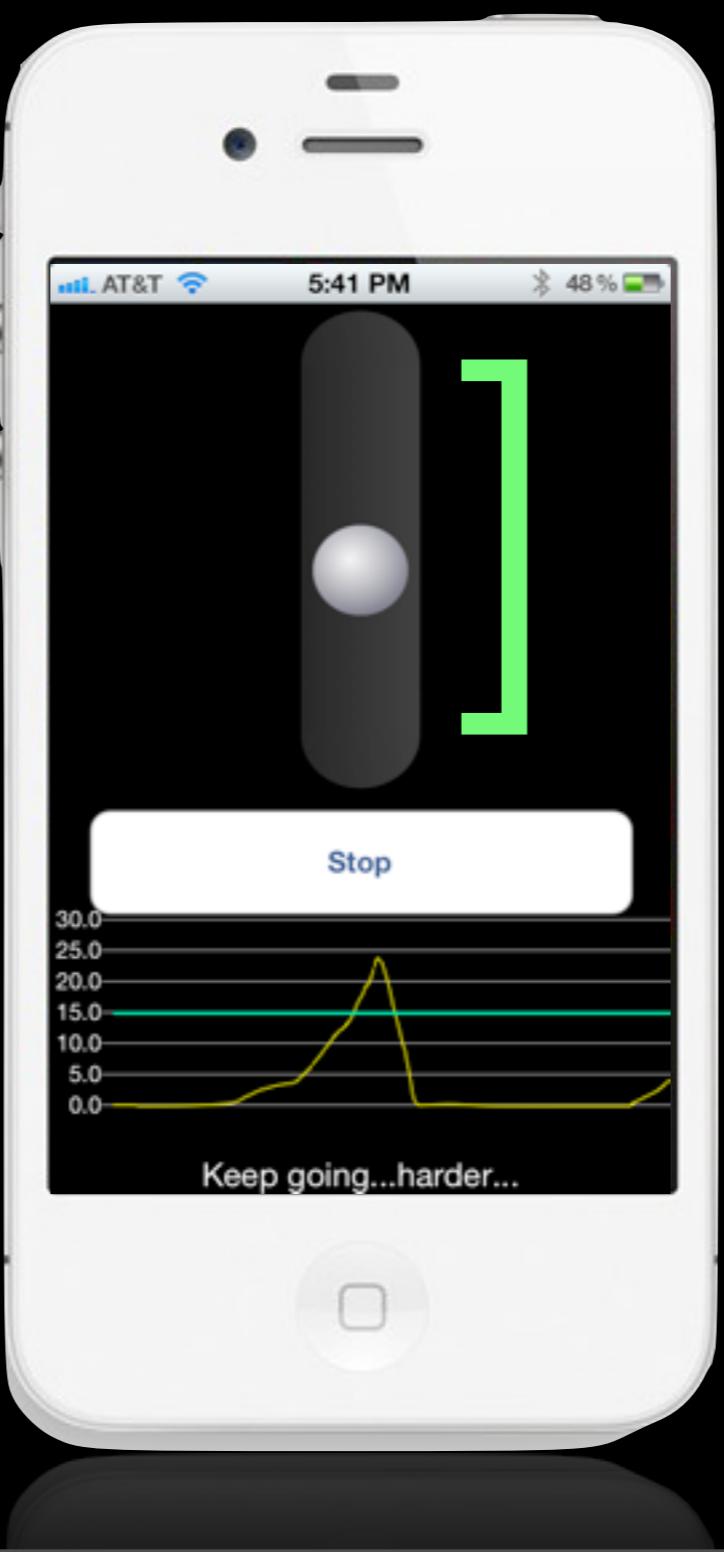
Using SpiroSmart



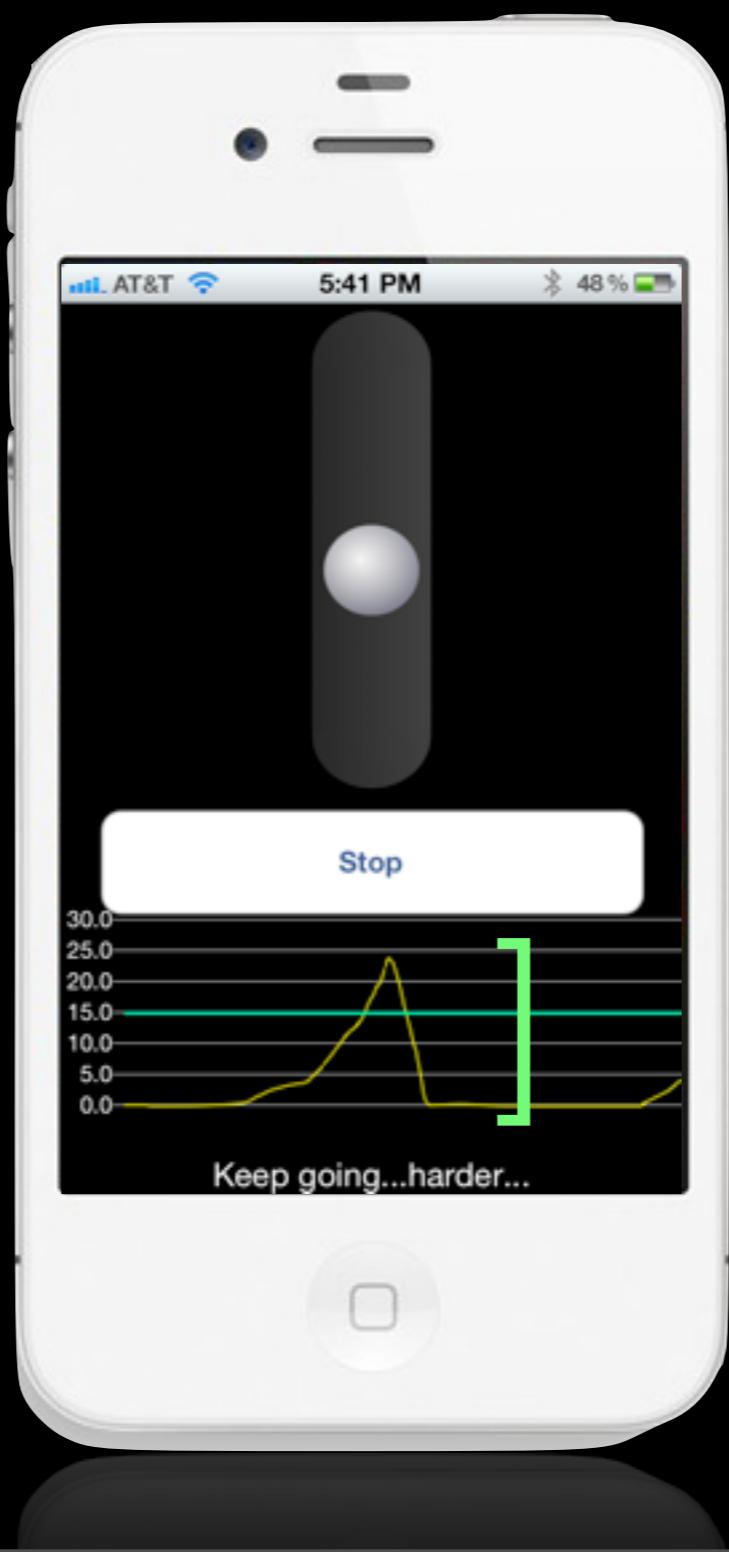
Using SpiroSmart



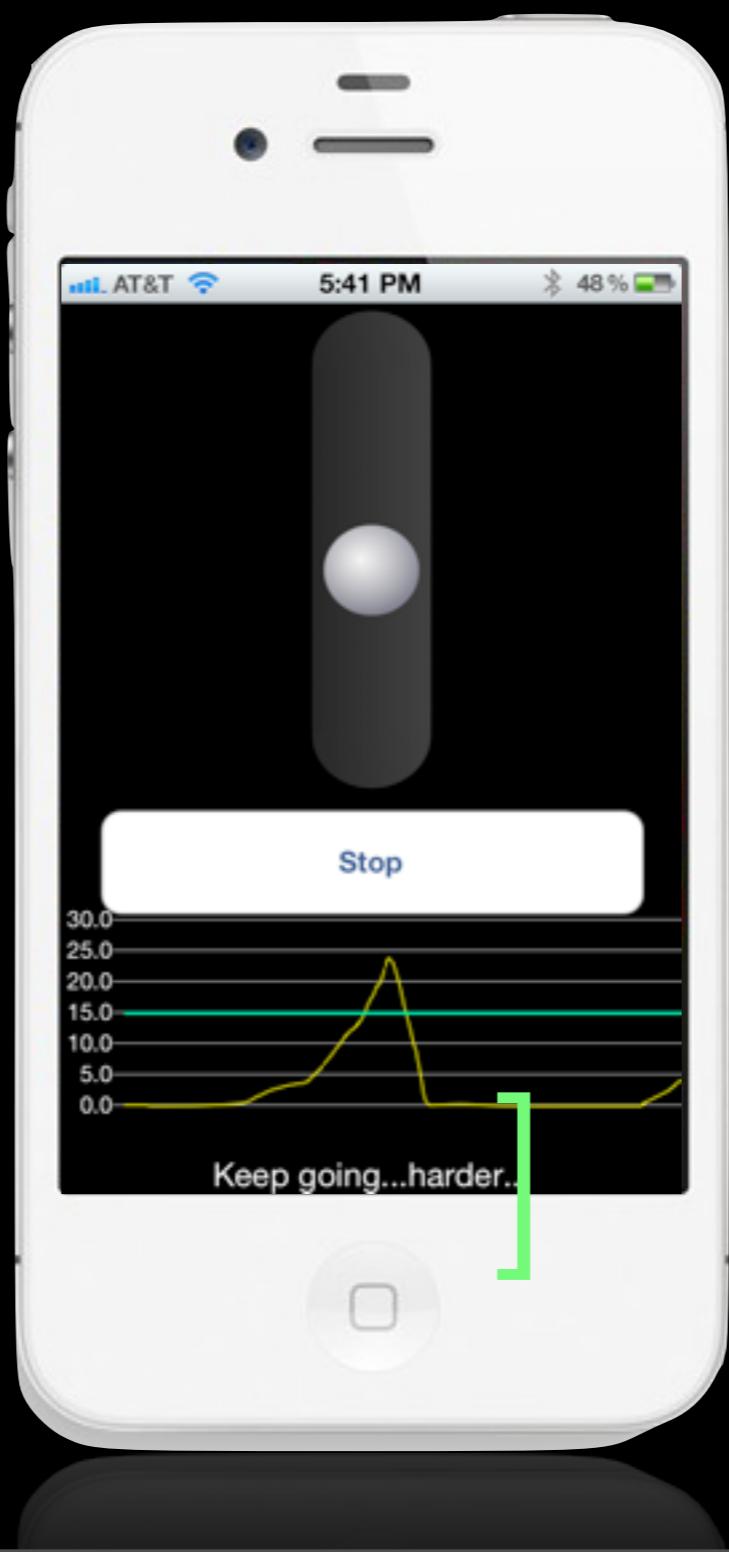
Using SpiroSmart



Using SpiroSmart



Using SpiroSmart



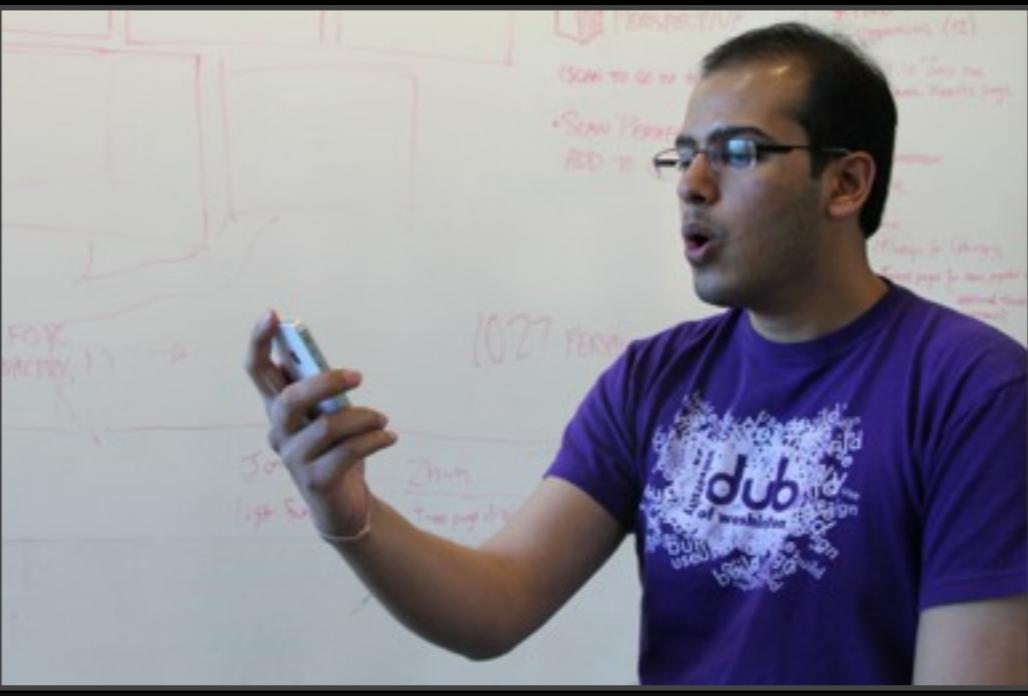
Using SpiroSmart



Initial Study Design

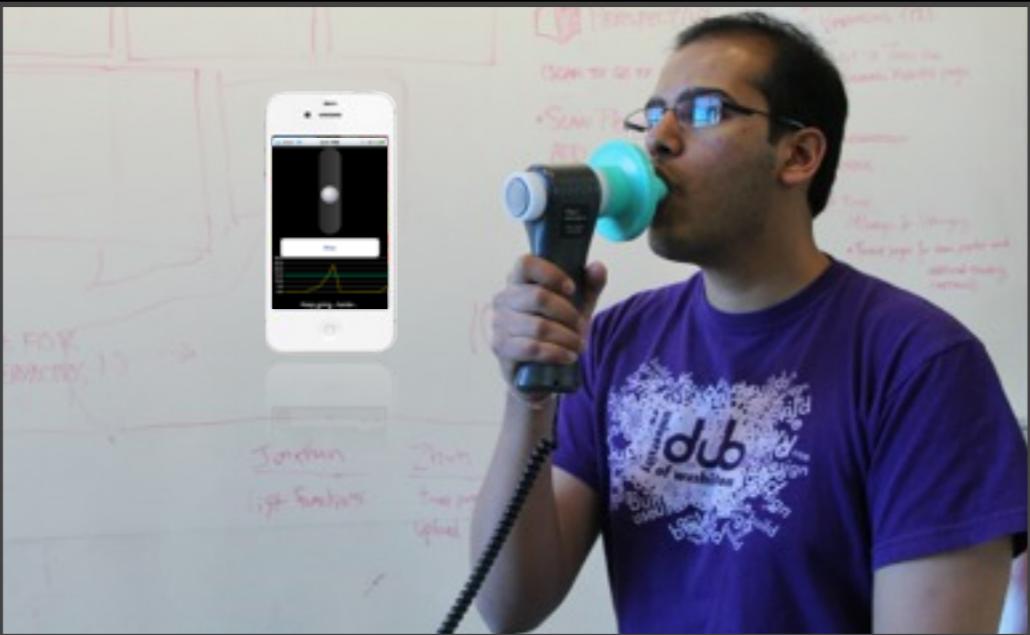


X 3

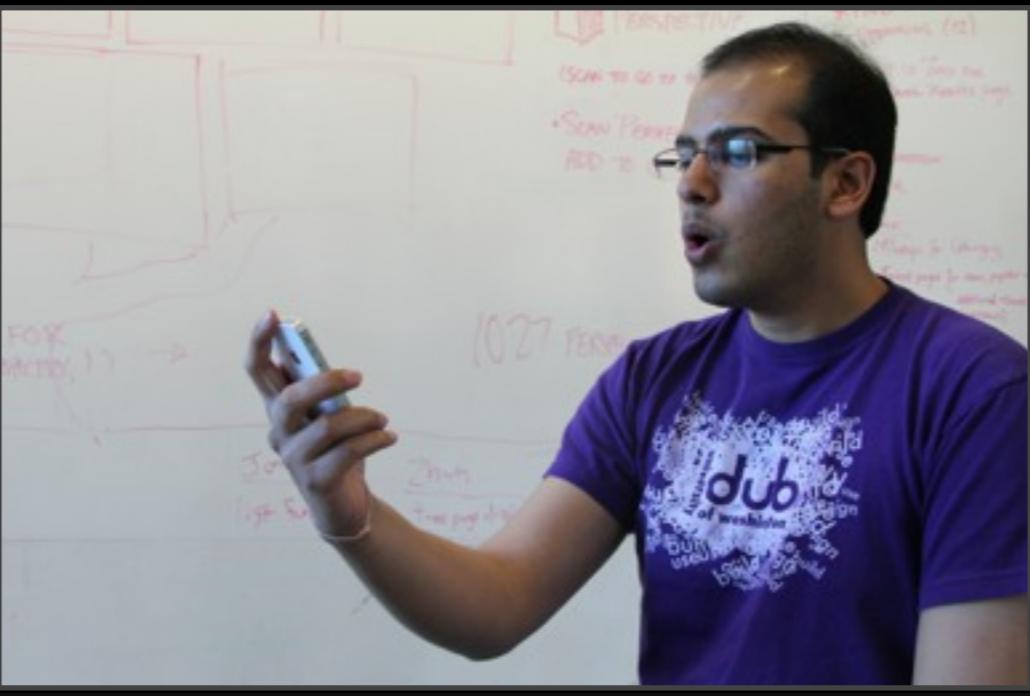


X 3

Initial Study Design

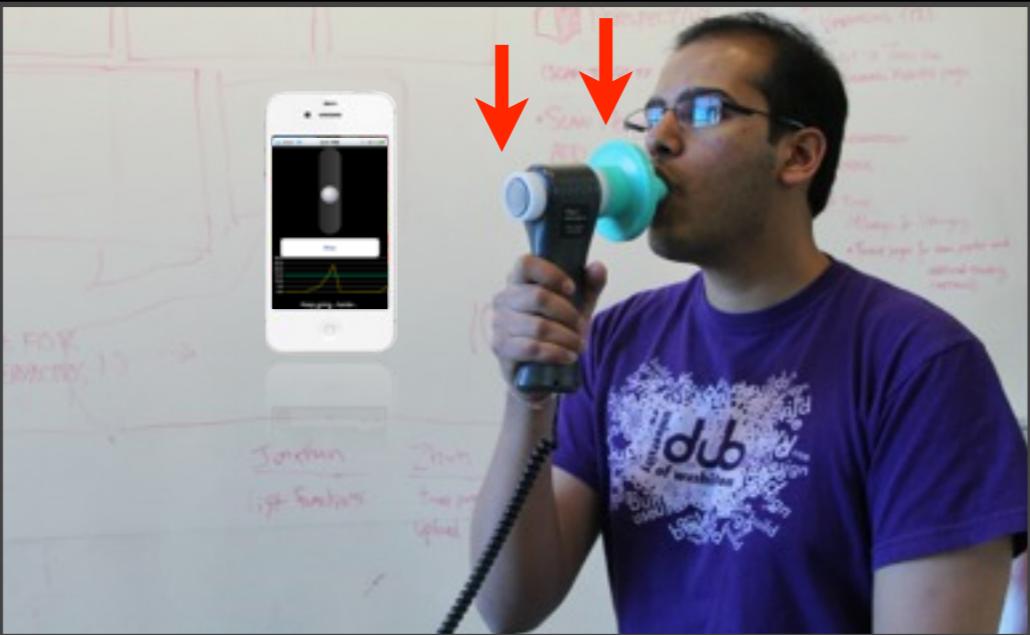


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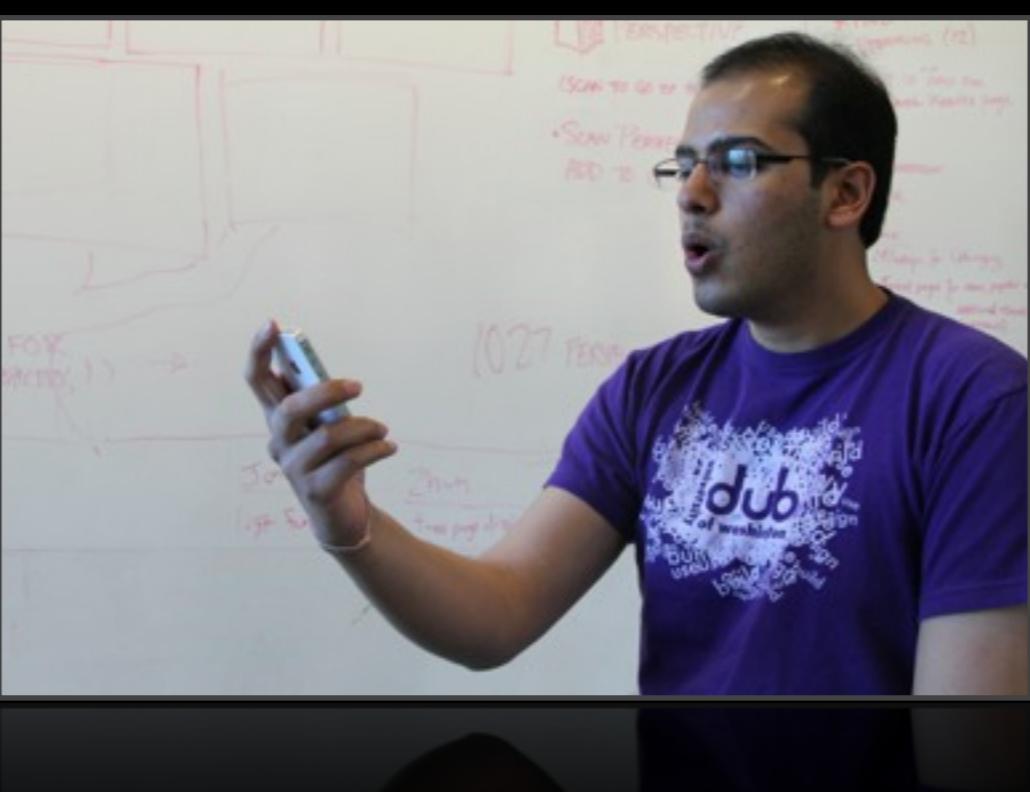


X 3

Initial Study Design



X 3



X 3

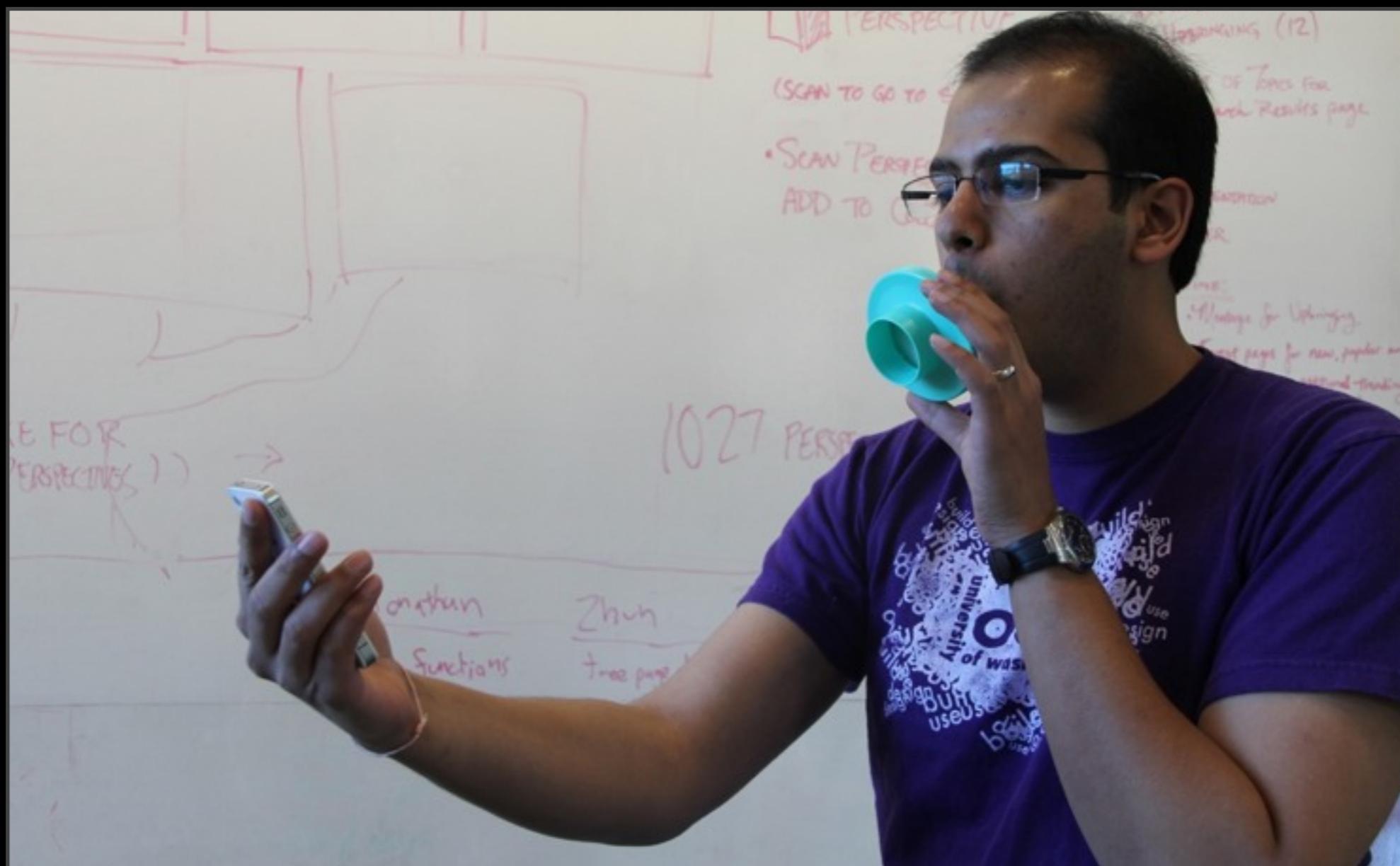
Need of attachments



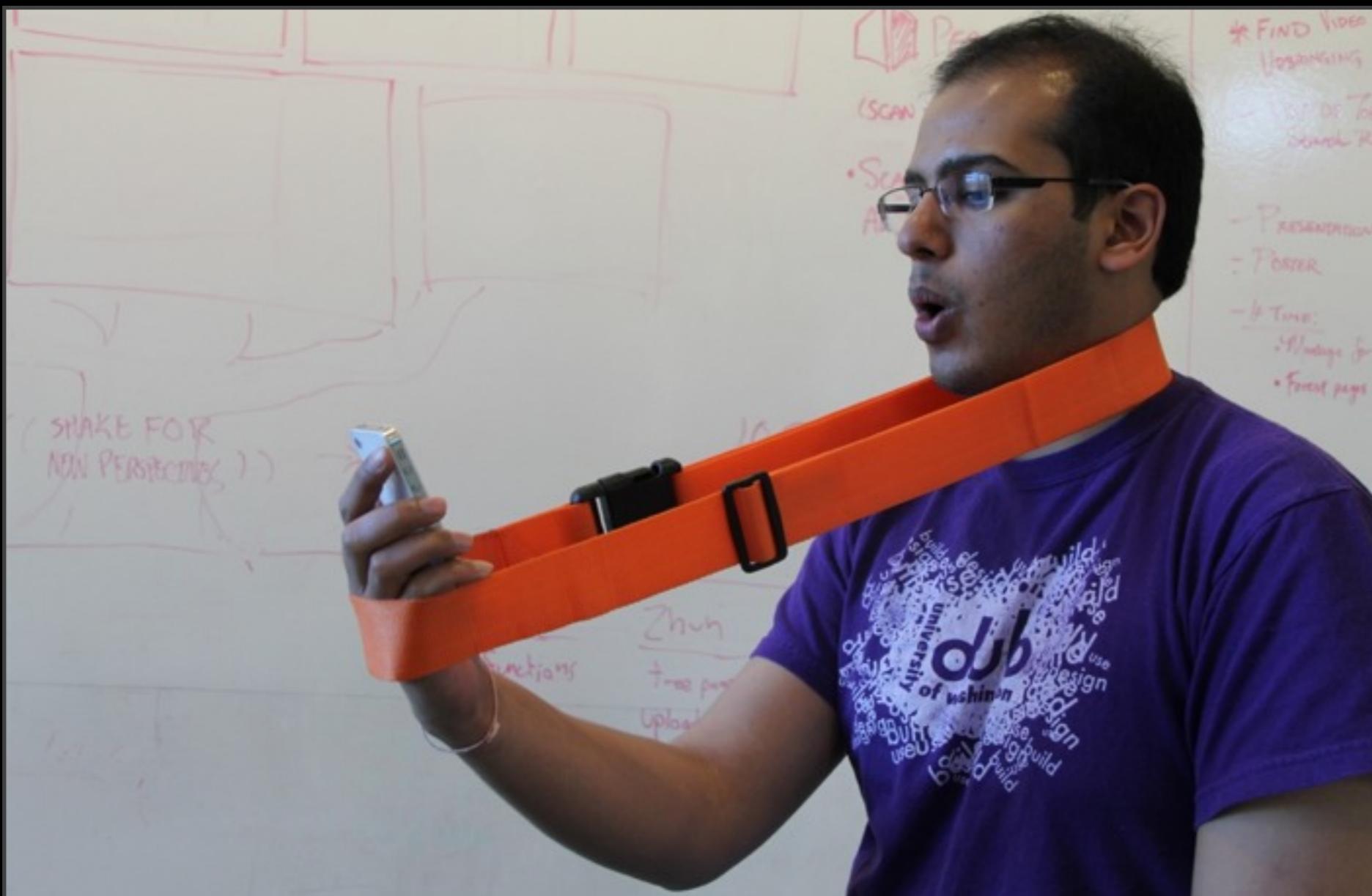
Need of attachments



Mouthpiece



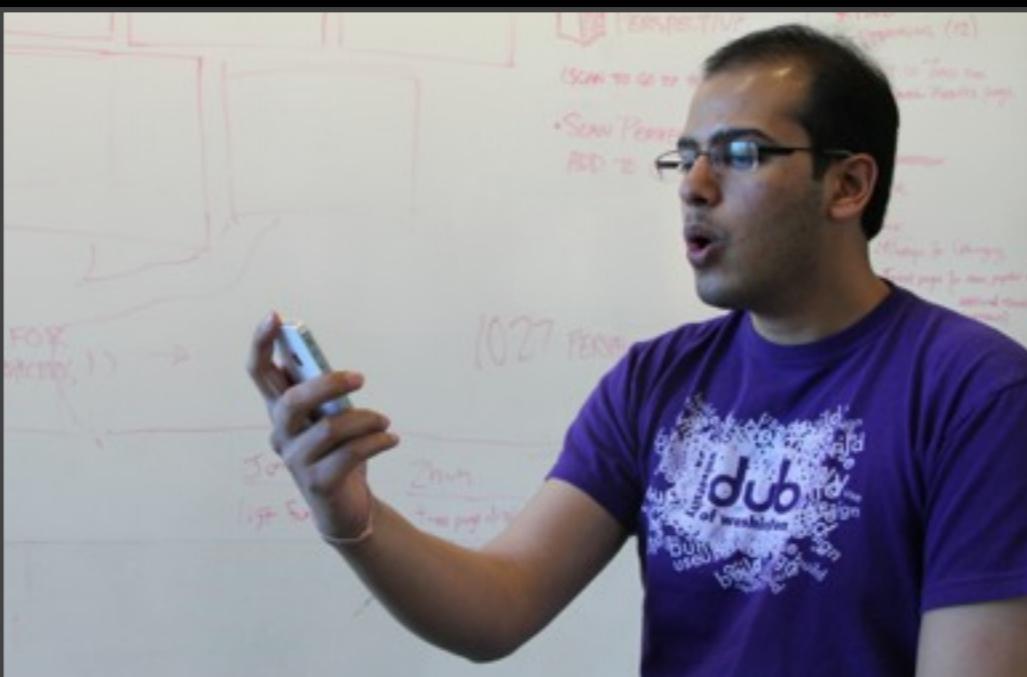
Sling



Study Design



X 3



X 3

Study Design



x 3



+



+



+



x 3

x 3

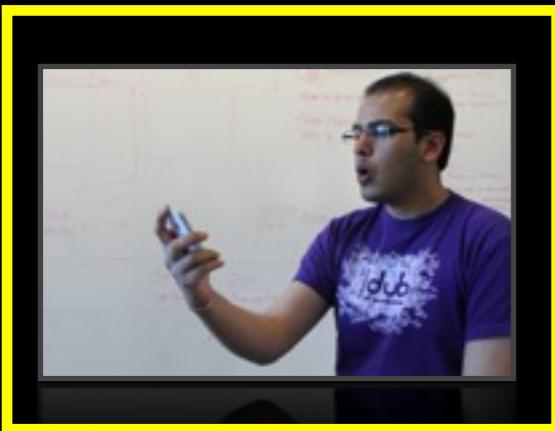
x 3

x 3

Study Design



X 3



X 3



+

X 3



+

X 3



+

X 3

Study Design



x 3



+



+



+



x 3

x 3

x 3

x 3

Study Design



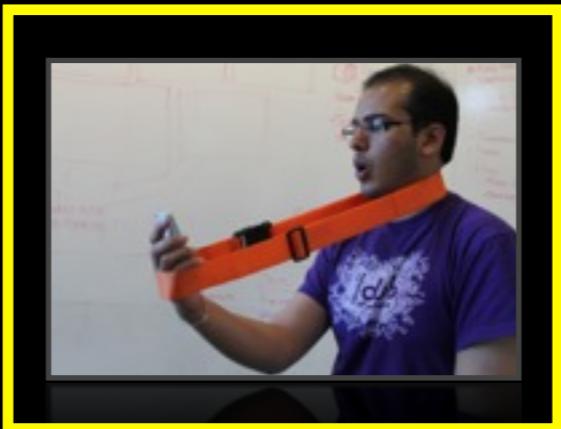
x 3



+



+



x 3



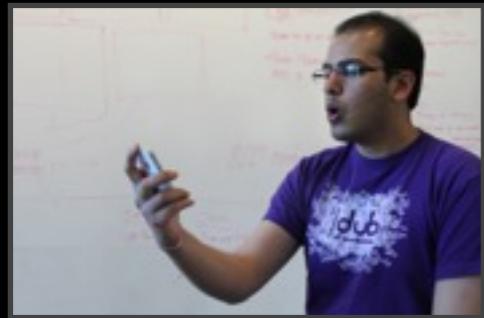
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x 3

Study Design



x 3



+



+



x 3

+



x 3



+



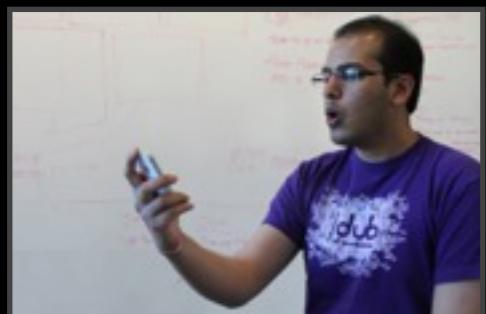
+



+



dataset



+



+



+



dataset

subjects

52



+



+



+



dataset

subjects	52
duration	45 minutes



+



+

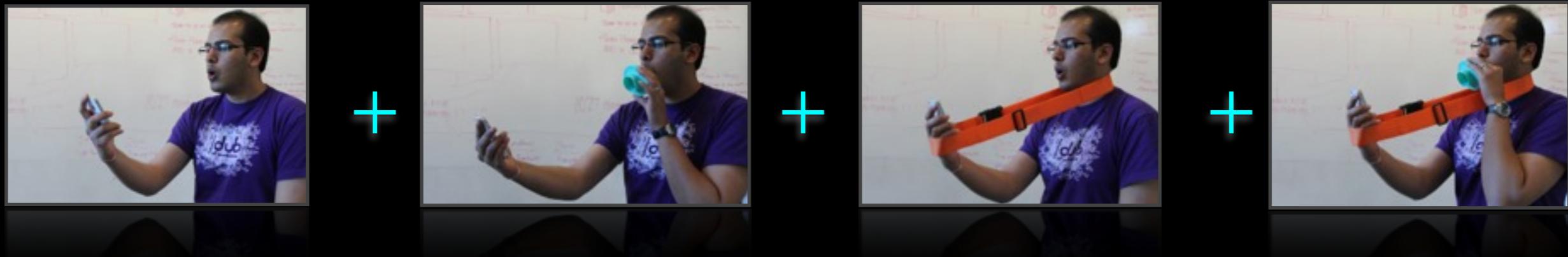


+



dataset

subjects	52
duration	45 minutes
first session	29



dataset

subjects	52
duration	45 minutes
first session	29
abnormals	12



+



+



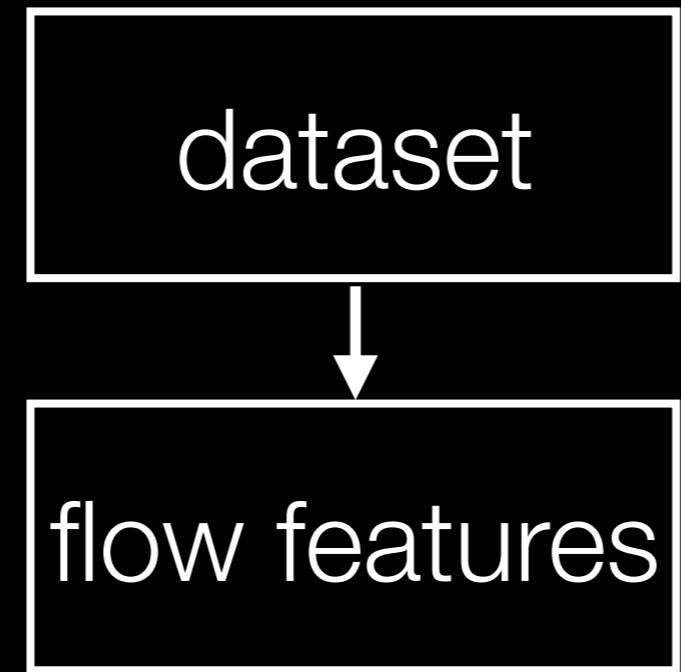
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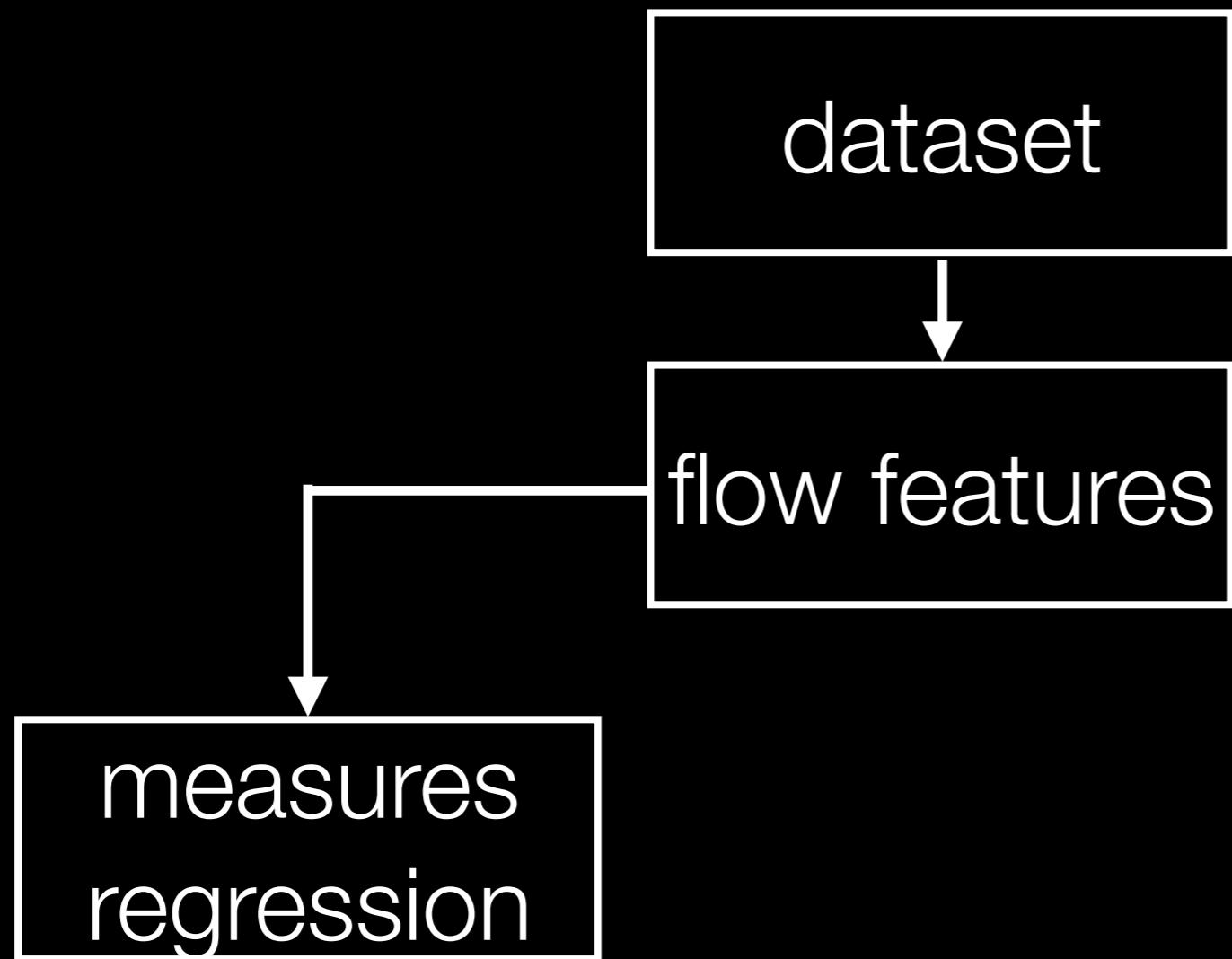


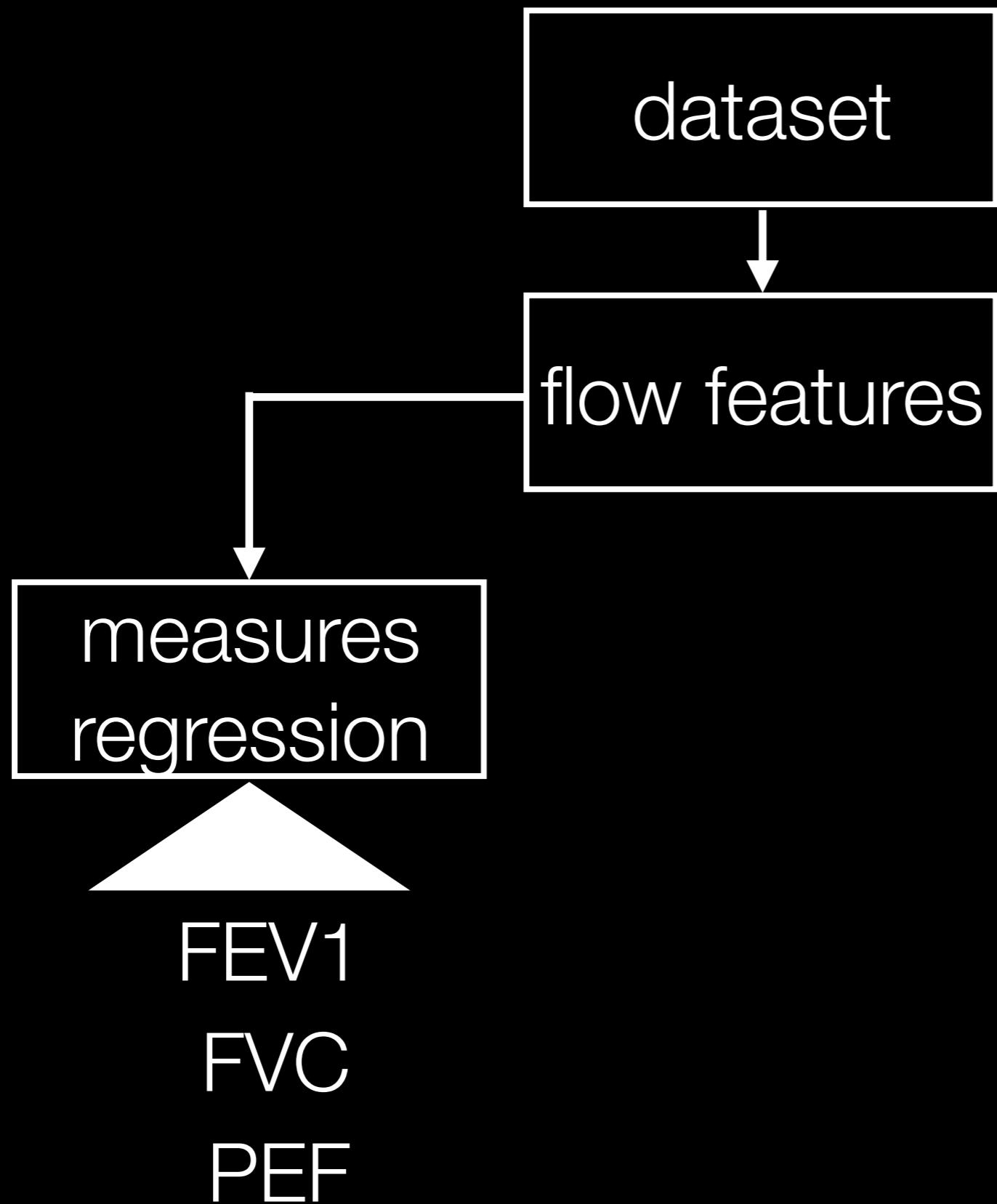
dataset

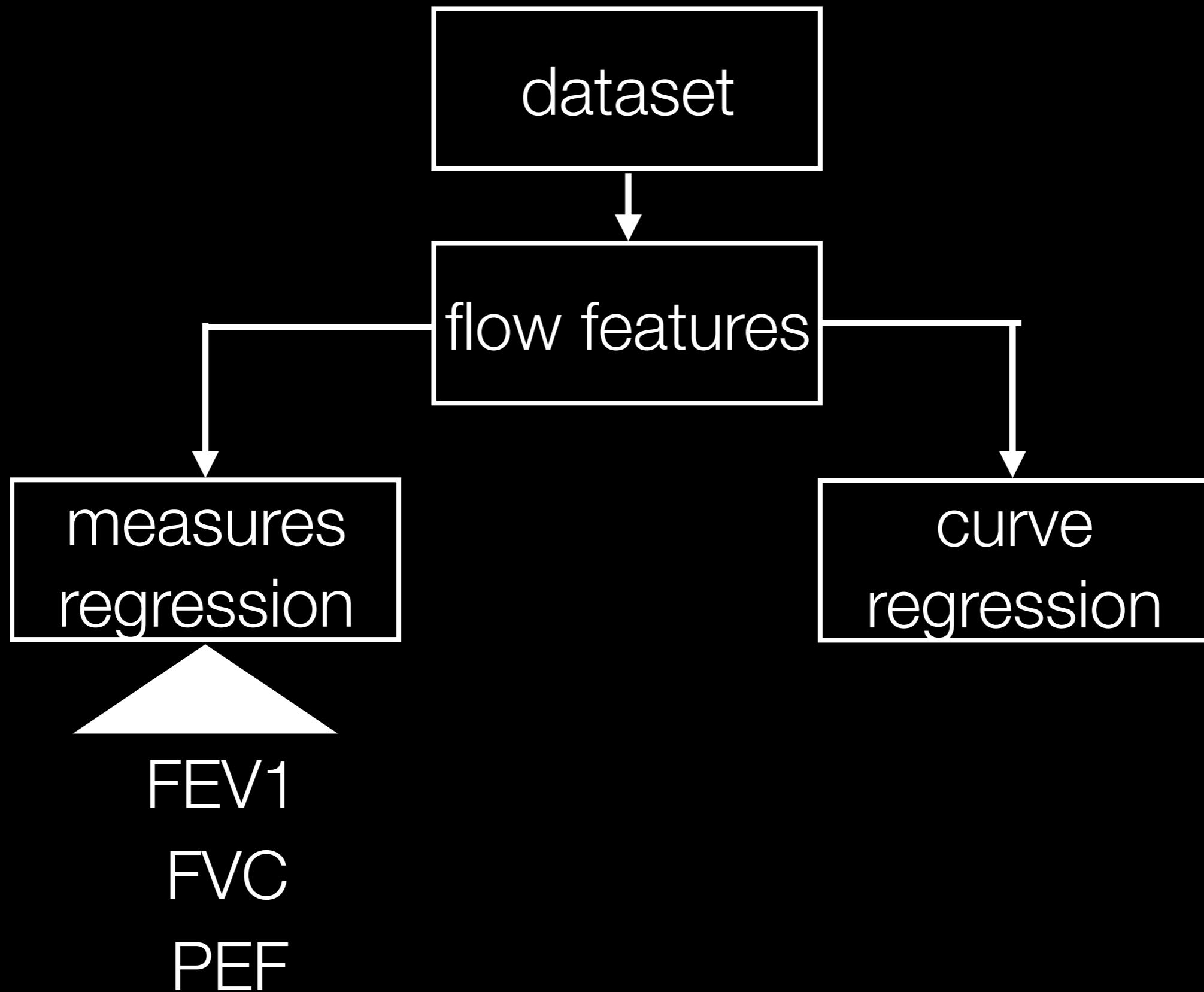
subjects	52
duration	45 minutes
first session	29
abnormals	12
revisits	10

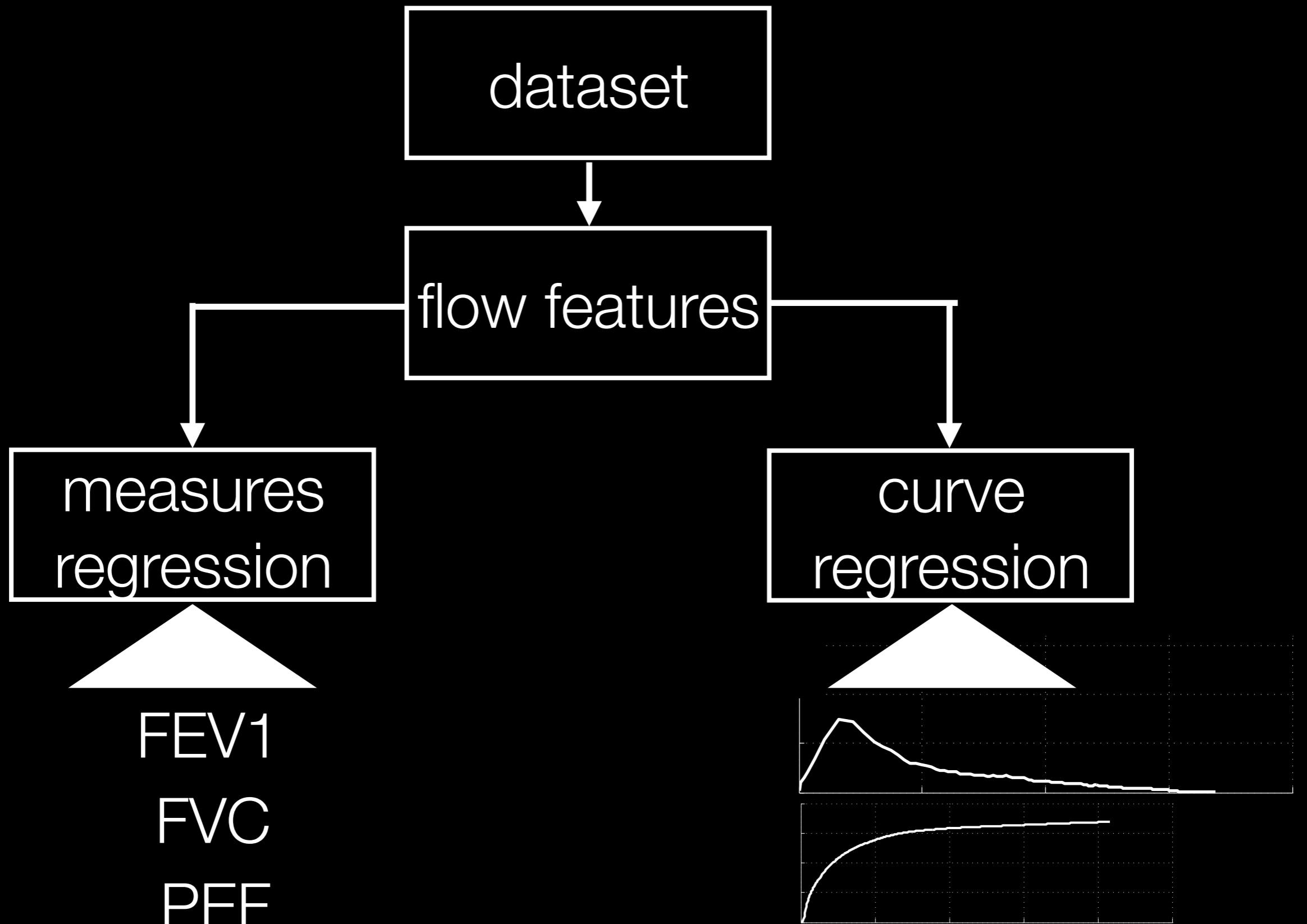
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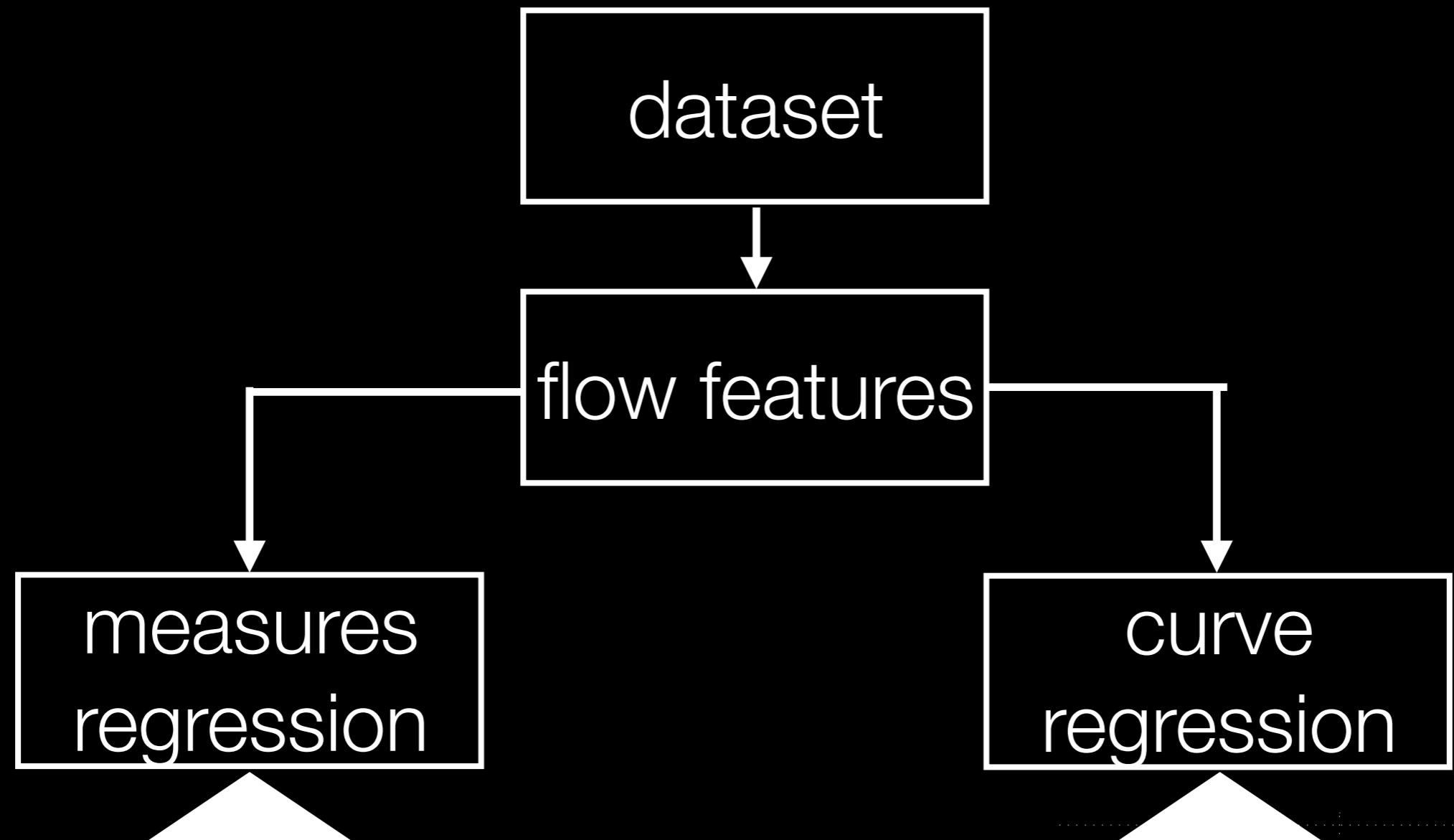










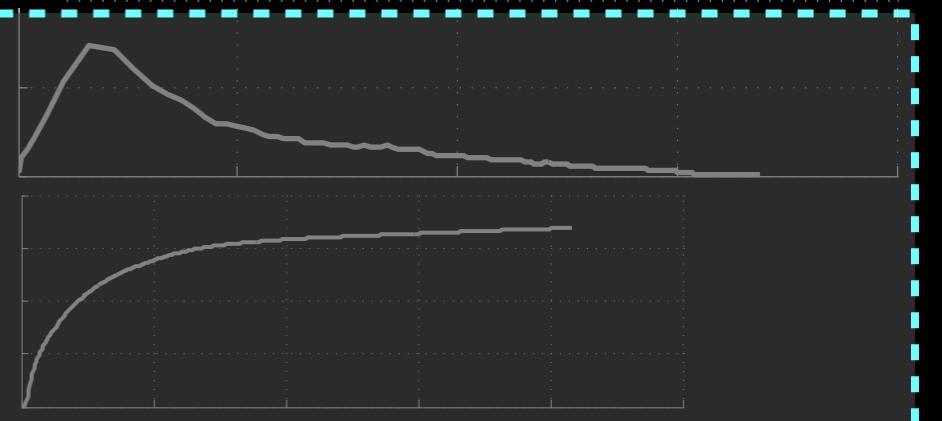


FEV1

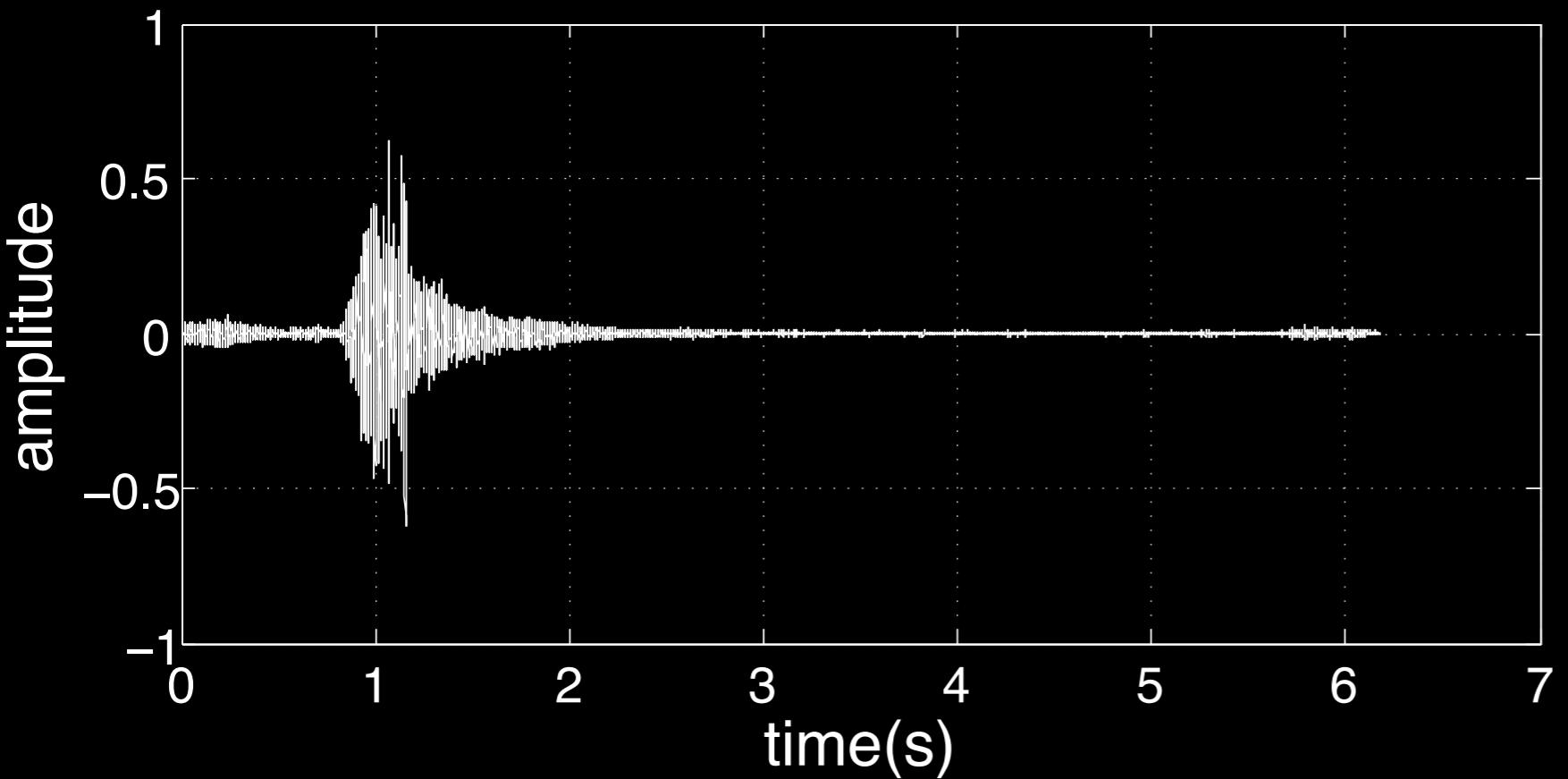
FVC

PEF

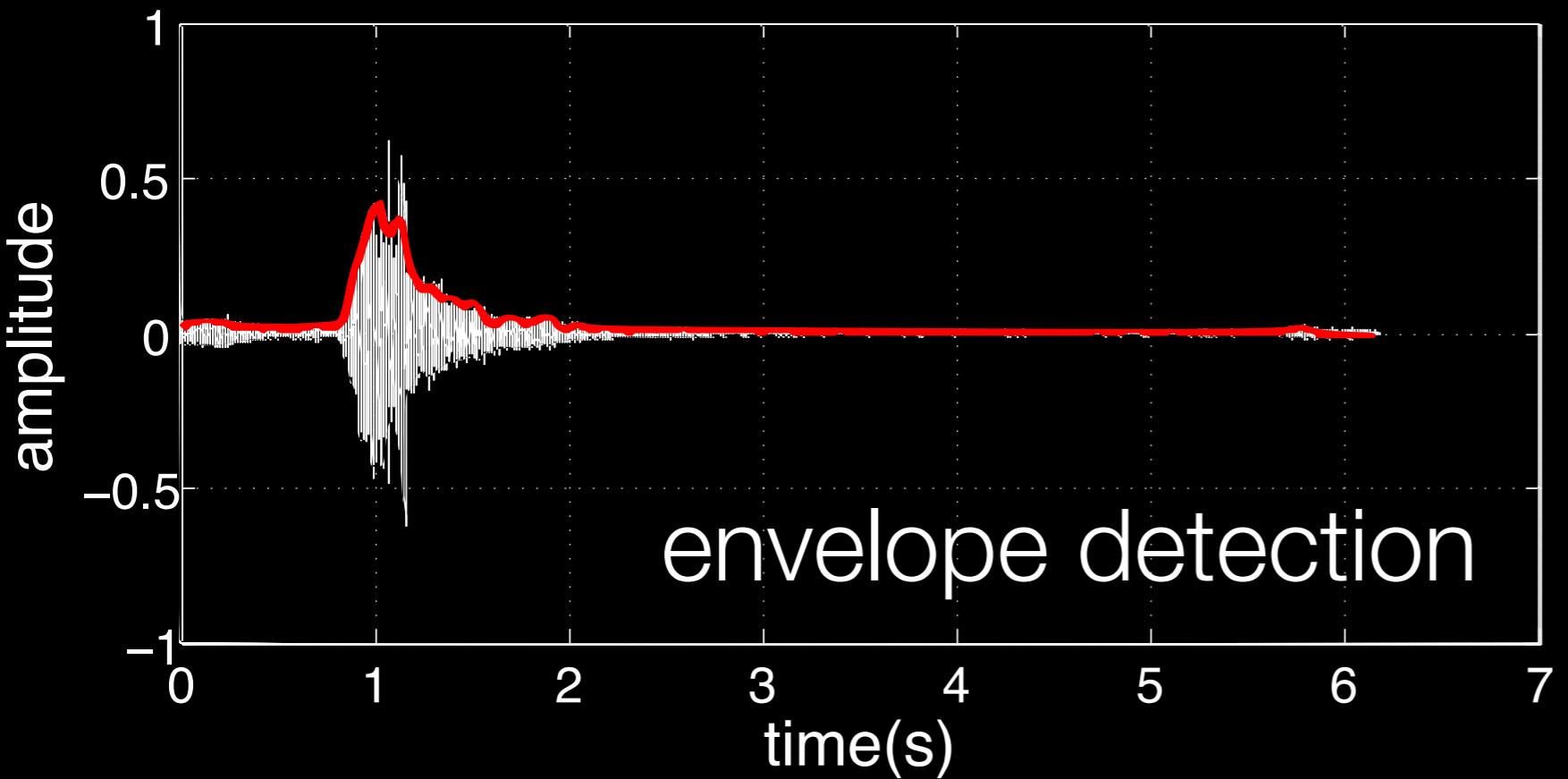
lung function



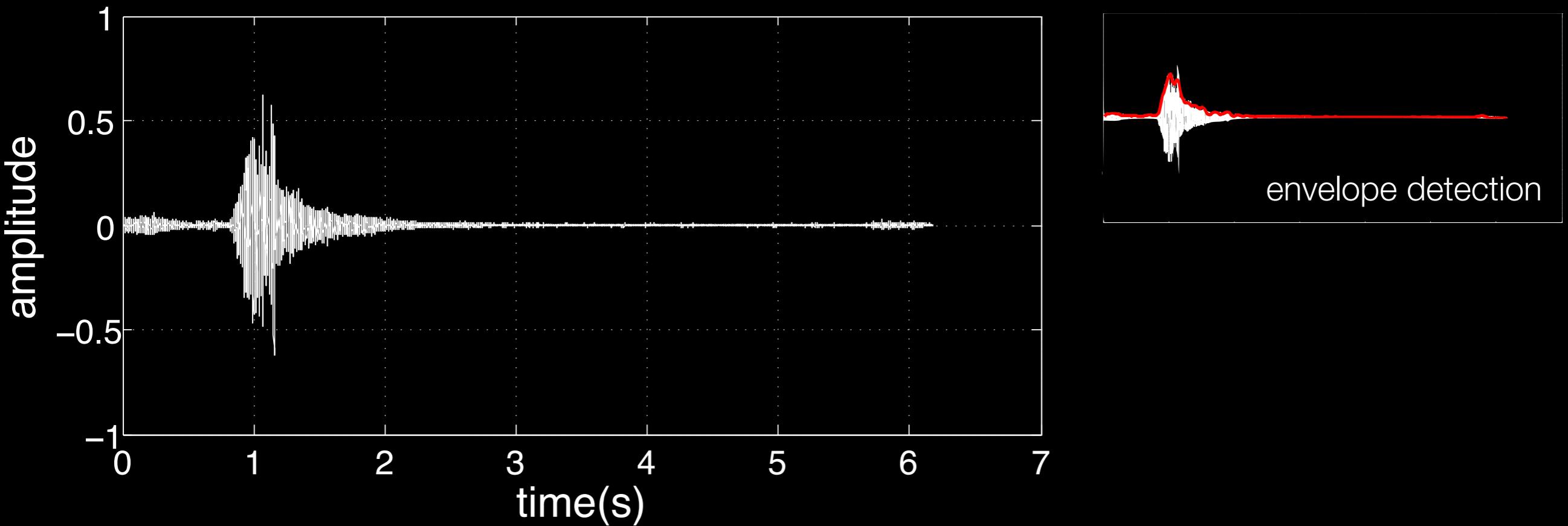
flow features



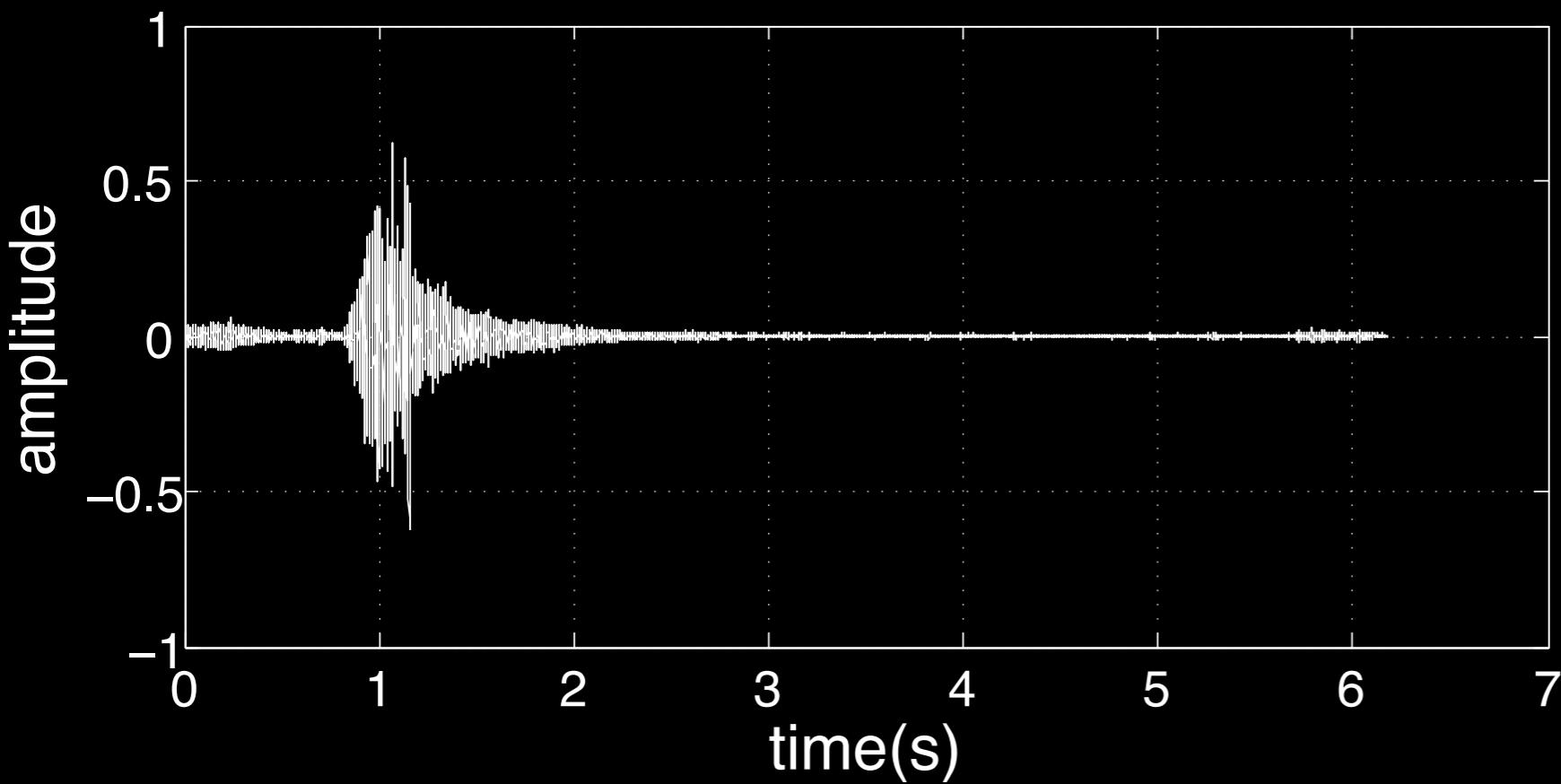
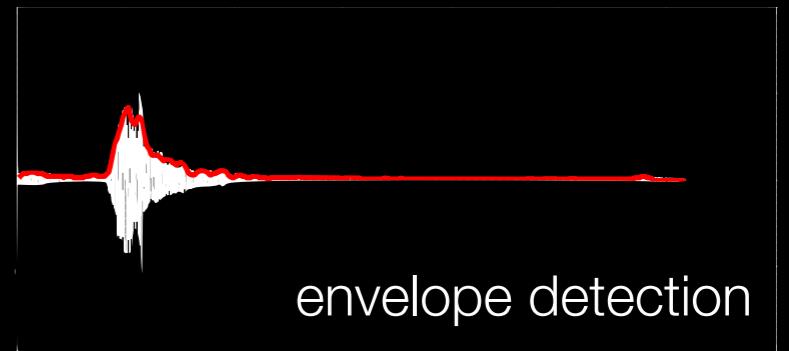
flow features



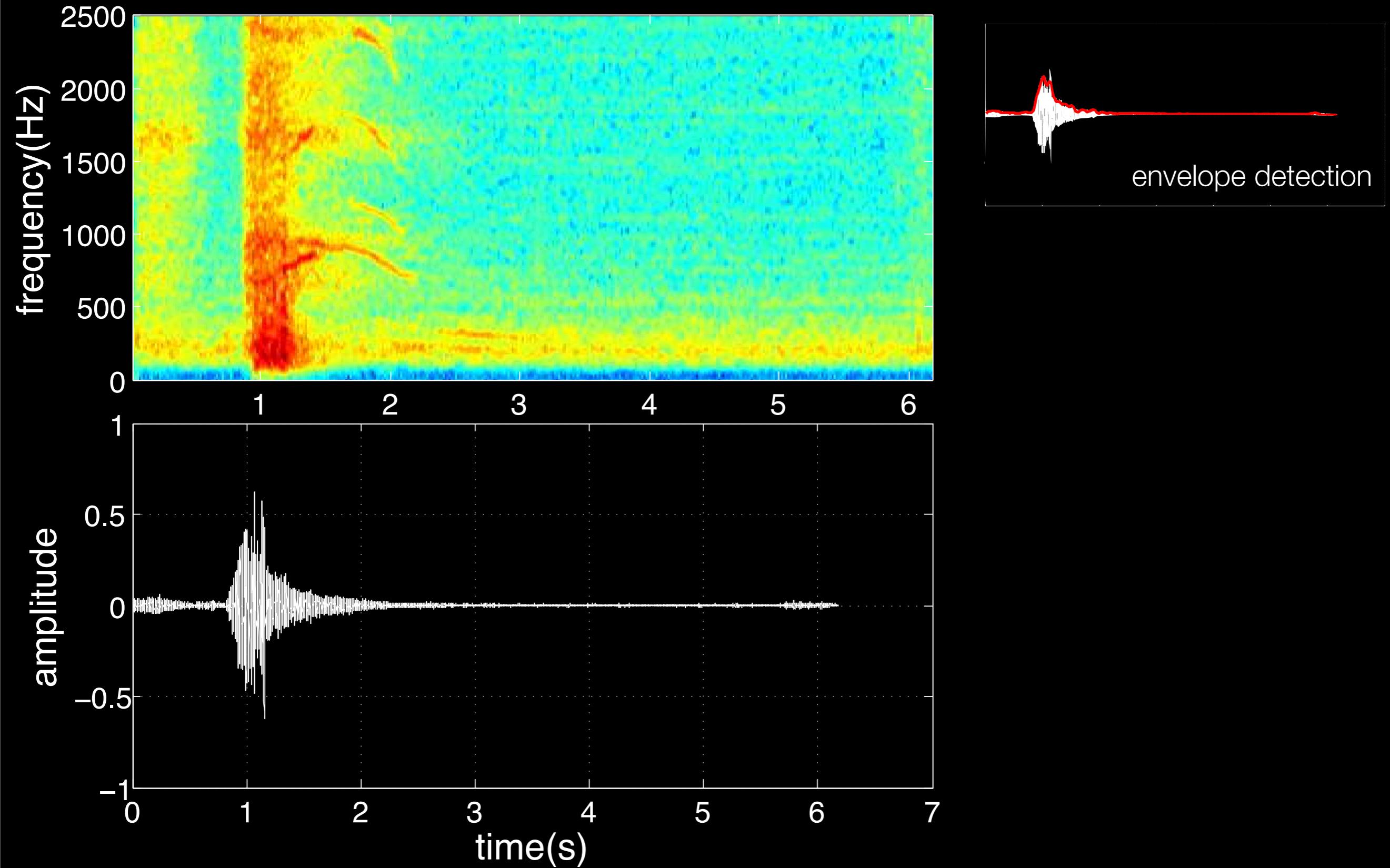
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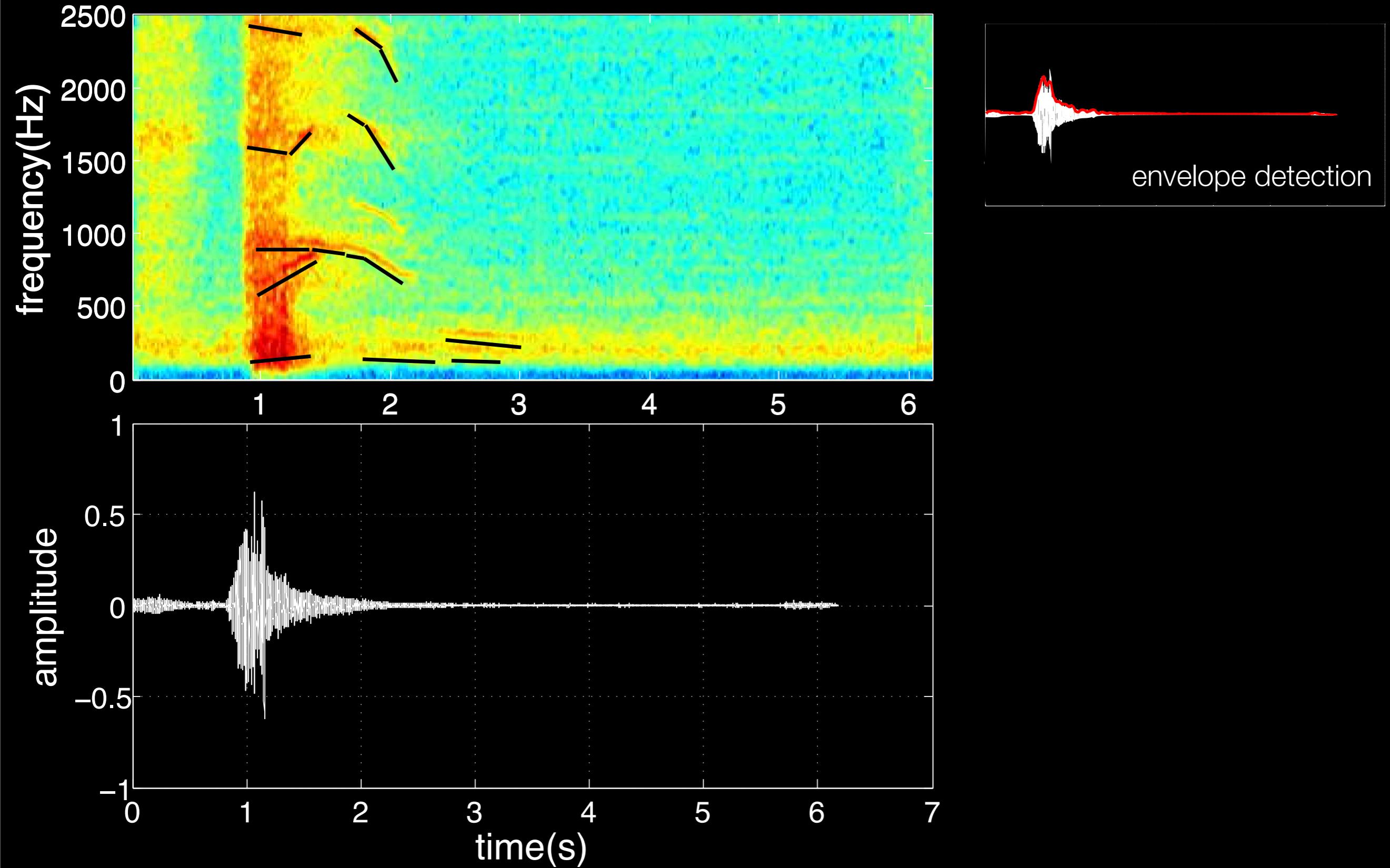
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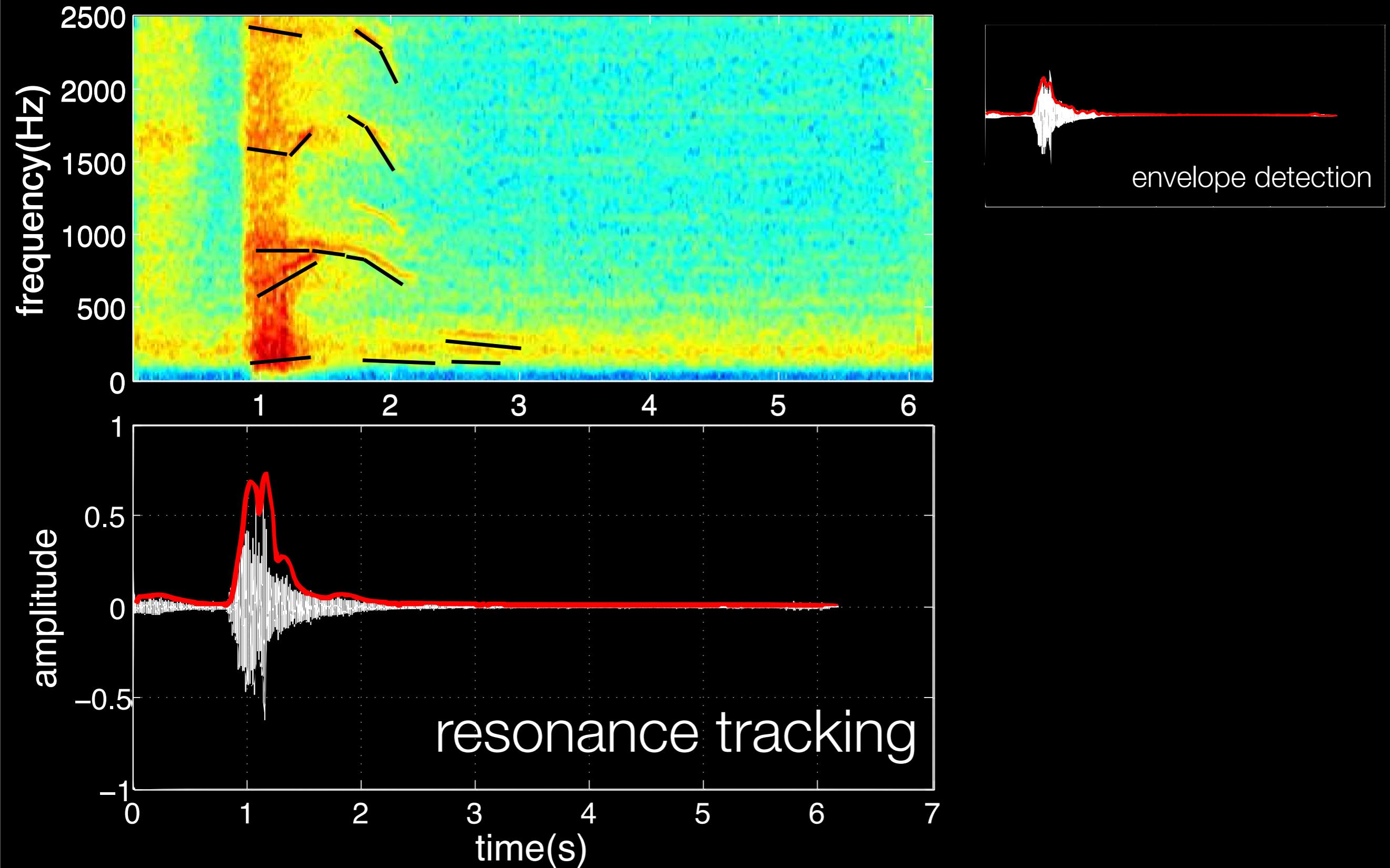
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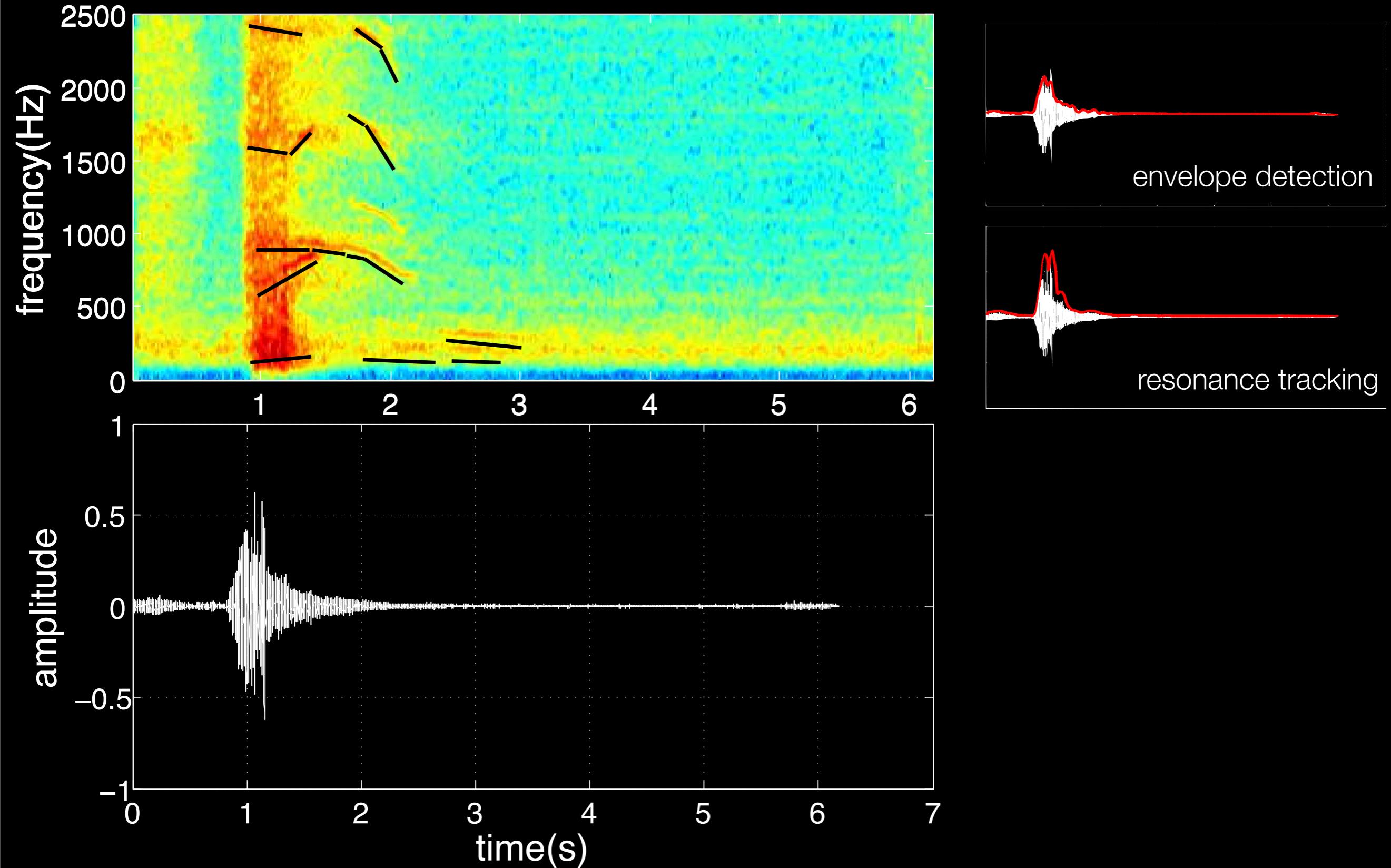
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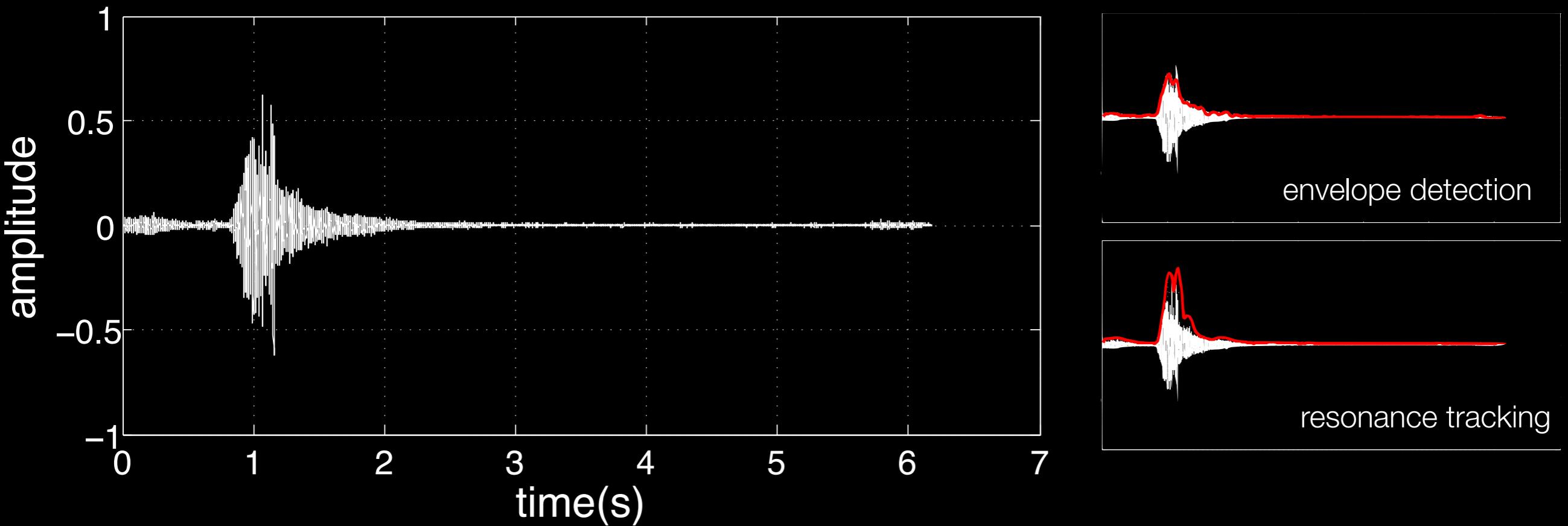
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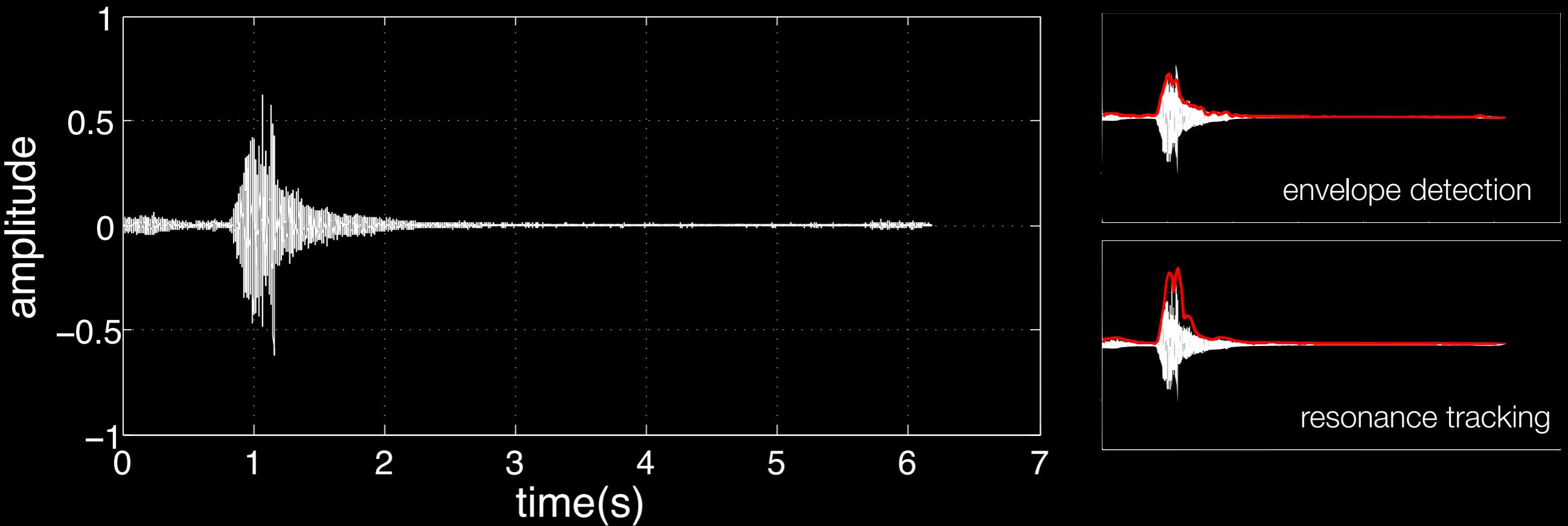
flow features



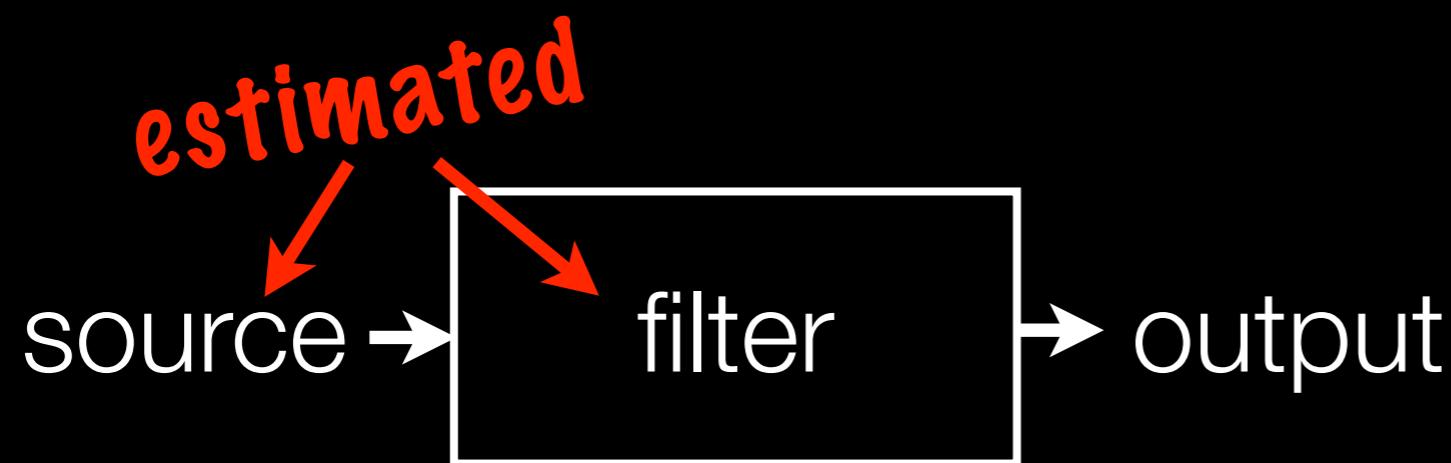
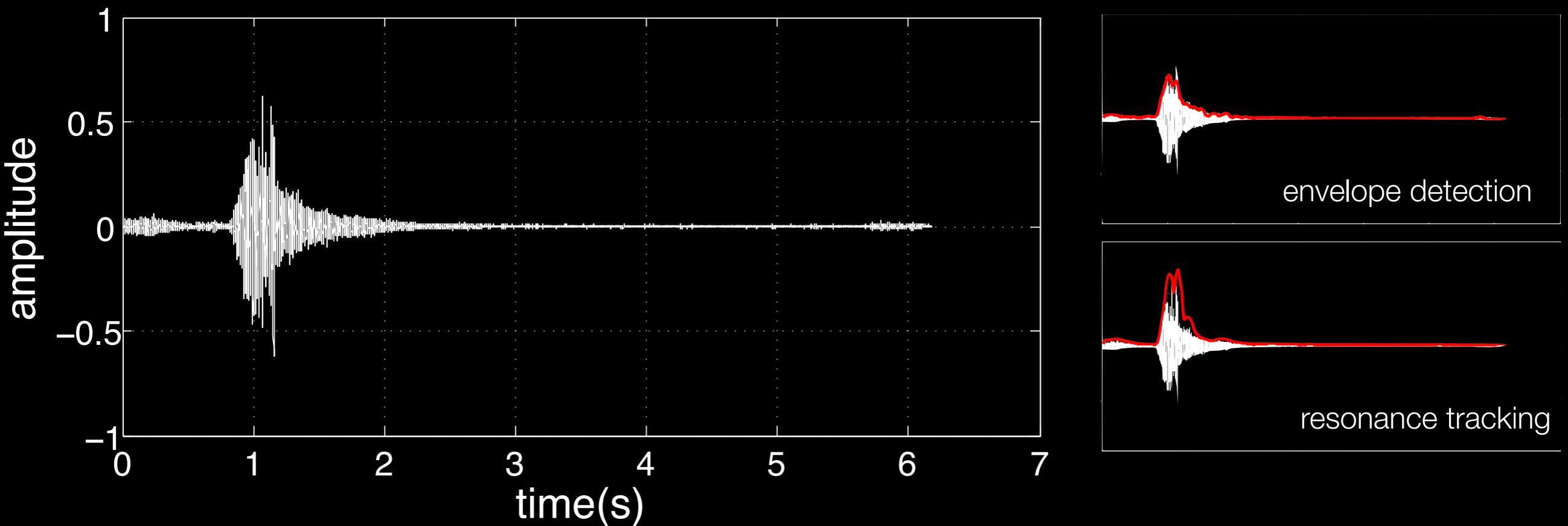
flow features



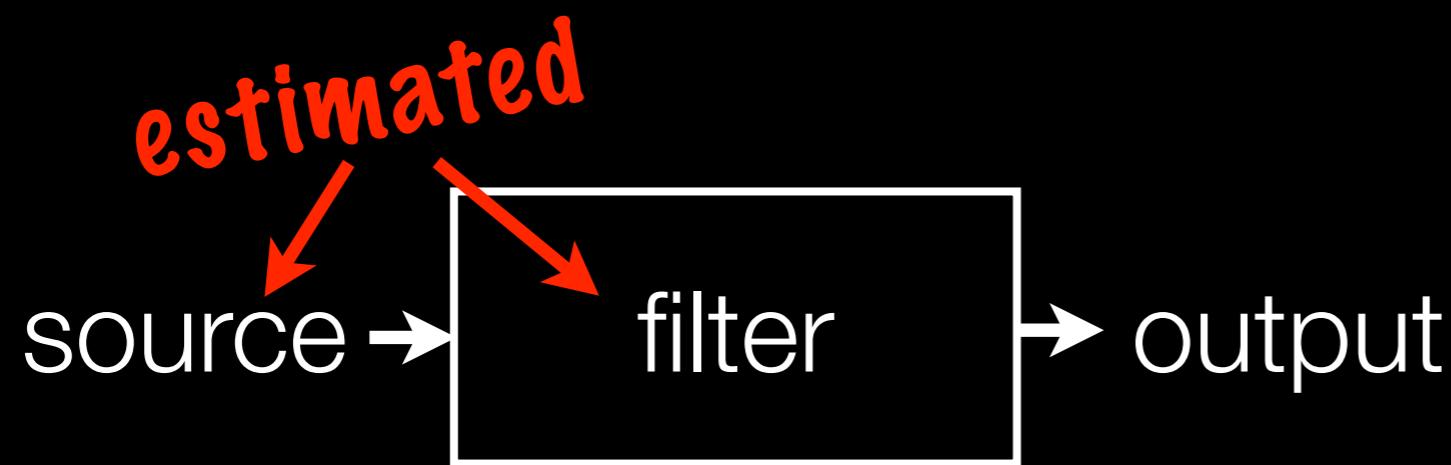
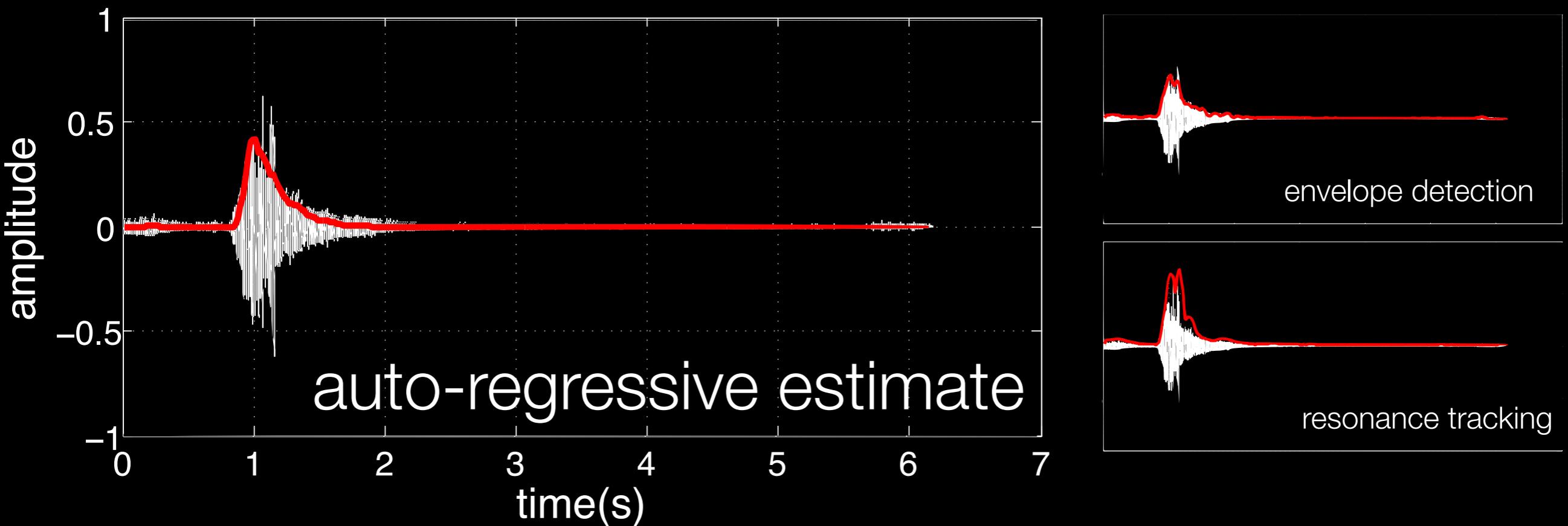
flow features



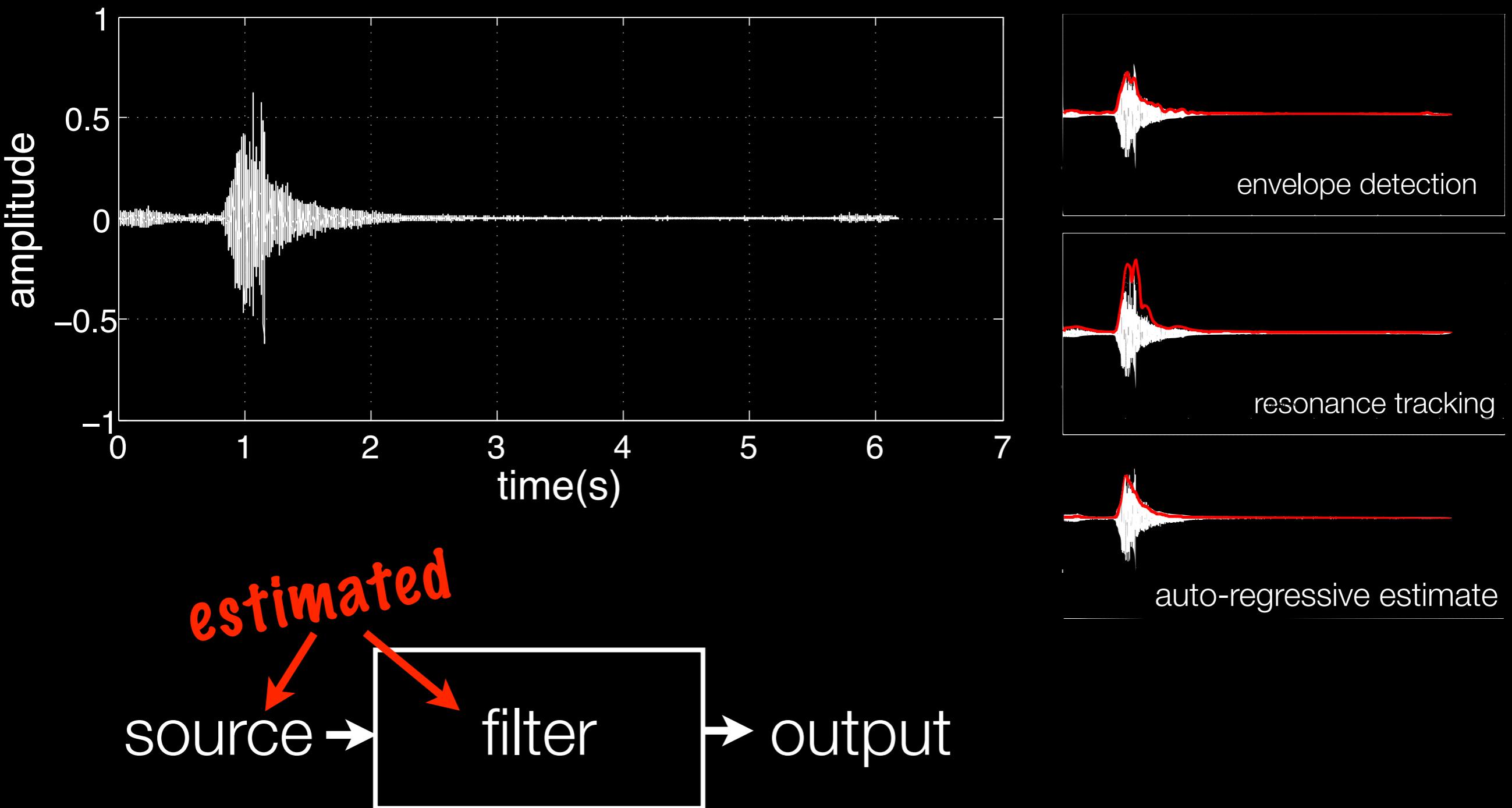
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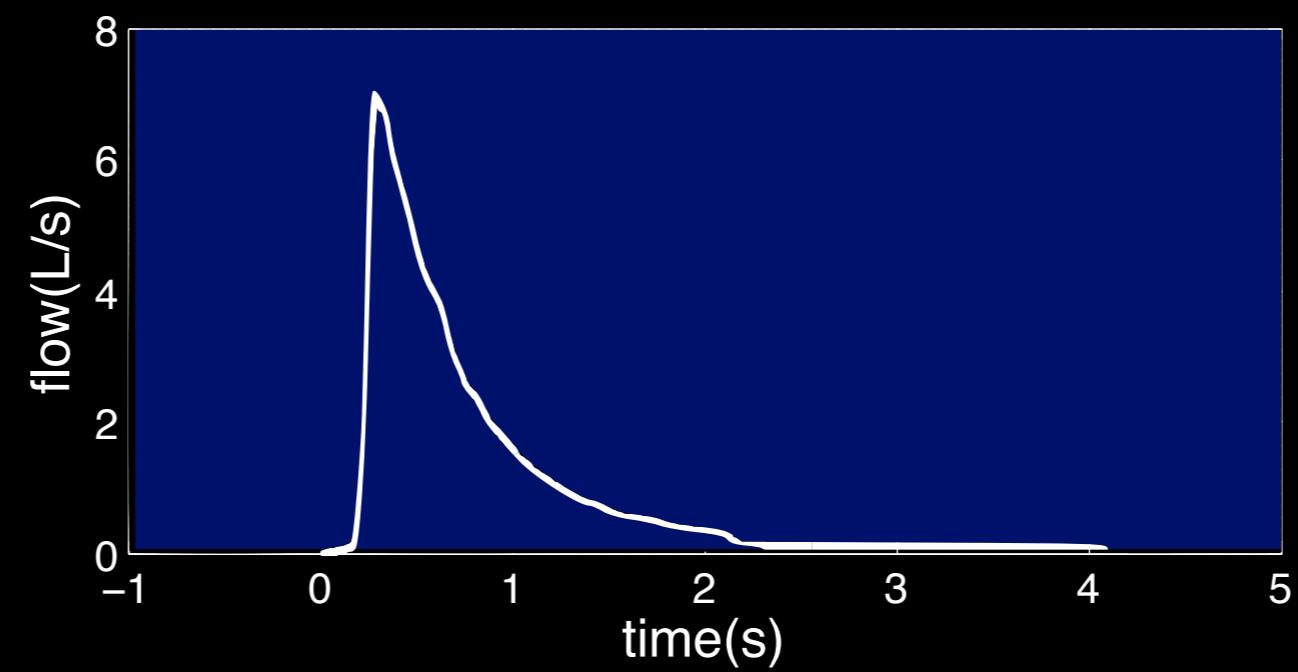
flow features



flow features

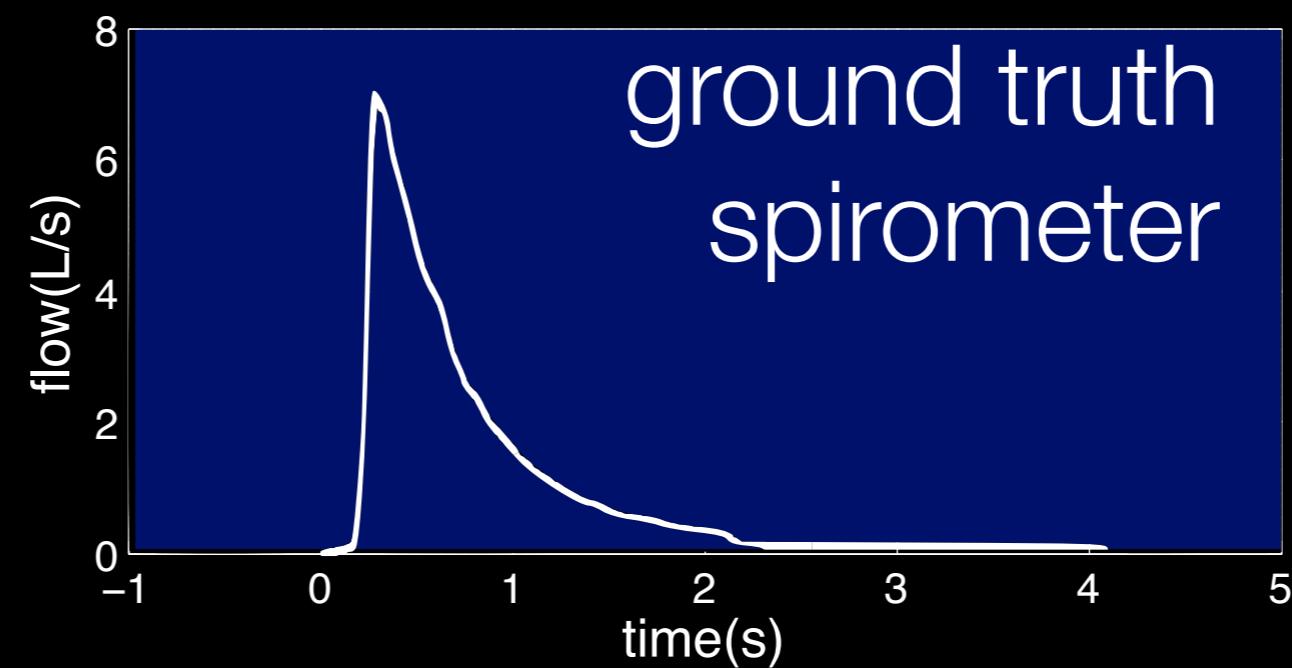


flow features

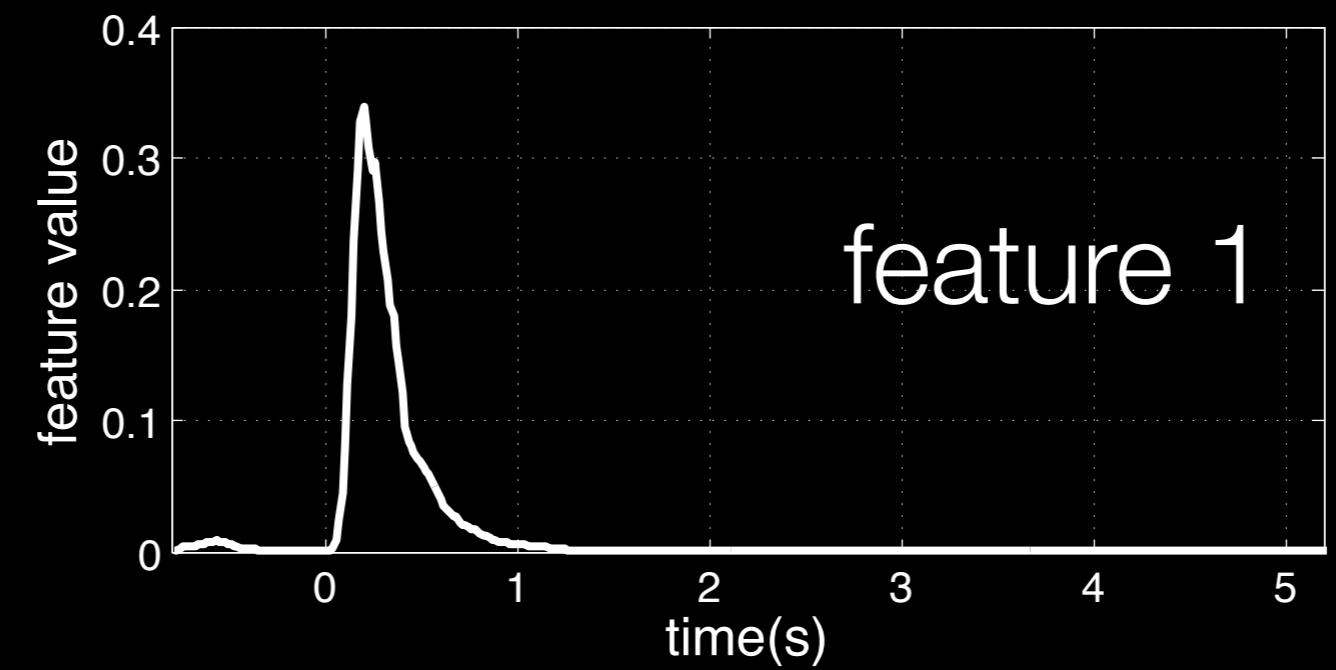
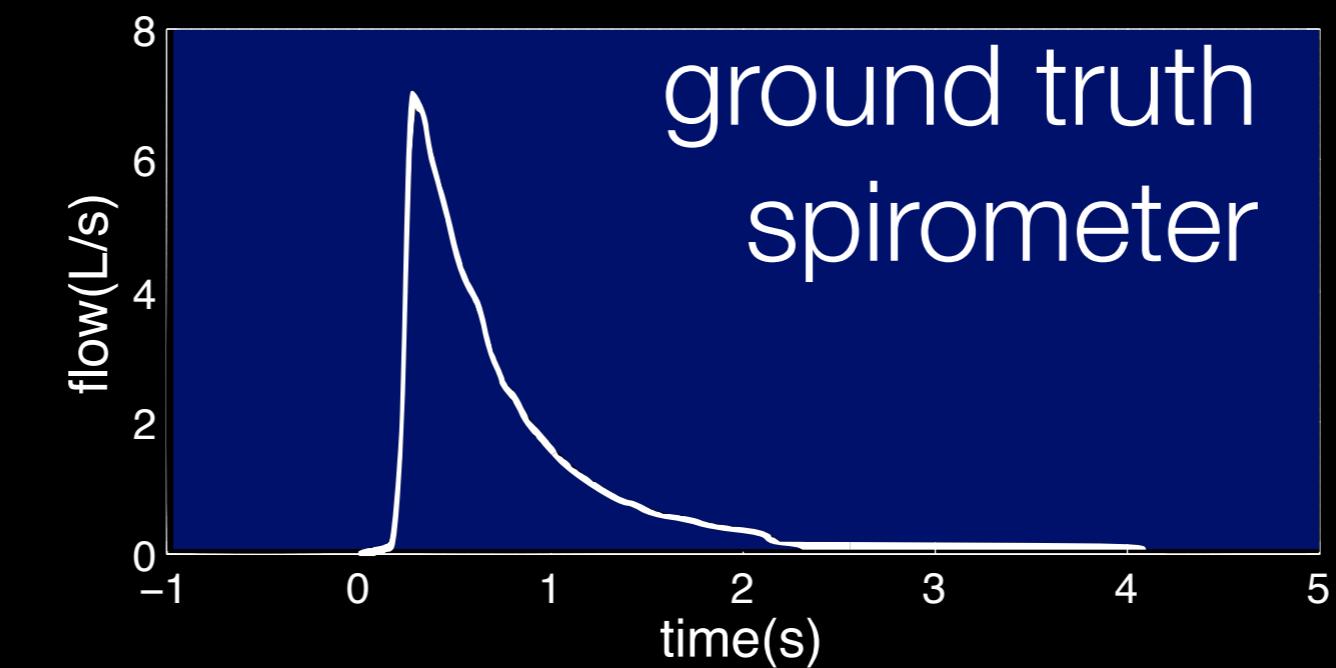


flow features

ground truth
spirometer

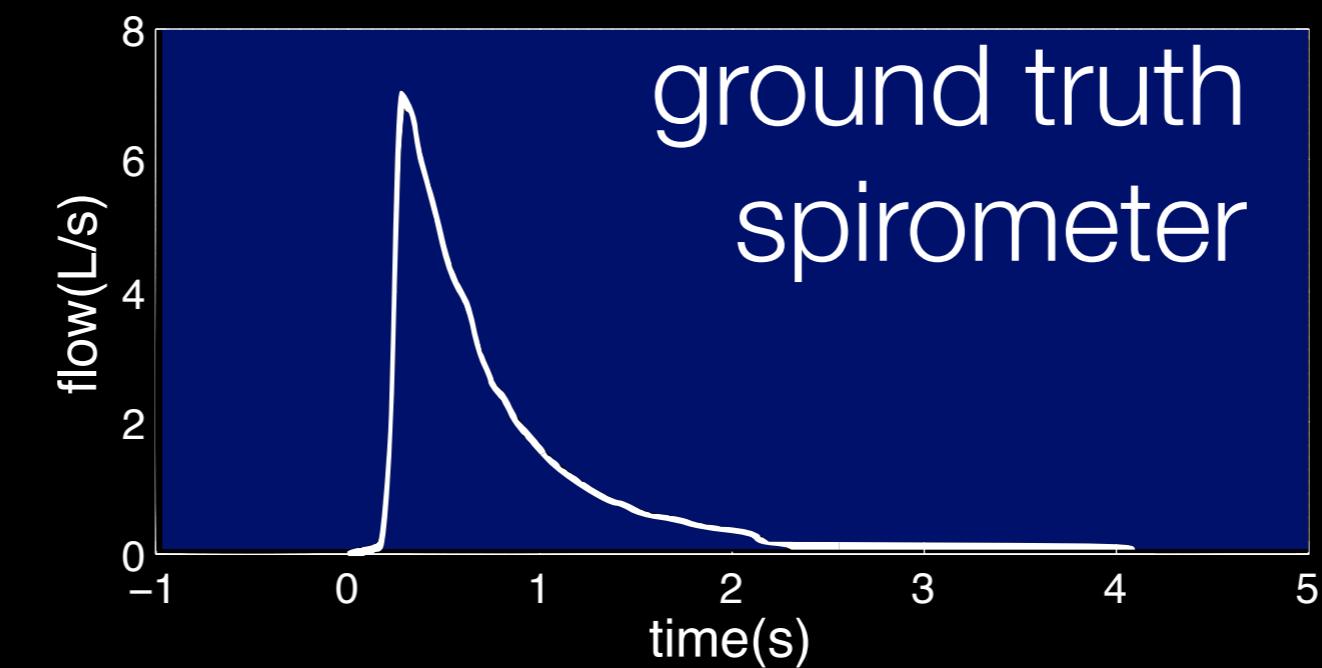


flow features

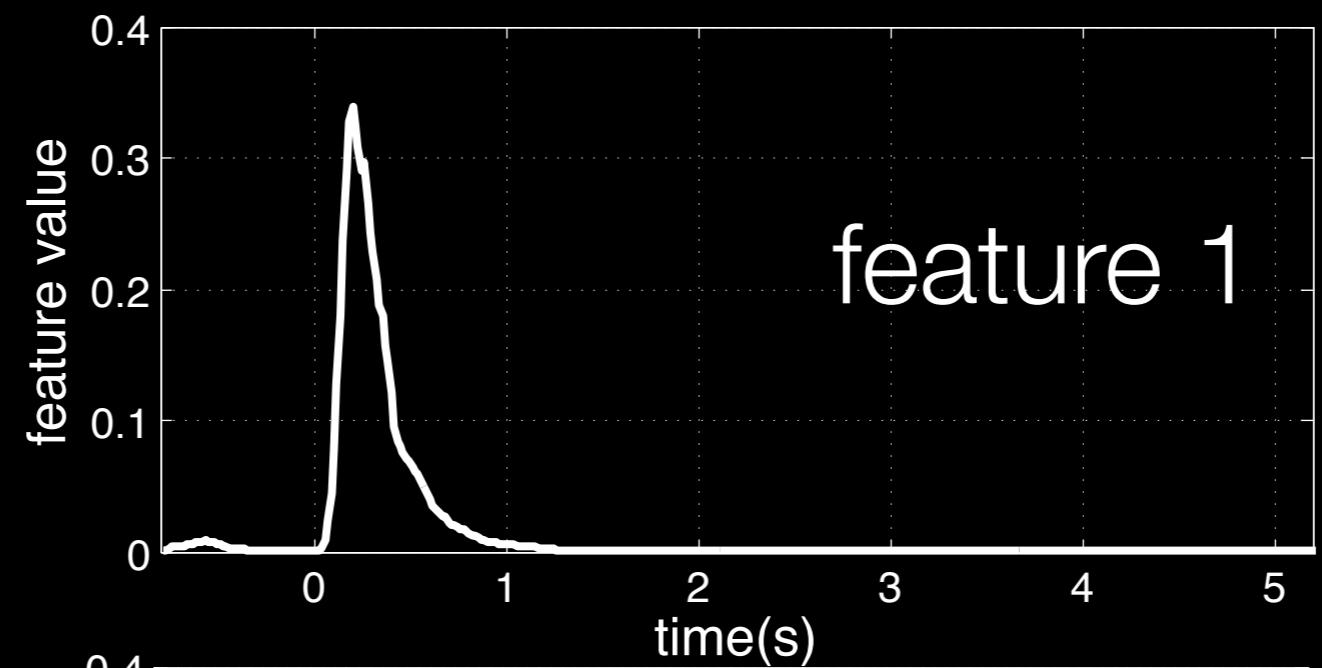


flow features

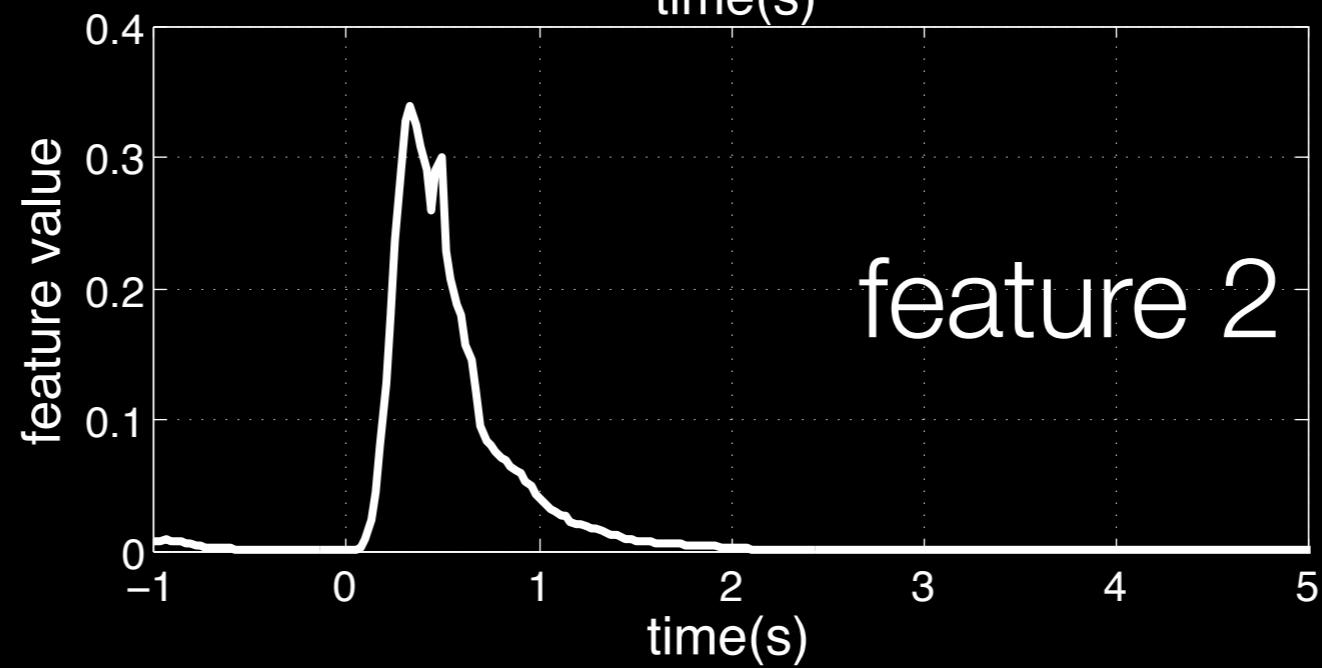
ground truth
spirometer



feature 1

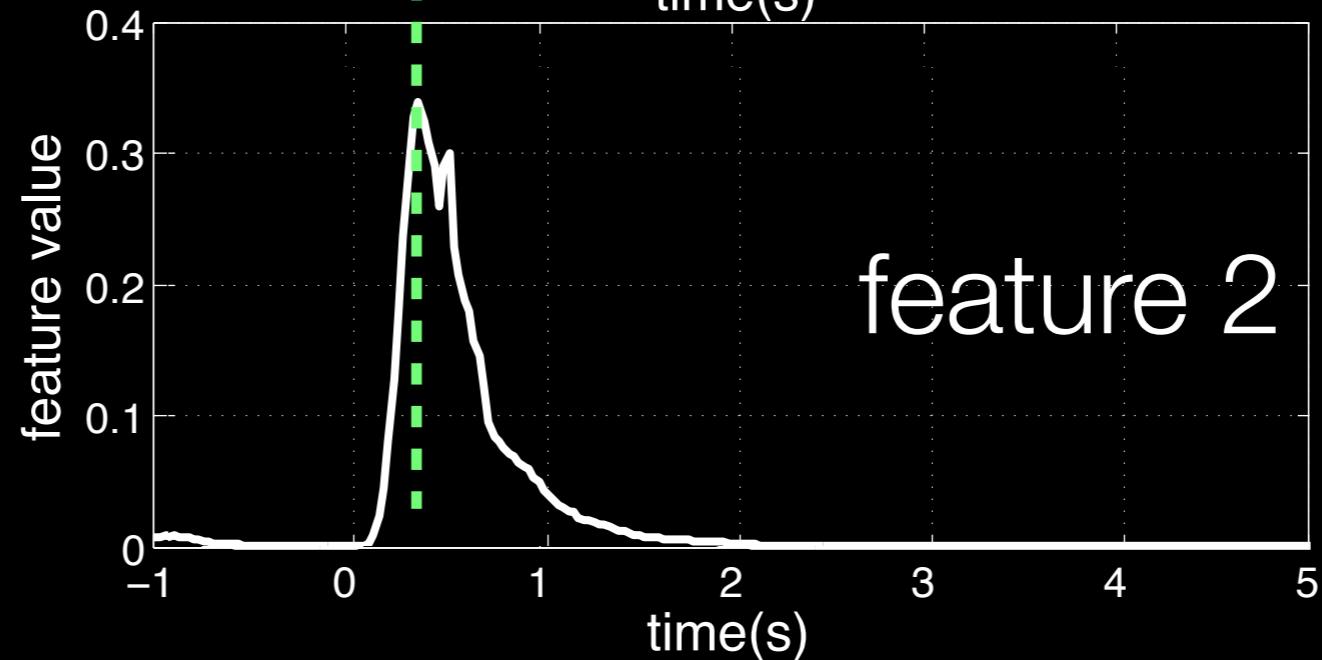
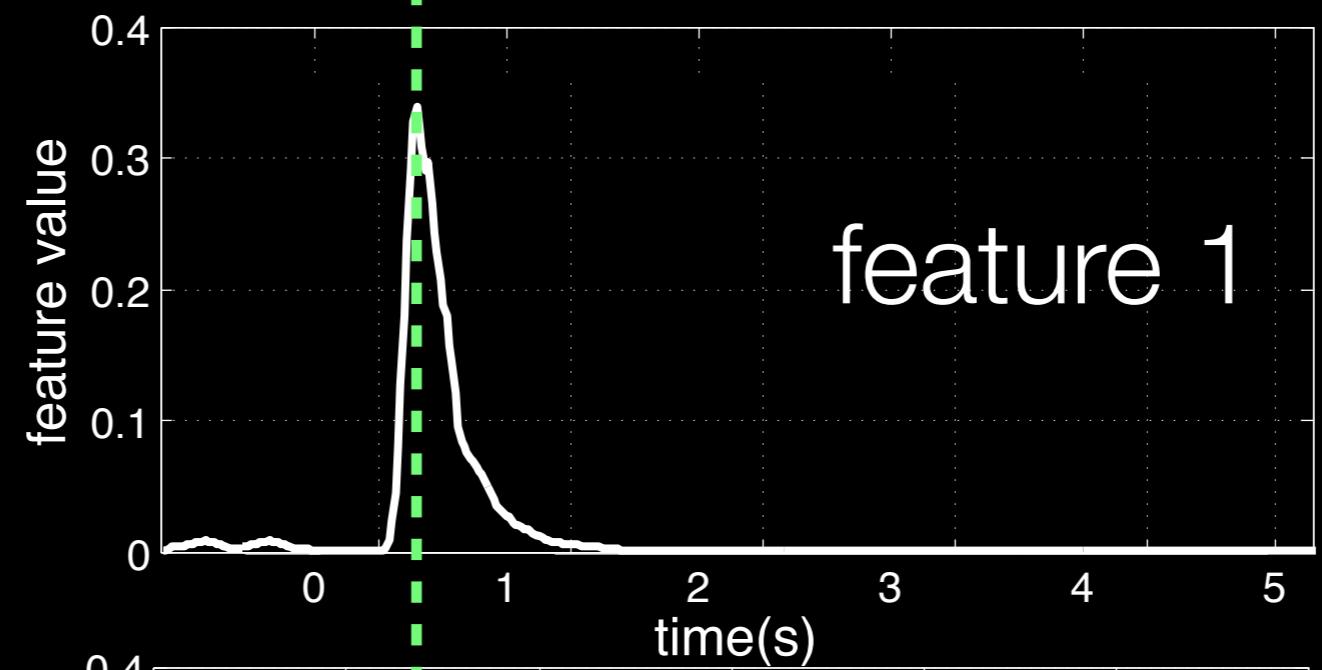
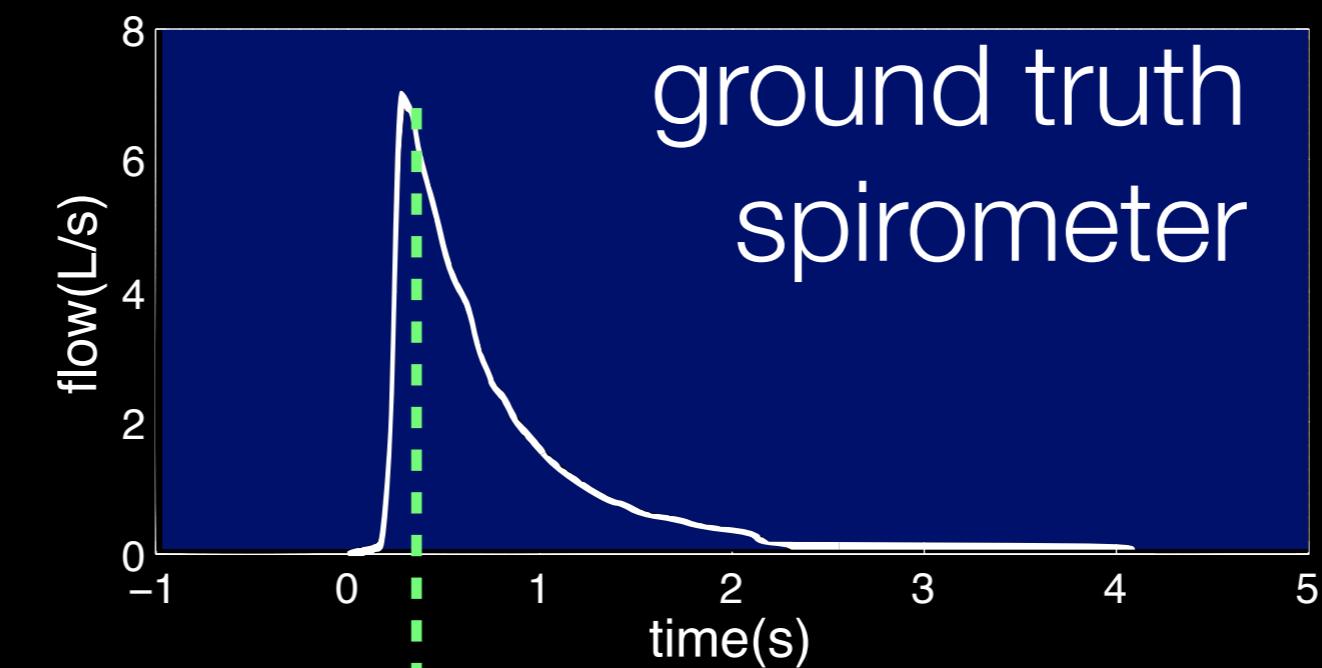


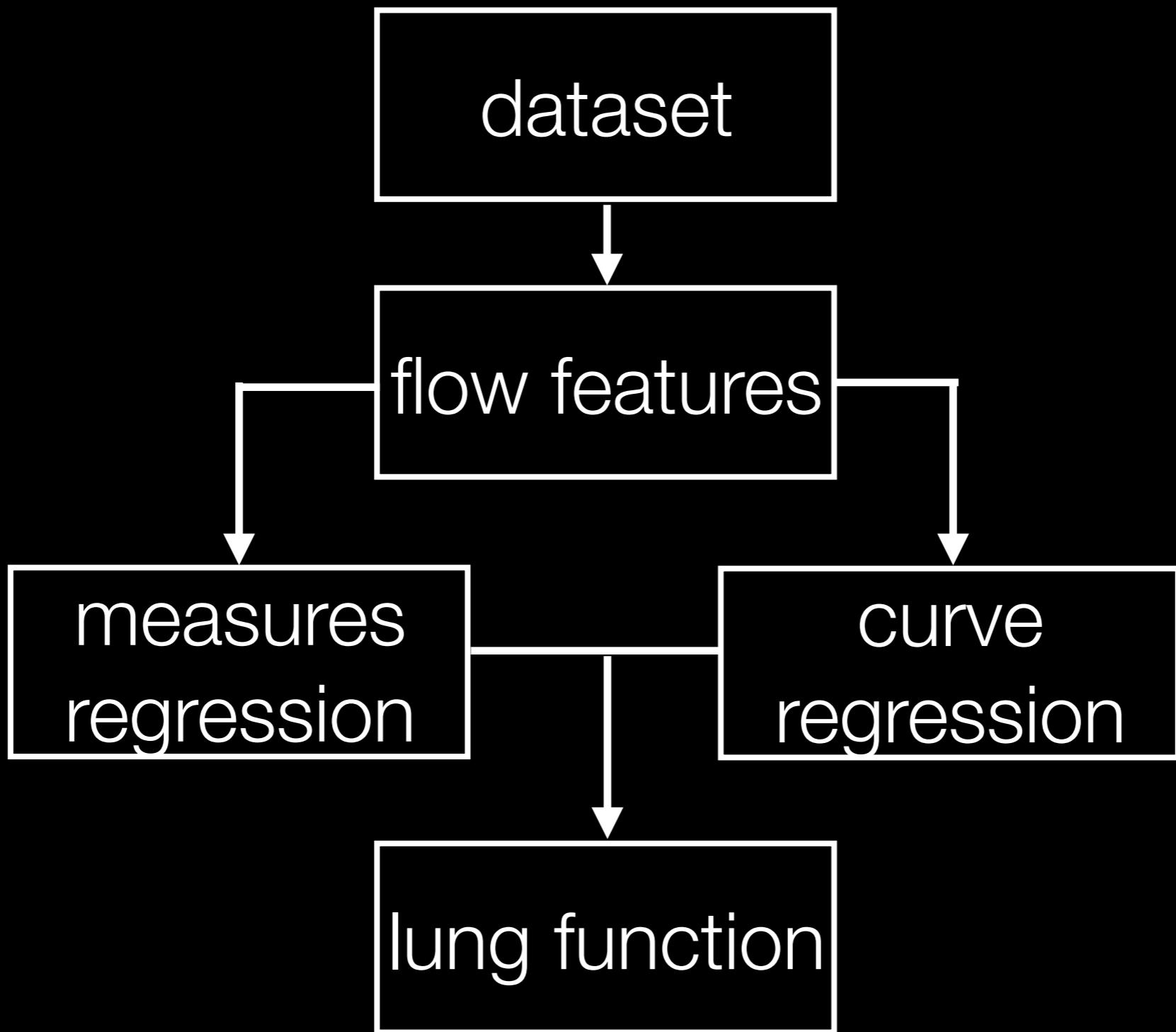
feature 2



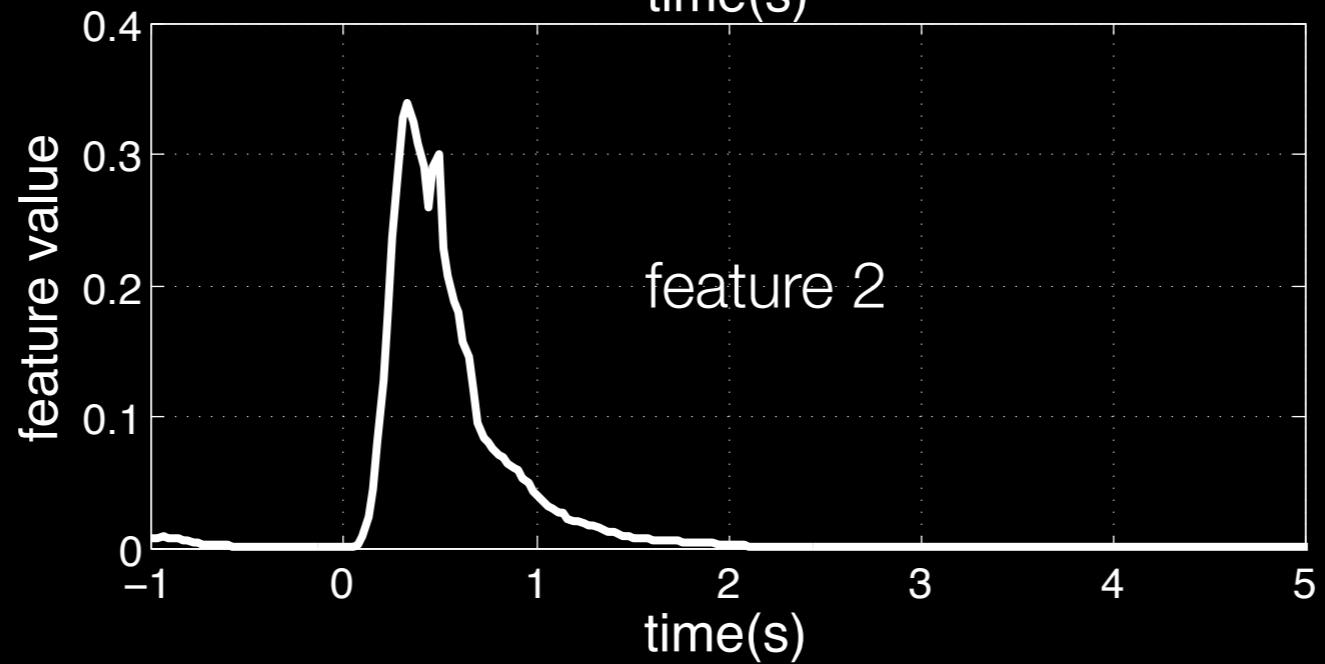
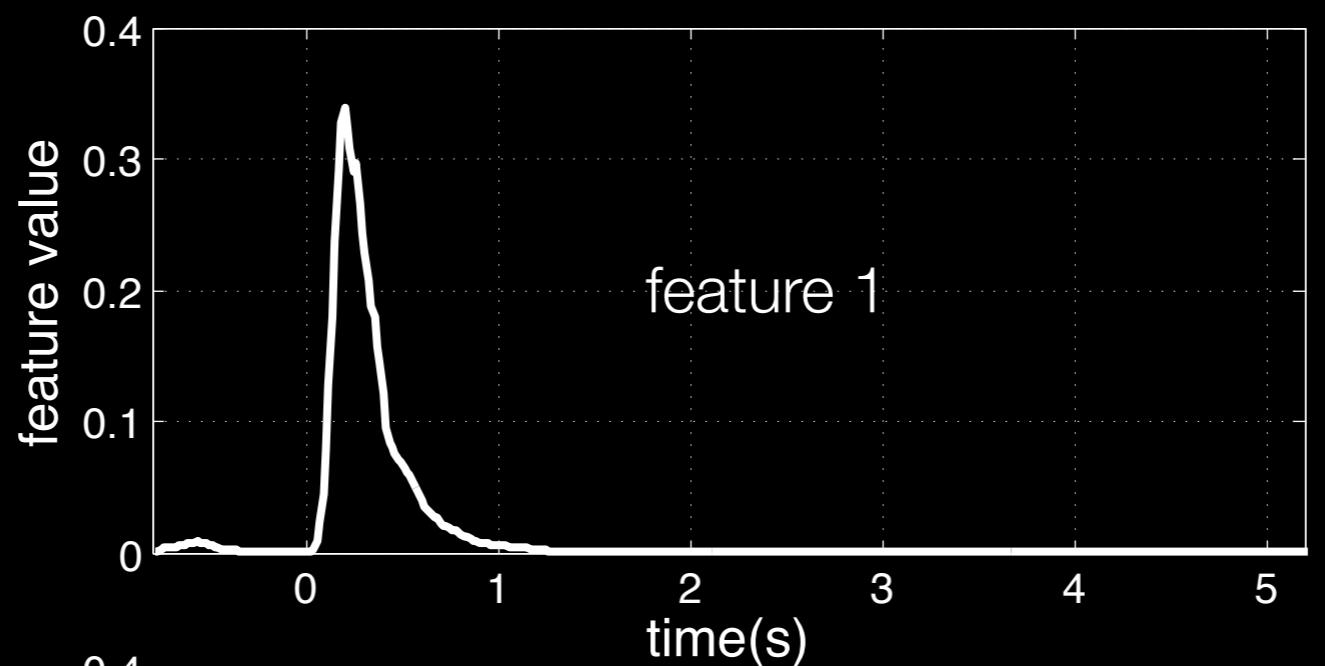
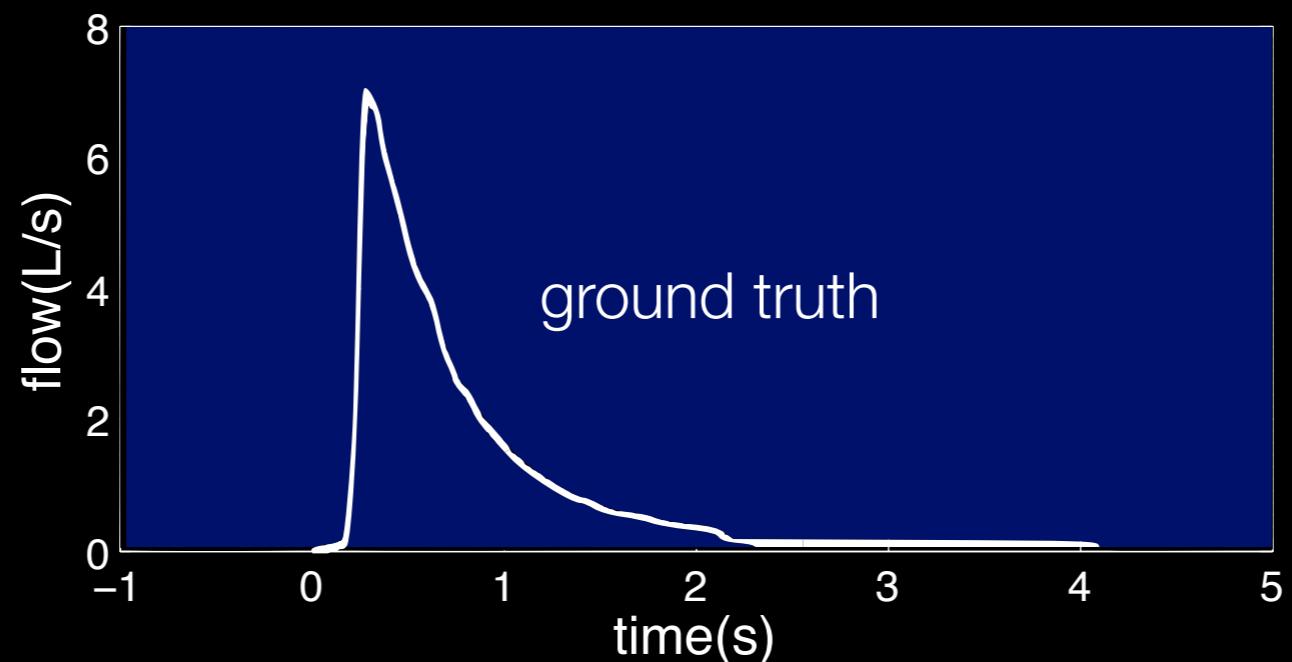
flow features

ground truth
spirometer

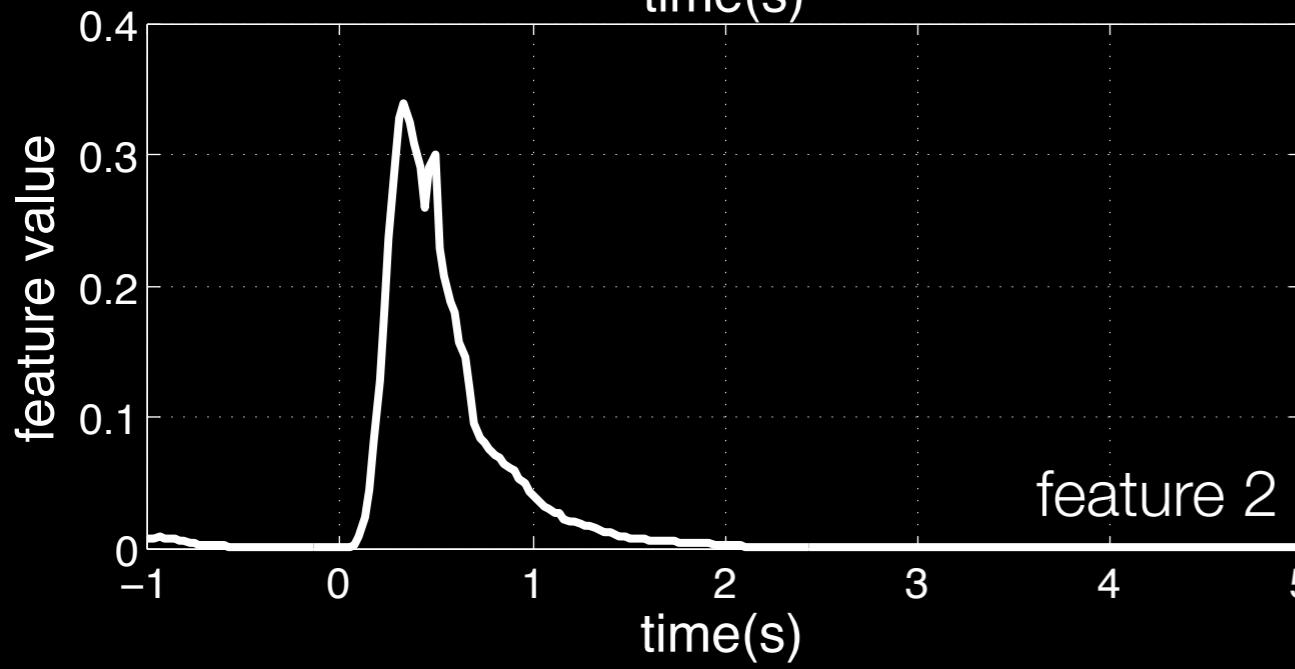
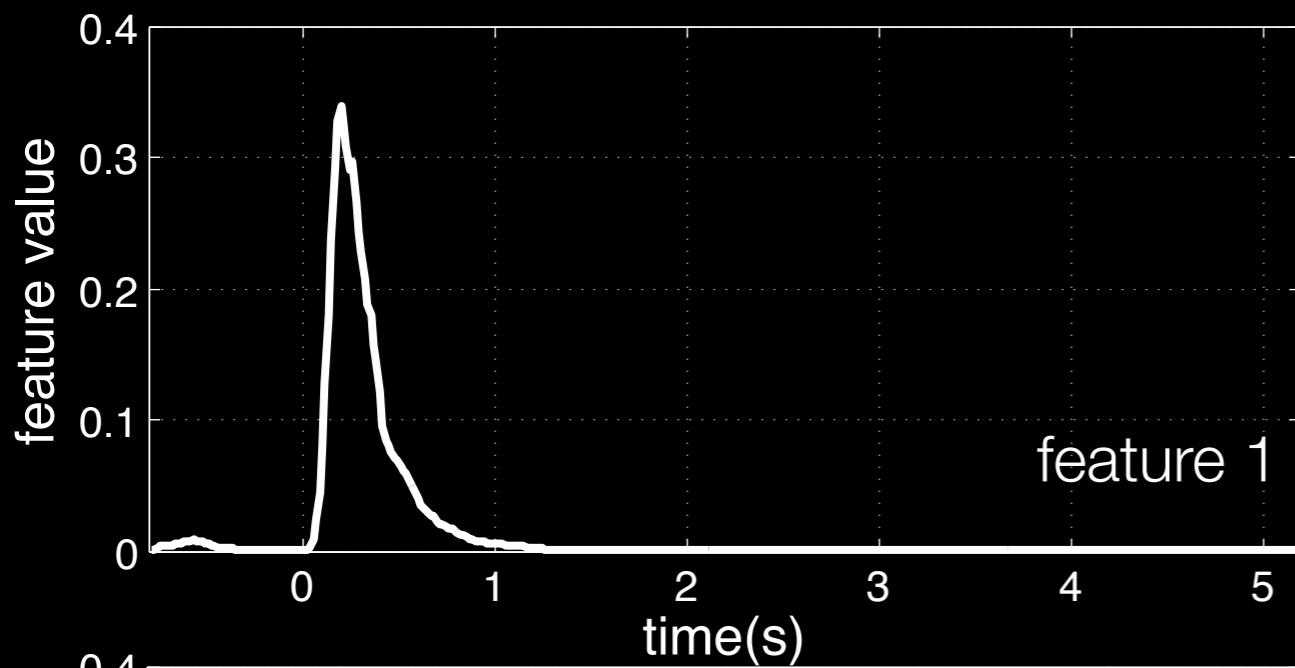
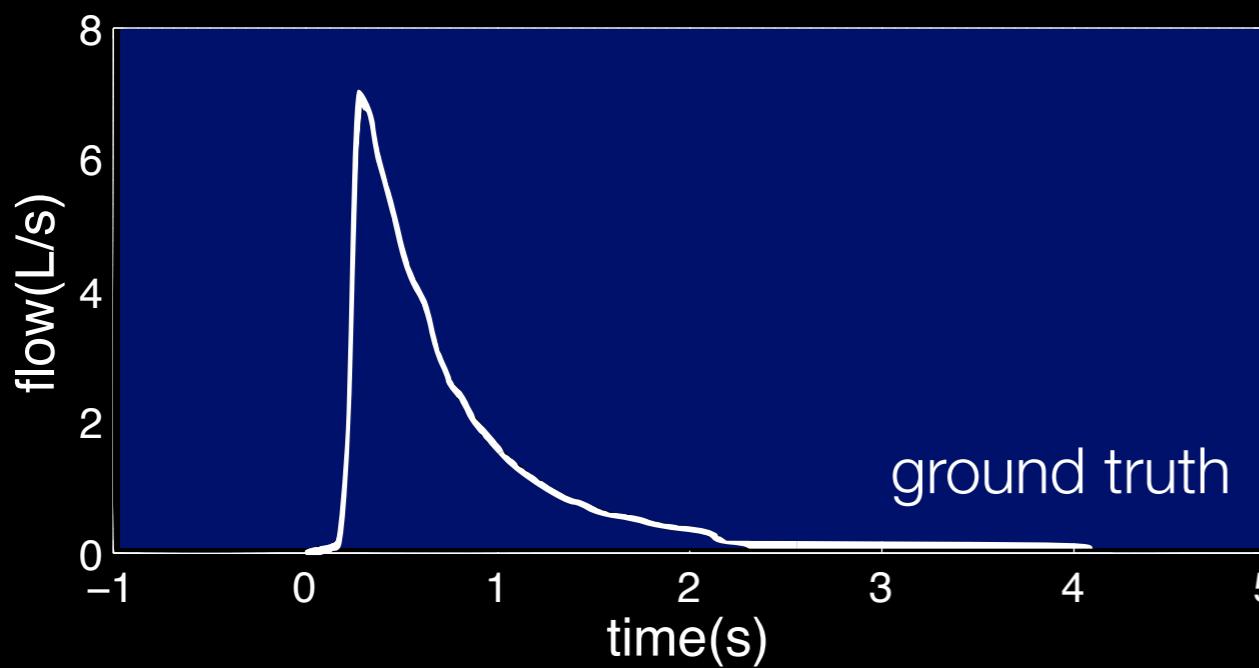


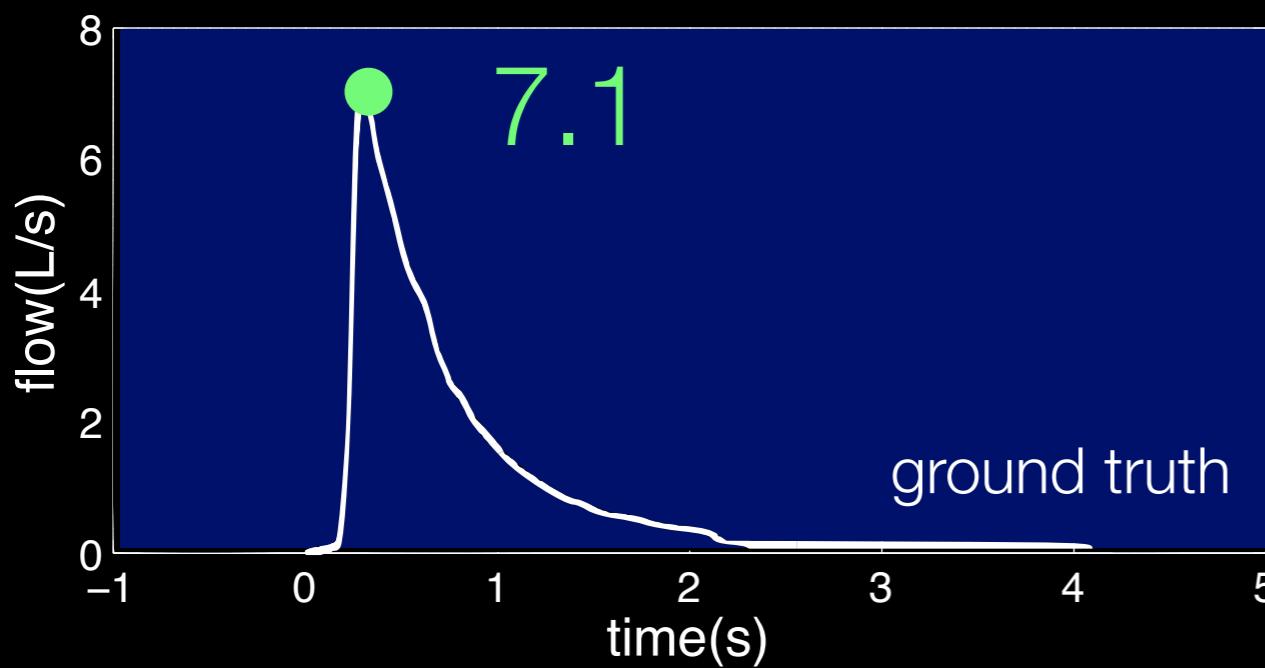


measures
regression



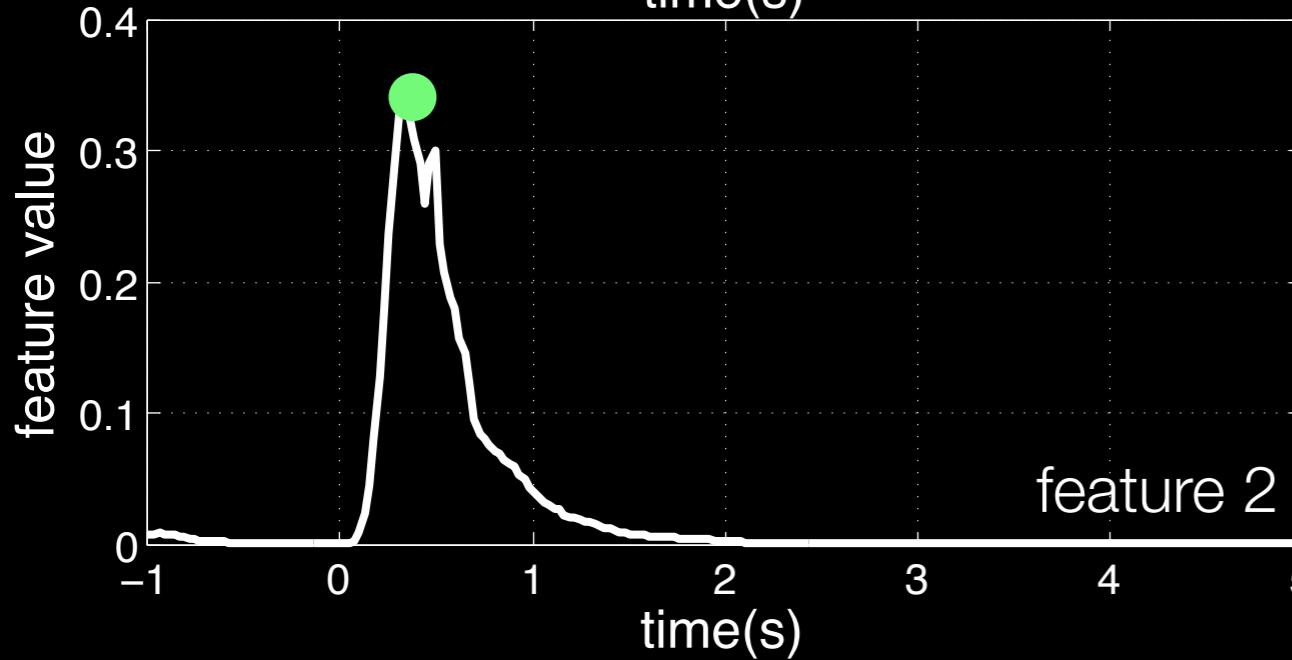
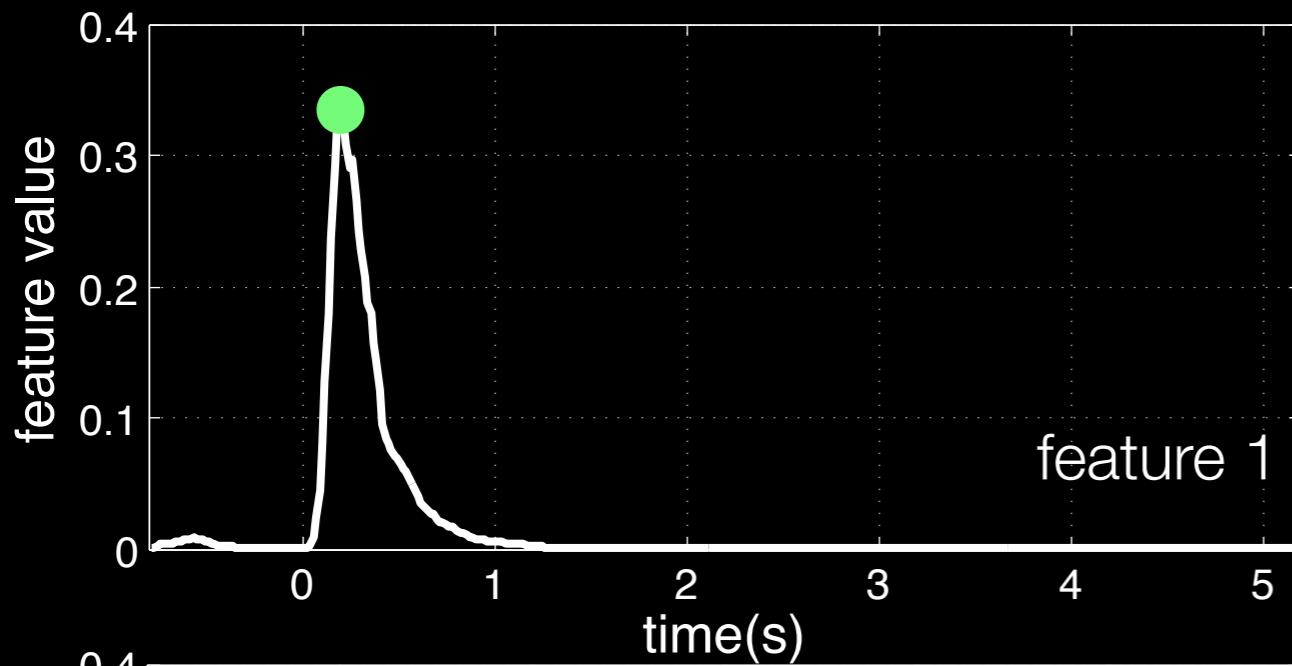
measures
regression

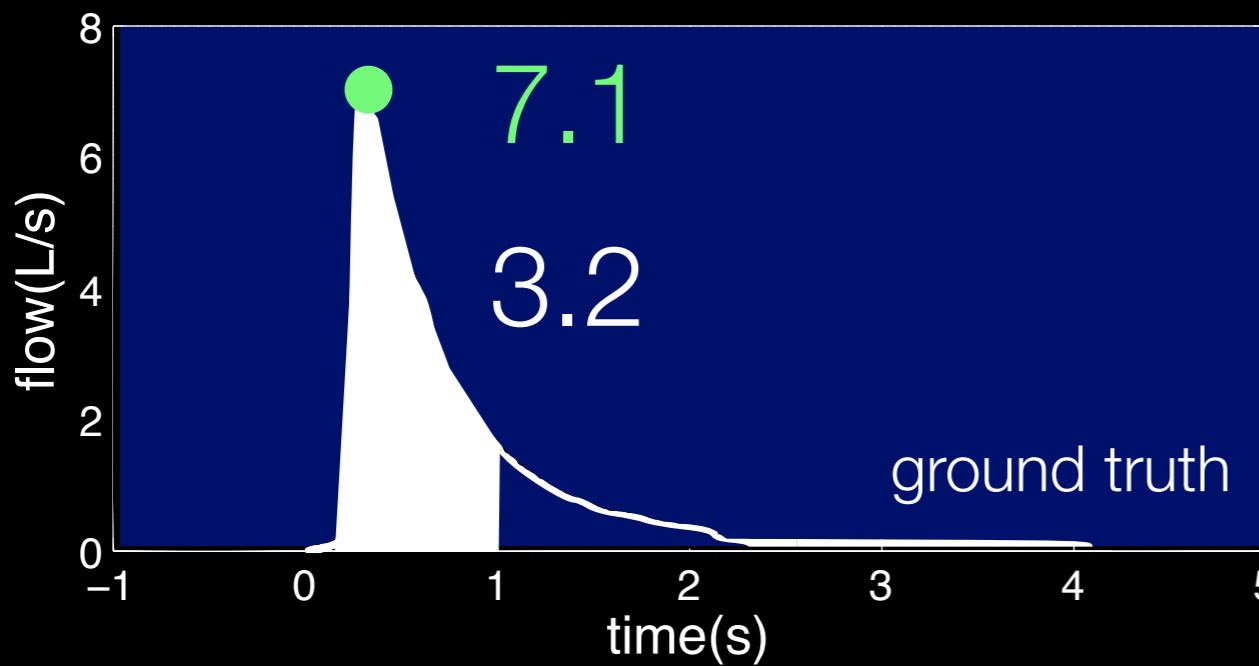




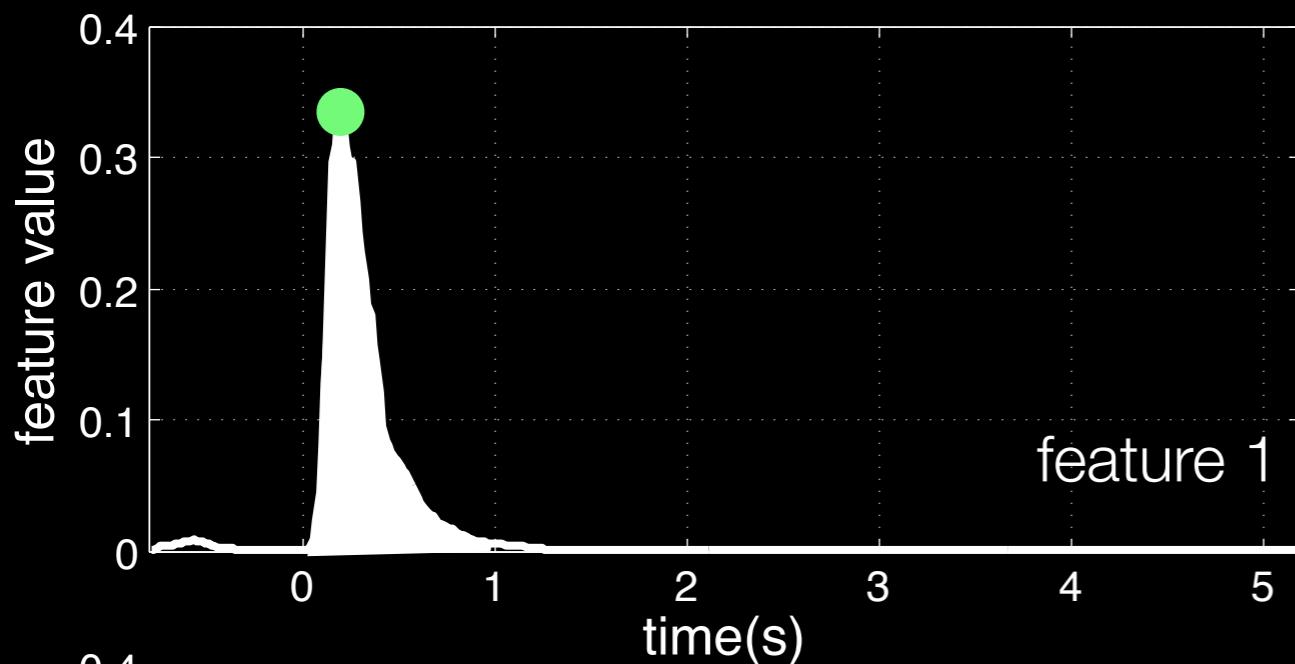
measures
regression

PEF features
0.35
0.33

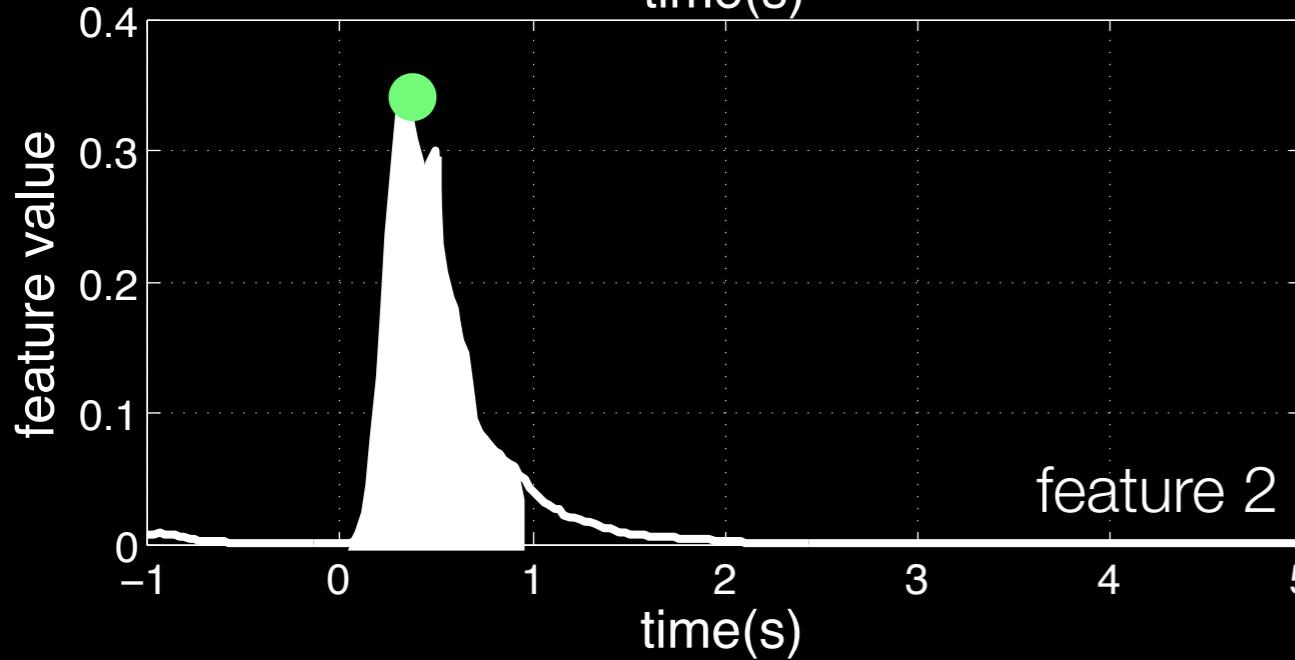




measures
regression



PEF features
0.35
0.33



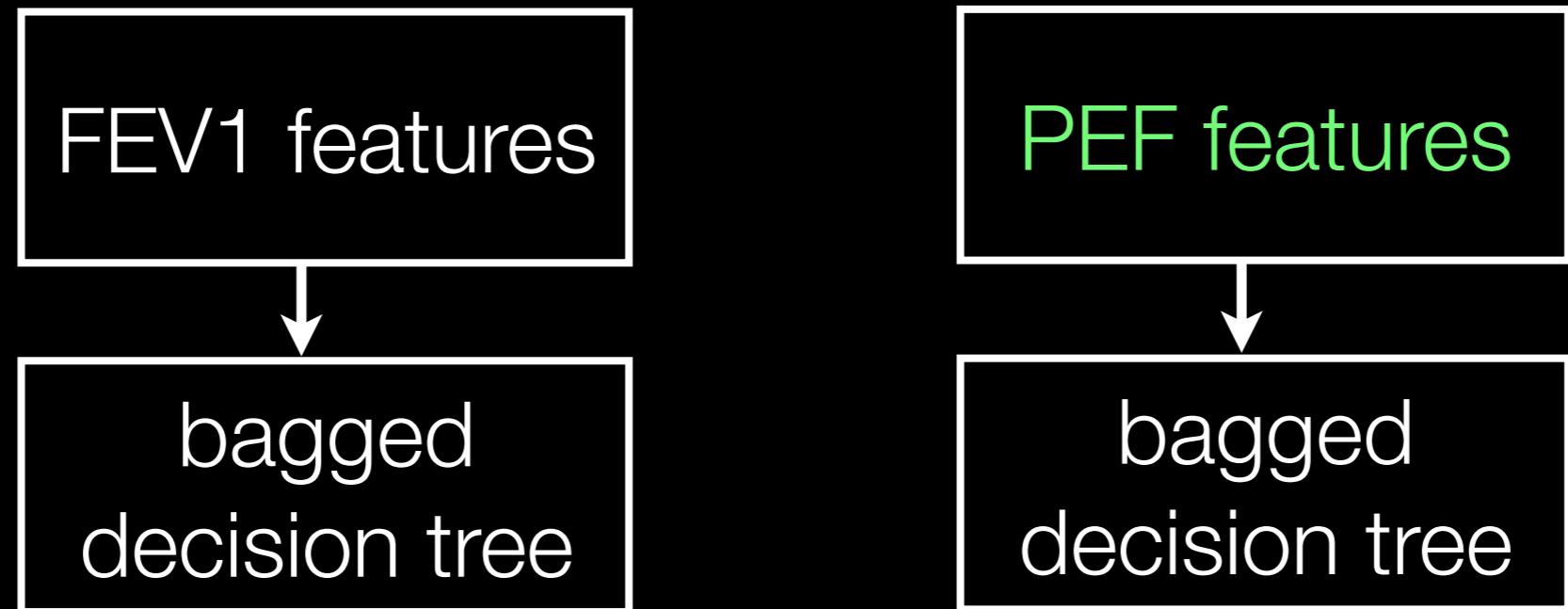
FEV1 features
0.12
0.17

measures
regression

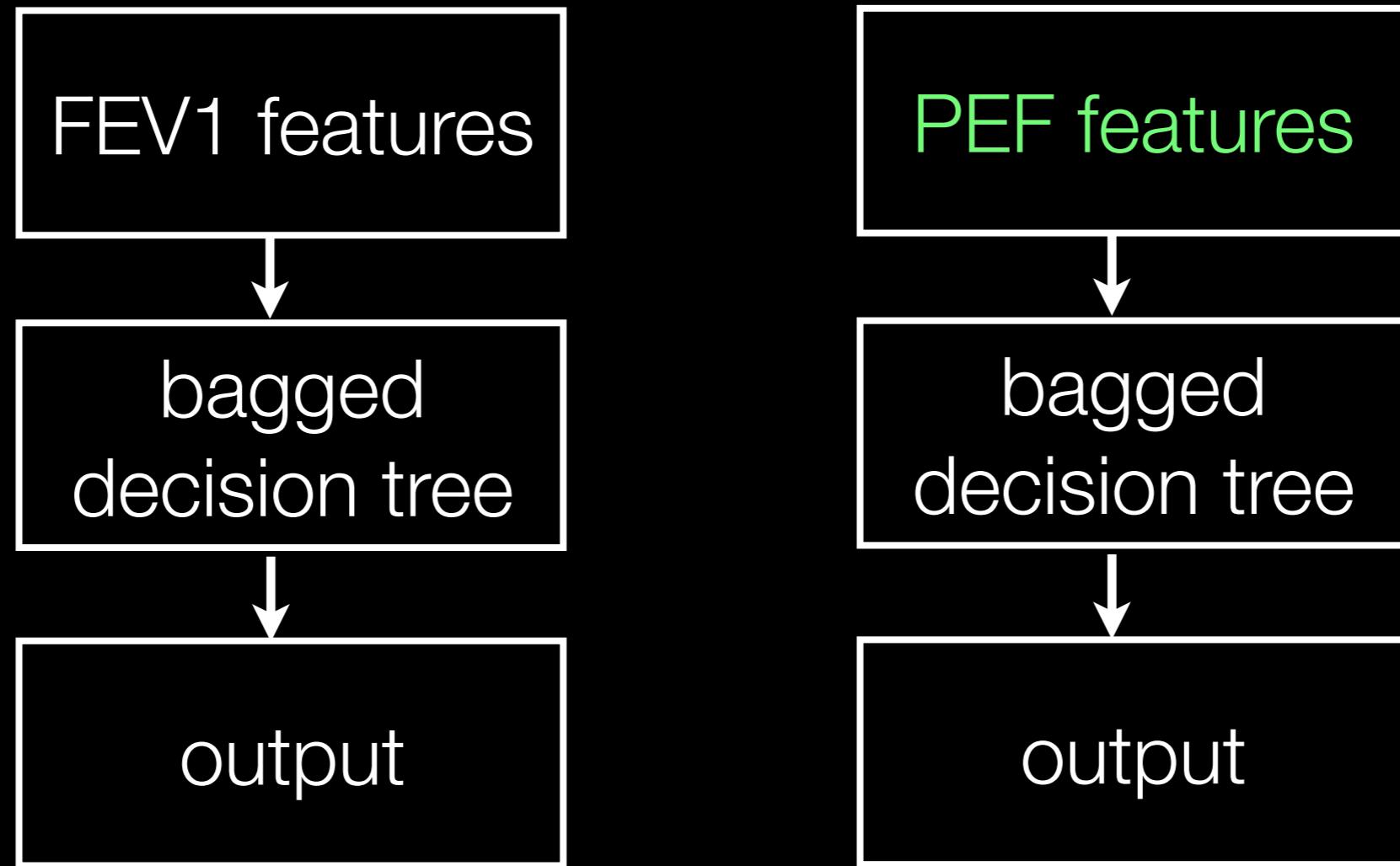
FEV1 features

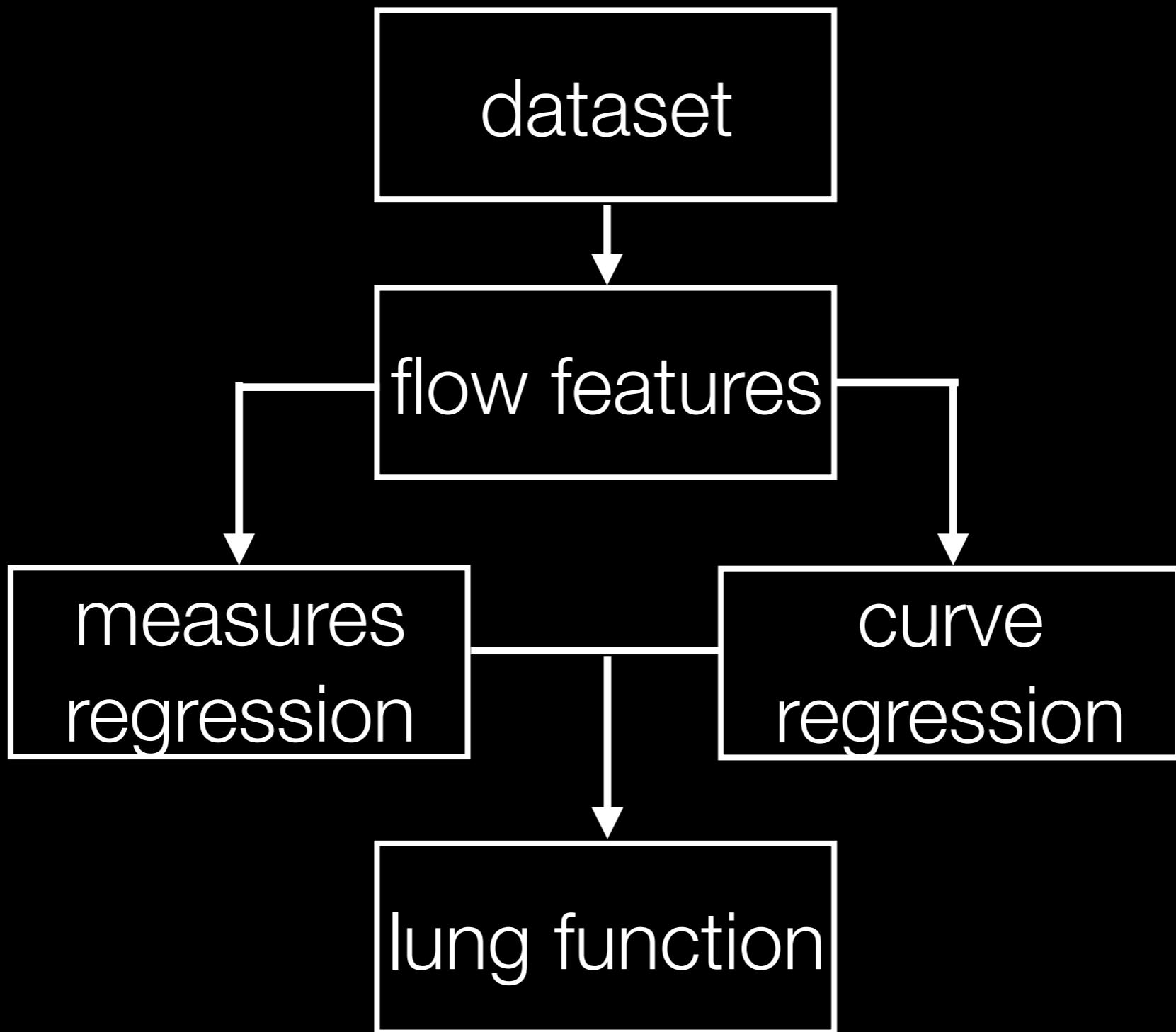
PEF features

measures
regression



measures regression





measures
regression



results

Lower is
better

Mean % Error

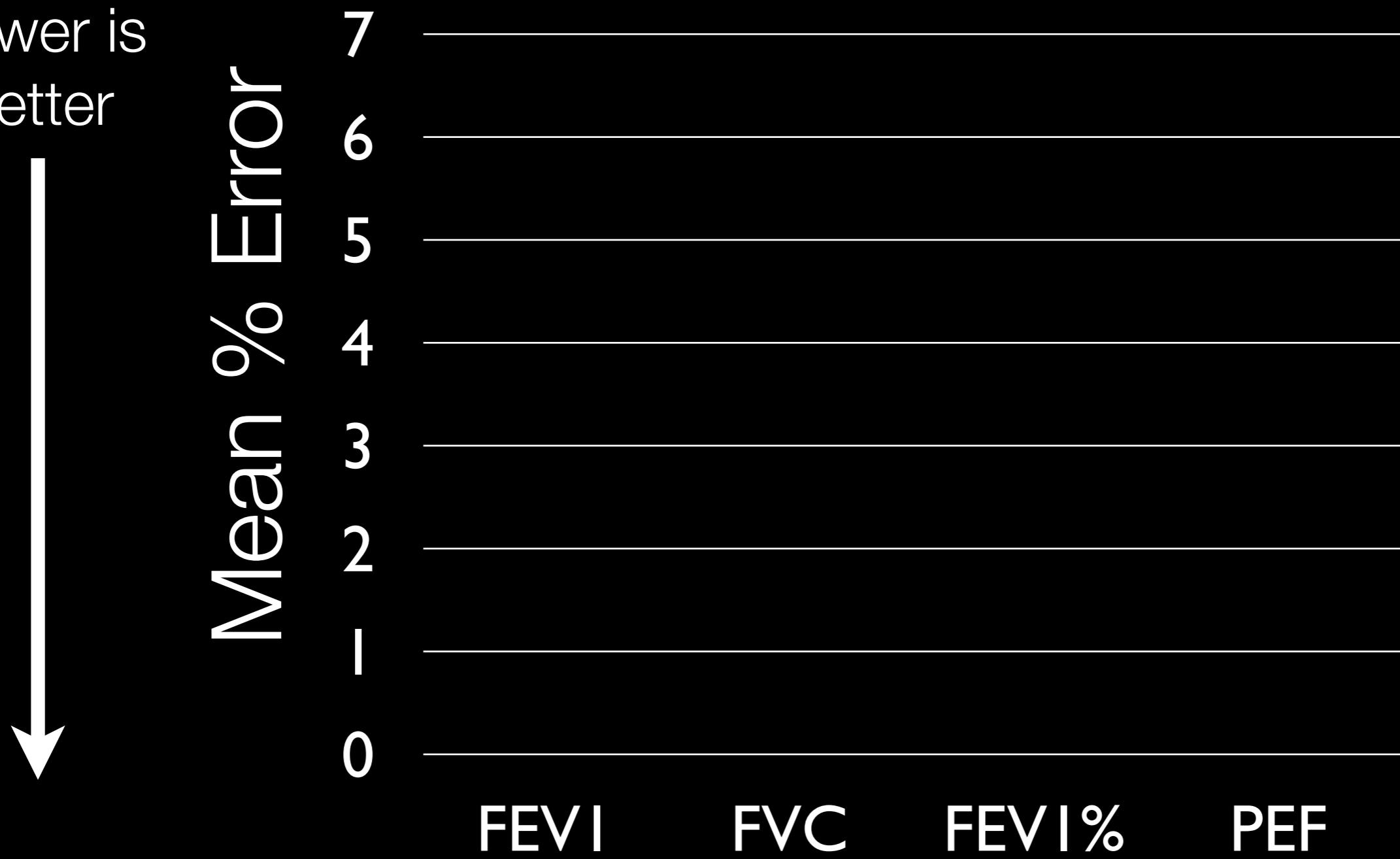


measures
regression



results

Lower is
better

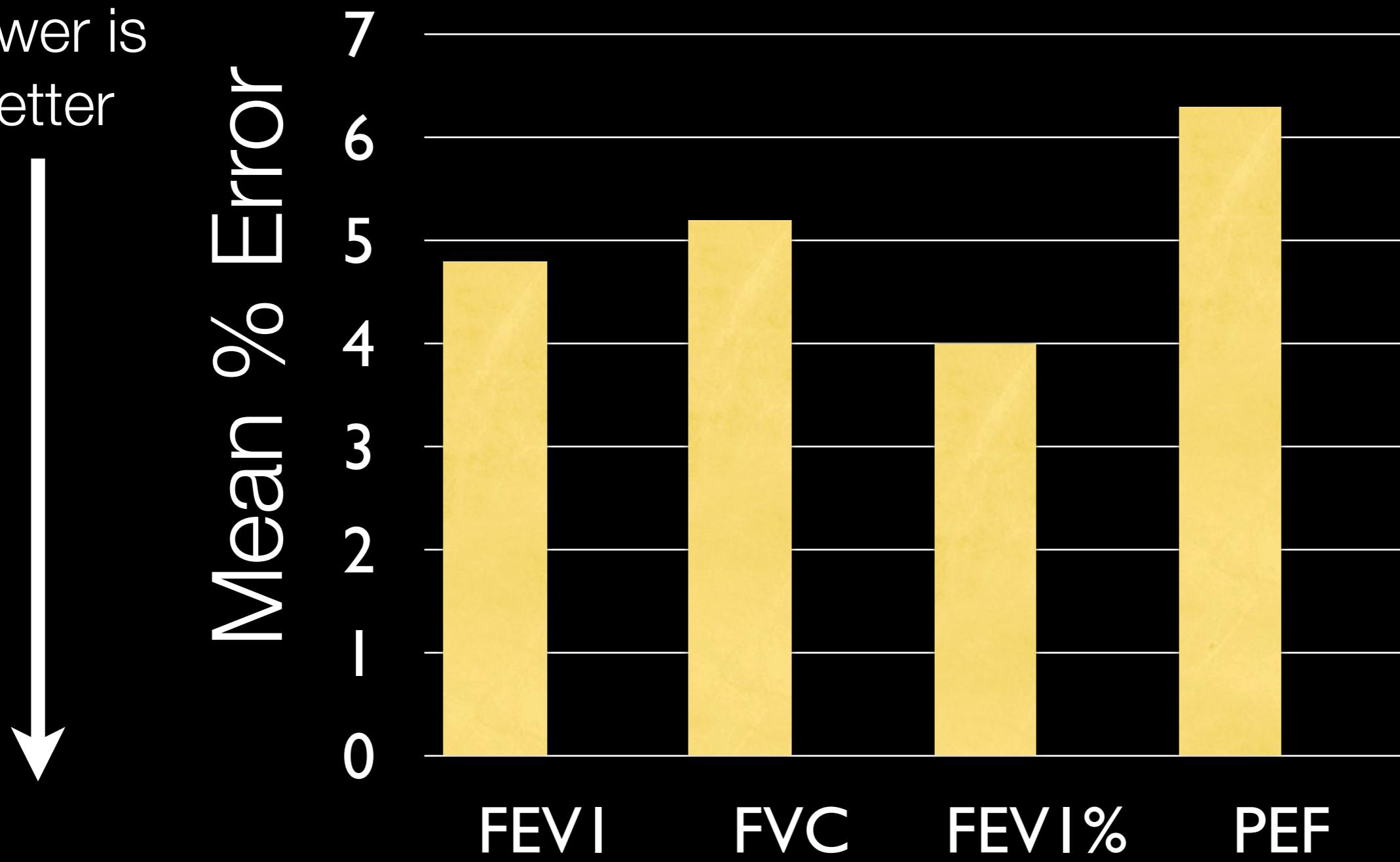


measures
regression



results

Lower is
better

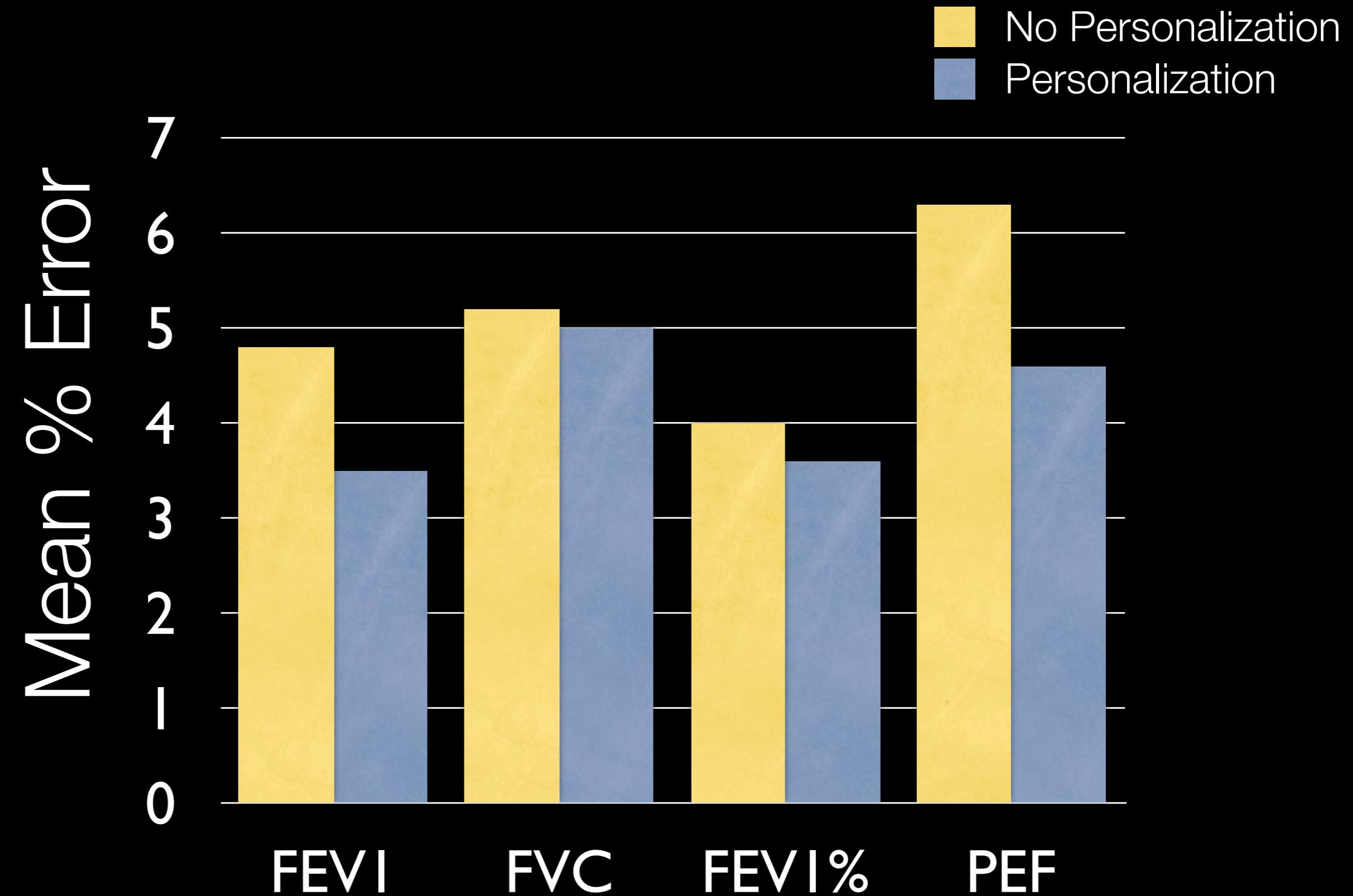


measures
regression

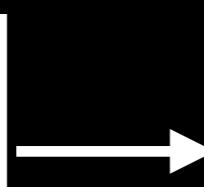


results

Lower is
better



measures
regression



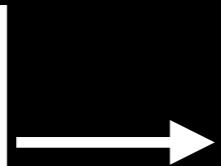
lung function

results

Average Error = 5.1%

ATS Criteria = 5-7%

measures
regression



lung function

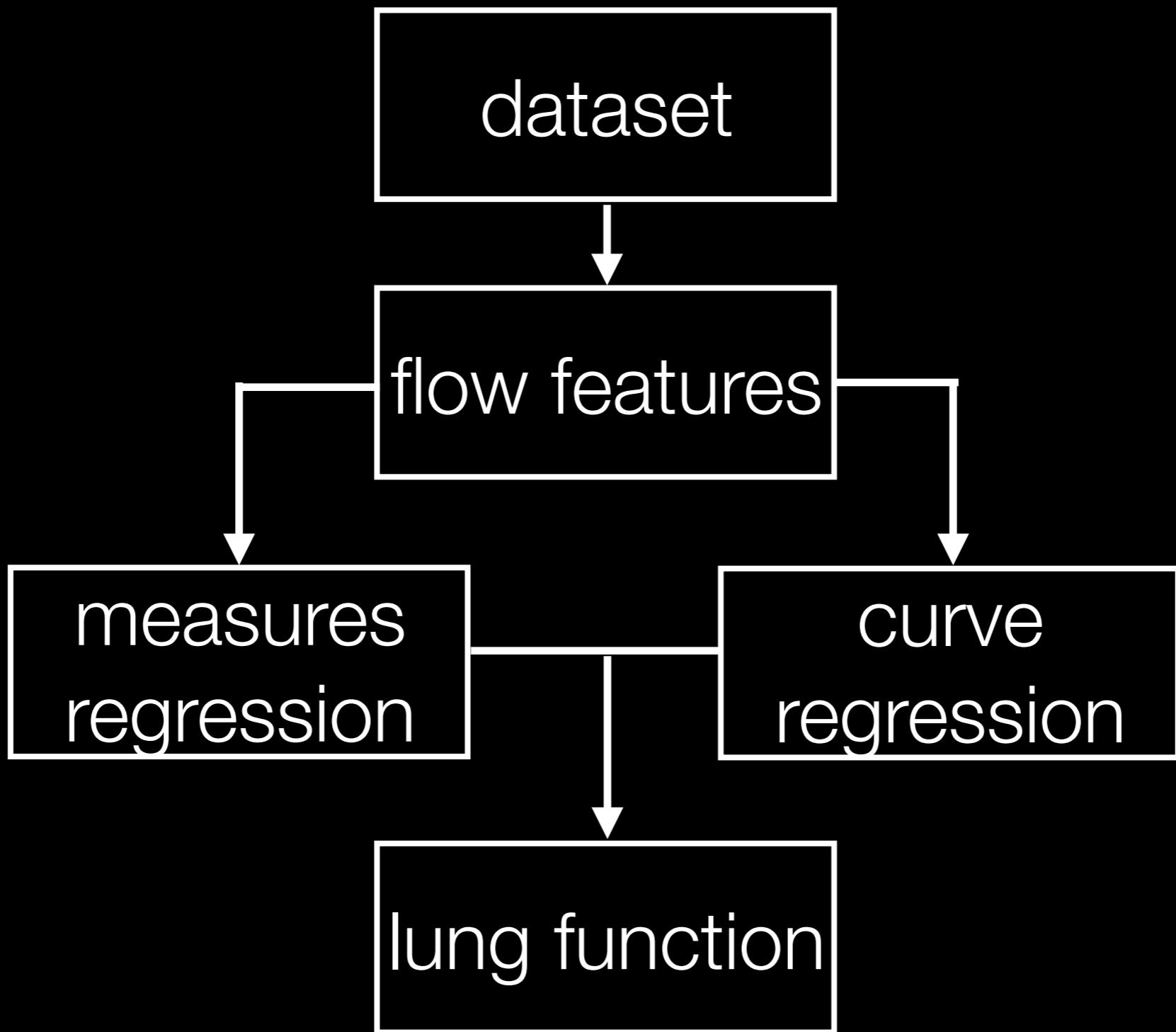
results

Average Error = 5.1%

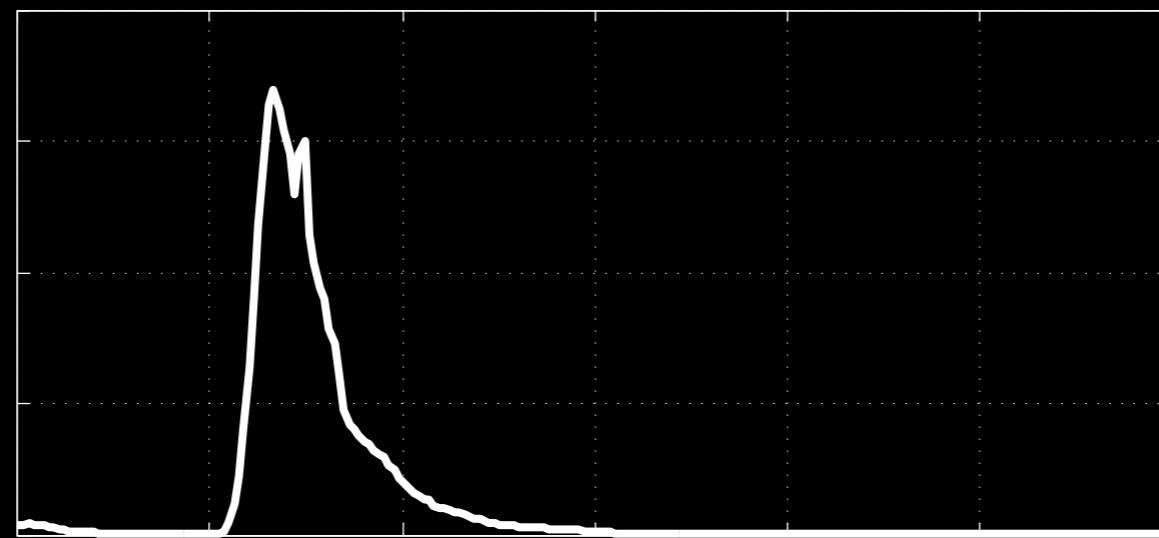
ATS Criteria = 5-7%

Attachments have no effect on Error

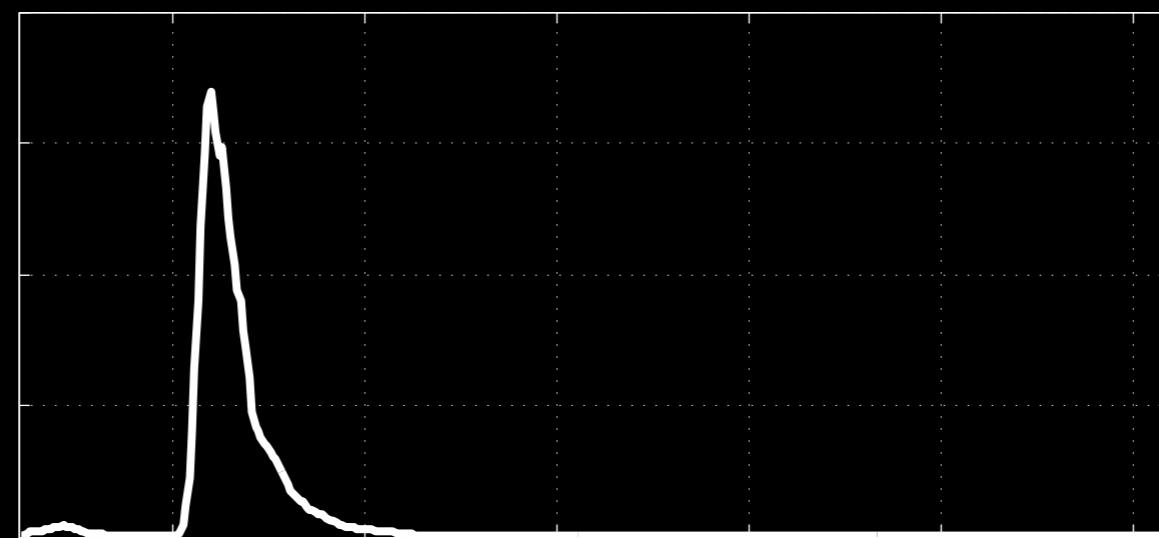




curve
regression

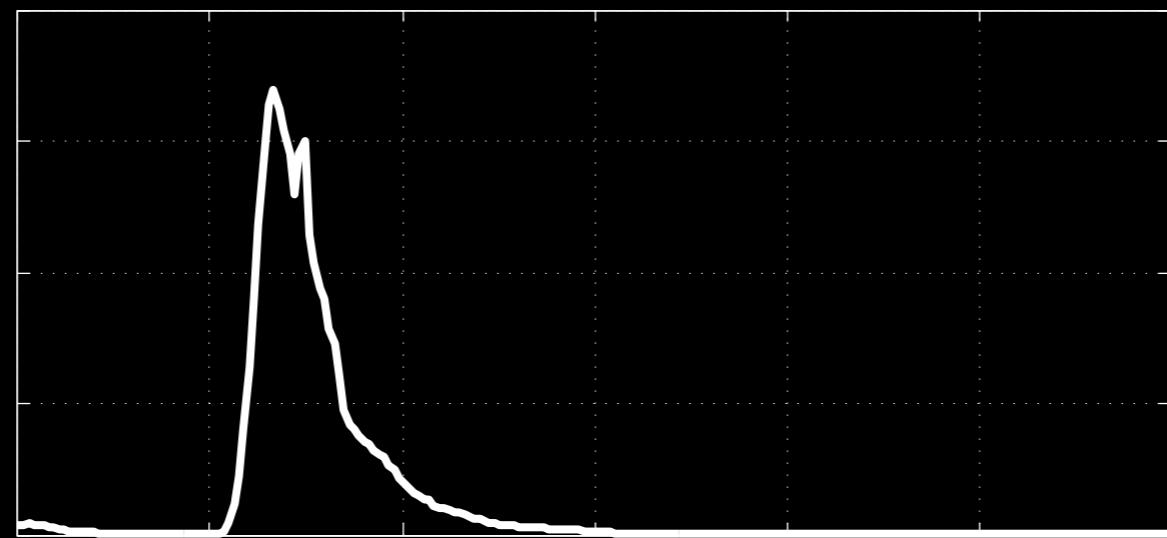


feature 1

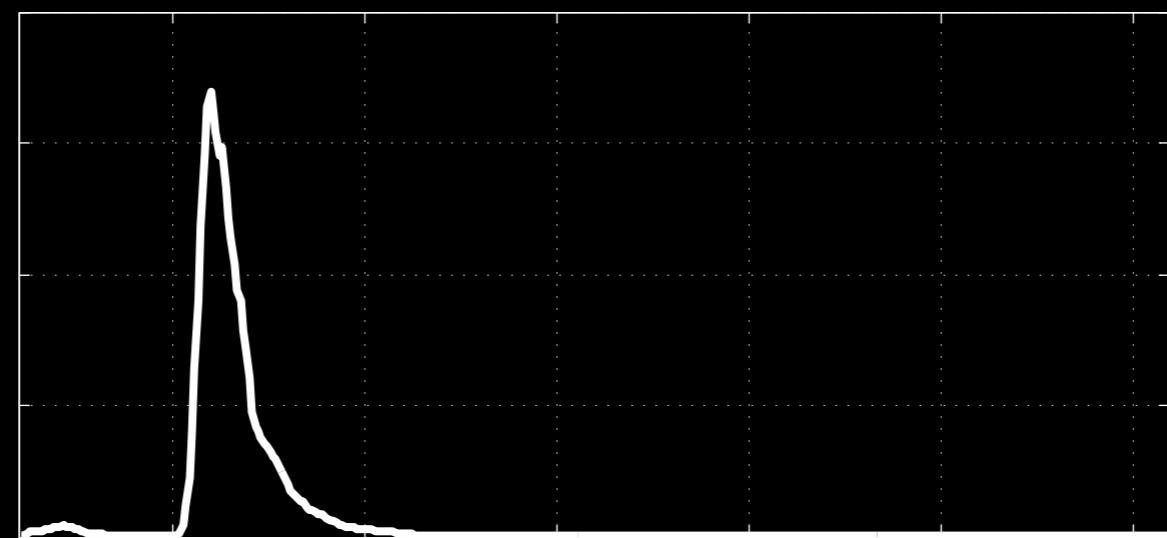


feature 2

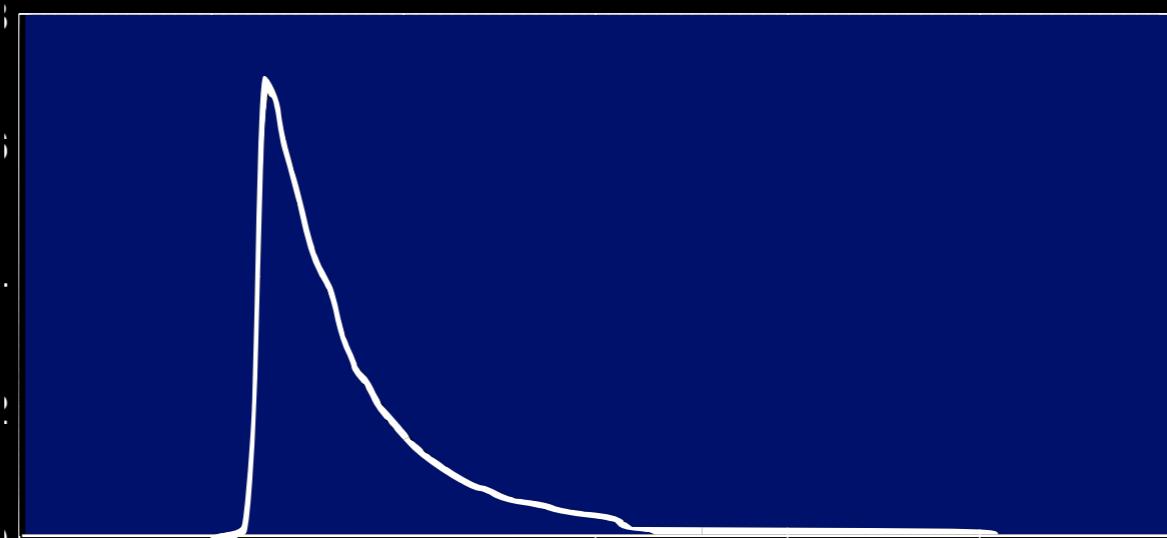
curve
regression



feature 1

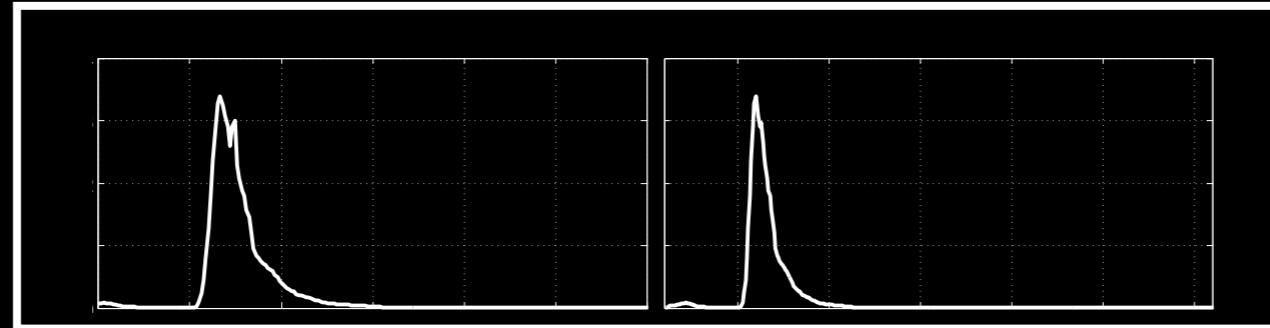


feature 2



curve
output

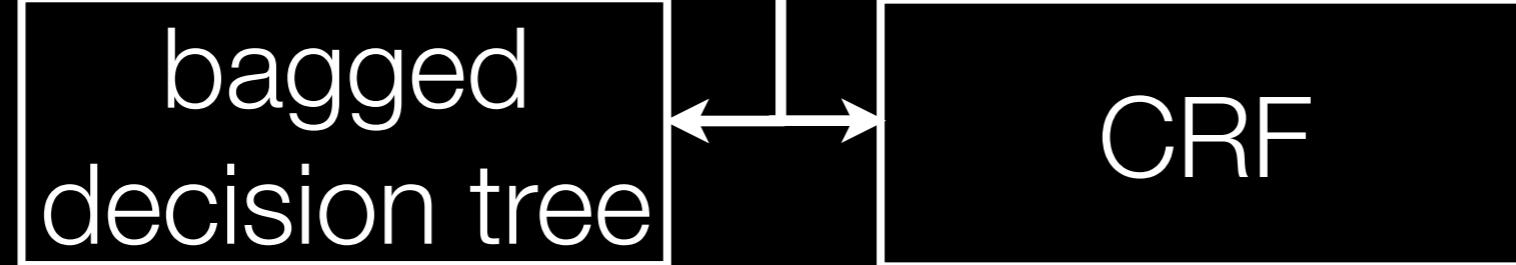
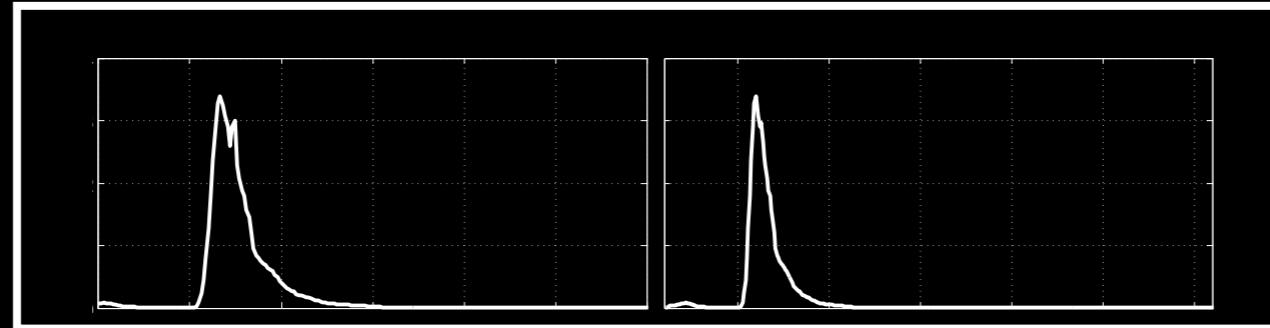
curve regression



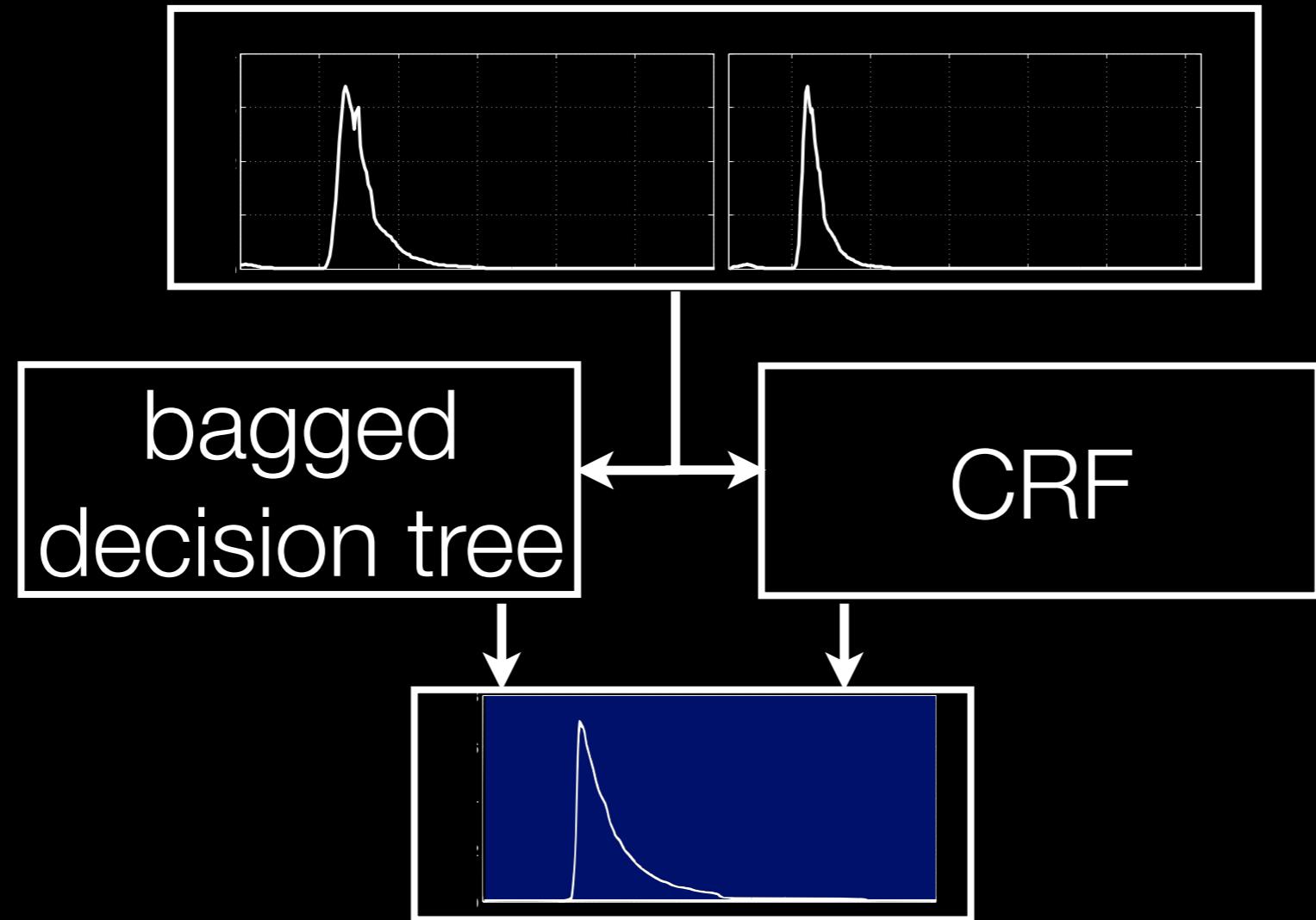
bagged
decision tree



curve regression

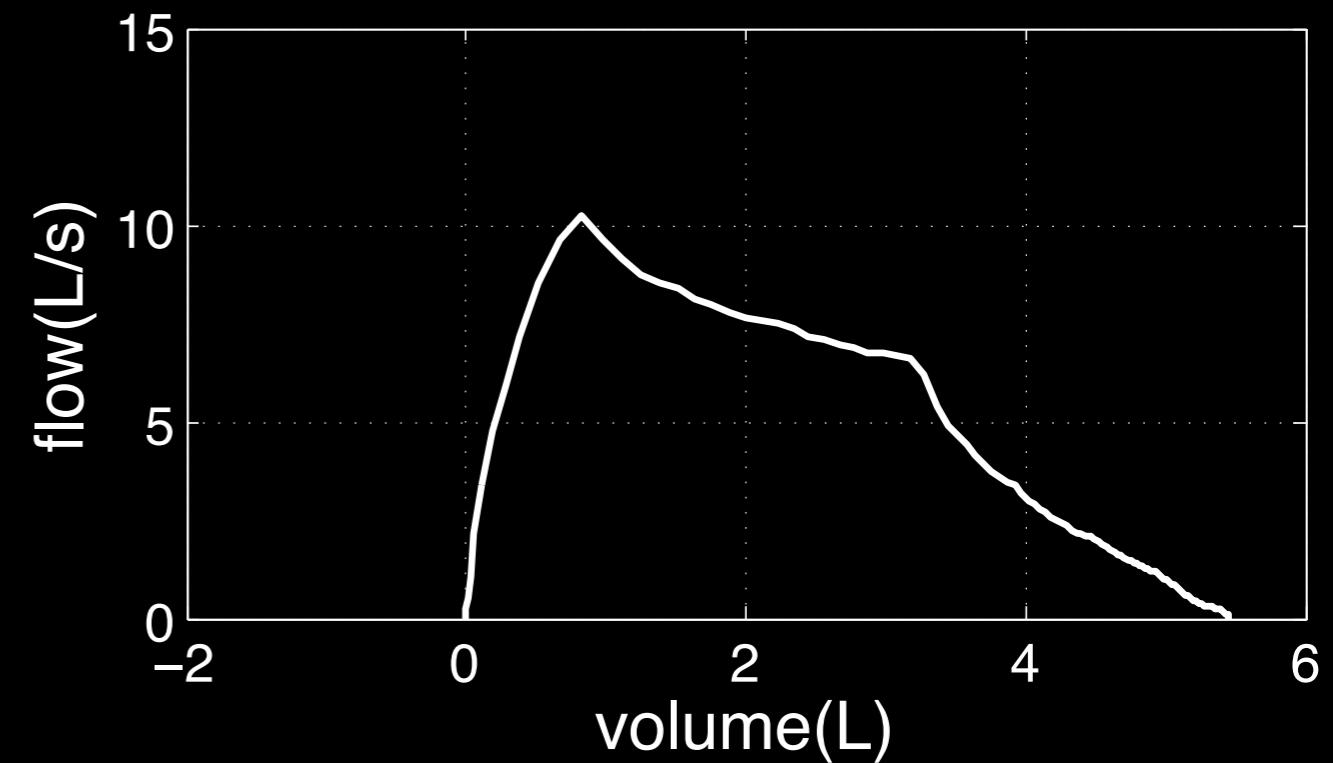
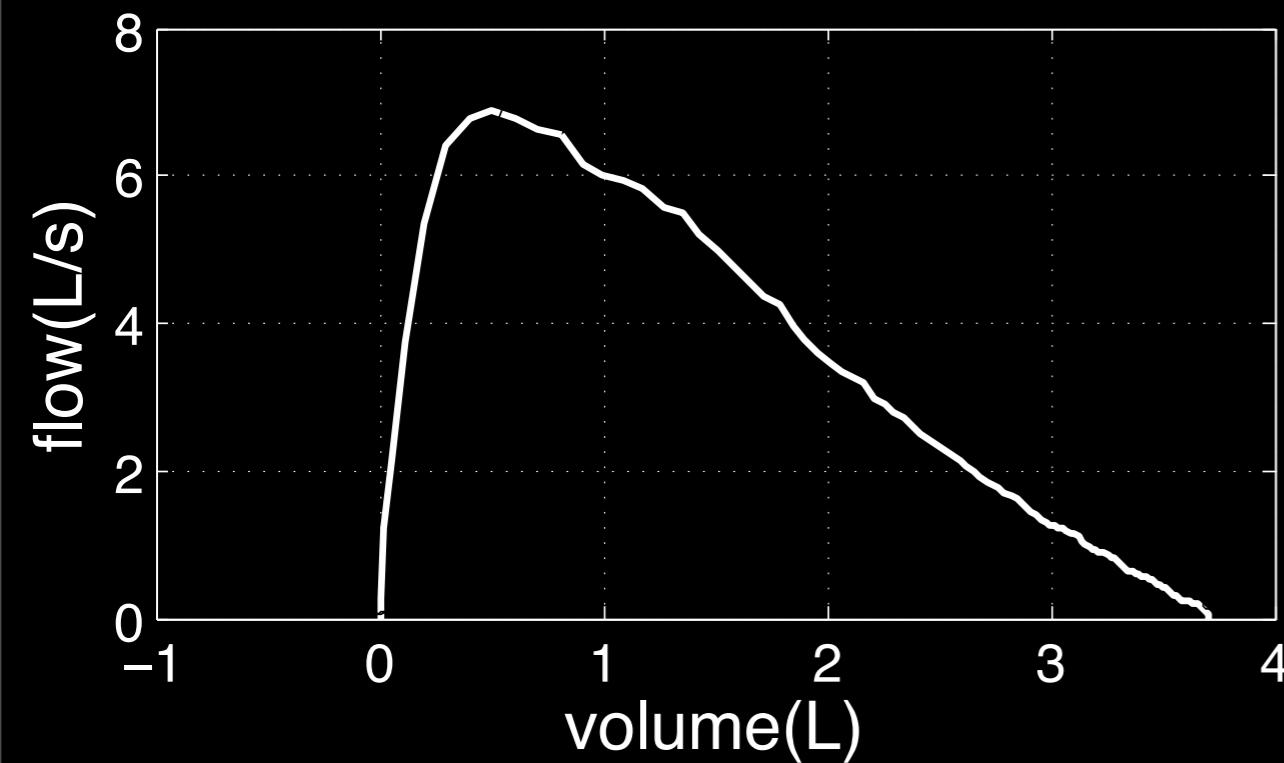


curve regression



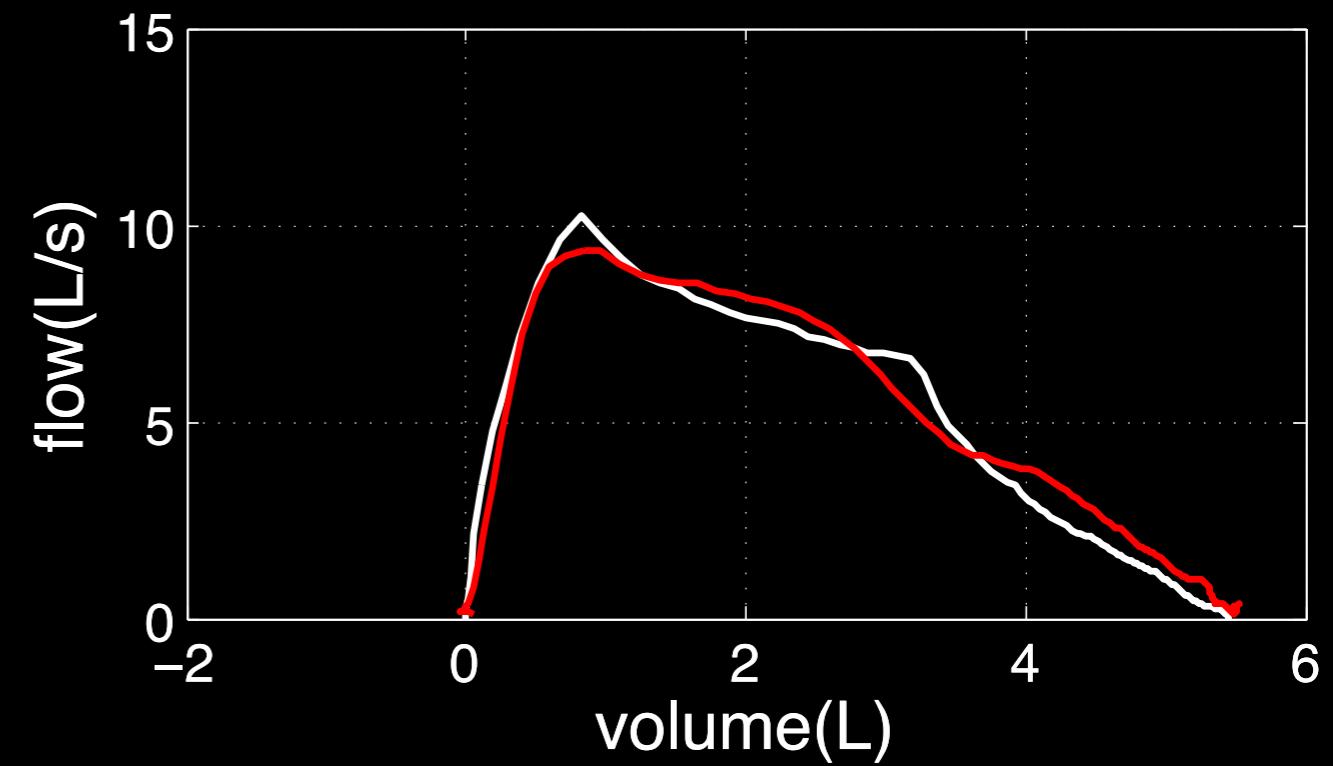
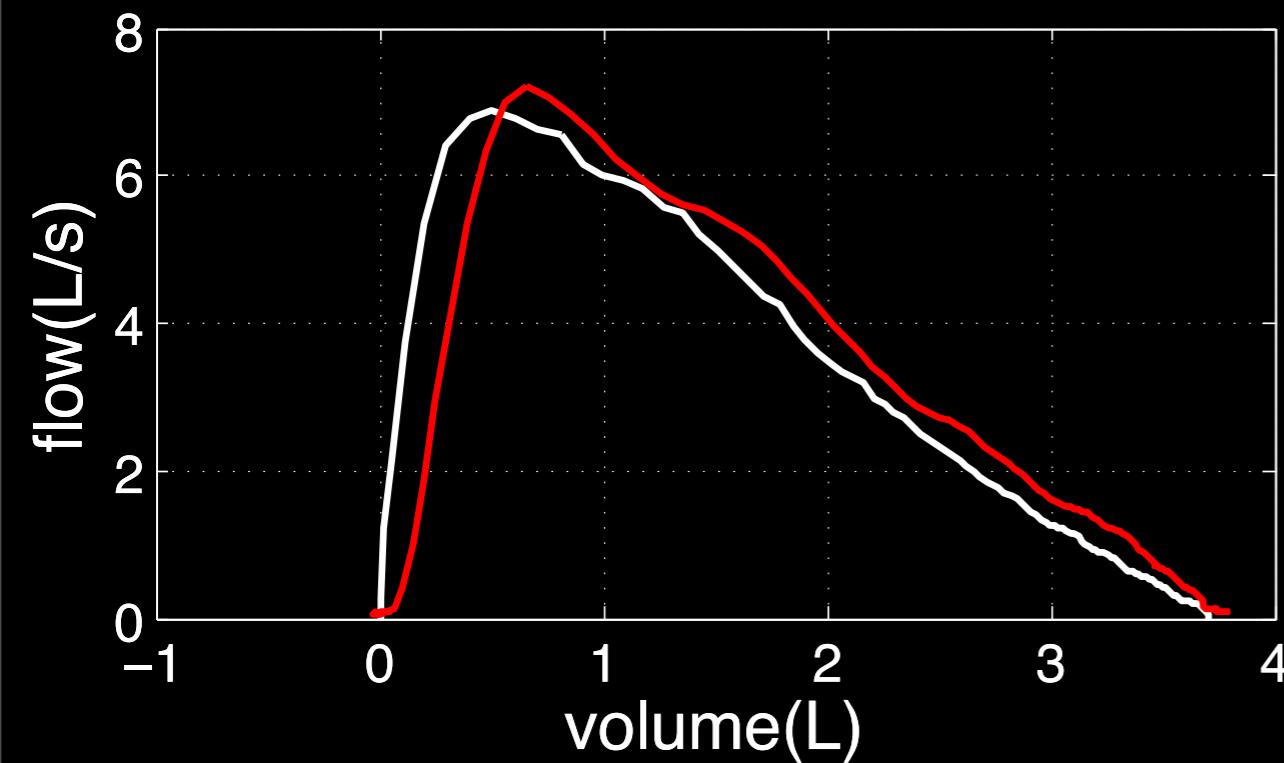
curve
regression

example curves



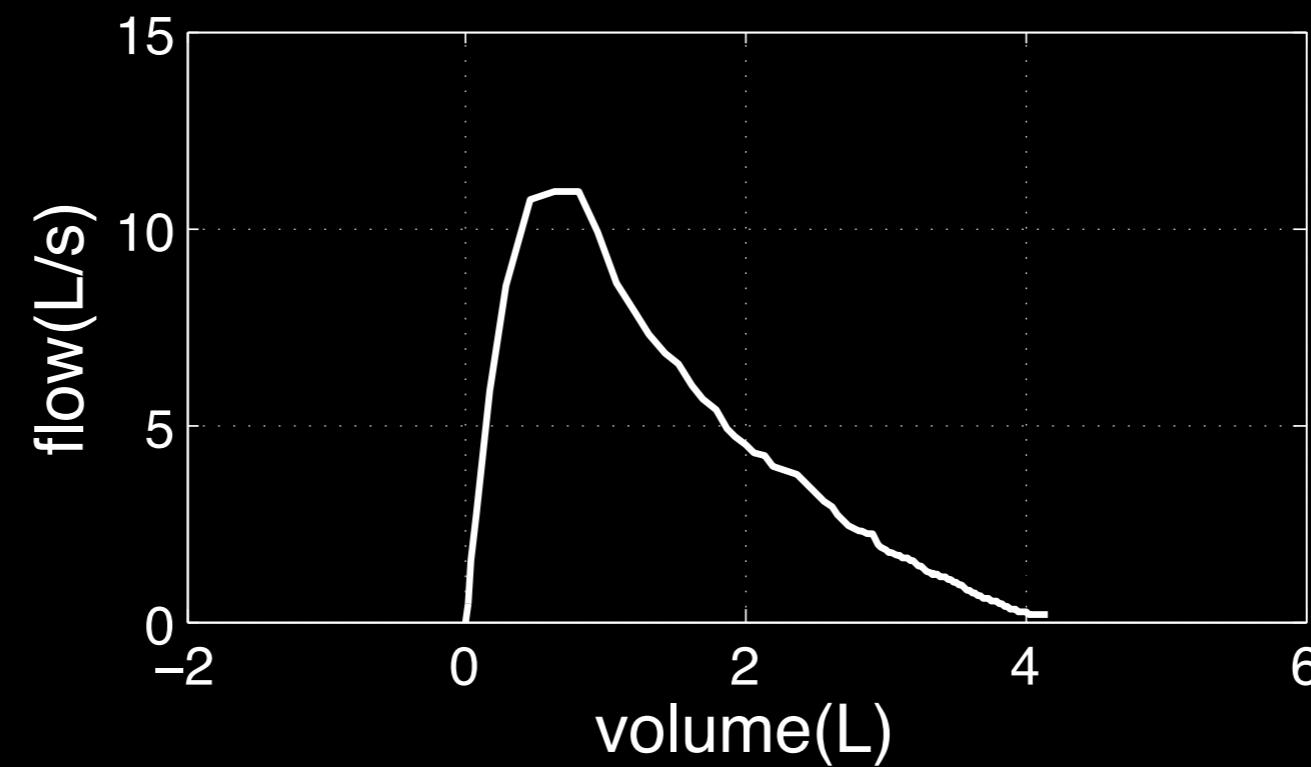
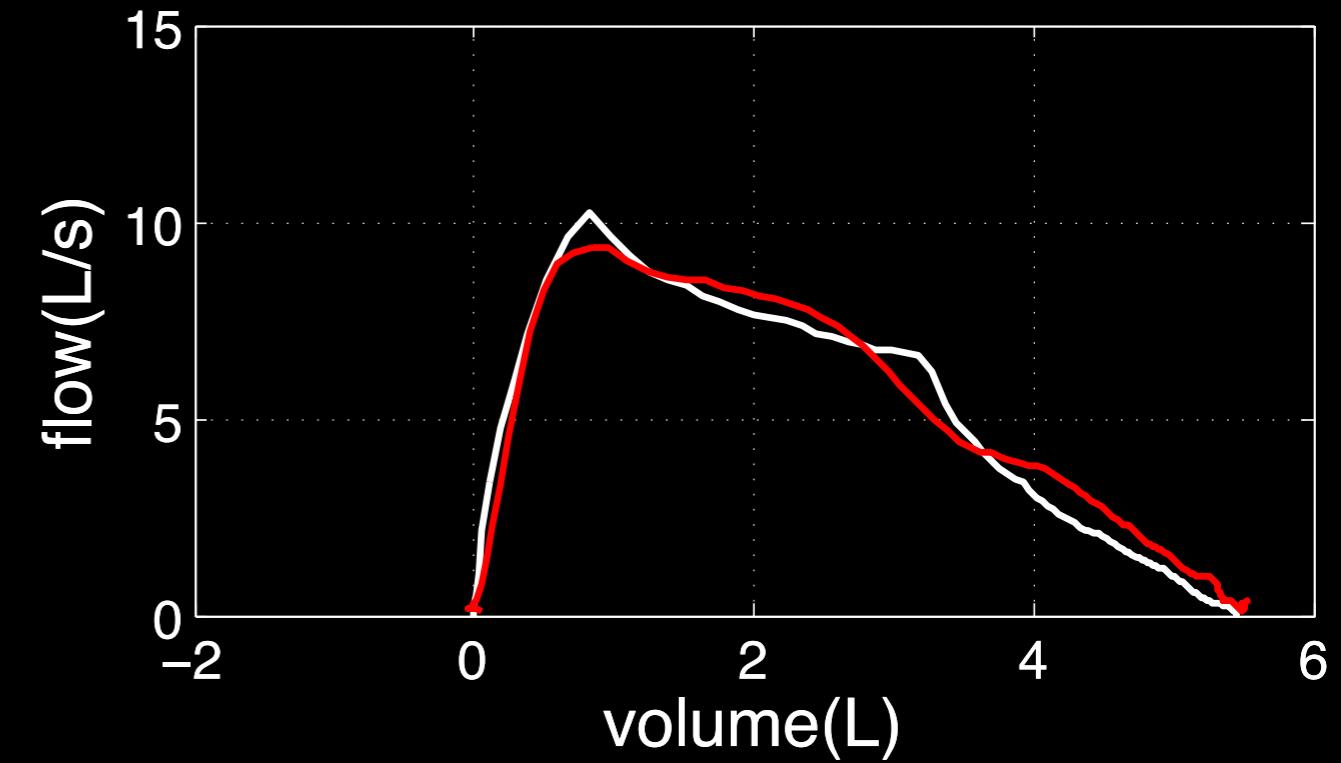
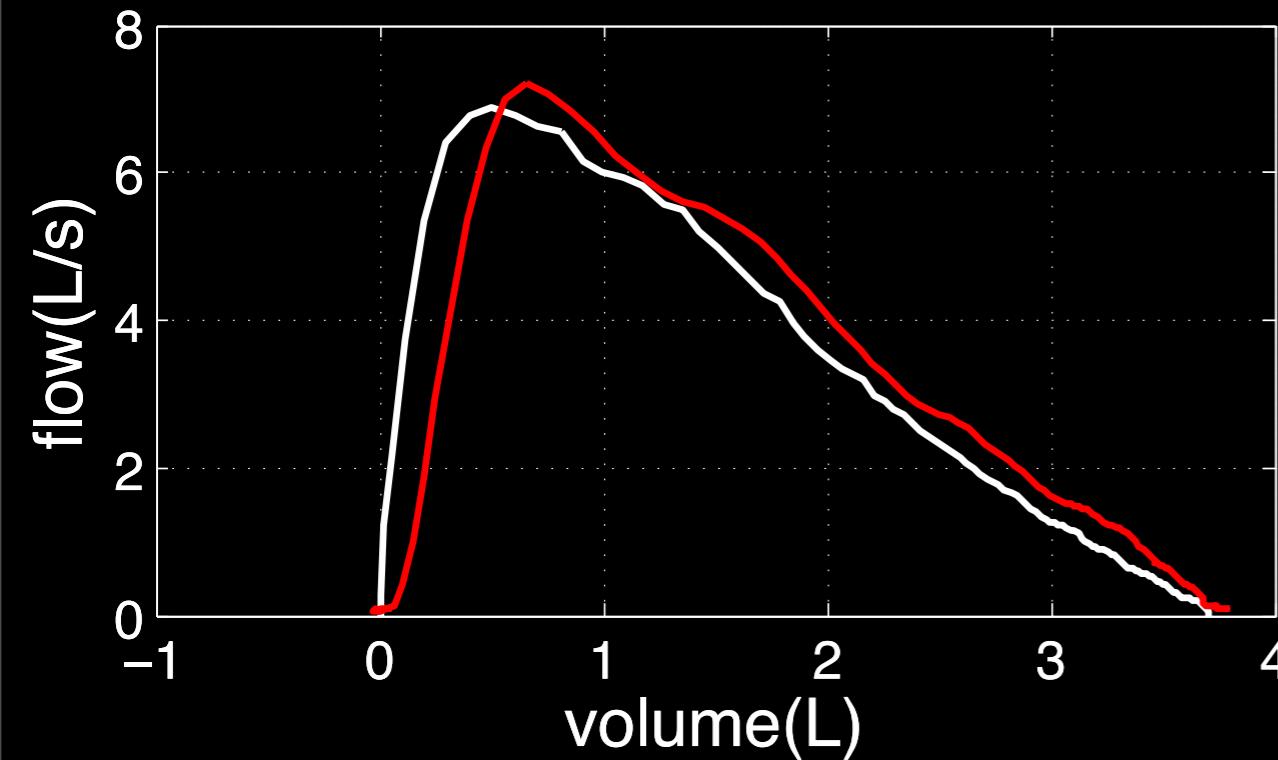
curve
regression

example curves



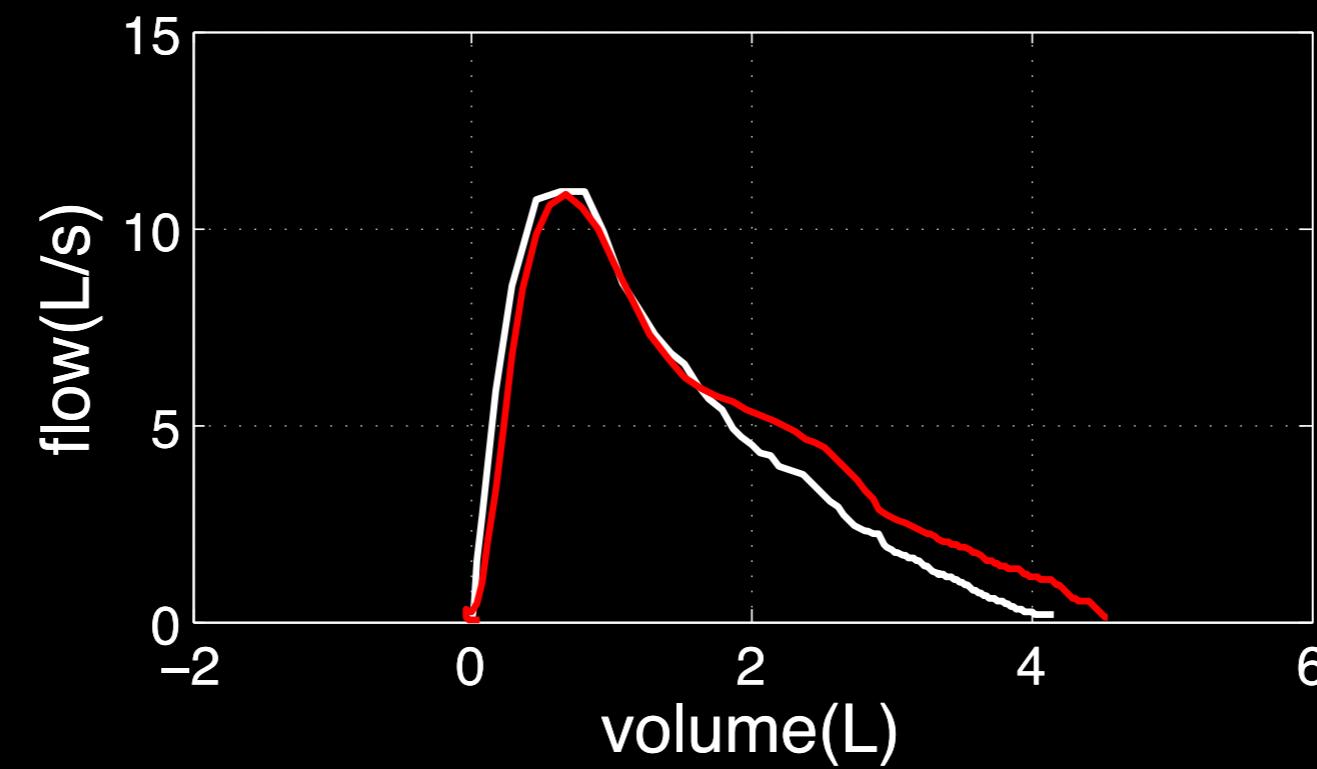
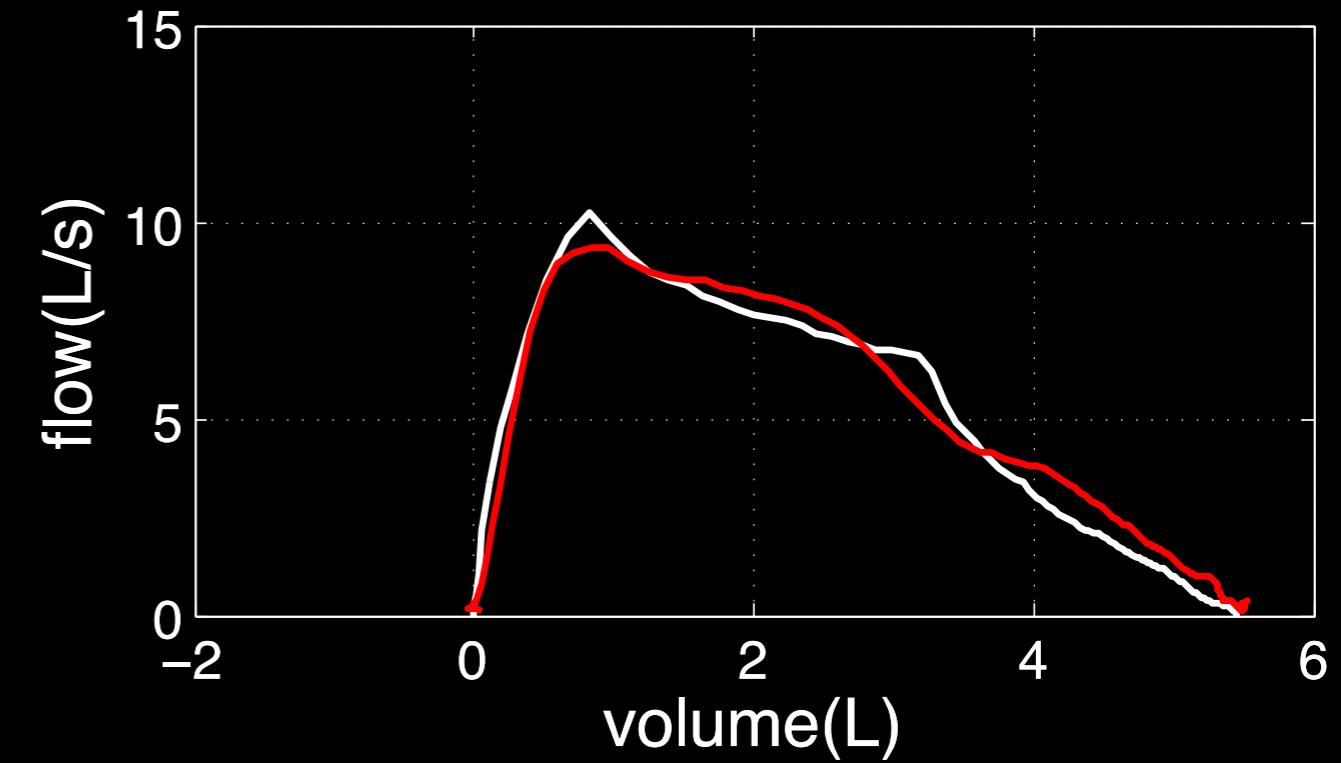
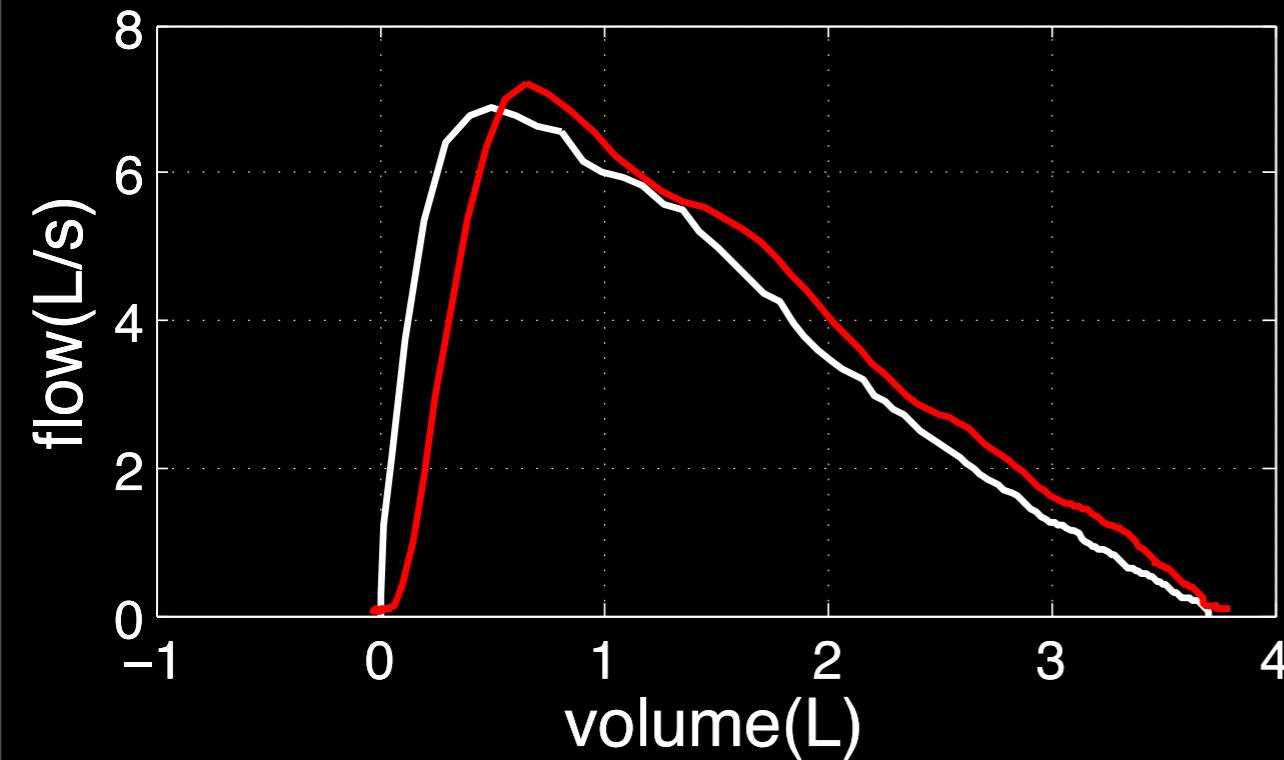
curve
regression

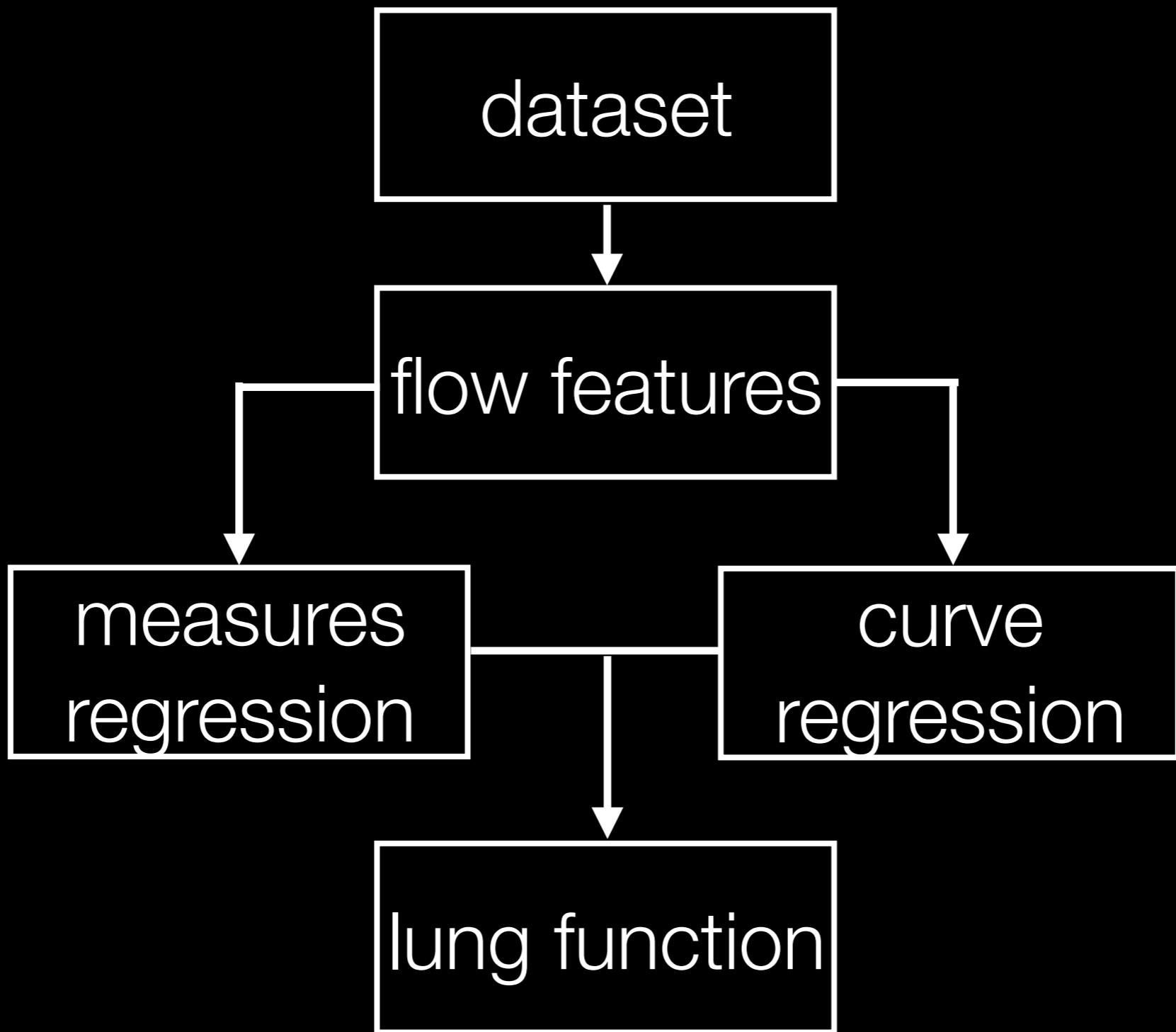
example curves



curve
regression

example curves





curve
regression



evaluation

curve
regression



10 subjects curves

curve
regression



evaluation

10 subjects curves

5 pulmonologists

curve
regression



evaluation

10 subjects curves

5 pulmonologists

unaware if from SpiroSmart / Spirometer

curve
regression

lung function

survey

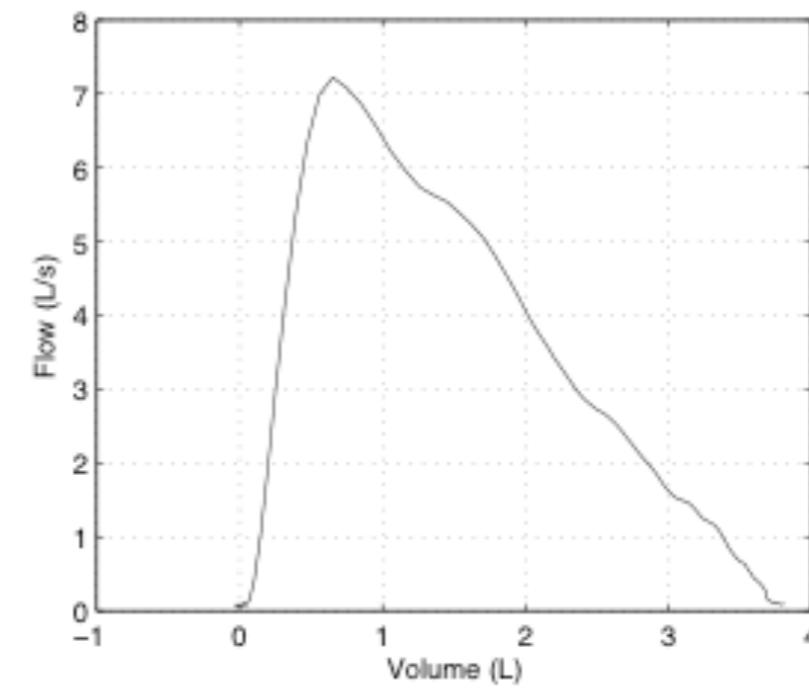
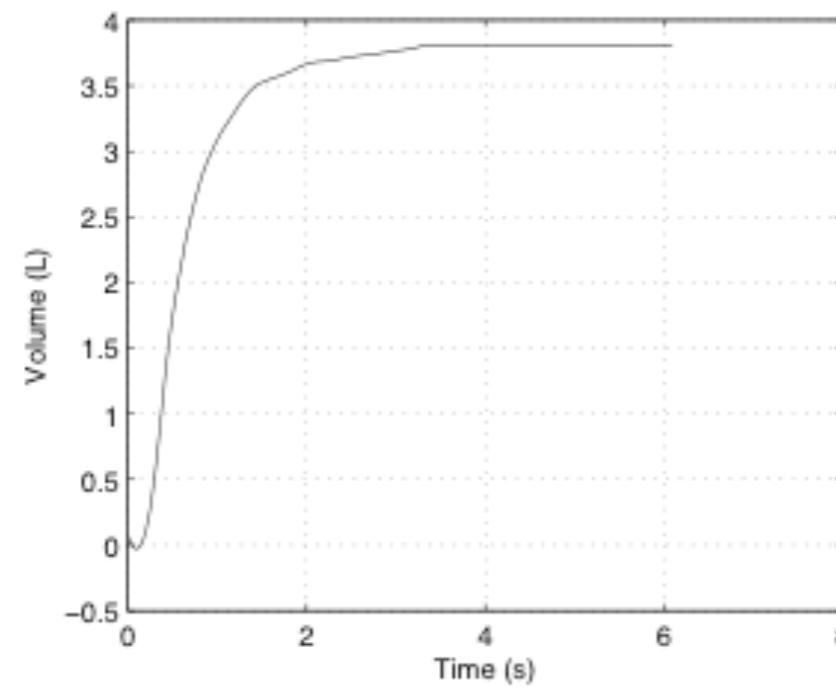
Name: XXXXX
Gender: Female
Age: 28
Height (in): 64 Weight (lbs): 132
Info: Needed baseline spirometry for work

Subject information (anonymous)

Spirometry

	BTPS	PRED	BEST	% PRED
FVC	Liters	3.62	3.82	105
FEV1	Liters	3.01	3.13	104
FEV1/FVC	%	86	82	--
FEF25-75%	L/sec	3.52	3.84	109

PF Reference Knudson 1983



Han 1

curve
regression

lung function

survey

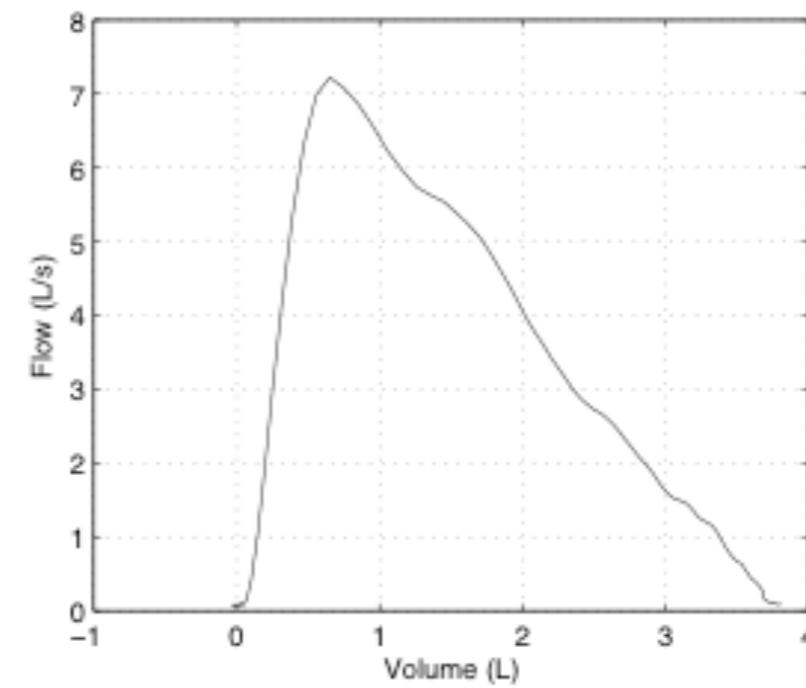
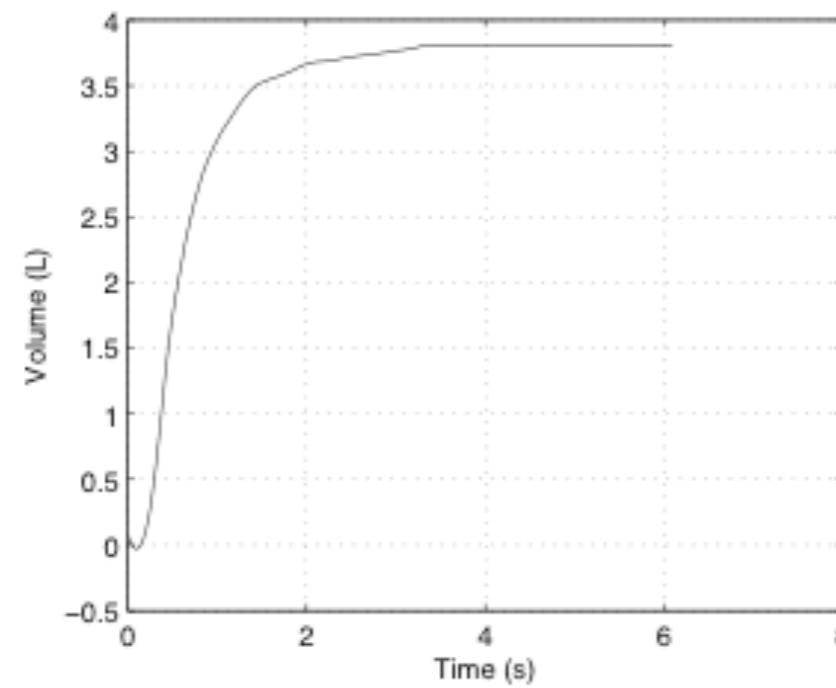
Name: XXXXX
Gender: Female
Age: 28
Height (in): 64 Weight (lbs): 132
Info: Needed baseline spirometry for work

Spirometry

	BTPS	PRED	BEST	% PRED
FVC	Liters	3.62	3.82	105
FEV1	Liters	3.01	3.13	104
FEV1/FVC	%	86	82	--
FEF25-75%	L/sec	3.52	3.84	109

measures of lung function

PF Reference Knudson 1983



Han 1

curve
regression

lung function

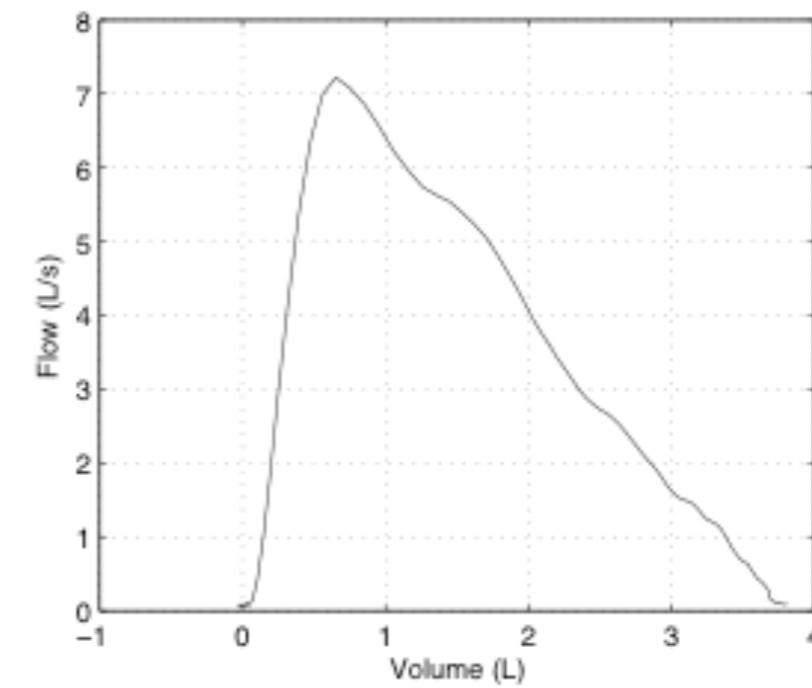
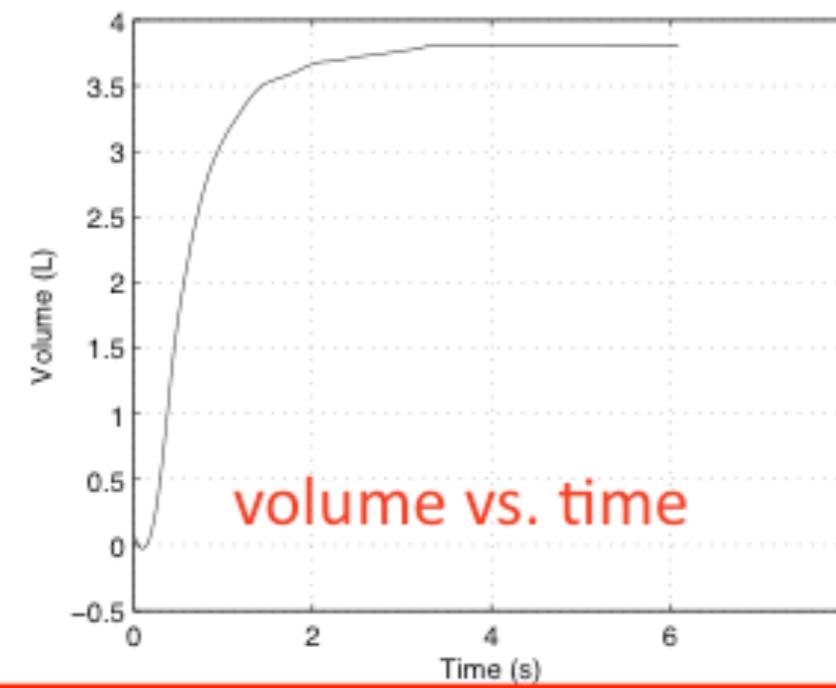
survey

Name: XXXXX
Gender: Female
Age: 28
Height (in): 64 Weight (lbs): 132
Info: Needed baseline spirometry for work

Spirometry

	BTPS	PRED	BEST	% PRED
FVC	Liters	3.62	3.82	105
FEV1	Liters	3.01	3.13	104
FEV1/FVC	%	86	82	--
FEF25-75%	L/sec	3.52	3.84	109

PF Reference Knudson 1983



Han 1

curve
regression

lung function

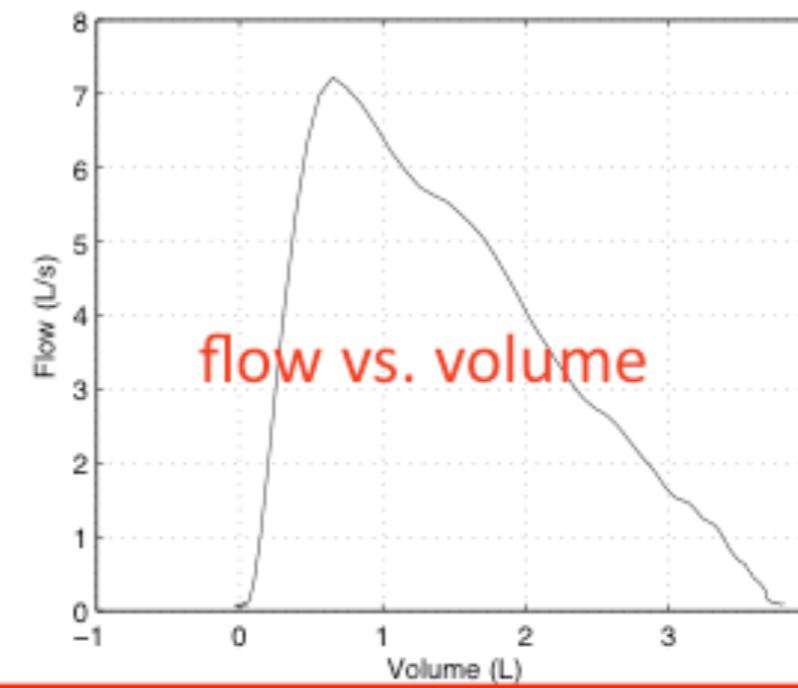
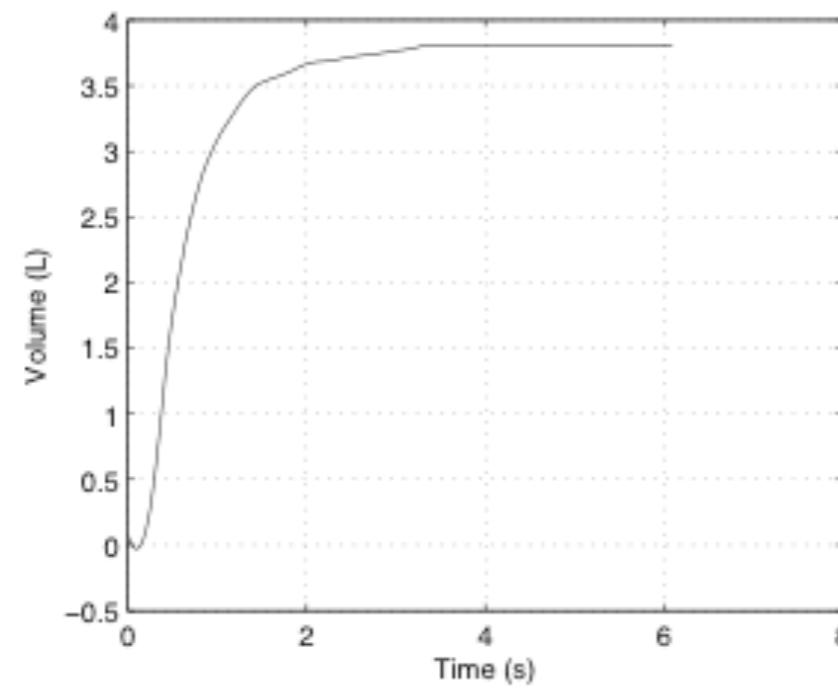
survey

Name: XXXXX
Gender: Female
Age: 28
Height (in): 64 Weight (lbs): 132
Info: Needed baseline spirometry for work

Spirometry

	BTPS	PRED	BEST	% PRED
FVC	Liters	3.62	3.82	105
FEV1	Liters	3.01	3.13	104
FEV1/FVC	%	86	82	--
FEF25-75%	L/sec	3.52	3.84	109

PF Reference Knudson 1983



curve
regression

lung function

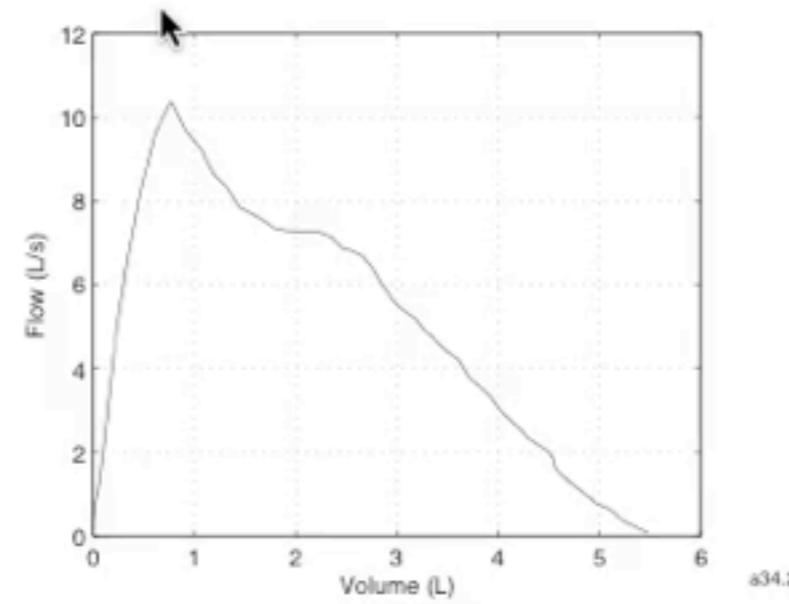
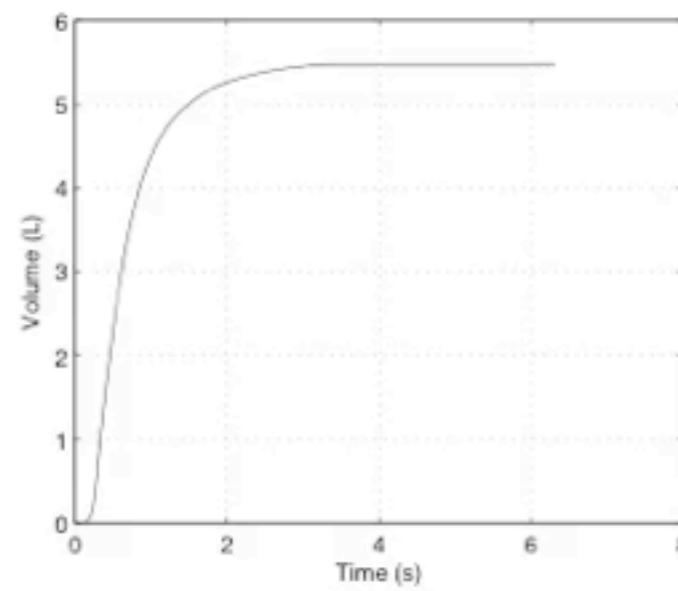
survey

Name: XXXXX
Gender: Male
Age: 32
Height (in): 71 Weight (lbs): 160
Info:

Spirometry

	BTPS	PRED	BEST	% PRED
FVC	Liters	5.25	5.57	104
FEV1	Liters	4.45	4.67	108
FEV1/FVC	%	85	84	--
FEF25-75%	L/sec	4.25	5.42	127

PF Reference Knudson 1983



a34.2

1. Based on the above, does this spirometry session indicate: *

curve
regression



results

restrictive

inadequate

normal

minimal obstructive

mild obstructive

moderate obstructive

severe obstructive

32 / 50

identical

curve
regression



results

restrictive

inadequate

normal

minimal obstructive

mild obstructive

moderate obstructive

severe obstructive

32 / 50

identical

5 / 18

one off

curve
regression



results

restrictive

inadequate

normal

minimal obstructive

mild obstructive

moderate obstructive

severe obstructive

32 / 50

identical

5 / 18

one off

curve
regression



results

restrictive

inadequate

normal

minimal obstructive

mild obstructive

moderate obstructive

severe obstructive

32 / 50

identical

5 / 18

one off

curve
regression



results

restrictive

inadequate

normal

minimal obstructive

mild obstructive

moderate obstructive

severe obstructive

32 / 50

identical

5 / 18

one off

limitations

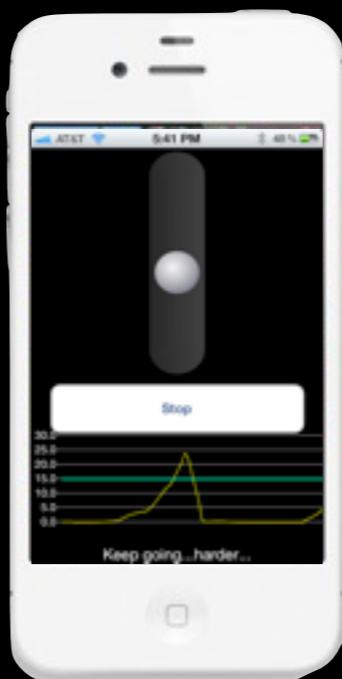
limitations

no inhalation
quiet surroundings



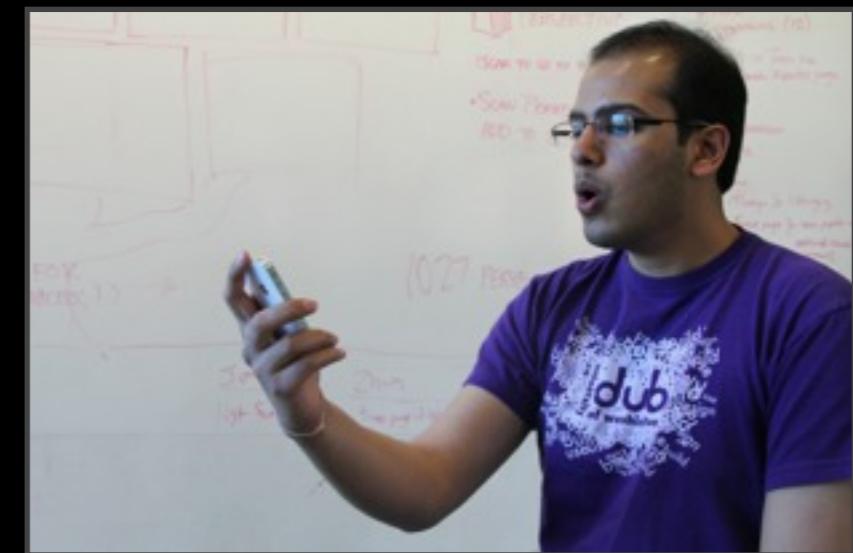
limitations

no inhalation
quiet surroundings
coaching



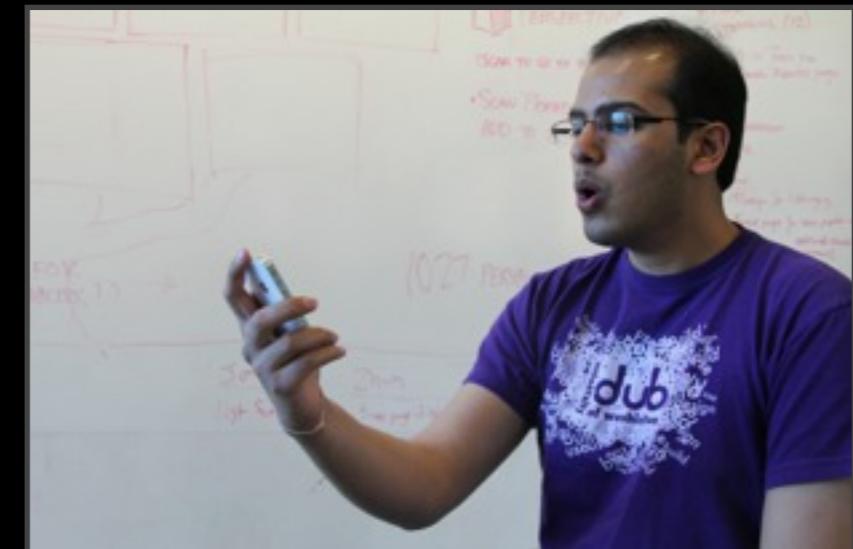
limitations

no inhalation
quiet surroundings
coaching
smartphone



limitations

no inhalation
quiet surroundings
coaching
smartphone
trends over time



current work

no inhalation

quiet surroundings

coaching

smartphone

trends over time

current work

asthma study underway

no inhalation

quiet surroundings

coaching

smartphone

trends over time

current work

no inhalation

quiet surroundings

coaching

smartphone

trends over time

asthma study underway

incentive graphics

current work

no inhalation

quiet surroundings

coaching

smartphone

trends over time

asthma study underway

incentive graphics

air quality, non-chronic disease

current work

no inhalation

quiet surroundings

coaching

smartphone

trends over time

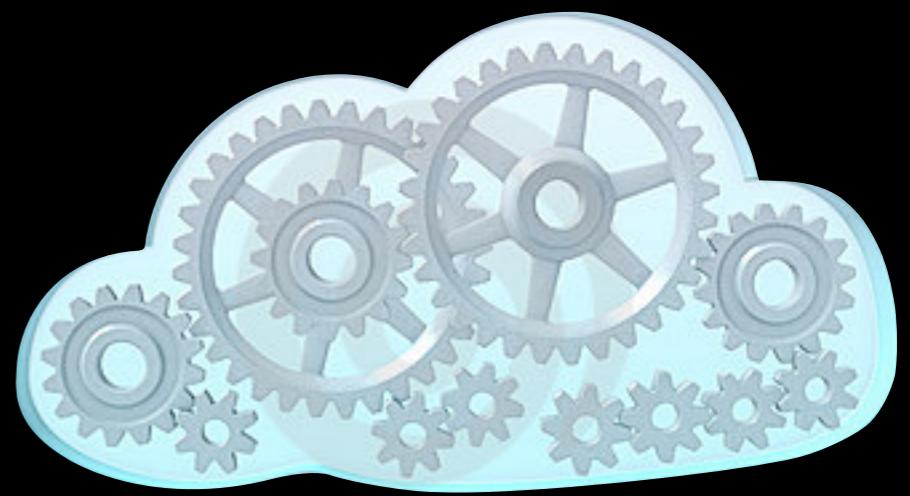
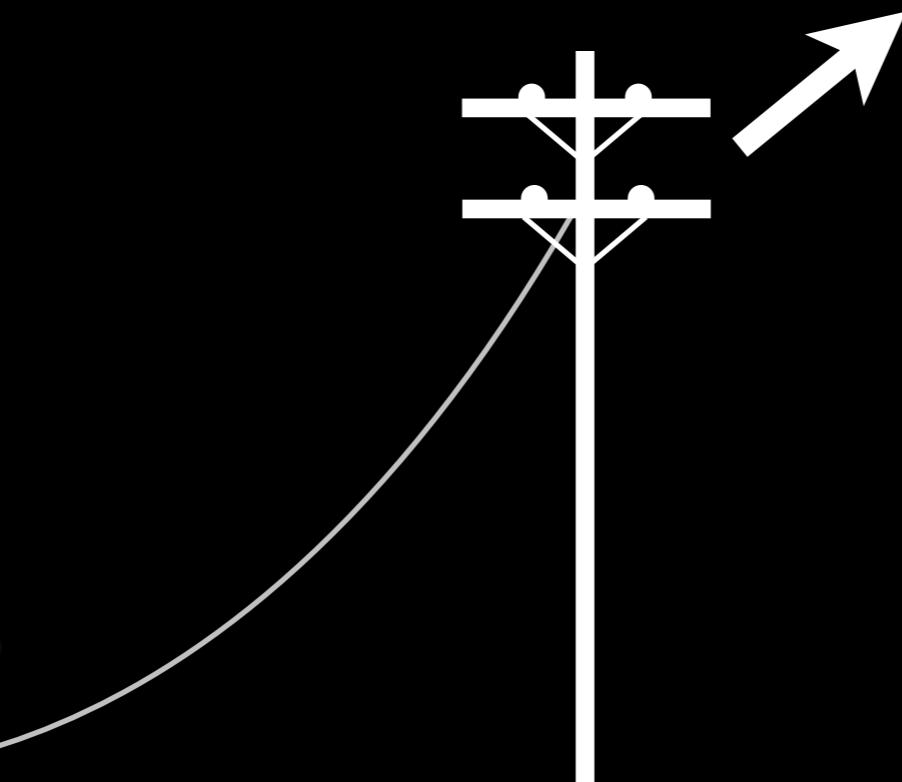
asthma study underway

incentive graphics

air quality, non-chronic disease

call in service

call in service



SpiroSmart

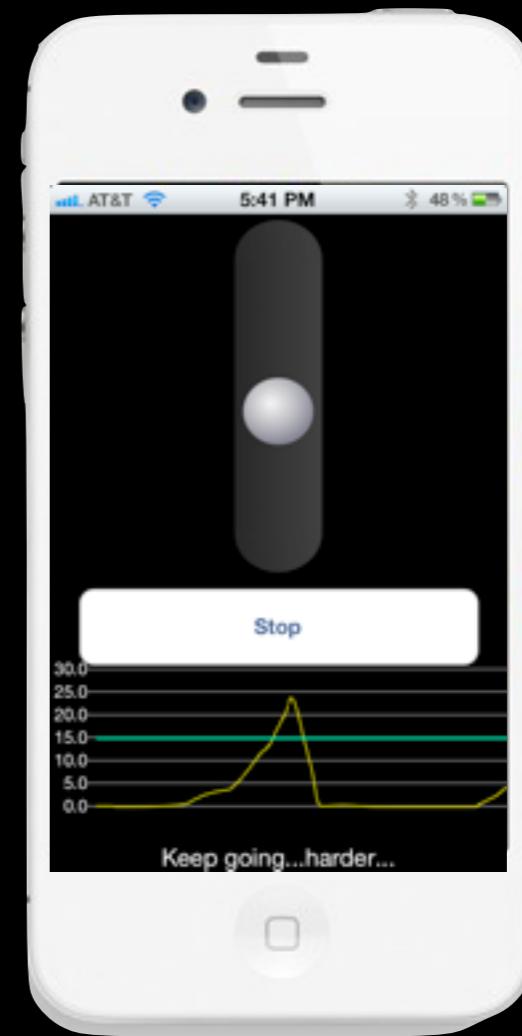
Using a Microphone to Measure Lung Function
on a Mobile Phone

eclarson.com

eclarson@uw.edu

mayankgoel.com

mayankg@uw.edu



Eric Larson, Mayank Goel,

Gaetano Borriello, Sonya Heltshe, Margaret Rosenfeld, Shwetak Patel

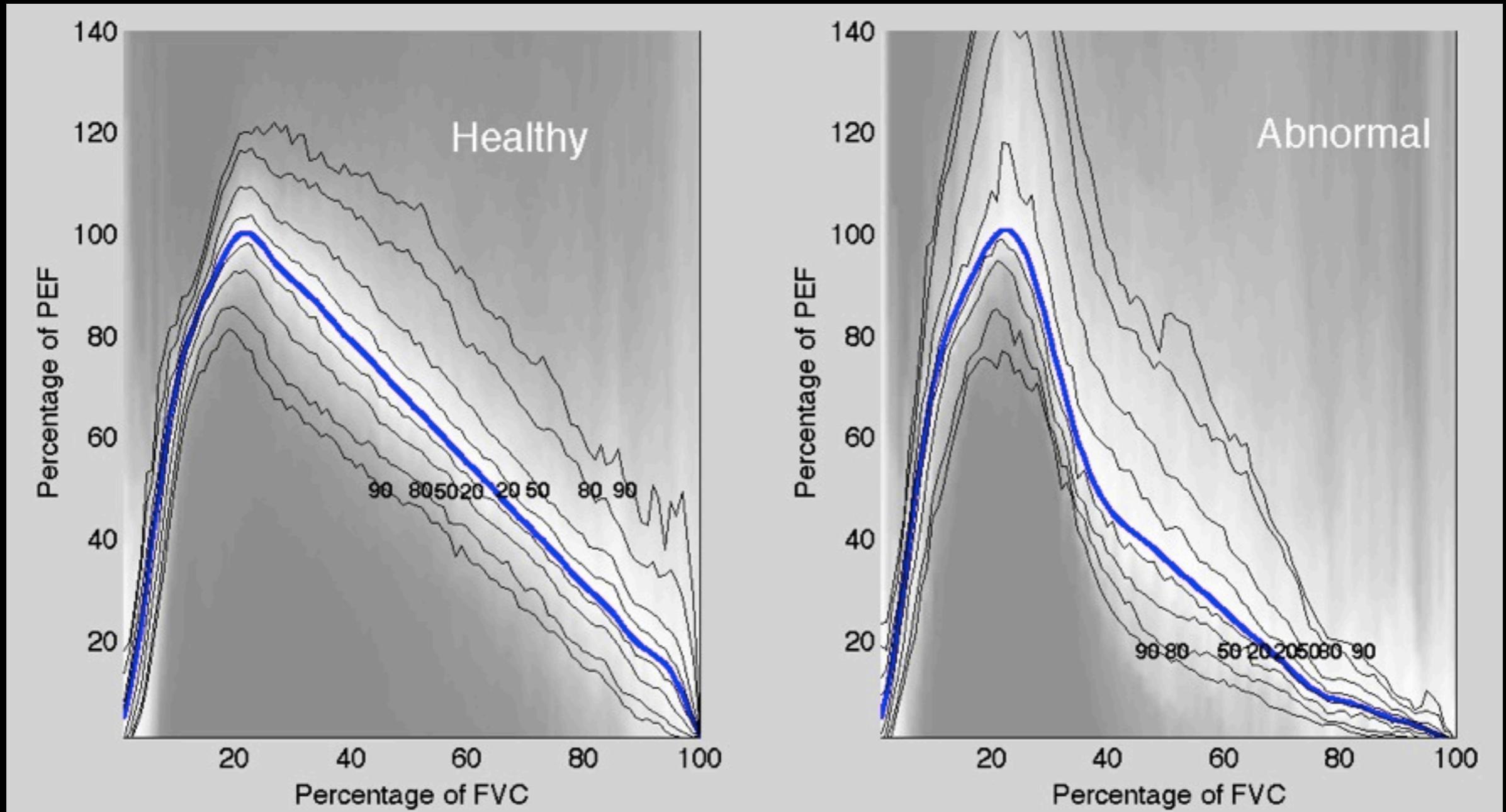
University of Washington

UbiComp Lab

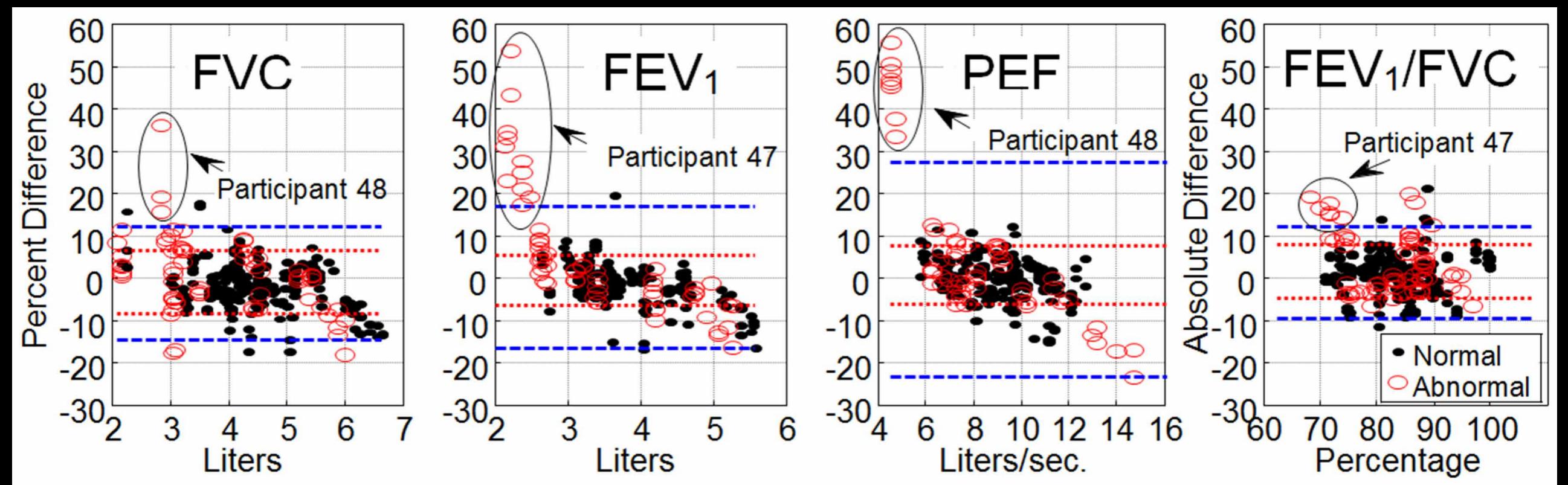
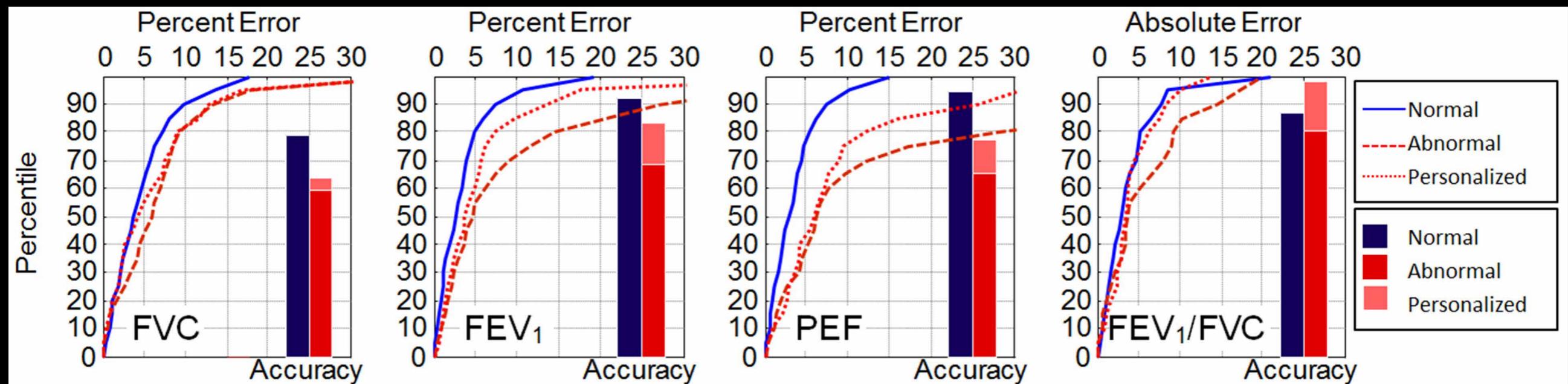


backup - curves

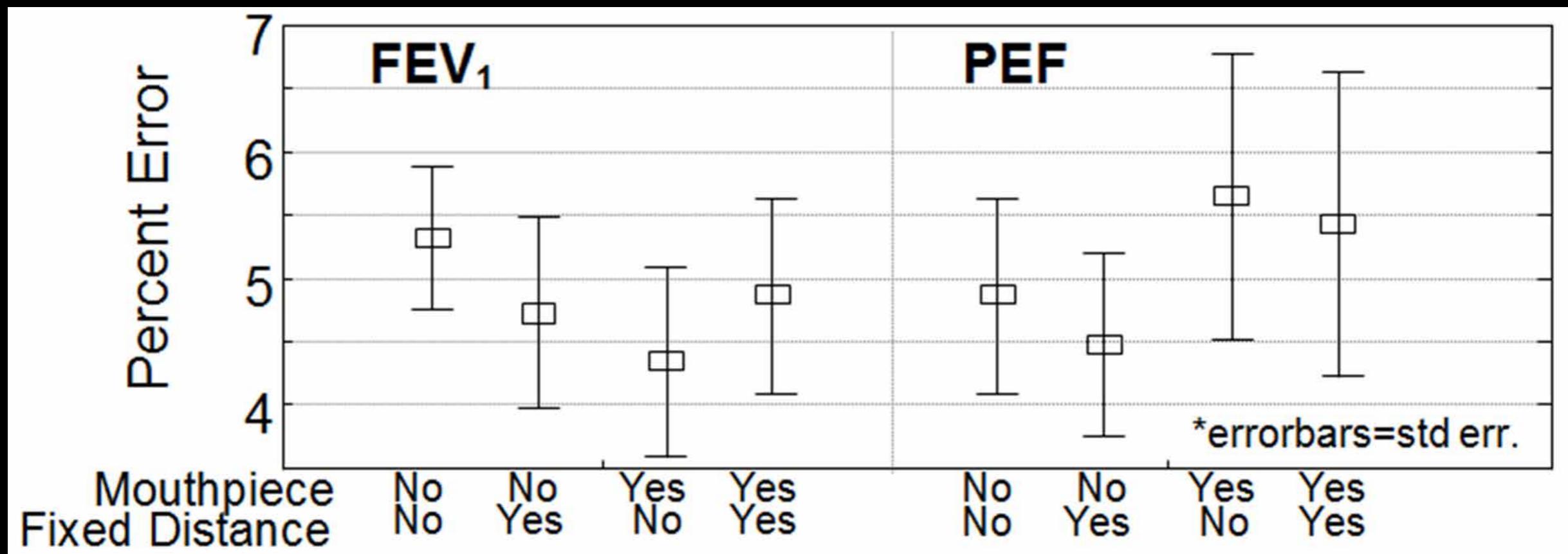
quantitative



backup - bland altman



backup - mouthpiece sling



backup - survey table

Curve	Range of Diagnoses		Within Rater	
	Spirometer	SpiroSmart	Agree	One-off
1	Norm-Obs. (Mild)	Norm-Obs. (Min.)	3	1
2	Norm-Obs. (Mild)	Norm-Obs. (Mild)	3	1
3	Normal	Norm-Obs. (Mild)	3	1
4	Normal	Normal	5	0
5	Normal	Normal	5	0
6	Obs. (Min.-Mod.)	Restrictive	0	0
7	Obs. (Mild-Mod.)	Norm-Obs. (Mild)	0	2
8	Insuff.-Norm	Insuff.-Norm	3	0
9	Normal	Normal	5	0
10	Normal	Normal	5	0
Total	N/A	N/A	32/50	5/18

backup - features after
gone through phone

backup -

- what else?
-