In [1]:

```
#import proper tools
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

#Access the csv files and remove the information that isn't necessary for this analysis
anne_raw = pd.read_csv('Anne.csv').drop(['Unnamed: 0'], axis=1)
sarah_raw = pd.read_csv('Sarah.csv').drop(['Unnamed: 0'], axis=1)
anne_df = anne_raw.drop(['File One','File Two'], axis=1)
sarah_df = sarah_raw.drop(['File One','File Two'], axis=1)
```

In [2]:

```
#add_confus adds columns to the dataframes that represent what kind of correct or incorr
ect they are
#in the style of a confusion matrix
def add_confus(mat):
    same = mat['Other Vowel'].isnull()
    diff = np.logical_not(mat['Other Vowel'].isnull())
    truth = mat['Correctness']
    falth = np.logical_not(mat['Correctness'])
    mix = lambda a,b: np.where(np.logical_and(a,b),True, False)
    mat['True Same'] = mix(same,truth)
    mat['False Same'] = mix(diff,falth)
    mat['True Different'] = mix(diff,truth)
    mat['False Different'] = mix(same,falth)

add_confus(anne_df)
add_confus(sarah_df)
```

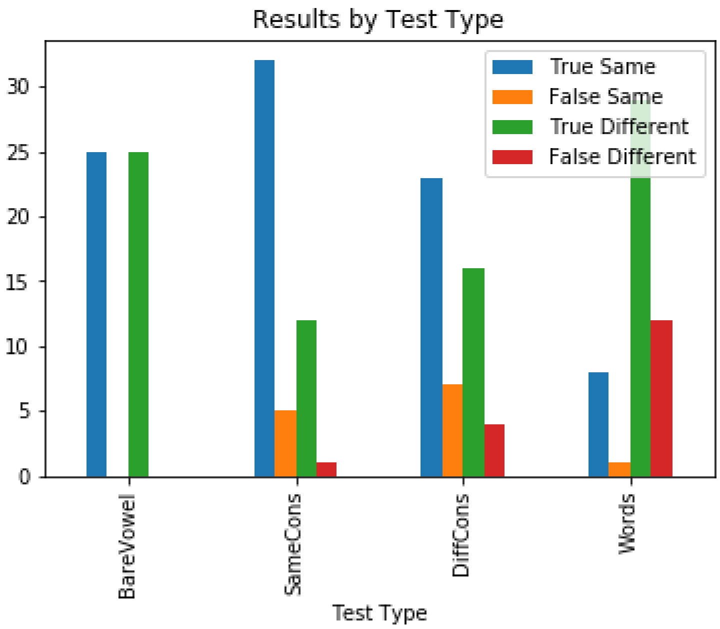
In [3]:

```
t_types = [anne_df['Test Type'][i] for i in [1,26,51,76]]
confus = list(anne_df.columns[-4:])
def get_test_type_stats(mat):
    data = dict([])
    for t in t_types:
        temp = dict([])
        for c in confus:
            temp[c] = len( (np.where(mat[mat['Test Type']==t][c]))[0])
        data[t]=temp
    result = pd.DataFrame(data).T
    result.index.name = 'Test Type'
    return result

test_type_matrix = get_test_type_stats(anne_df)+get_test_type_stats(sarah_df)
test_type_matrix
```

Out[3]:

	True Same	False Same	True Different	False Different
Test Type				
BareVowel	25	0	25	0
SameCons	32	5	12	1
DiffCons	23	7	16	4
Words	8	1	29	12

```
In [4]: test_type_matrix.plot.bar(title='Results by Test Type')

Out[4]: <matplotlib.axes._subplots.AxesSubplot at 0x2a6f6534d48>
```



In [5]:

```python
#find_confused_vowels gets a dataframe with each pair of confused vowels and the frequency of that pair
def find_confused_vowels(mat):
    false_sames = mat[mat['False Same']==True]
    pairs = list(zip(false_sames['Vowel'],false_sames['Other Vowel']))
    for i in range(len(pairs)):
        if pairs[i][0] > pairs[i][1]:
            pairs[i] = (pairs[i][1],pairs[i][0])
    counts = {}
    for i in pairs:
        counts[i] = counts.get(i, 0) + 1
    return pd.DataFrame.from_dict(counts,orient='index')

#Then we aggregate the confusions between each listener
confused_vowels = find_confused_vowels(anne_df).append(find_confused_vowels(sarah_df))
confused_vowels.reset_index(inplace=True)
confused_vowels = confused_vowels.groupby(confused_vowels['index']).aggregate({0:'sum'})

#And then it'd be nice to have it clearly labeled and sorted
confused_vowels.index.name = "Vowels"
confused_vowels.columns = ["Times Confused"]
confused_vowels.sort_values(by='Times Confused',inplace=True,ascending=False)
confused_vowels
```

Out[5]:

	Times Confused
Vowels	
(ɛ, ɪ)	3
(æ, ɪ)	2
(a, eɪ)	1
(a, ʌ)	1
(eɪ, ɪ)	1
(oʊ, u)	1
(æ, ɛ)	1
(æ, ʌ)	1
(ɪ, ʊ)	1
(ʊ, ʌ)	1

In [6]:

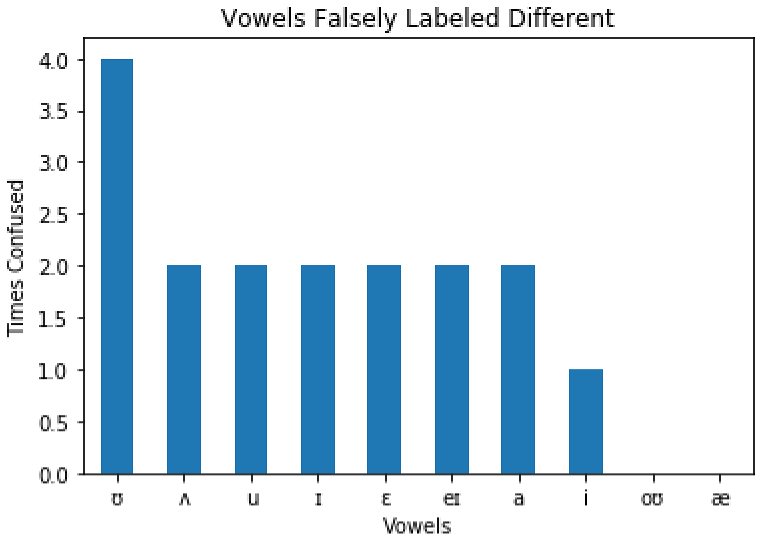
```
#get_false_diff_data returns a Series containing each vowel
#and the number of times it was falsely marked as different from itself
vowels = ['a','æ','eɪ','ɛ','i','ɪ','oʊ','u','ʊ','ʌ']
def get_false_diff_data(mat):
    false_diffs = mat[mat['False Different']==True]
    false_diffs = false_diffs['Vowel'].value_counts()
    result = pd.Series([0 for i in range(len(vowels))],index=vowels)
    result += false_diffs
    return result.fillna(0).astype('int32')

false_diff_data = get_false_diff_data(anne_df) + get_false_diff_data(sarah_df)

#And then we sort it and label it
false_diff_data.sort_values(ascending=False,inplace=True)
false_diff_data.index.name = 'Vowels'
false_diff_data = pd.DataFrame(false_diff_data)
false_diff_data.columns = ['Times Confused']
false_diff_data
```

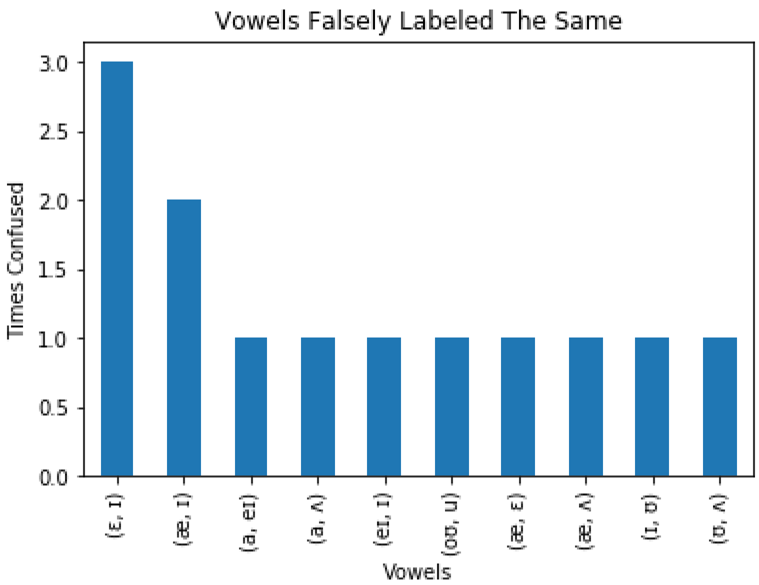
Out[6]:

	Times Confused
Vowels	
ʊ	4
ʌ	2
u	2
ɪ	2
ɛ	2
eɪ	2
a	2
i	1
oʊ	0
æ	0

In [7]:

```
axs = [None,None]
axs[0] = false_diff_data.plot.bar(legend=False,title='Vowels Falsely Labeled Different')
plt.xticks(rotation='horizontal')
axs[1] = confused_vowels.plot.bar(legend=False,title='Vowels Falsely Labeled The Same')
for i in axs:
    i.set_ylabel('Times Confused')
    i.plot()
```


Vowels Falsely Labeled Different


Vowels Falsely Labeled The Same

In [8]:

```
#Now let's analyze in terms of formants
#First, load up the formant measurements
formants = {}
for i in vowels:
    df = pd.read_csv('Vowel Formants/'+i+' formants.csv').drop('Unnamed: 0', axis=1)
    df.index = df['File']
    formants[i] = df.drop('File', axis=1)
```

In [9]:

```
#Now, we're going to get all the formant data for each type of correct/incorrect answer

#compare_formants takes a list with two vowels and two recording names
#and returns a DataFrame with a row for each recording and a row of the differences betw
een them
def compare_formants(args):
    [v1,v2,rec1,rec2] = args
    v2 = v1 if type(v2)==type(0.1) else v2
    if v2!=v1:
        data = {}
        data[v1] = formants[v1].loc[rec1]
        data[v2] = formants[v2].loc[rec2]
        data['Differences'] = np.abs(data[v1] - data[v2])
        return pd.DataFrame(data).T
    else:
        row1 = {v1: formants[v1].loc[rec1]}
        row2 = {v2: formants[v2].loc[rec2]}
        result = pd.DataFrame(row1).T.append(pd.DataFrame(row2).T)
        result.loc['Differences'] = np.abs(result.iloc[0]-result.iloc[1])
        return result

#get_formant_diffs gets all the formant difference DataFrames from compare_formants for
#a particular person's data and a particular type of correct/incorrect answer
def get_formant_diffs(mat_raw,mat,confus_type):
    start = mat_raw[mat[confus_type]==True].drop(['Test Type','Correctness'],axis=1)
    data = []
    for i in range(len(start.index)):
        data.append(compare_formants(list(start.iloc[i])))
    return pd.concat(data)

getfd = lambda i: get_formant_diffs(anne_raw,anne_df,i).append(get_formant_diffs(sarah_r
aw,sarah_df,i))
formant_differences = [getfd(i) for i in confus]
```

In [10]:

```
true_sames = formant_differences[0]
true_sames
```

Out[10]:

```
                    F1           F2           F3
          ʊ  446.734368  1879.037848  2618.457233
          ʊ  449.088141  1382.682606  2827.117488
Differences    2.353773   496.355243   208.660255
         eɪ  482.892249  1916.911926  2495.003712
         eɪ  420.962731  1990.003836  2616.078624
        ...         ...          ...          ...
          ɪ  471.408238  1859.902305  2620.249795
Differences   11.625154    23.288098   159.321337
          æ  629.130745  1403.061221  1870.294175
          æ  592.698554  1849.083031  2573.279145
Differences   36.432190   446.021810   702.984970

264 rows × 3 columns
```

In [11]:

```
false_sames = formant_differences[1]
false_sames
```

```
Out[11]:
                     F1           F2           F3
          ε  515.572416  1775.775877  2718.365807
          æ  612.443391  1630.905556  2461.901065
Differences   96.870975   144.870321   256.464743
          ε  515.572416  1775.775877  2718.365807
          ɪ  457.423837  1893.682812  2810.138605
Differences   58.148579   117.906935    91.772798
          æ  663.025620  1249.984673  2181.902514
          ɪ  449.237974  1618.567623  2243.761852
Differences  213.787645   368.582950    61.859338
          ɪ  404.352901  1816.292037  2575.728933
          æ  607.018446  1473.480897  2351.374491
Differences  202.665545   342.811139   224.354443
         oʊ  519.866292   994.608746  2949.863284
          u  371.032908  1218.497455  2369.649039
Differences  148.833383   223.888709   580.214245
          ɪ  457.423837  1893.682812  2810.138605
          ε  525.408082  1749.796837  2705.798191
Differences   67.984245   143.885975   104.340414
          ʌ  599.391475  1403.895563  2701.419439
          ʊ  475.125557  1551.899372  2761.487721
Differences  124.265918   148.003809    60.068282
          a  798.367313  1313.082533  2928.810008
         eɪ  483.991883  1950.212322  2633.034089
Differences  314.375430   637.129789   295.775919
          æ  663.025620  1249.984673  2181.902514
          ʌ  575.382804  1400.388502  2549.863140
Differences   87.642816   150.403829   367.960626
          ɪ  449.237974  1618.567623  2243.761852
         eɪ  442.380112  1784.093832  2557.371887
Differences    6.857862   165.526209   313.610035
          a  654.151902  1144.355144  2408.698477
          ʌ  550.966384  1498.301414  2355.856070
Differences  103.185518   353.946270    52.842407
          ε  563.915391  1538.017191  2605.840116
          ɪ  404.352901  1816.292037  2575.728933
Differences  159.562490   278.274846    30.111182
          ɪ  449.237974  1618.567623  2243.761852
          ʊ  448.093340  1814.923652  2949.367416
```

	F1	F2	F3
Differences	1.144635	196.356029	705.605564

In [12]:

```
true_diffs = formant_differences[2]
true_diffs
```

Out[12]:

	F1	F2	F3
ʌ	628.643811	1335.637772	2445.672216
ɪ	443.777124	1881.837542	2672.748522
Differences	184.866686	546.199769	227.076306
i	258.124019	2268.928046	3198.124924
a	799.338950	1121.237671	2835.682242
...	...	...	...
ɪ	483.033392	1836.614208	2460.928458
Differences	19.644212	673.168488	83.591145
eɪ	464.894189	1571.287326	1802.909397
ɛ	576.352814	1628.385992	2415.239600
Differences	111.458625	57.098667	612.330203

246 rows × 3 columns

In [13]:

```
false_diffs = formant_differences[3]
false_diffs
```

Out[13]:

	F1	F2	F3
u	362.472216	1832.593644	2424.908777
u	387.673587	1837.815405	2588.727893
Differences	25.201371	5.221762	163.819116
ɛ	527.694699	1782.176279	2566.590856
ɛ	563.915391	1538.017191	2605.840116
Differences	36.220692	244.159088	39.249260
ʊ	448.093340	1814.923652	2949.367416
ʊ	445.342566	1335.476542	2629.003941
Differences	2.750774	479.447110	320.363475
eɪ	442.380112	1784.093832	2557.371887
eɪ	567.976686	1814.452738	2460.873349
Differences	125.596574	30.358907	96.498539
ɛ	576.352814	1628.385992	2415.239600
ɛ	642.513263	1465.413486	2728.941647
Differences	66.160449	162.972507	313.702047
ɪ	471.408238	1859.902305	2620.249795
ɪ	483.033392	1836.614208	2460.928458
Differences	11.625154	23.288098	159.321337
ʌ	648.839196	1348.077438	2385.181954
ʌ	593.614902	1548.153806	2435.873722
Differences	55.224294	200.076368	50.691767
ɪ	471.408238	1859.902305	2620.249795
ɪ	483.033392	1836.614208	2460.928458
Differences	11.625154	23.288098	159.321337
u	363.635113	1417.043586	1705.878628
u	371.032908	1218.497455	2369.649039
Differences	7.397796	198.546131	663.770411
a	609.356546	1372.475214	2138.313398
a	756.772726	1019.069894	3097.826607
Differences	147.416180	353.405320	959.513208
a	609.356546	1372.475214	2138.313398
a	756.772726	1019.069894	3097.826607
Differences	147.416180	353.405320	959.513208
ʌ	593.614902	1548.153806	2435.873722
ʌ	648.839196	1348.077438	2385.181954
Differences	55.224294	200.076368	50.691767
ʊ	448.093340	1814.923652	2949.367416
ʊ	445.342566	1335.476542	2629.003941

	F1	F2	F3
Differences	2.750774	479.447110	320.363475
ʊ	502.677604	1163.445720	2377.337314
ʊ	530.832678	1253.084204	2306.391676
Differences	28.155073	89.638484	70.945638
ʊ	530.832678	1253.084204	2306.391676
ʊ	502.677604	1163.445720	2377.337314
Differences	28.155073	89.638484	70.945638
eɪ	429.501661	1938.924039	2457.808429
eɪ	464.894189	1571.287326	1802.909397
Differences	35.392528	367.636713	654.899032
i	283.523330	2208.375493	2951.898843
i	337.670373	2276.986644	2983.364057
Differences	54.147042	68.611151	31.465214

In [14]:

```
#Is there a connection between average formant magnitude and confusion type?
formant_heights = {}
for i in range(len(formant_differences)):
    checker = formant_differences[i].drop('Differences')
    formant_heights[confus[i]] = checker.mean()
pd.DataFrame(formant_heights).T
#Not really, no
```

Out[14]:

	F1	F2	F3
True Same	503.427791	1677.298617	2578.756461
False Same	525.230721	1568.985872	2561.303527
True Different	510.817117	1599.091735	2513.850159
False Different	508.858198	1571.073796	2512.380914

In [15]:

```
#Is there a connection between formant differences and confusion type?
just_differences = {}
for i in range(len(formant_differences)):
    checker = formant_differences[i].loc['Differences']
    just_differences[confus[i]] = checker.mean()
pd.DataFrame(just_differences).T
#Looks promising! Let's get more detail
```

Out[15]:

	F1	F2	F3
True Same	30.112704	104.988122	168.788264
False Same	121.948080	251.660524	241.921538
True Different	179.544871	463.075380	346.896550
False Different	49.438788	198.189236	299.122028

In [16]:
```
all_differences = []
for i in range(len(formant_differences)):
    add_df = formant_differences[i][formant_differences[i].index=='Differences'].copy()
    add_df['Confusion Type'] = confus[i]
    all_differences.append(add_df)

all_differences = pd.concat(all_differences).reset_index().drop('index',axis=1)
for i in ['1','2','3']:
    all_differences['F'+i+' Decile'] = list(pd.qcut(all_differences['F'+i],10,range(1,11
)))
deciles = all_differences.drop(['F1','F2','F3'], axis=1)
deciles
```

Out[16]:

	Confusion Type	F1 Decile	F2 Decile	F3 Decile
0	True Same	1	9	7
1	True Same	6	3	4
2	True Same	1	3	2
3	True Same	5	6	4
4	True Same	2	1	3
...	...	...	...	...
195	False Different	1	8	8
196	False Different	4	4	3
197	False Different	4	4	3
198	False Different	4	8	10
199	False Different	5	3	2

200 rows × 4 columns

In [17]:
```
decile_counts = {}
for i in ['F1 Decile','F2 Decile','F3 Decile']:
    formant_counter = {}
    for j in range(1,11):
        confus_counter = {}
        for k in confus:
            l = lambda d: np.logical_and( d[i]==j, d['Confusion Type']==k)
            confus_counter[k] = len(deciles.loc[l, :])
        formant_counter[j] = confus_counter
    decile_counts[i] = formant_counter
```

In [18]:
```
decile_counts['F1 Decile'] = pd.DataFrame(decile_counts['F1 Decile'])
decile_counts['F1 Decile']
```

Out[18]:

	1	2	3	4	5	6	7	8	9	10
True Same	16	15	17	15	13	7	3	2	0	0
False Same	2	0	0	0	0	2	4	2	2	1
True Different	1	1	5	0	5	7	14	12	18	19
False Different	2	3	0	5	1	3	1	2	0	0

In [19]:

```
decile_counts['F2 Decile'] = pd.DataFrame(decile_counts['F2 Decile'])
decile_counts['F2 Decile']
```

Out[19]:

	1	2	3	4	5	6	7	8	9	10
True Same	16	17	18	10	8	11	3	4	1	0
False Same	0	0	0	0	6	2	2	2	0	1
True Different	2	1	4	5	6	4	13	10	18	19
False Different	3	1	1	2	1	3	1	5	0	0

In [20]:

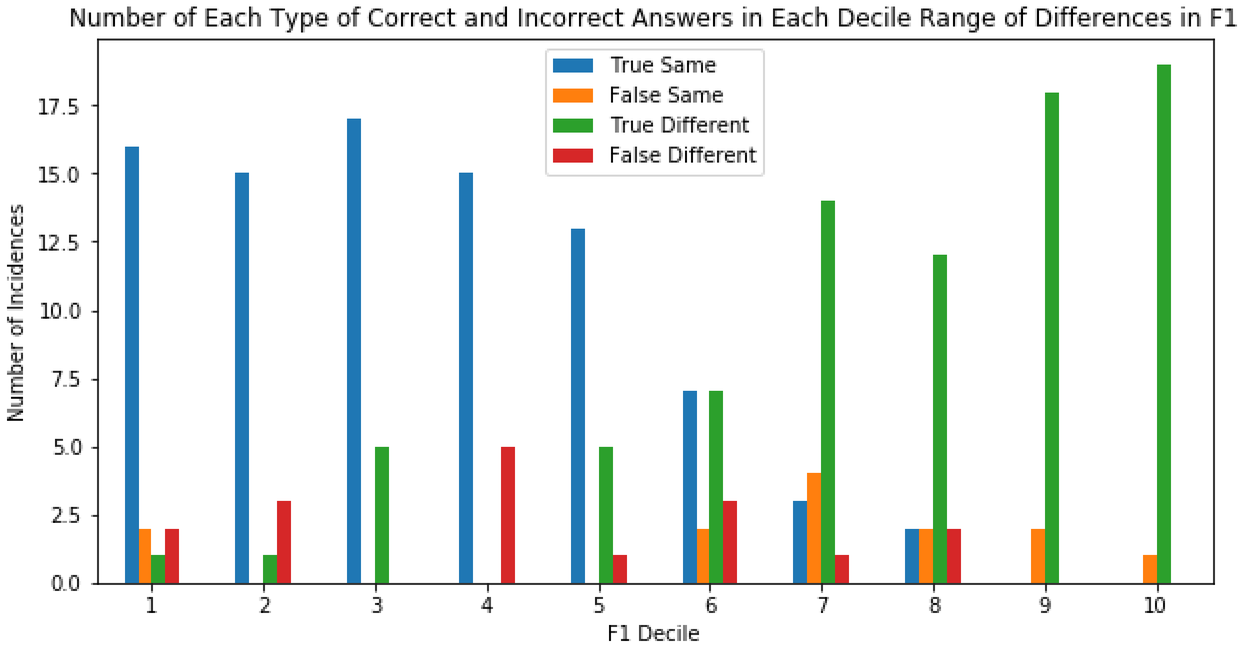
```
decile_counts['F3 Decile'] = pd.DataFrame(decile_counts['F3 Decile'])
decile_counts['F3 Decile']
```

Out[20]:

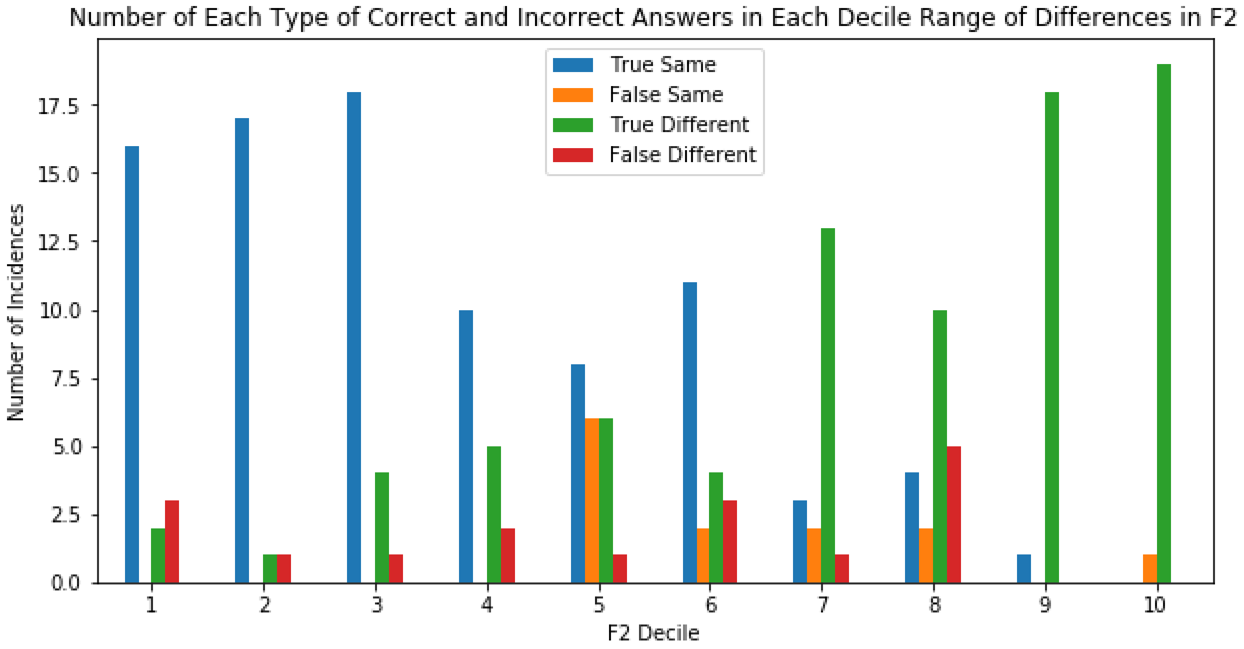
	1	2	3	4	5	6	7	8	9	10
True Same	16	15	7	11	12	10	4	4	3	6
False Same	0	1	4	1	0	0	3	2	1	1
True Different	4	2	5	9	3	10	14	10	16	9
False Different	0	2	5	0	3	0	0	3	0	4

In [21]:

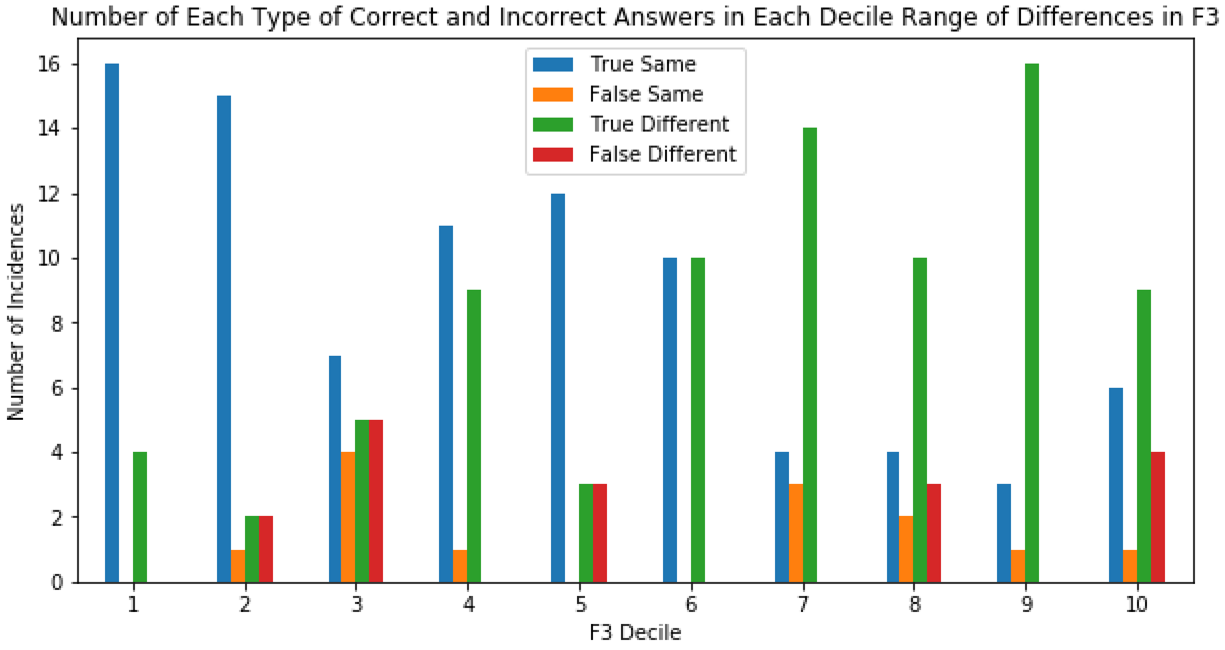
```
axs = [None,None,None]
ttl = 'Number of Each Type of Correct and Incorrect Answers in Each Decile Range of Differences in F'
titles = [ttl+i for i in ['1','2','3']]
for i in enumerate(decile_counts):
    axs[i[0]] = decile_counts[i[1]].T.plot.bar(title=titles[i[0]], figsize=(10,5))
    plt.xticks(rotation='horizontal')
    axs[i[0]].set_xlabel(i[1])
    axs[i[0]].set_ylabel('Number of Incidences')
    axs[i[0]].plot()
```



Number of Each Type of Correct and Incorrect Answers in Each Decile Range of Differences in F1



Number of Each Type of Correct and Incorrect Answers in Each Decile Range of Differences in F2



Number of Each Type of Correct and Incorrect Answers in Each Decile Range of Differences in F3