SPIROMETRY

(Assignment 1)

Ankita Jain (BM21MTECH14001)

13^{th} November 2021

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Biomedical Devices

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Prof. Kousik Sarathy S

INSTRUCTIONS

General instructions

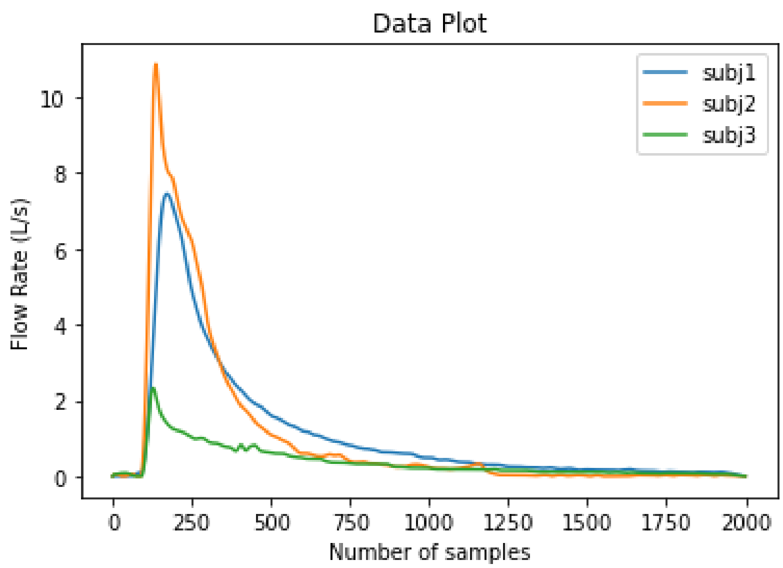
● Work individually - discussion of results & content is strongly discouraged.
Any similarities in answers will lead to disqualification of the assignment for grading
● Plagiarism is strictly prohibited
● Do not use any toolbox/functions
● Add all the codes written to the report

Assignment

● Attached to this assignment are three spirometry datasets from subjects who were asked to perform forced expiration on a spirometer
● What parameters can be extracted from this data?
● Using relevant measures comment on the status of the subjects' respiratory system and display relevant plots.
● Can you comment on any disorders the subjects might have? Is the information available enough to differentiate between obstructive and restrictive lung diseases?

About the data

● The column indicates flow rate (L/s)
● Sampling rate 500 Hz
● Data credits withheld till end of exam deadline
● Dataset IDs: subj1.txt, subj2.txt, subj3.txt



UNDERSTANDING THE DATA

The data provided to us reflects the flow rate of a forced expiration. From a general plot of the provided data, we can observe the range of values of flow rate.

At this point **the plot as pictured above** is inconclusive.

The following code snippet shows:

- Importing the required libraries
- Importing the data
- Plotting an initial plot of the provided data **(as shown above)**

```python
import numpy as np
from numpy import genfromtxt
import matplotlib.pyplot as plt
import pandas as pd
import math
import matplotlib

headers = ["FlowRate"]
X_1 = np.matrix(genfromtxt("/content/subj1.txt"))
df1 = pd.DataFrame(X_1.T, columns = headers).apply(pd.to_numeric)
X_2= np.matrix(genfromtxt("/content/subj2.txt"))
df2 = pd.DataFrame(X_2.T, columns = headers).apply(pd.to_numeric)
X_3 = np.matrix(genfromtxt("/content/subj3.txt"))
df3 = pd.DataFrame(X_3.T, columns = headers).apply(pd.to_numeric)


plt.plot(df1, label ="subj1")
plt.plot(df2, label ="subj2")
plt.plot(df3,label ="subj3")
plt.xlabel("Number of samples")
plt.ylabel("Flow Rate (L/s)")
plt.legend()
plt.title("Data Plot")
```

PARAMETERS THAT CAN BE EXTRACTED FROM THE DATA

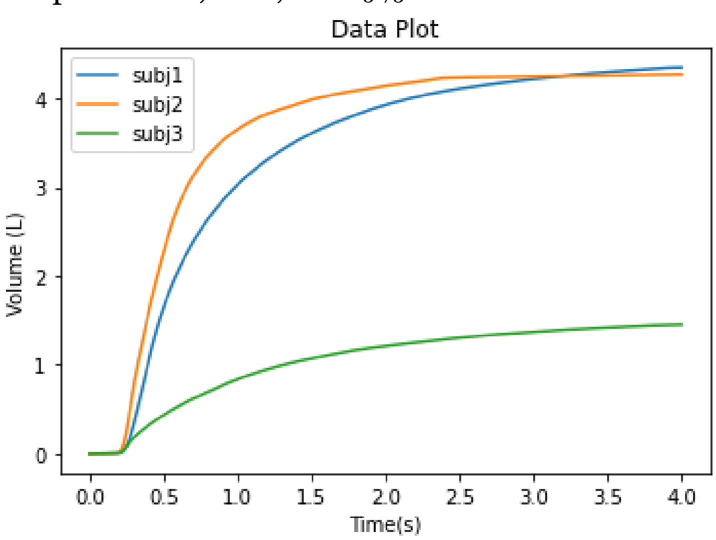
1. Forced Expiration Volume

From the given data we can perform numerical integration on flow rate using the Trapezoidal Rule. Since the frequency of sampling has been provided to us we can find the Δt as follows:

$f = 500Hz$

$\Delta t = 1/f = 0.002$ sec

The following code snippet shows the above formulation and a **Volume-Time Plot** which helps us compute FEV1, FVC, $FEF_{25\text{-}75\%}$



```
dt = 1/500
t=[]
df_1 = list(df1['FlowRate'])
df_2 = list(df2['FlowRate'])
df_3 = list(df3['FlowRate'])

for i in range(len(df_1)):
  t=t+[i*dt]

vol1=[0]
vol2=[0]
vol3=[0]

for i in range(len(df_1)-1):
  dx1=(df_1[i]+df_1[i+1])*dt/2
  dx2=(df_2[i]+df_2[i+1])*dt/2
  dx3=(df_3[i]+df_3[i+1])*dt/2

  vol1.append(vol1[i]+dx1)
  vol2.append(vol2[i]+dx2)
  vol3.append(vol3[i]+dx3)
plt.xlabel("Time(s)")
plt.ylabel("Volume (L)")
plt.title("Data Plot")
plt.plot(t,vol1,label = 'subj1')
plt.plot(t,vol2, label = 'subj2')
plt.plot(t,vol3, label = 'subj3')
plt.legend()
```

2. FEV1

FEV1 stands for Forced Expiratory Volume in 1 second – the volume expired by the subject in the 1st second of the process.

3. FVC

FVC stands for Forced Vital Capacity – maxima amount of air the subject can forcibly exhale after maximum inhalation.

4. PEFR

PEFR stands for Peak Expiratory Flow Rate – maximal speed of airflow as the subject exhales.

5. $FEF_{25\text{-}75\%}$

$FEF_{25\text{-}75\%}$ stands for Forced Expiratory Flow – represents an average flow produced during the middle half of the forced vital capacity (FVC). It can be computed as below:

$$FEF_{25\text{-}75\%} = (0.5\ FVC) / (t_{25\%FVC} - t_{75\%FVC})$$

6. FEV1/FVC

The above ratio is very useful in characterizing various types of Lung disorders.

7. Flow-Volume Loop

This curve provides us with the PEFR value.

8. TVC Curve

TVC stands for Timed Vital Capacity Spirogram - Flow limitations can be studied from the above plot. It is a plot between “integral of expired gas -volume flow subtracted from FVC” against “time”.

9. MEFV curve

MEFV stands for Maximum Expiratory Flow Curve - State of the various parts of the respiratory system can be studied. It is a plot between “volume flow of gas at the airway opening” against “integral of expired gas -volume flow subtracted from FVC”.

STATUS OF SUBJECT’S RESPIRATORY SYSTEM

The status of a given subject’s respiratory system can be studied using the below two plots.

1. MEFV Curve

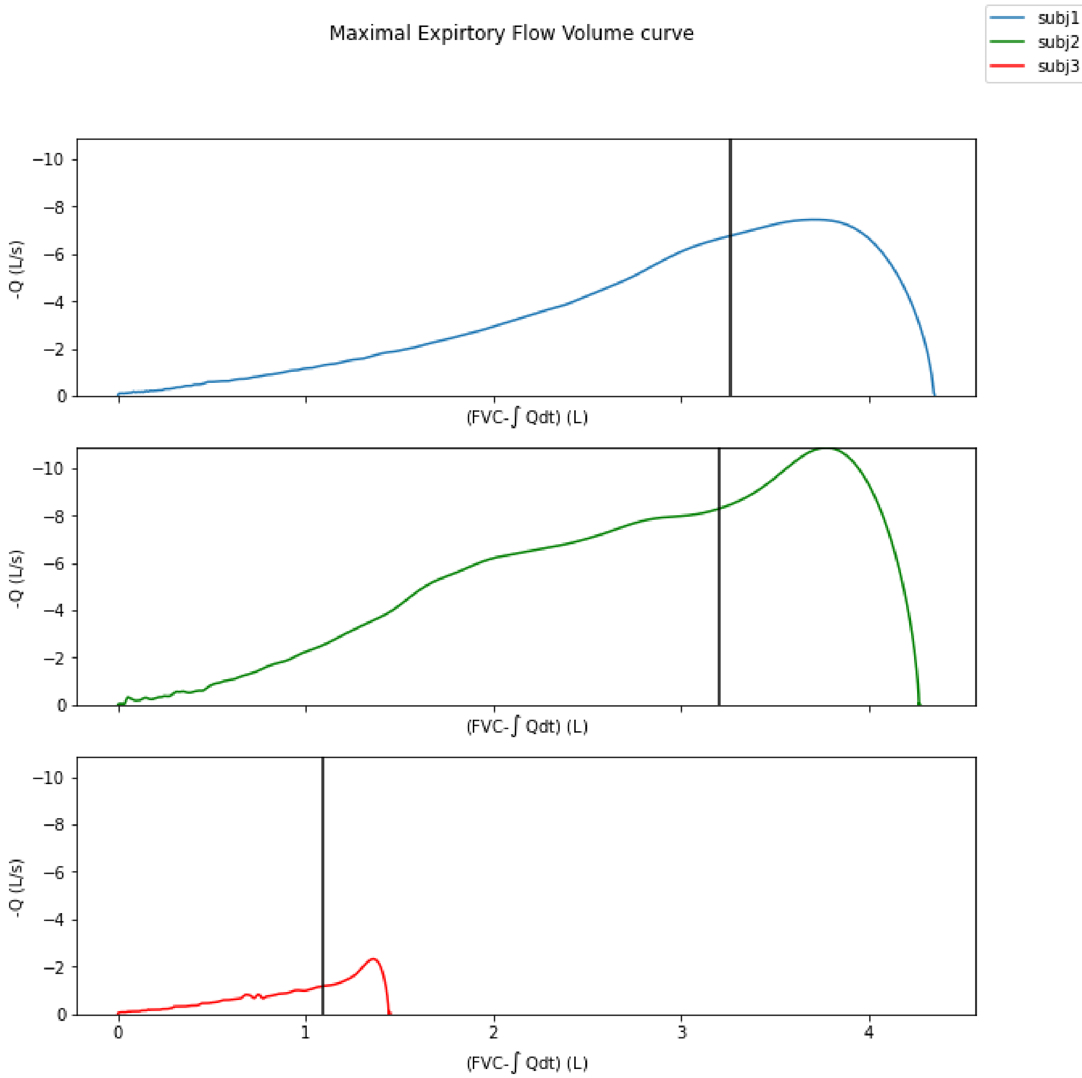
The following conclusions have been made with reference to the text from “Medical Instrumentation Application and Design 3rd edition John G. Webster Ch-9, WILEY”.

- **Normal** -Effort independent part (25% of FVC below TLC to zero) must be linearly decreasing.
- **Abnormal** – Effort independent part is non-linear.

The curves for the three subjects are as plotted below followed by the code snippet.

Hence from the curves we can conclude the following:

- **Subj1** – Abnormal (Closest to normal – minimal flow limitation)
- **Subj2** – Abnormal
- **Subj3** – Abnormal


Maximal Expirtory Flow Volume curve
subj1
subj2
subj3
-Q (L/s)
(FVC-∫ Qdt) (L)
−10
−8
−6
−4
−2
0
1
2
3
4

```
fig, ax1 = plt.subplots(3, sharex = True)
fig.set_figheight(10)
fig.set_figwidth(10)
ax1[0].set_xlabel(r'(FVC-$\int$ Qdt) (L)')
ax1[0].set_ylabel("-Q (L/s)")
ax1[1].set_xlabel(r'(FVC-$\int$ Qdt) (L)')
ax1[1].set_ylabel("-Q (L/s)")
ax1[2].set_xlabel(r'(FVC-$\int$ Qdt) (L)')
ax1[2].set_ylabel("-Q (L/s)")
fig.suptitle("Maximal Expirtory Flow Volume curve")
ax1[0].set_ylim((-1*df2).max()[0],(-1*df2).min()[0])
ax1[1].set_ylim((-1*df2).max()[0],(-1*df2).min()[0])
ax1[2].set_ylim((-1*df2).max()[0],(-1*df2).min()[0])
ax1[0].plot(list(vol1[0]),list(-1*df1['FlowRate']), label = 'subj1')
ax1[1].plot(list(vol2[0]),list(-
1*df2['FlowRate']),c = 'g', label = 'subj2')
ax1[2].plot(list(vol3[0]),list(-
1*df3['FlowRate']), c = 'r',label = 'subj3')
ax1[0].axvline(vol1.iloc[0,0]-0.25*FVC11, c = 'k')
ax1[1].axvline(vol2.iloc[0,0]-0.25*FVC21, c = 'k')
ax1[2].axvline(vol3.iloc[0,0]-0.25*FVC31, c = 'k')
fig.legend()
```

2. TVC curve

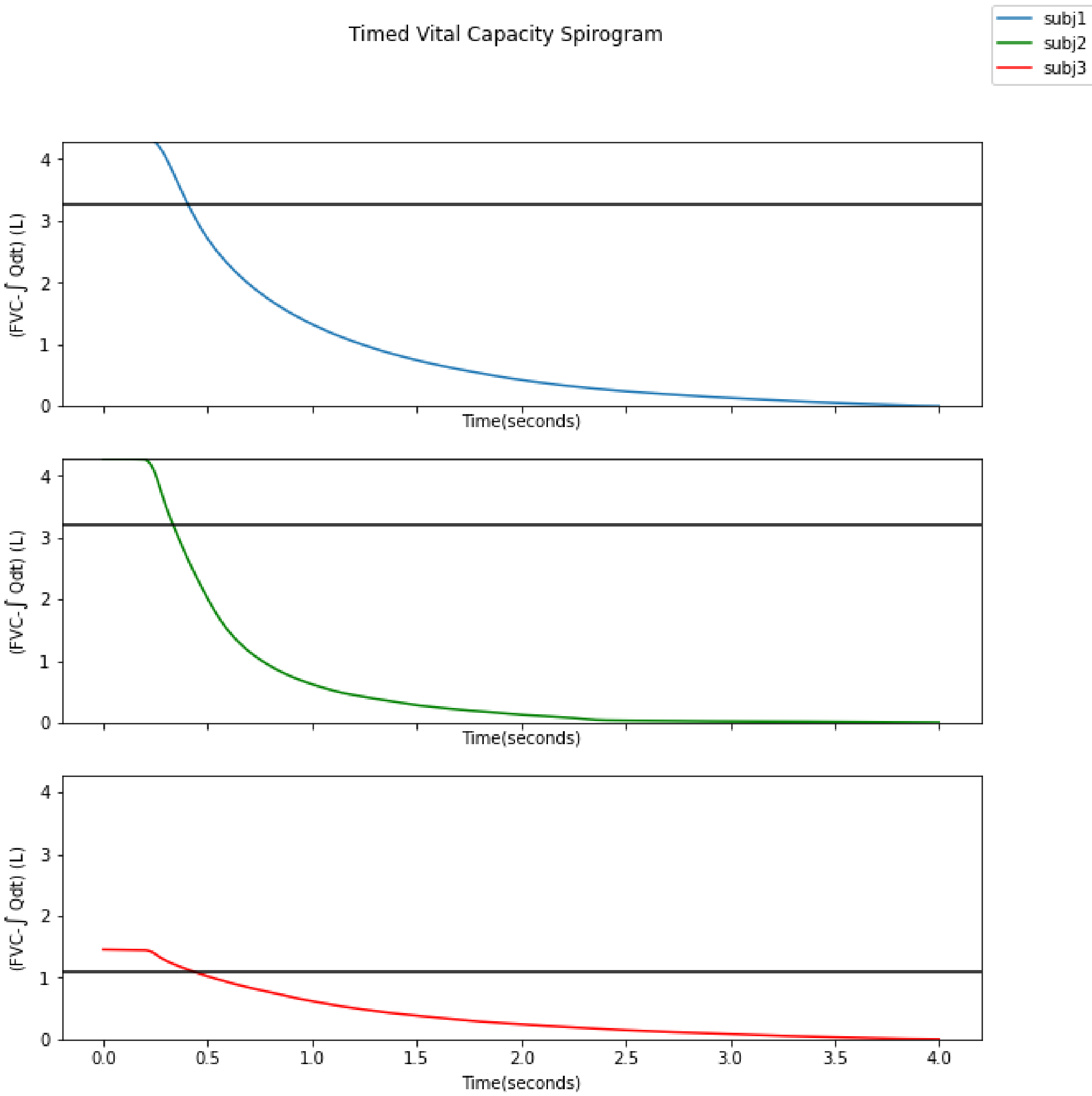
The following conclusions have been made with reference to the text from “Medical Instrumentation Application and Design 3rd edition John G. Webster Ch-9, WILEY”.

- **Normal** -Effort independent part (25% of FVC below TLC to zero) must be exponentially decreasing.
- **Abnormal** – Effort independent part is not exponential.

The curves for the three subjects are as plotted below followed by the code snippet.

Hence from the curves we can conclude the following:

- **Subj1** – Normal
- **Subj2** – Abnormal (Close to normal – minimal flow limitation)
- **Subj3** – Abnormal


Timed Vital Capacity Spirogram
subj1
subj2
subj3
(FVC-∫ Qdt) (L)
Time(seconds)
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

```
fig, ax2 = plt.subplots(3, sharex= True)
ax2[0].set_xlabel("Time(seconds)")
ax2[0].set_ylabel(r'(FVC-$\int$ Qdt) (L)')
ax2[1].set_xlabel("Time(seconds)")
ax2[1].set_ylabel(r'(FVC-$\int$ Qdt) (L)')
ax2[2].set_xlabel("Time(seconds)")
ax2[2].set_ylabel(r'(FVC-$\int$ Qdt) (L)')
fig.set_figheight(10)
fig.set_figwidth(10)
fig.suptitle("Timed Vital Capacity Spirogram")
ax2[0].set_ylim(vol2.min()[0],vol2.max()[0])
ax2[1].set_ylim(vol2.min()[0],vol2.max()[0])
ax2[2].set_ylim(vol2.min()[0],vol2.max()[0])
ax2[0].plot(t,list(vol1[0]), label = 'subj1')
ax2[1].plot(t,list(vol2[0]),c ='g', label = 'subj2')
ax2[2].plot(t,list(vol3[0]),c = 'r', label = 'subj3')
ax2[0].axhline(vol1.iloc[0,0]-0.25*FVC11,c = 'k')
ax2[1].axhline(vol2.iloc[0,0]-0.25*FVC21,c = 'k')
ax2[2].axhline(vol3.iloc[0,0]-0.25*FVC31,c = 'k')
print("\nTotal volume for subj1 = ",vol1.iloc[0,0]," L")
print("\nTotal volume for subj2 = ",vol2.iloc[0,0]," L")
print("\nTotal volume for subj3 = ",vol3.iloc[0,0]," L")
fig.legend()
```

```
Total volume for subj1 =  4.349944000000001  L

Total volume for subj2 =  4.271376000000028  L

Total volume for subj3 =  1.4526070000000177  L
```

COMMENT ON DISORDERS THE SUBJECT MIGHT HAVE

1. Flow Volume Loop

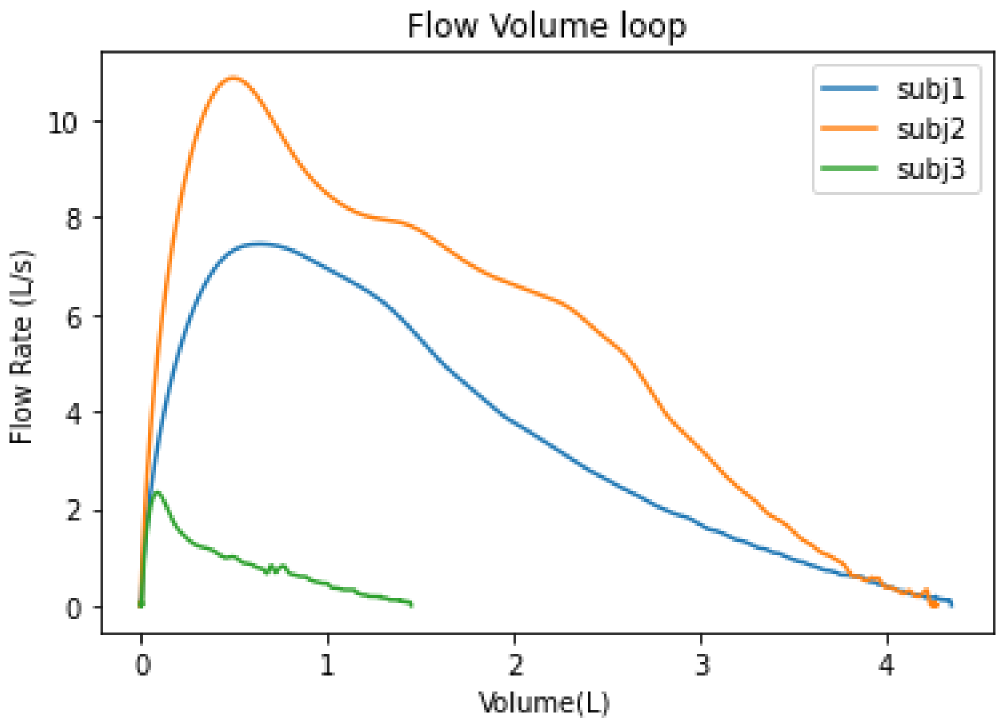
The following conclusions have been made with reference to the text from “Medical Instrumentation Application and Design 3rd edition John G. Webster Ch-9, WILEY”.

Since the shape of the flow volume curves plotted do not match a general flow volume curve, the plot is inconclusive for subj2 and subj3. And the PEFR values are:

PEFR1 = 10.58
PEFR2 = 7.25
PEFR3 = 2.2

The plot and the code snippet for the flow volume loop is as follows:

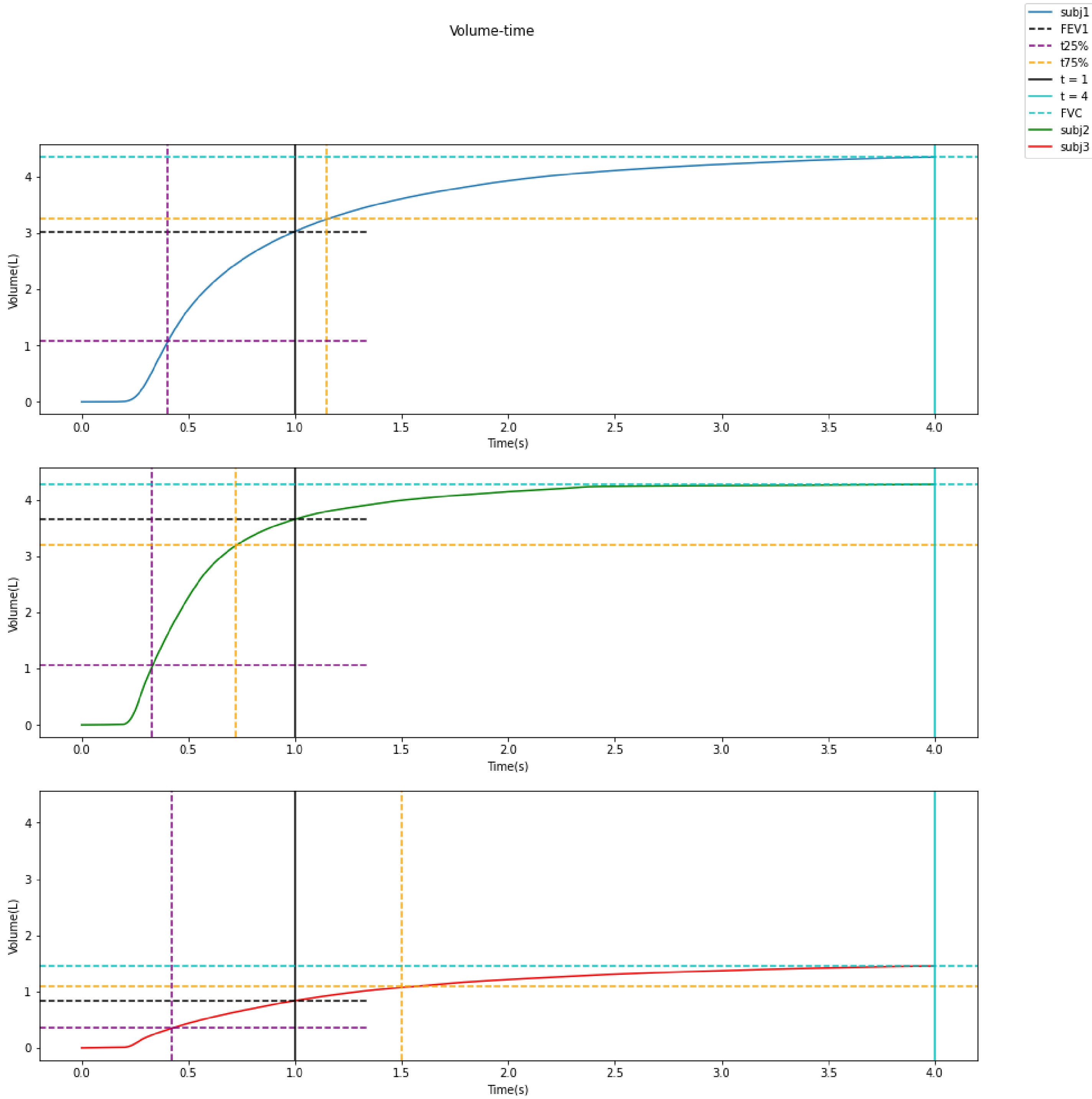
```
plt.plot(vol1,df1, label = 'subj1')
plt.plot(vol2,df2, label = 'subj2')
plt.plot(vol3,df3, label = 'subj3')
plt.xlabel("Volume(L)")
plt.ylabel("Flow Rate (L/s)")
plt.legend()
plt.title("Flow Volume loop")
```



2. Volume-Time Curve

The volume – time curve provides us FEV11, FVC and $FEF_{25\text{-}75\%}$
The code and the plot showing the above values are as below

```
fig, ax = plt.subplots(3, sharey=True)
fig.set_figheight(15)
fig.set_figwidth(15)
ax[0].set_xlabel("Time(s)")
ax[0].set_ylabel("Volume(L)")
ax[1].set_xlabel("Time(s)")
ax[1].set_ylabel("Volume(L)")
ax[2].set_xlabel("Time(s)")
ax[2].set_ylabel("Volume(L)")
ax[0].plot(t,vol1,label = 'subj1')
ax[1].plot(t,vol2,c = 'g', label='subj2')
ax[2].plot(t,vol3, c = 'r', label='subj3')
ax[0].axhline(vol1[499],xmax =0.35, c ='k',linestyle = '--
', label = 'FEV1')
ax[1].axhline(vol2[499],xmax=0.35, c='k',linestyle = '--')
ax[2].axhline(vol3[499],xmax=0.35,c = 'k',linestyle = '--')

ax[0].axvline(1.15, c ='orange',linestyle = '--')
ax[1].axvline(0.72, c='orange',linestyle = '--')
ax[2].axvline(1.5,c = 'orange',linestyle = '--')

ax[0].axvline(0.40, c ='purple',linestyle = '--')
ax[1].axvline(0.33, c='purple',linestyle = '--')
ax[2].axvline(0.42,c = 'purple',linestyle = '--')

ax[0].axhline(FVC11*0.25,xmax=0.35, c ='purple',linestyle = '--
', label = 't25%')
ax[1].axhline(FVC21*0.25, xmax=0.35,c='purple',linestyle = '--')
ax[2].axhline(FVC31*0.25,xmax=0.35,c = 'purple',linestyle = '--')

ax[0].axhline(FVC11*0.75, c ='orange',linestyle = '--', label = 't75%')
ax[1].axhline(FVC21*0.75, c='orange',linestyle = '--')
ax[2].axhline(FVC31*0.75,c = 'orange',linestyle = '--')

ax[0].axvline(1,c='k', label = 't = 1')
ax[1].axvline(1,c='k')
ax[2].axvline(1,c='k')

ax[0].axvline(4,c='c', label = 't = 4')
ax[1].axvline(4,c='c')
ax[2].axvline(4,c='c')
ax[0].axhline(vol1[1999], c ='c',linestyle = '--', label = 'FVC')
ax[1].axhline(vol2[1999], c='c',linestyle = '--')
ax[2].axhline(vol3[1999],c = 'c',linestyle = '--')
fig.legend()
fig.suptitle("Volume-time")
```


Volume-time
subj1
FEV1
t25%
t75%
t = 1
t = 4
FVC
subj2
subj3
Volume(L)
Time(s)
0
1
2
3
4
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0

```
FEV11 = vol1[499]
FVC11 = vol1[1999]
R1 = (FEV11/FVC11)

FEV21 = vol2[499]
FVC21 = vol2[1999]
R2 = (FEV21/FVC21)

FEV31 = vol3[499]
FVC31 = vol3[1999]
R3 = (FEV31/FVC31)

FEF1 = 0.5*FVC11/(1.15-0.4)
FEF2 = 0.5*FVC21/(0.72-0.33)
FEF3 = 0.5*FVC31/(1.5-0.42)

print("FEF1 = ", FEF1)
print("FEF2 = ", FEF2)
print("FEF3 = ", FEF3)

print("\nsubj FEV1                  FVC                  FEV1/FVC ratio")
print("1    ",FEV11," ",FVC11," ",R1,"%")
print("2    ",FEV21,"  ",FVC21," ",R2,"%")
print("3    ",FEV31," ",FVC31,"",R3,"%")
```

```
FEF1 =  2.8999626666666676
FEF2 =  5.476123076923113
FEF3 =  0.672503240740749

subj FEV1                 FVC                  FEV1/FVC ratio
1    3.0252090000000003   4.349944000000001    0.695459297866823 %
2    3.649608000000001    4.271376000000028    0.8544337937001981 %
3    0.8362340000000004   1.4526070000000177   0.5756780739732014 %
```

** **ERS TASK FORCE: Multi-ethnic reference values for spirometry for the 3–95-yr age range: the global lung function 2012 equations**** is the reference for the following conclusions.

1. Subj1
    1. The FEV1/FVC ratio is < 0.7 this implies pathological airflow limitation.
    2. Hence the person most likely has a mild obstructive lung disorder.
2. Subj2
    1. Since the FEV1/FVC ratio is > 0.7 the subject can be normal
       Hence on tracing back the FEV1/FVC ratio value using Spirometry NHANES III Reference Values which have their calculations based on the above-mentioned reference. One of the possible characteristics of the subject can be:
        i. Gender: Male
        ii. Ethnicity: African-American
        iii. Height: 170cm
        iv. Age: 21
    2. No lung disorders

3. Subj3
    1. The FEV1/FVC ratio is < 0.7, hence obstructive
    2. But we see a highly decreased FVC which leads me to believe a case of mixed obstructive-restrictive disorder

IS THE INFORMATION AVAILABLE ENOUGH TO DIFFERENTIATE BETWEEN OBSTRUCTIVE AND RESTRICTIVE LUNG DISEASES?

No, the available information is not enough to differentiate between Obstructive and restrictive diseases. We need the TLC(Total Lung Capacity) value also to be sure of our inferences.