heart_disease

October 23, 2023

[ ]:
```
# IMPORTING NECESSARY PACKAGES
import warnings
import pandas as pd
import seaborn as sns
import matplotlib.pyplot as plt
import numpy as np
import statsmodels.api as sm
from statsmodels.stats.outliers_influence import variance_inflation_factor
from statsmodels.tools.tools import add_constant

from scipy.stats import chi2_contingency
from scipy.stats import ttest_ind

from sklearn.model_selection import train_test_split
from sklearn.metrics import classification_report

from imblearn.over_sampling import SMOTE
from imblearn.under_sampling import RandomUnderSampler
from sklearn.tree import DecisionTreeClassifier

warnings.filterwarnings("ignore", category=DeprecationWarning)
warnings.filterwarnings("ignore", category=FutureWarning)

from sklearn.tree import export_graphviz

# Specify the URL of the dataset
url = "https://raw.githubusercontent.com/AAI-500-Team/aai_500_dataset/main/
 ↪heart_2022_no_nans.csv"

# Use pandas to read the CSV file from the URL into a DataFrame
df = pd.read_csv(url)
```

0.1 Introduction

First, we're going to understand the given dataset.

[ ]:
```
display(df)
```

```
                State     Sex GeneralHealth  PhysicalHealthDays  \
0             Alabama  Female     Very good                 4.0
1             Alabama    Male     Very good                 0.0
2             Alabama    Male     Very good                 0.0
3             Alabama  Female          Fair                 5.0
4             Alabama  Female          Good                 3.0
…                 …     …            …                   …
246017  Virgin Islands    Male     Very good                 0.0
246018  Virgin Islands  Female          Fair                 0.0
246019  Virgin Islands    Male          Good                 0.0
246020  Virgin Islands  Female     Excellent                 2.0
246021  Virgin Islands    Male     Very good                 0.0

        MentalHealthDays                                    LastCheckupTime  \
0                    0.0  Within past year (anytime less than 12 months …
1                    0.0  Within past year (anytime less than 12 months …
2                    0.0  Within past year (anytime less than 12 months …
3                    0.0  Within past year (anytime less than 12 months …
4                   15.0  Within past year (anytime less than 12 months …
…                    …                                                 …
246017               0.0  Within past 2 years (1 year but less than 2 ye…
246018               7.0  Within past year (anytime less than 12 months …
246019              15.0  Within past year (anytime less than 12 months …
246020               2.0  Within past year (anytime less than 12 months …
246021               0.0  Within past year (anytime less than 12 months …

       PhysicalActivities  SleepHours            RemovedTeeth HadHeartAttack  \
0                     Yes         9.0            None of them             No
1                     Yes         6.0            None of them             No
2                      No         8.0  6 or more, but not all             No
3                     Yes         9.0            None of them             No
4                     Yes         5.0                  1 to 5             No
…                     …           …                      …            …
246017                Yes         6.0            None of them             No
246018                Yes         7.0            None of them             No
246019                Yes         7.0                  1 to 5             No
246020                Yes         7.0            None of them             No
246021                 No         5.0            None of them            Yes

        … HeightInMeters WeightInKilograms    BMI AlcoholDrinkers  \
0       …           1.60             71.67  27.99              No
1       …           1.78             95.25  30.13              No
2       …           1.85            108.86  31.66             Yes
3       …           1.70             90.72  31.32              No
4       …           1.55             79.38  33.07              No
…     …             …                …    …                …
246017  …           1.78            102.06  32.28             Yes
246018  …           1.93             90.72  24.34              No
```

```
246019  …           1.68             83.91  29.86             Yes
246020  …           1.70             83.01  28.66              No
246021  …           1.83            108.86  32.55              No

       HIVTesting FluVaxLast12 PneumoVaxEver  \
0              No          Yes           Yes
1              No          Yes           Yes
2              No           No           Yes
3              No          Yes           Yes
4              No          Yes           Yes
…             …           …             …
246017         No           No            No
246018         No           No            No
246019        Yes          Yes           Yes
246020        Yes          Yes            No
246021        Yes          Yes           Yes

                                      TetanusLast10Tdap HighRiskLastYear  \
0                                    Yes, received Tdap               No
1       Yes, received tetanus shot but not sure what type               No
2       No, did not receive any tetanus shot in the pa…              No
3       No, did not receive any tetanus shot in the pa…              No
4       No, did not receive any tetanus shot in the pa…              No
…                                                    …             …
246017  Yes, received tetanus shot but not sure what type               No
246018  No, did not receive any tetanus shot in the pa…              No
246019  Yes, received tetanus shot but not sure what type               No
246020  Yes, received tetanus shot but not sure what type               No
246021  No, did not receive any tetanus shot in the pa…              No

       CovidPos
0            No
1            No
2           Yes
3           Yes
4            No
…           …
246017       No
246018      Yes
246019      Yes
246020       No
246021      Yes

[246022 rows x 40 columns]
```

[ ]:
```
# Use the describe method to find descriptive statistics (including the 5-summary stats)
```

```
df.describe()
```

[ ]:

	PhysicalHealthDays	MentalHealthDays	SleepHours	HeightInMeters	\
count	246022.000000	246022.000000	246022.000000	246022.000000	
mean	4.119026	4.167140	7.021331	1.705150	
std	8.405844	8.102687	1.440681	0.106654	
min	0.000000	0.000000	1.000000	0.910000	
25%	0.000000	0.000000	6.000000	1.630000	
50%	0.000000	0.000000	7.000000	1.700000	
75%	3.000000	4.000000	8.000000	1.780000	
max	30.000000	30.000000	24.000000	2.410000	

	WeightInKilograms	BMI
count	246022.000000	246022.000000
mean	83.615179	28.668136
std	21.323156	6.513973
min	28.120000	12.020000
25%	68.040000	24.270000
50%	81.650000	27.460000
75%	95.250000	31.890000
max	292.570000	97.650000

0.1.1 Conclusion:

The dataset has **40** columns, with numerical and categorical data. Most of the columns are categorical, with **5** numerical columns.

```
rows, columns = df.shape
print(f"Number of rows: {rows}, Number of columns: {columns}")
```

[ ]:

```
Number of rows: 246022, Number of columns: 40
```

0.2 Data Cleaning / Preparation

Let's inspect any missing, incomplete data.

```
print(f"Number of duplicates: {df.duplicated().sum()}")
print(f"Number of missing values: {df.isnull().sum().sum()}")
```

[ ]:

```
Number of duplicates: 9
Number of missing values: 0
Number of missing values: 0
```

There is no missing values, but. there are duplicates. Let's drop them. We're also going to drop BMI, since it is a function of height and weight, and there is multicollinearity. Lastly, we're going to drop the features that are relevant to our research question.

```
# Drop duplicated
df.drop_duplicates(inplace=True)
```

[ ]:

```
# Drop Unrelated variables and BMI for multicollinearity with Height and Weight
df = df.drop(columns=['State', 'LastCheckupTime','BMI'])
```

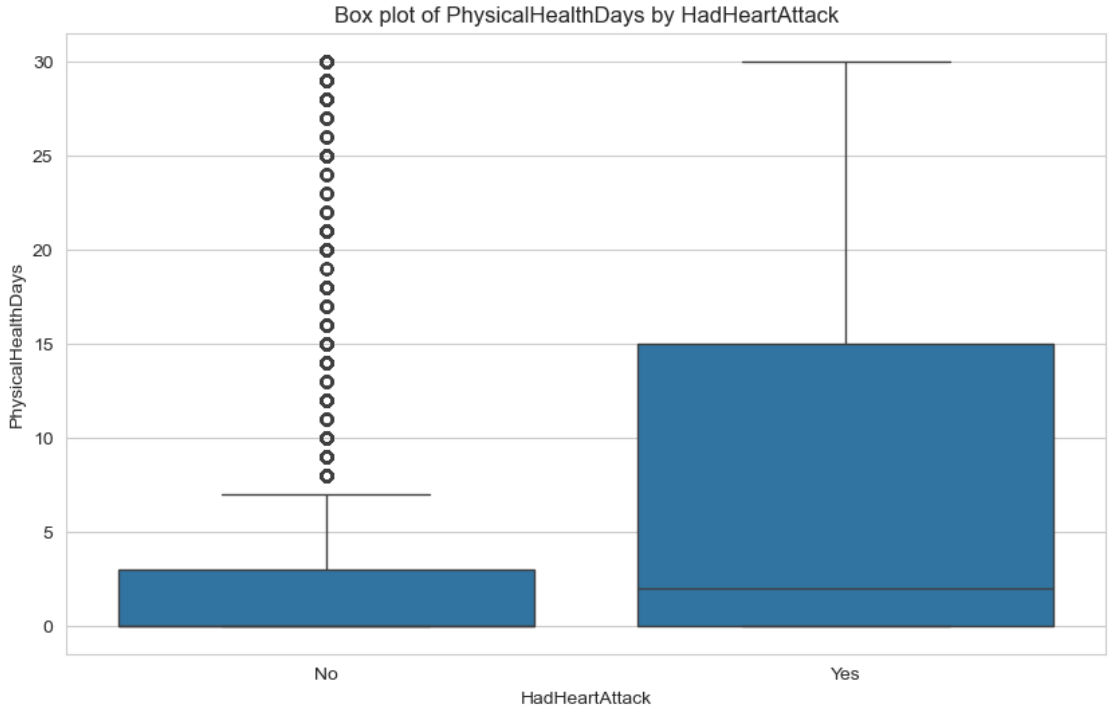
[ ]:
```
# Create lists of numerical variables, categorical variables and target␣
 ↪variable for future use
numerical_vars = ['PhysicalHealthDays', 'MentalHealthDays', 'SleepHours',␣
 ↪'HeightInMeters', 'WeightInKilograms']
categorical_includes_taget = ['Sex', 'GeneralHealth', 'PhysicalActivities',␣
 ↪'RemovedTeeth', 'HadAngina',
       'HadStroke', 'HadAsthma', 'HadSkinCancer', 'HadCOPD',
       'HadDepressiveDisorder', 'HadKidneyDisease', 'HadArthritis',
       'HadDiabetes', 'DeafOrHardOfHearing', 'BlindOrVisionDifficulty',
       'DifficultyConcentrating', 'DifficultyWalking',
       'DifficultyDressingBathing', 'DifficultyErrands', 'SmokerStatus',
       'ECigaretteUsage', 'ChestScan', 'RaceEthnicityCategory', 'AgeCategory',␣
 ↪'AlcoholDrinkers',
       'HIVTesting', 'FluVaxLast12', 'PneumoVaxEver', 'TetanusLast10Tdap',
       'HighRiskLastYear', 'CovidPos','HadHeartAttack']

categorical_vars = ['Sex', 'GeneralHealth', 'PhysicalActivities',␣
 ↪'RemovedTeeth', 'HadAngina',
       'HadStroke', 'HadAsthma', 'HadSkinCancer', 'HadCOPD',
       'HadDepressiveDisorder', 'HadKidneyDisease', 'HadArthritis',
       'HadDiabetes', 'DeafOrHardOfHearing', 'BlindOrVisionDifficulty',
       'DifficultyConcentrating', 'DifficultyWalking',
       'DifficultyDressingBathing', 'DifficultyErrands', 'SmokerStatus',
       'ECigaretteUsage', 'ChestScan', 'RaceEthnicityCategory', 'AgeCategory',␣
 ↪'AlcoholDrinkers',
       'HIVTesting', 'FluVaxLast12', 'PneumoVaxEver', 'TetanusLast10Tdap',
       'HighRiskLastYear', 'CovidPos']
target = 'HadHeartAttack'

print(f"Numerical variables: {numerical_vars}")
print(f"Catergorical variables: {categorical_vars}")
print(f"Target variable: {target}")
```

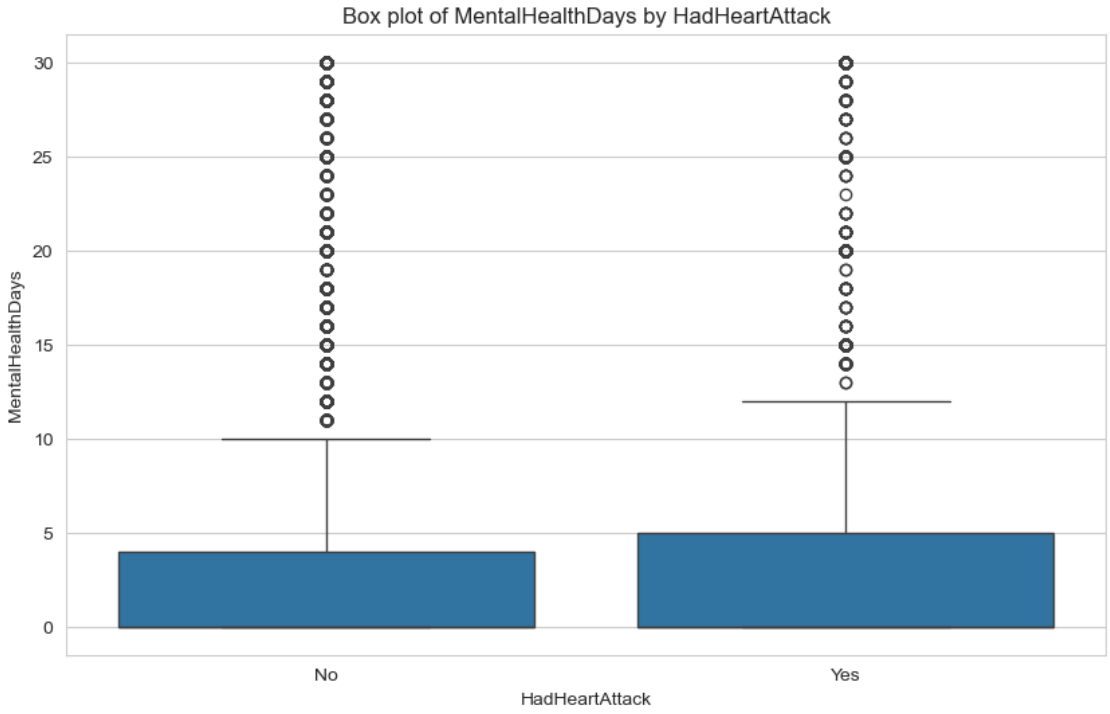
```
Numerical variables: ['PhysicalHealthDays', 'MentalHealthDays', 'SleepHours',
'HeightInMeters', 'WeightInKilograms']
Catergorical variables: ['Sex', 'GeneralHealth', 'PhysicalActivities',
'RemovedTeeth', 'HadAngina', 'HadStroke', 'HadAsthma', 'HadSkinCancer',
'HadCOPD', 'HadDepressiveDisorder', 'HadKidneyDisease', 'HadArthritis',
'HadDiabetes', 'DeafOrHardOfHearing', 'BlindOrVisionDifficulty',
'DifficultyConcentrating', 'DifficultyWalking', 'DifficultyDressingBathing',
'DifficultyErrands', 'SmokerStatus', 'ECigaretteUsage', 'ChestScan',
'RaceEthnicityCategory', 'AgeCategory', 'AlcoholDrinkers', 'HIVTesting',
'FluVaxLast12', 'PneumoVaxEver', 'TetanusLast10Tdap', 'HighRiskLastYear',
'CovidPos']
```

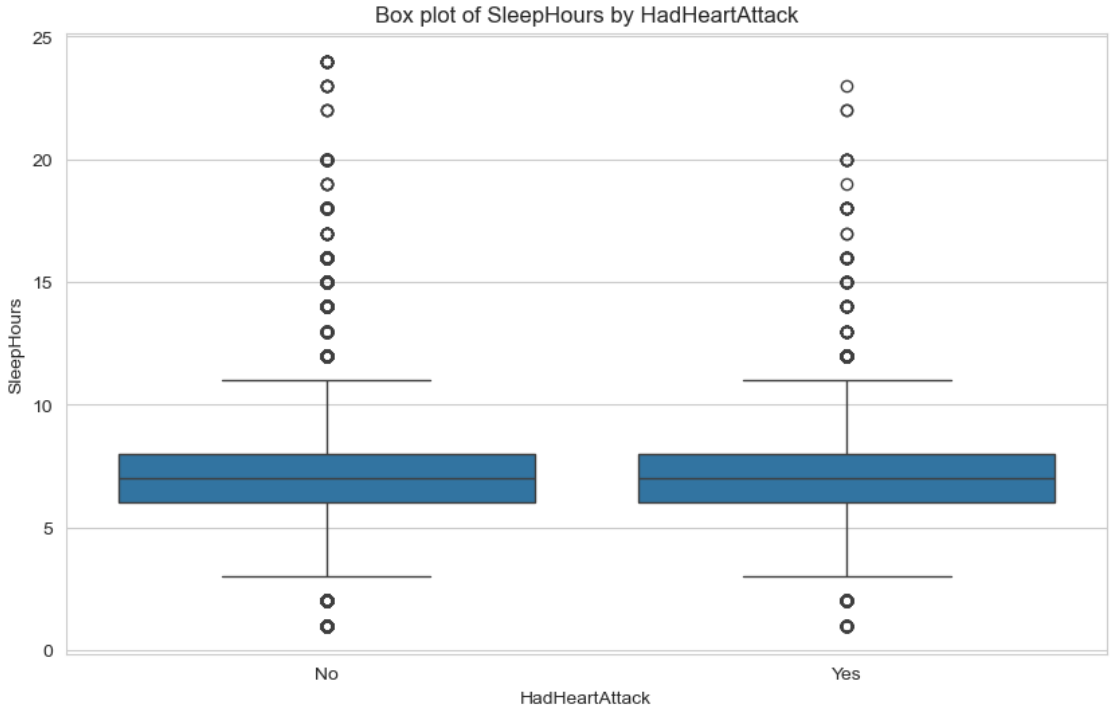
```
Target variable: HadHeartAttack
```

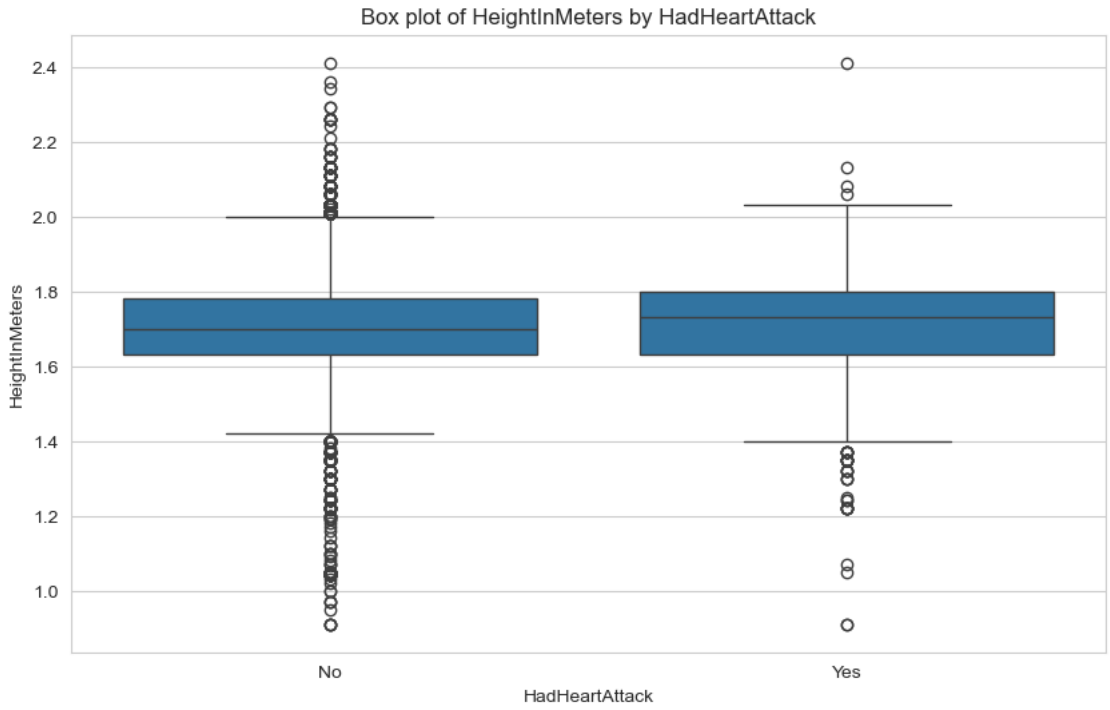
0.3 Exploratory Data Analysis

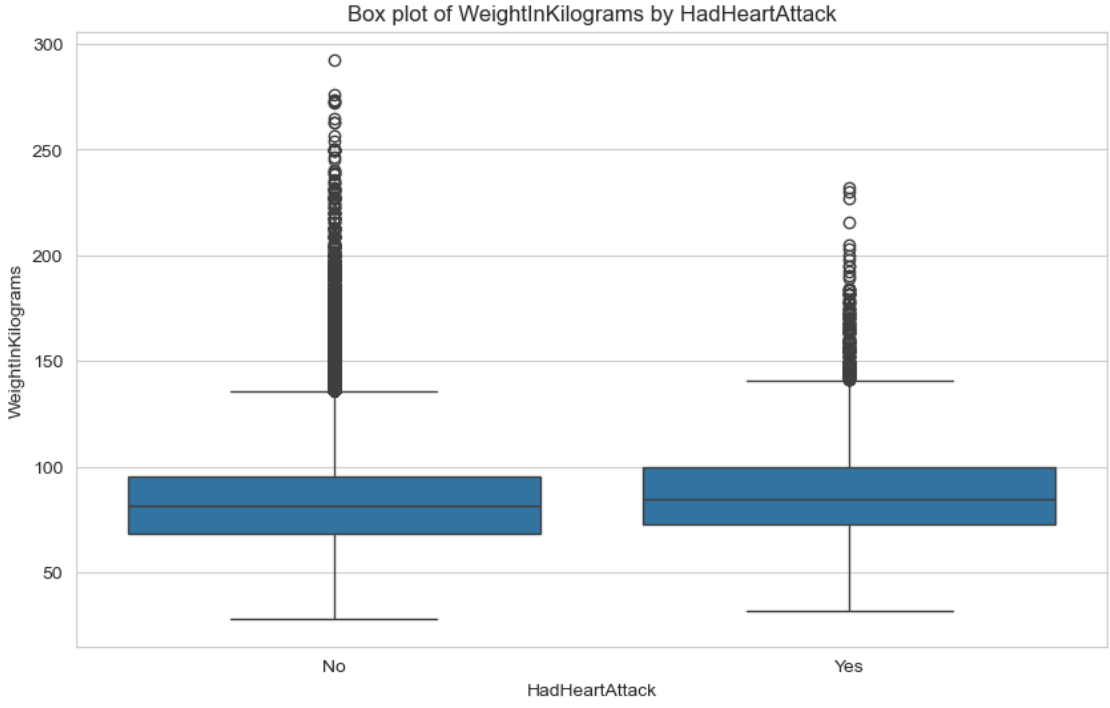
[ ]:
```python
# Create box plots, histograms, and violin plots for numerical data
sns.set_style("whitegrid")
# Box Plots
for var in numerical_vars:
    plt.figure(figsize=(10, 6))
    sns.boxplot(x=target, y=var, data=df)
    plt.title(f"Box plot of {var} by {target}")
    plt.show()
# Histograms
for var in numerical_vars:
    plt.figure(figsize=(10, 6))
    sns.histplot(df, x=var, hue=target, element="step", stat="density",␣
 ↪common_norm=False)
    plt.title(f"Histogram of {var} by {target}")
    plt.show()
# Violin Plots
for var in numerical_vars:
    plt.figure(figsize=(10, 6))
    sns.violinplot(x=target, y=var, data=df)
    plt.title(f"Violin plot of {var} by {target}")
    plt.show()
```

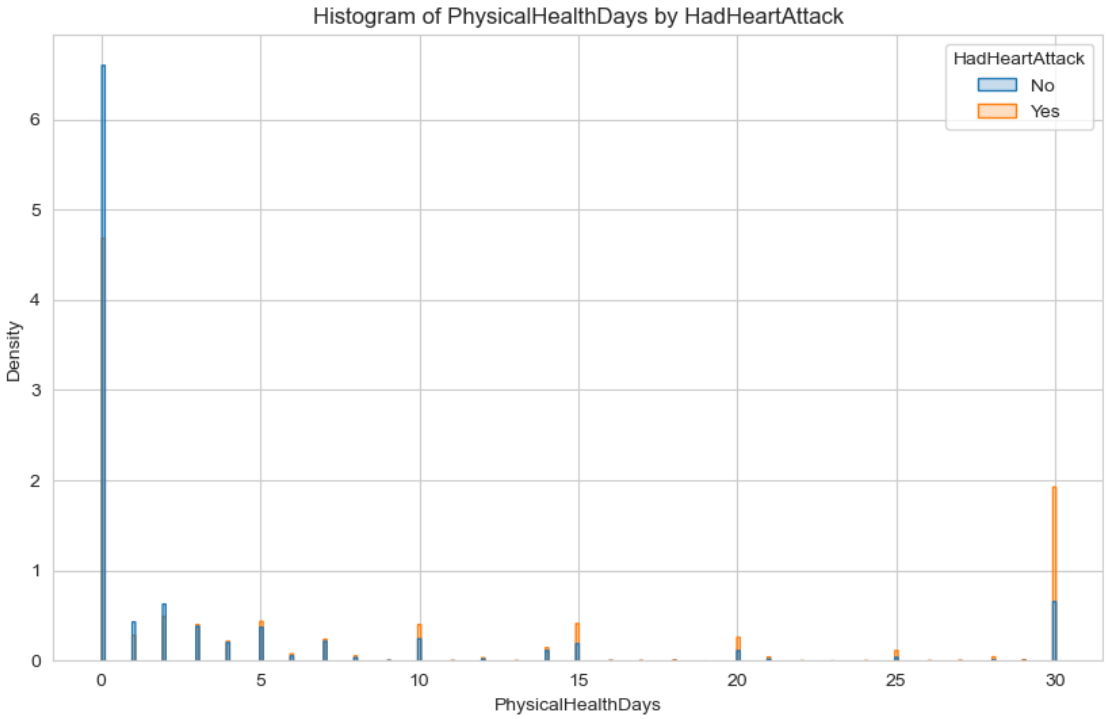


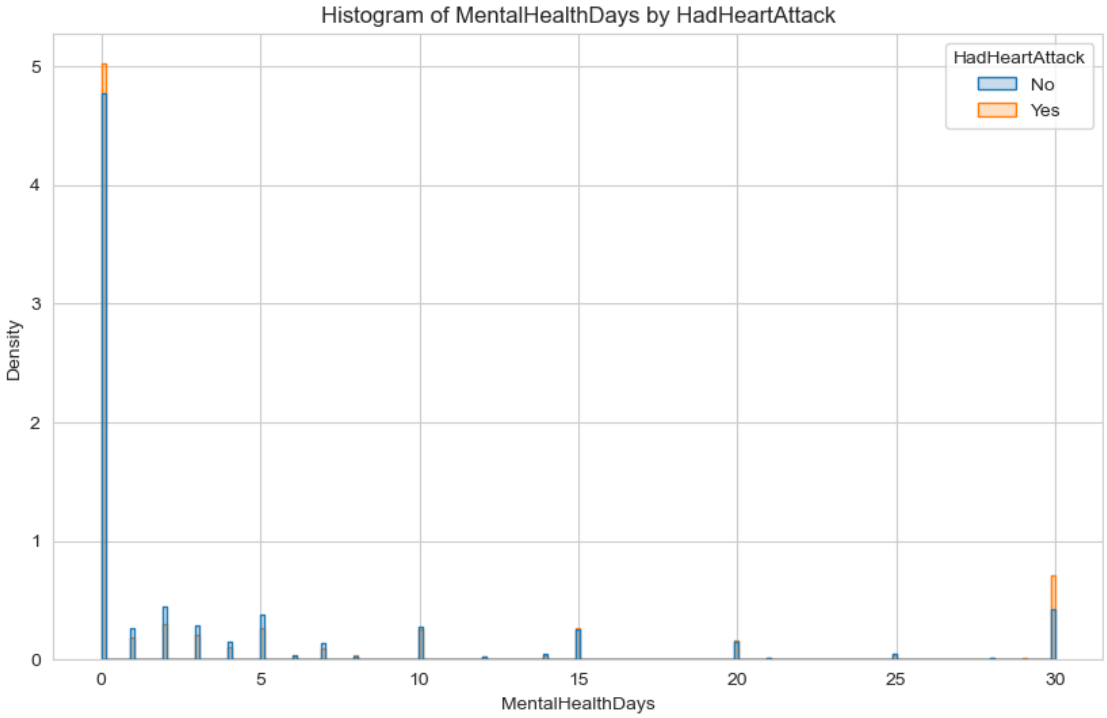

Box plot of MentalHealthDays by HadHeartAttack
MentalHealthDays
30
25
20
15
10
5
0
No
Yes
HadHeartAttack

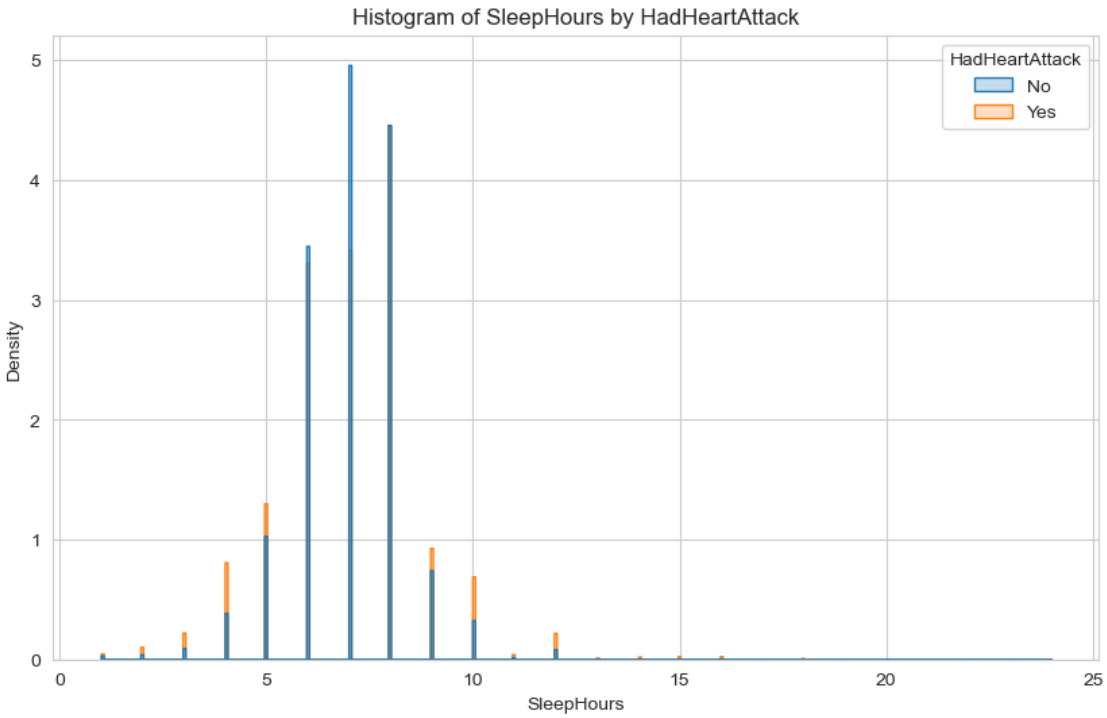

Box plot of SleepHours by HadHeartAttack
SleepHours
25
20
15
10
5
0
No
Yes
HadHeartAttack

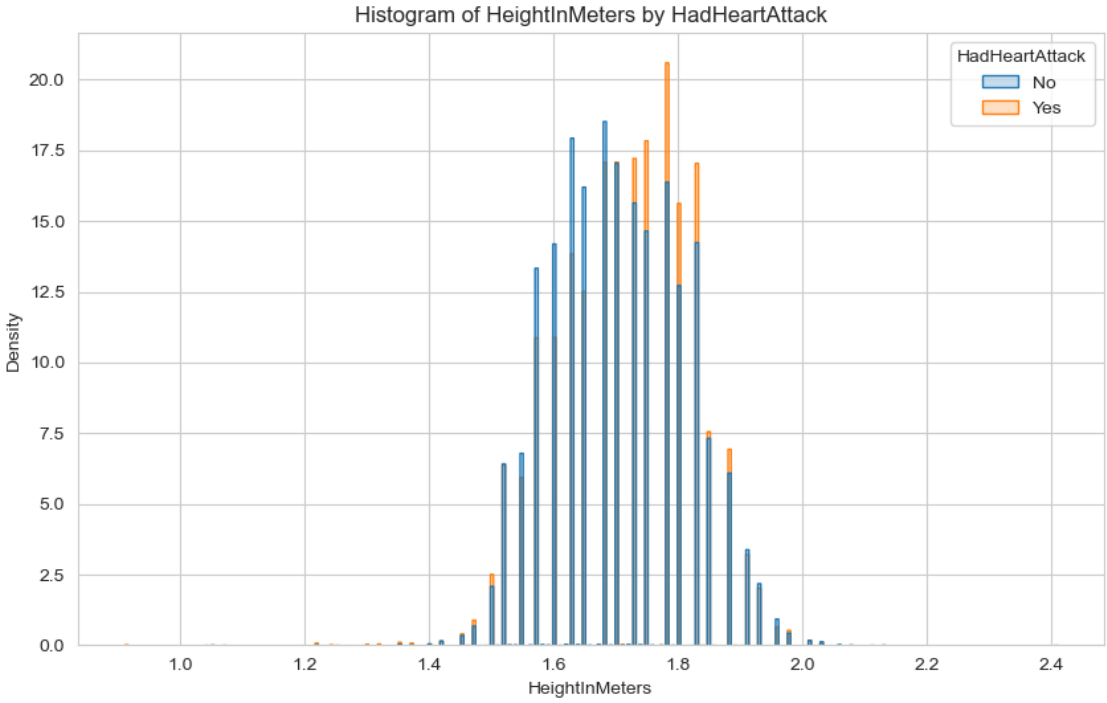

Box plot of HeightInMeters by HadHeartAttack
HeightInMeters
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
No
Yes
HadHeartAttack

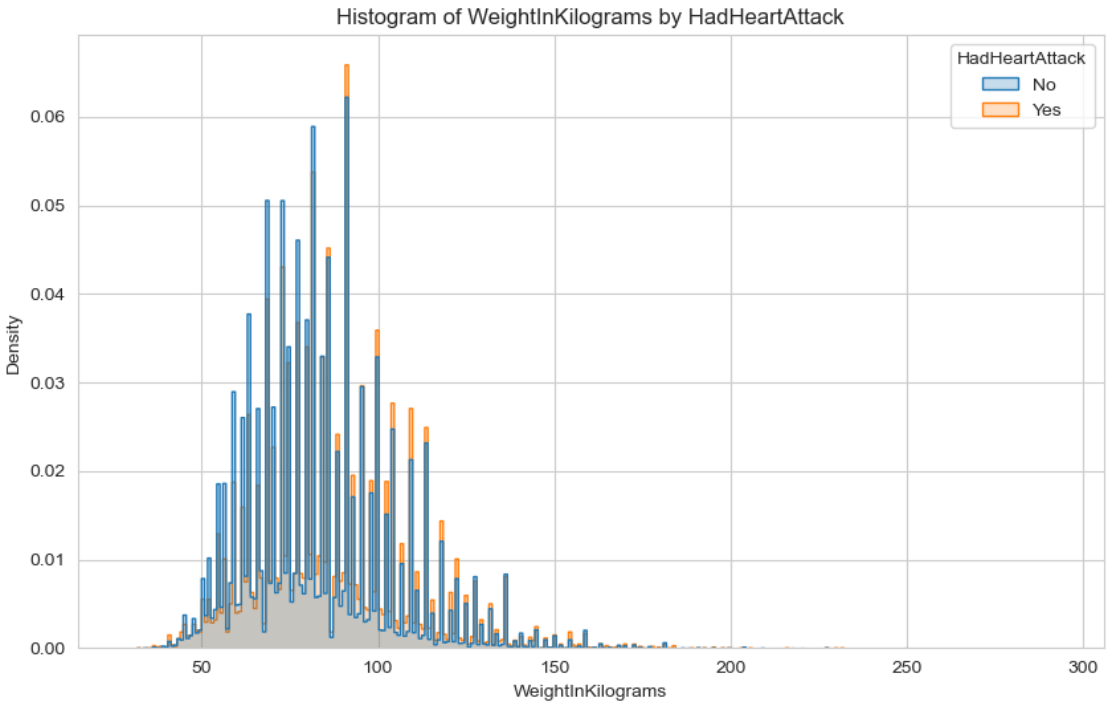

Box plot of WeightInKilograms by HadHeartAttack
WeightInKilograms
300
250
200
150
100
50
No
Yes
HadHeartAttack

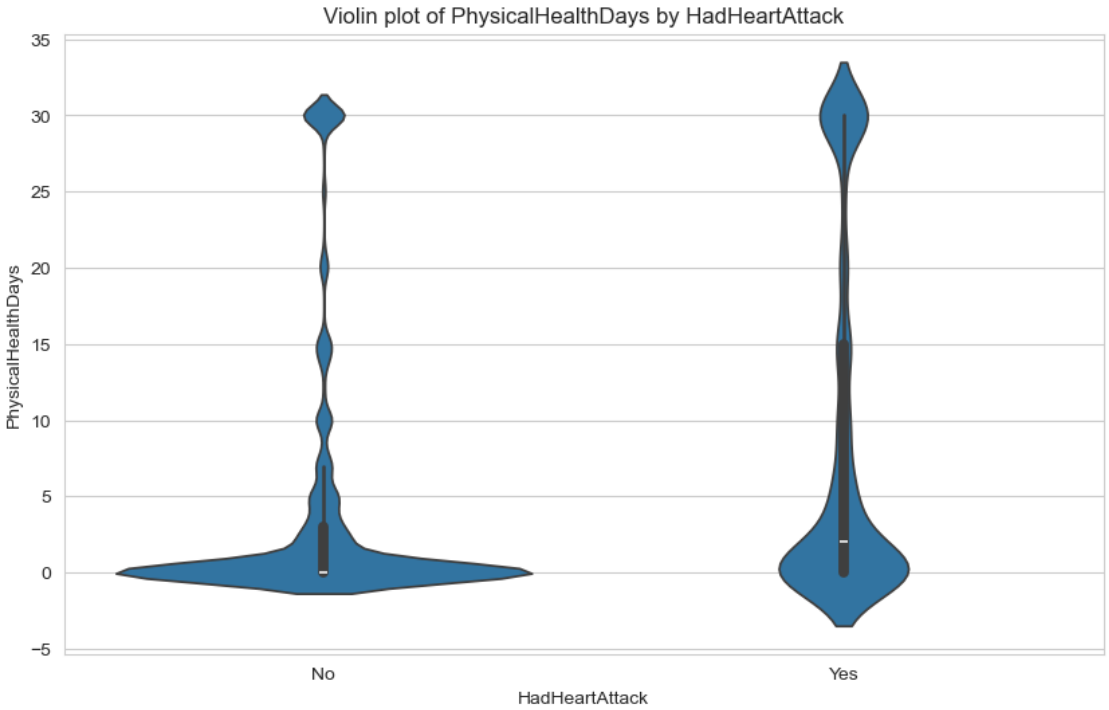

Histogram of PhysicalHealthDays by HadHeartAttack
HadHeartAttack
No
Yes
Density
0
1
2
3
4
5
6
0
5
10
15
20
25
30
PhysicalHealthDays

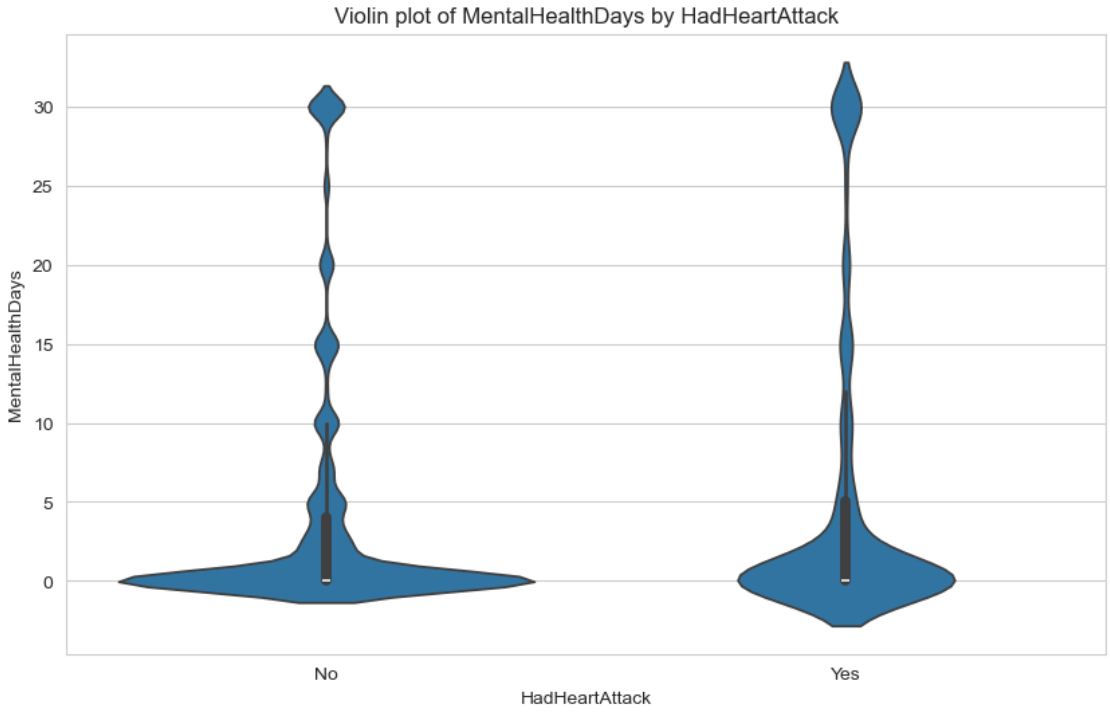

Histogram of MentalHealthDays by HadHeartAttack
HadHeartAttack
No
Yes
Density
0
1
2
3
4
5
0
5
10
15
20
25
30
MentalHealthDays

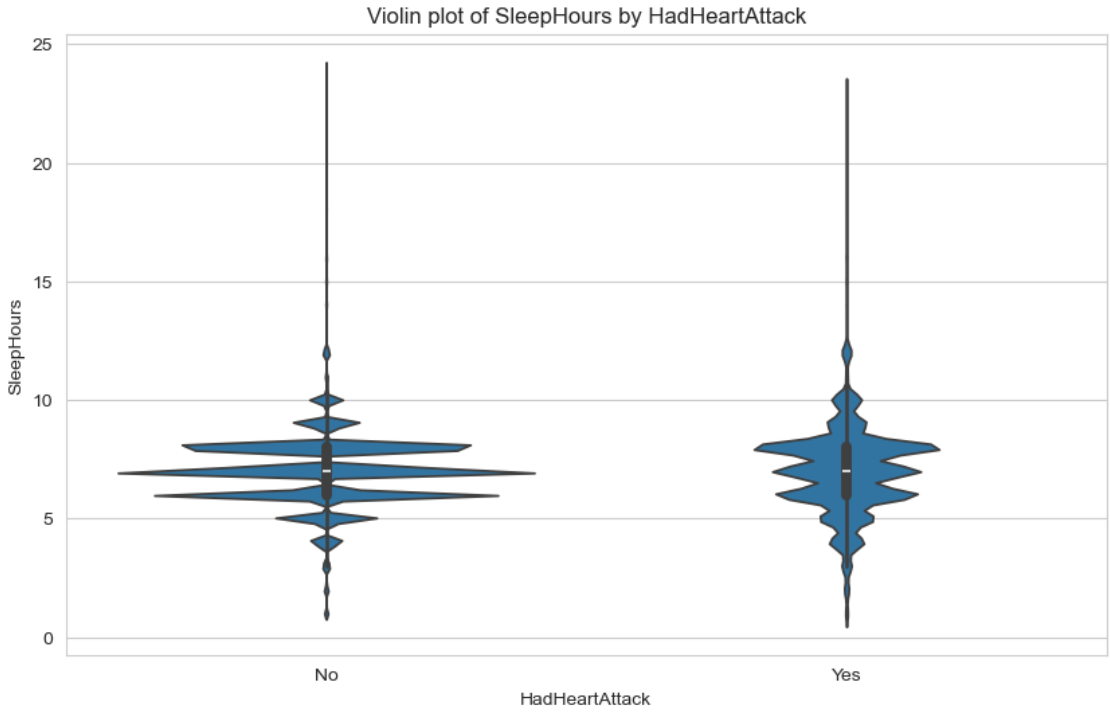

Histogram of SleepHours by HadHeartAttack
HadHeartAttack
No
Yes
Density
SleepHours
0
1
2
3
4
5
0
5
10
15
20
25

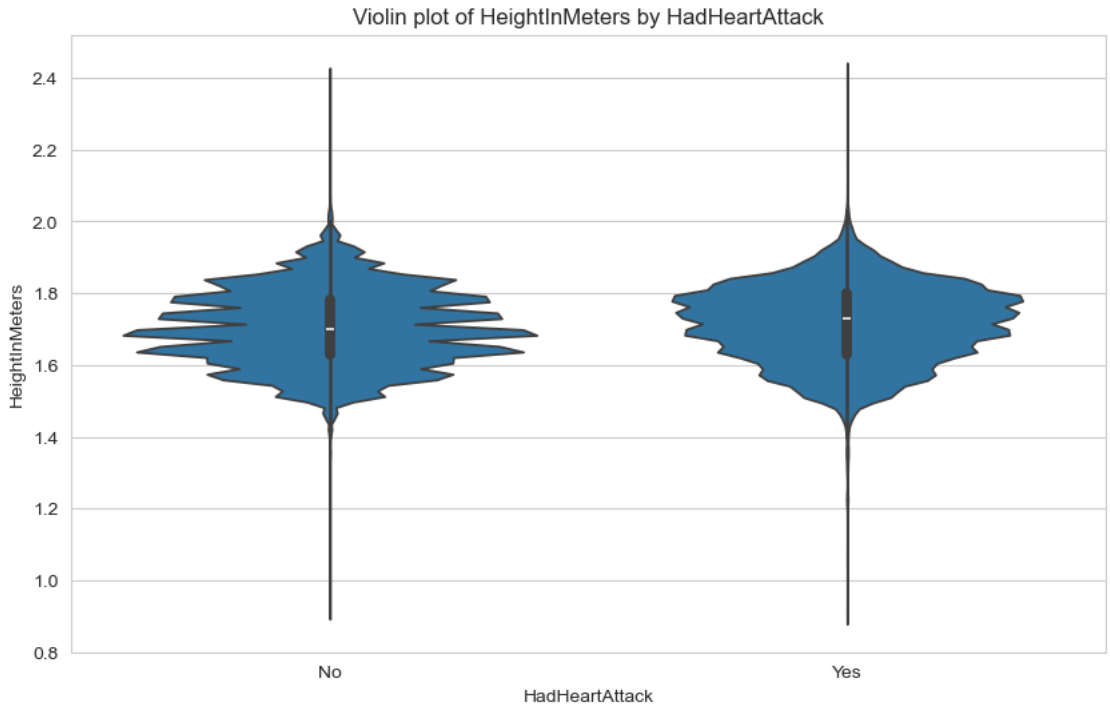

Histogram of HeightInMeters by HadHeartAttack
HadHeartAttack
No
Yes
Density
HeightInMeters
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

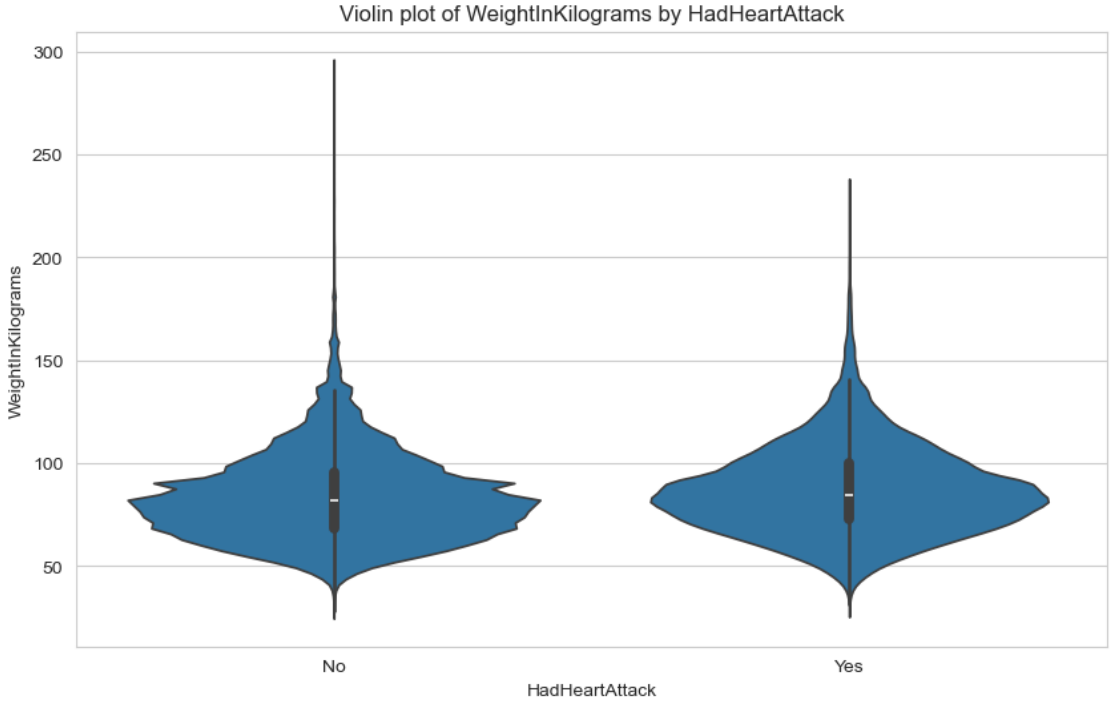

Histogram of WeightInKilograms by HadHeartAttack
HadHeartAttack
No
Yes
Density
0.06
0.05
0.04
0.03
0.02
0.01
0.00
50
100
150
200
250
300
WeightInKilograms


Violin plot of PhysicalHealthDays by HadHeartAttack
PhysicalHealthDays
35
30
25
20
15
10
5
0
−5
No
Yes
HadHeartAttack


Violin plot of MentalHealthDays by HadHeartAttack
MentalHealthDays
30
25
20
15
10
5
0
No
Yes
HadHeartAttack

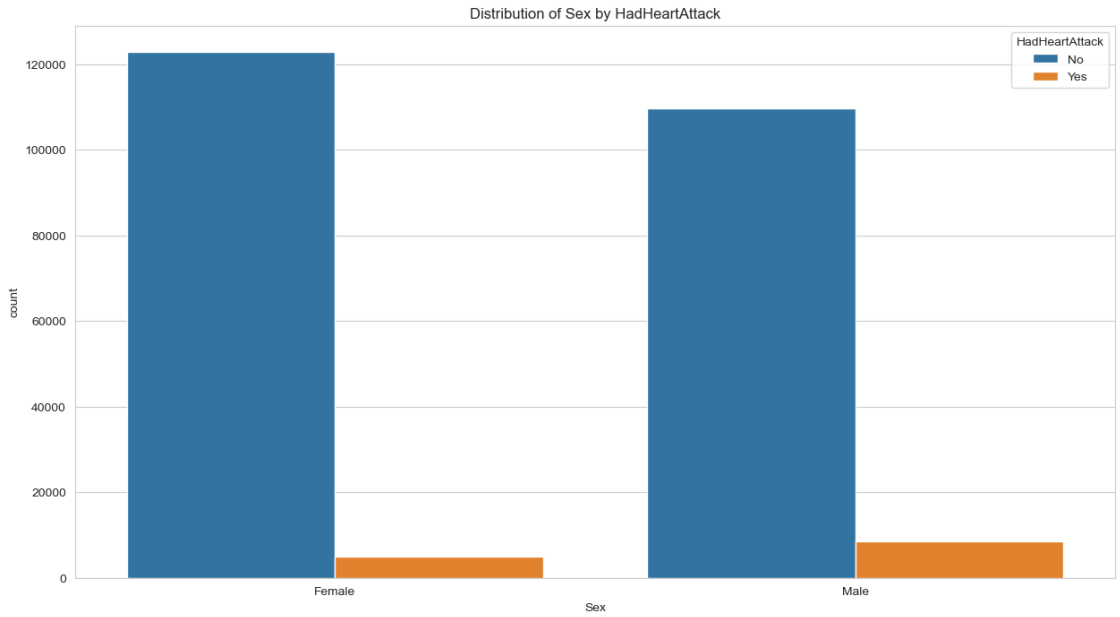

Violin plot of SleepHours by HadHeartAttack
SleepHours
25
20
15
10
5
0
No
Yes
HadHeartAttack


Violin plot of HeightInMeters by HadHeartAttack
HeightInMeters
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
No
Yes
HadHeartAttack


Violin plot of WeightInKilograms by HadHeartAttack
WeightInKilograms
300
250
200
150
100
50
No
Yes
HadHeartAttack

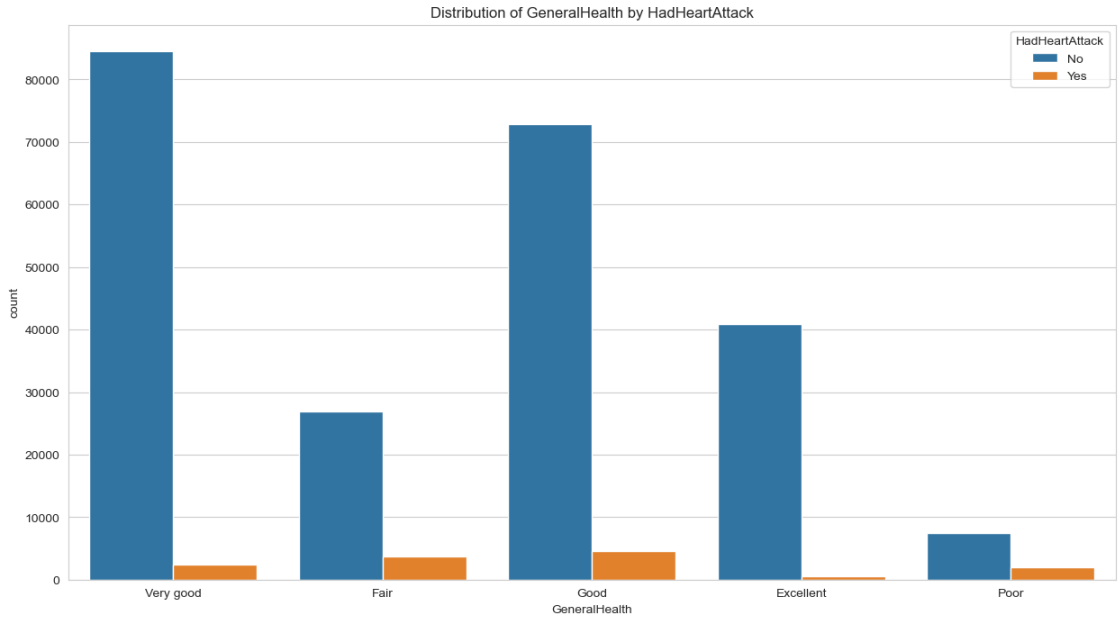
[ ]:
```
# Dataframe to store result of Chi2 test
results_df_cat = pd.DataFrame(columns=['Feature', 'Chi2', 'P-Value'])

# Copy to keep the original dataframe
cat_df = df.copy()
cat_df["HadHeartAttack"] = cat_df["HadHeartAttack"].astype('category')

# For each categorical ver perform Chi2 test
# Print results, create bar plot
for var in categorical_vars:
  cat_df[var] = cat_df[var].astype('category')
  contingency_table = pd.crosstab(cat_df[var], cat_df["HadHeartAttack"])
  chi2, p, _, _ = chi2_contingency(contingency_table)
  print(contingency_table)
  print(f"Chi-Squared Test for {var} and {target}")
  print(f"Chi2 value = {chi2}, p-value = {p}\n")
  # Add the results to the DataFrame
  new_row = {'Feature': var, 'Chi2': chi2, 'P-Value': p}
  results_df_cat = pd.concat([results_df_cat, pd.DataFrame(new_row,␣
 ↪index=[0])], ignore_index=True)
  # Bar Plots
  plt.figure(figsize=(15, 8))
  sns.countplot(data=df, x=var, hue=target)
  plt.title(f"Distribution of {var} by {target}")
  plt.show()
```

```
HadHeartAttack      No   Yes
Sex
Female          122874  4932
Male            109704  8503
Chi-Squared Test for Sex and HadHeartAttack
Chi2 value = 1321.7634745274654, p-value = 2.1073833823909984e-289
```

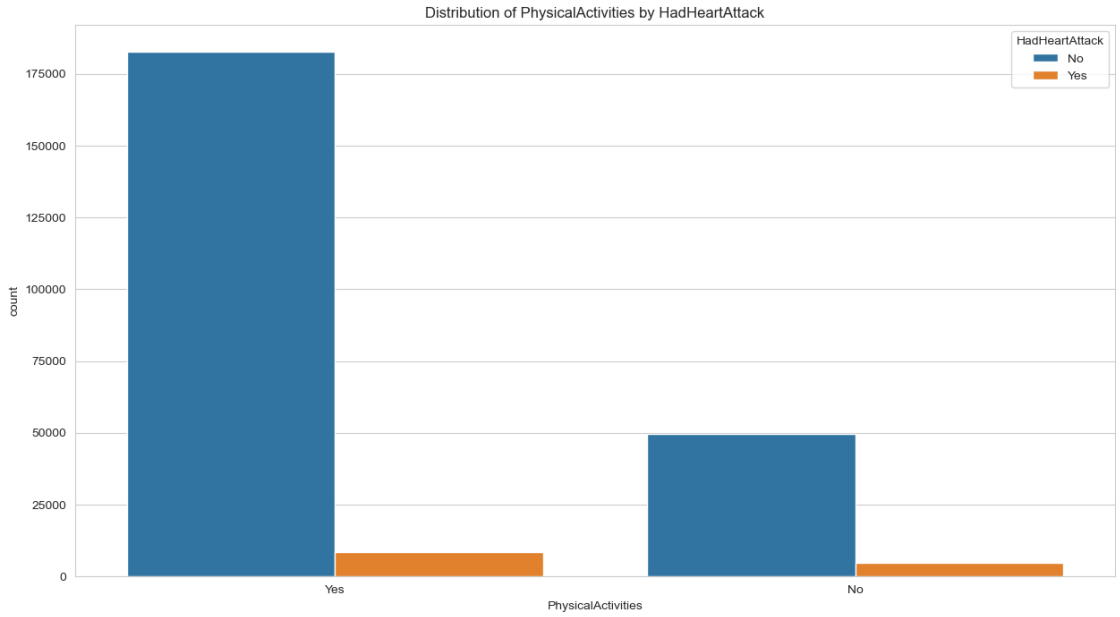


HadHeartAttack	No	Yes
GeneralHealth		
Excellent	40928	594
Fair	26910	3748
Good	72808	4599
Poor	7406	2024
Very good	84526	2470

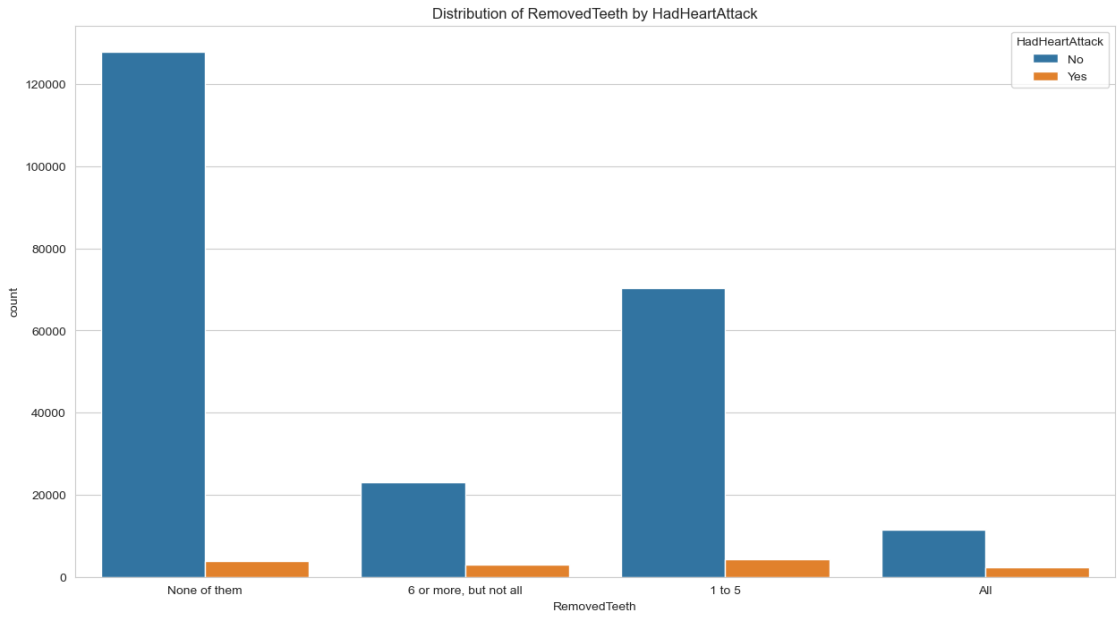
Chi-Squared Test for GeneralHealth and HadHeartAttack
Chi2 value = 9893.539444125969, p-value = 0.0



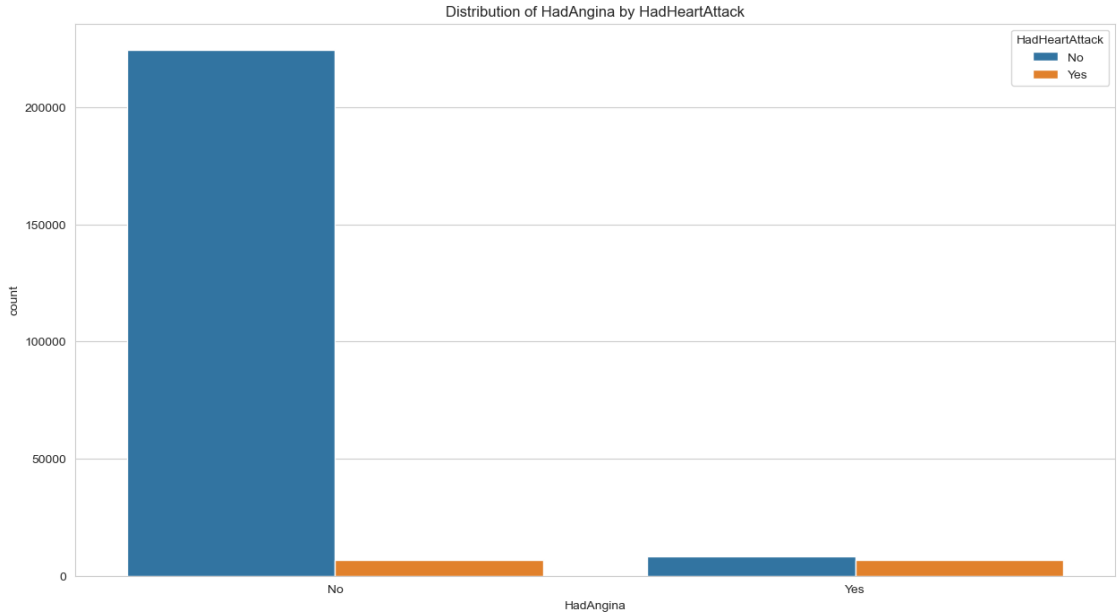

```
HadHeartAttack          No   Yes
PhysicalActivities
No                   49782  4921
Yes                 182796  8514
Chi-Squared Test for PhysicalActivities and HadHeartAttack
Chi2 value = 1701.5150212822982, p-value = 0.0
```



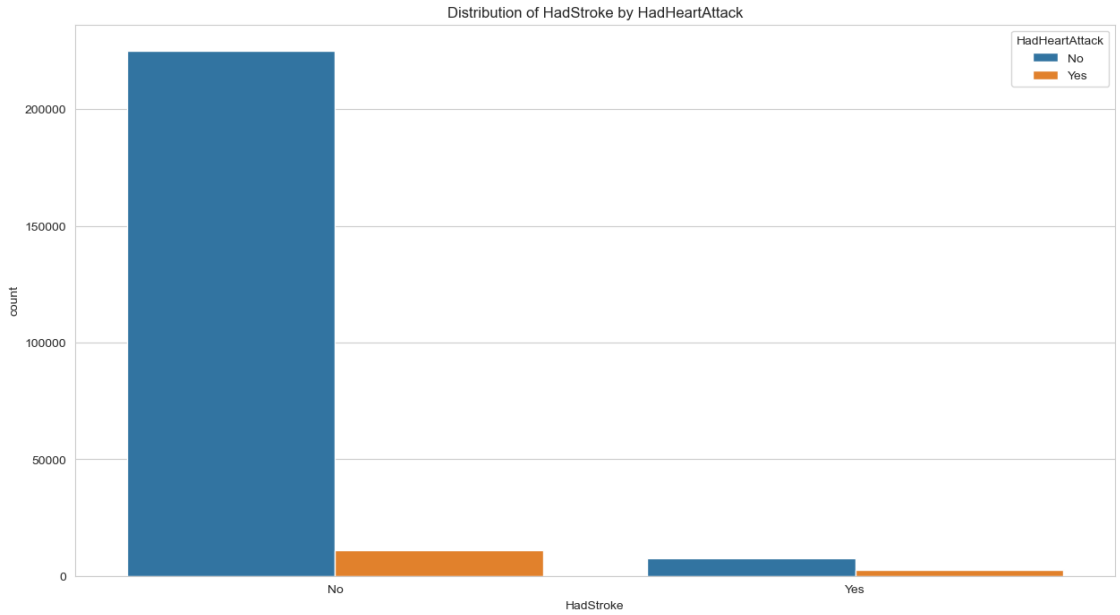
```
HadHeartAttack              No   Yes
RemovedTeeth
1 to 5                   70342  4359
6 or more, but not all   22944  3005
All                      11476  2302
None of them            127816  3769
Chi-Squared Test for RemovedTeeth and HadHeartAttack
Chi2 value = 6996.544849252672, p-value = 0.0
```



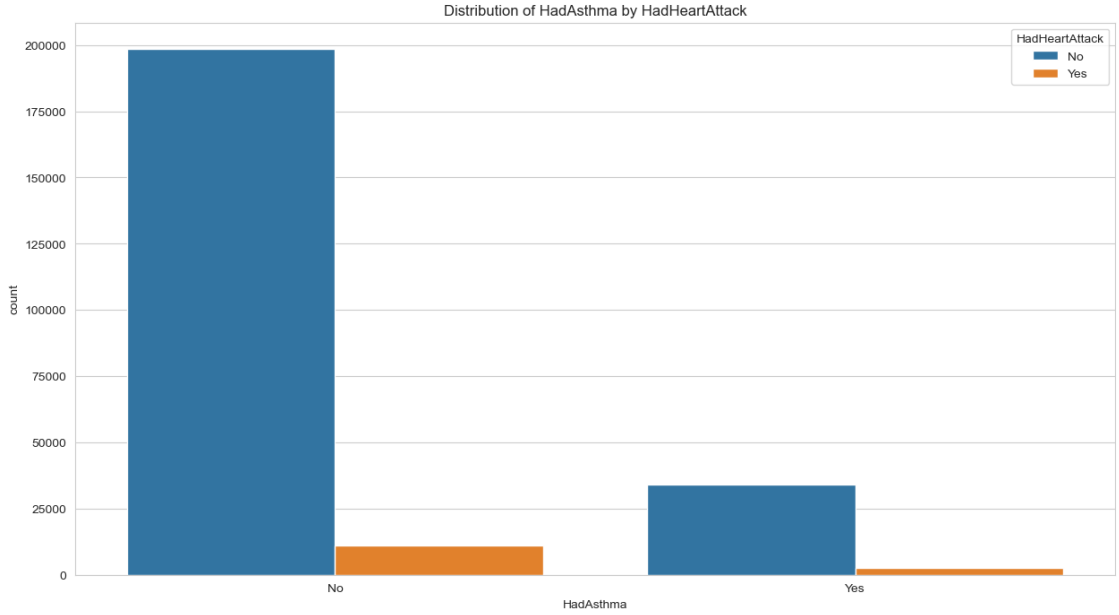

```
HadHeartAttack      No   Yes
HadAngina
No              224397  6663
Yes               8181  6772
Chi-Squared Test for HadAngina and HadHeartAttack
Chi2 value = 48906.22074894924, p-value = 0.0
```



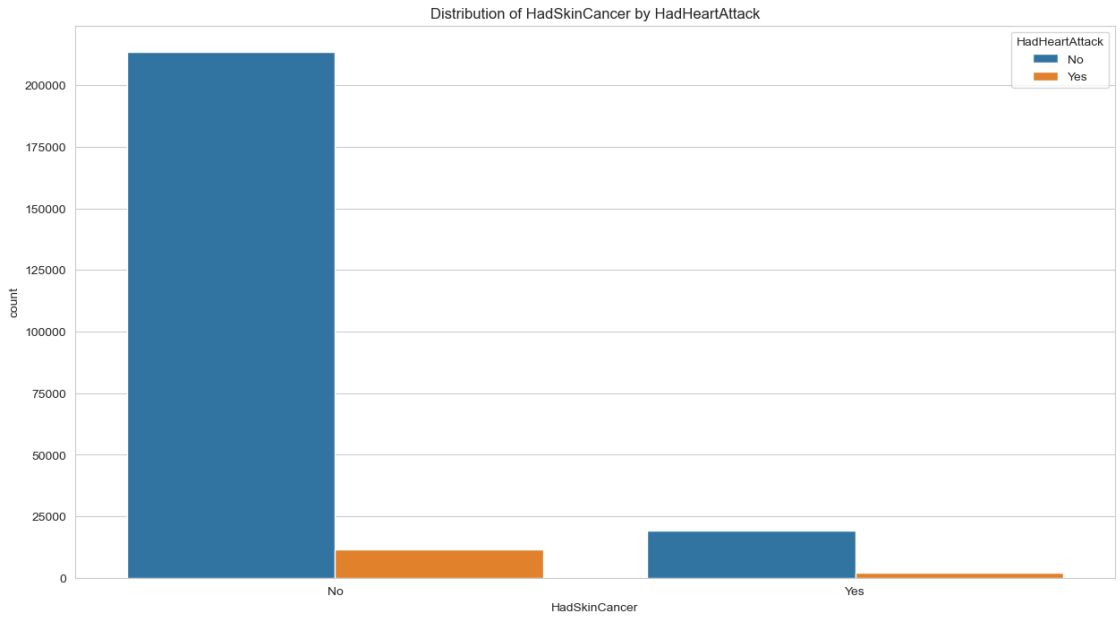

```
HadHeartAttack      No    Yes
HadStroke
No              224985  10917
Yes               7593   2518
Chi-Squared Test for HadStroke and HadHeartAttack
Chi2 value = 7716.361887180489, p-value = 0.0
```



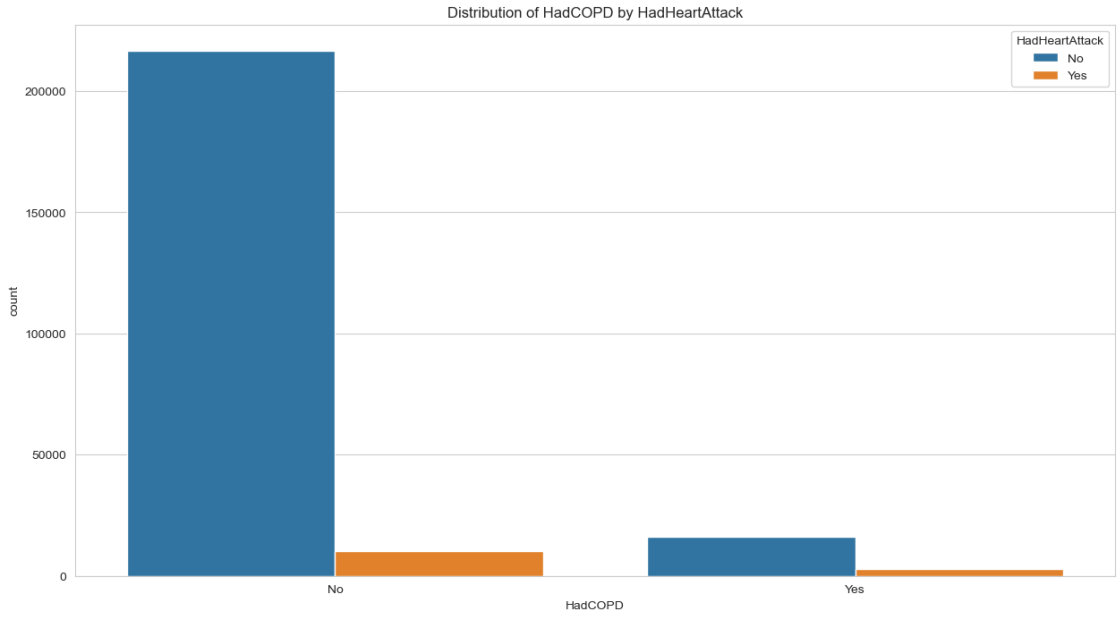
```
HadHeartAttack      No    Yes
HadAsthma
No              198518  10968
Yes              34060   2467
Chi-Squared Test for HadAsthma and HadHeartAttack
Chi2 value = 138.57317541492714, p-value = 5.460574633393451e-32
```



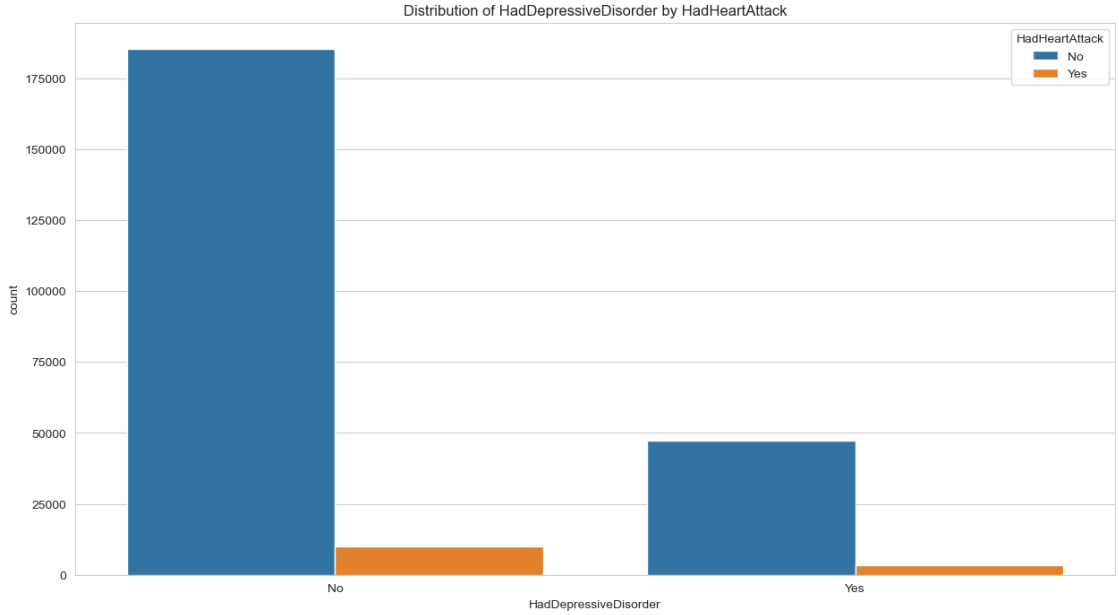

```
HadHeartAttack      No    Yes
HadSkinCancer
No              213479  11515
Yes              19099   1920
Chi-Squared Test for HadSkinCancer and HadHeartAttack
Chi2 value = 599.9377487258555, p-value = 1.7271862867830458e-132
```



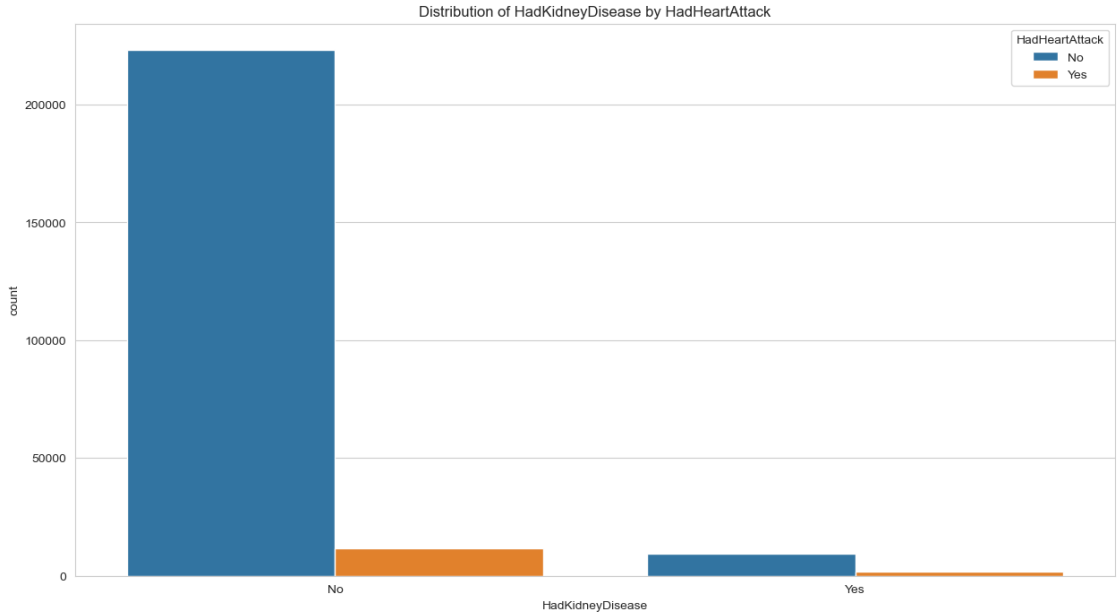

```
HadHeartAttack      No    Yes
HadCOPD
No              216609  10410
Yes              15969   3025
Chi-Squared Test for HadCOPD and HadHeartAttack
Chi2 value = 4363.963228084566, p-value = 0.0
```



```
HadHeartAttack             No    Yes
HadDepressiveDisorder
No                     185258  10135
Yes                     47320   3300
Chi-Squared Test for HadDepressiveDisorder and HadHeartAttack
Chi2 value = 137.94235523398163, p-value = 7.502329516886957e-32
```

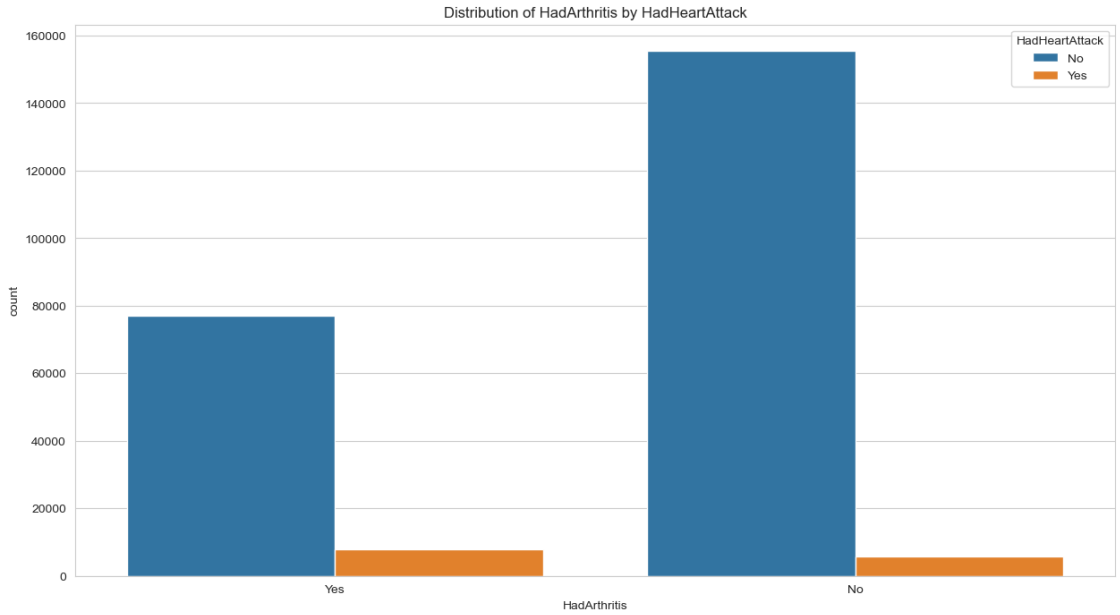



```
HadHeartAttack        No    Yes
HadKidneyDisease
No                223189  11540
Yes                 9389   1895
Chi-Squared Test for HadKidneyDisease and HadHeartAttack
Chi2 value = 2939.5670891414943, p-value = 0.0
```

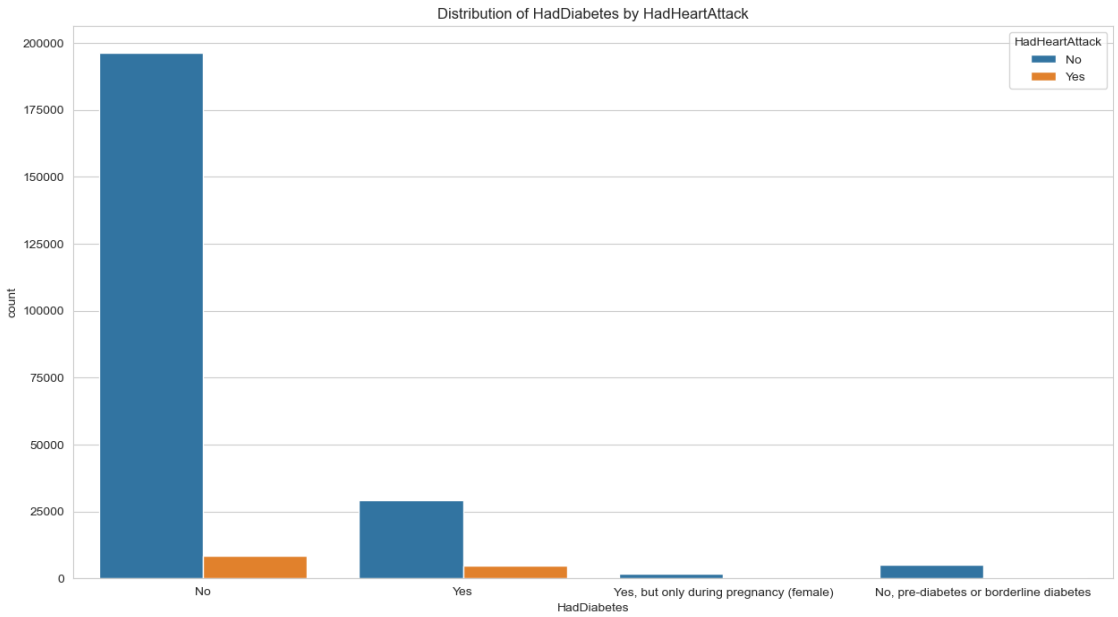


HadHeartAttack	No	Yes
HadArthritis		
No	155462	5670
Yes	77116	7765

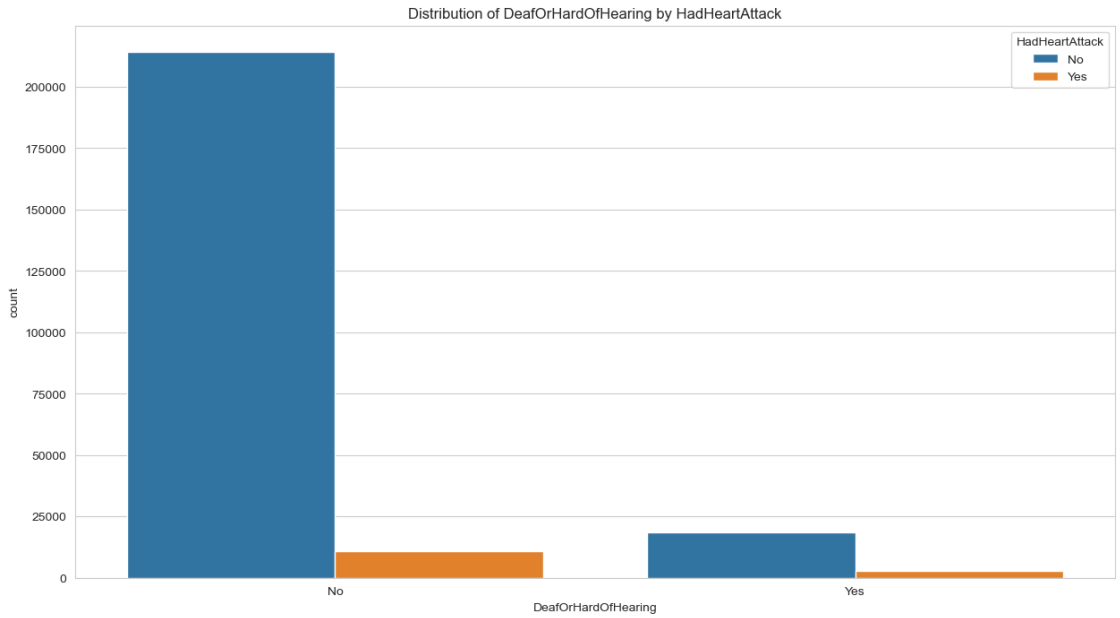
Chi-Squared Test for HadArthritis and HadHeartAttack
Chi2 value = 3411.190093972503, p-value = 0.0



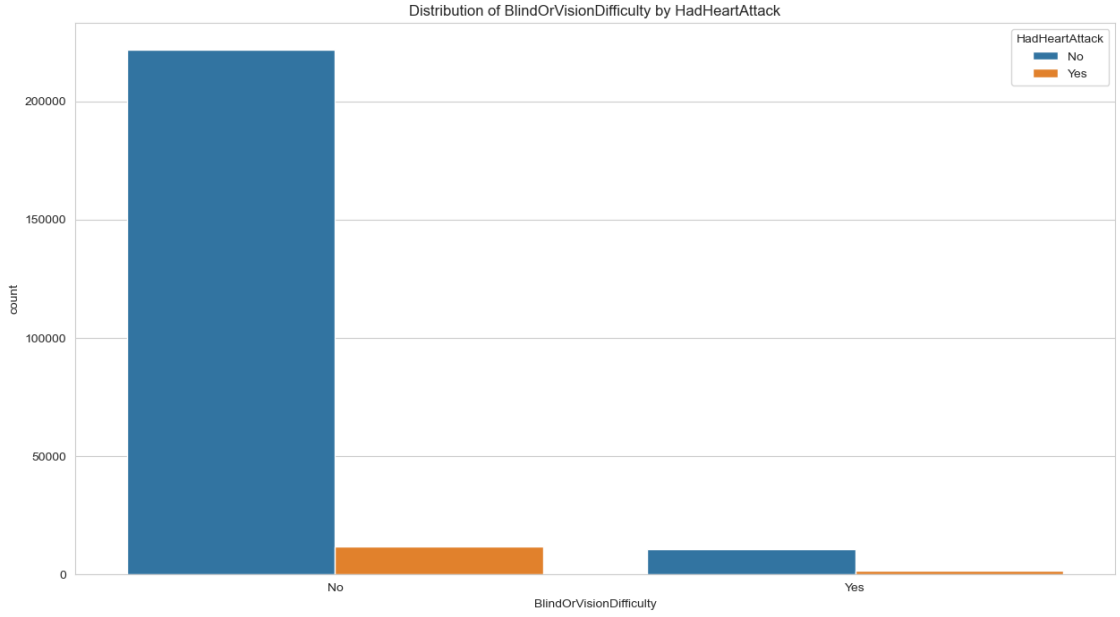
```
HadHeartAttack                                  No   Yes
HadDiabetes
No                                          196494  8333
No, pre-diabetes or borderline diabetes       5000   392
Yes                                          29157  4654
Yes, but only during pregnancy (female)       1927    56
Chi-Squared Test for HadDiabetes and HadHeartAttack
Chi2 value = 5345.9912570977585, p-value = 0.0
```



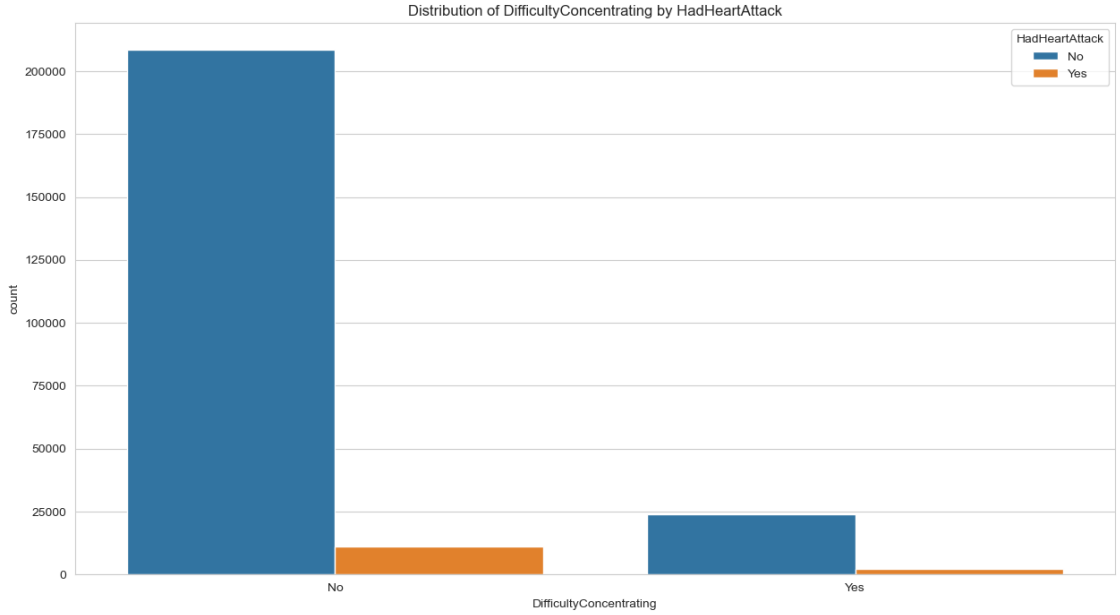

```
HadHeartAttack           No    Yes
DeafOrHardOfHearing
No                   214221  10760
Yes                   18357   2675
Chi-Squared Test for DeafOrHardOfHearing and HadHeartAttack
Chi2 value = 2344.8042006382593, p-value = 0.0
```



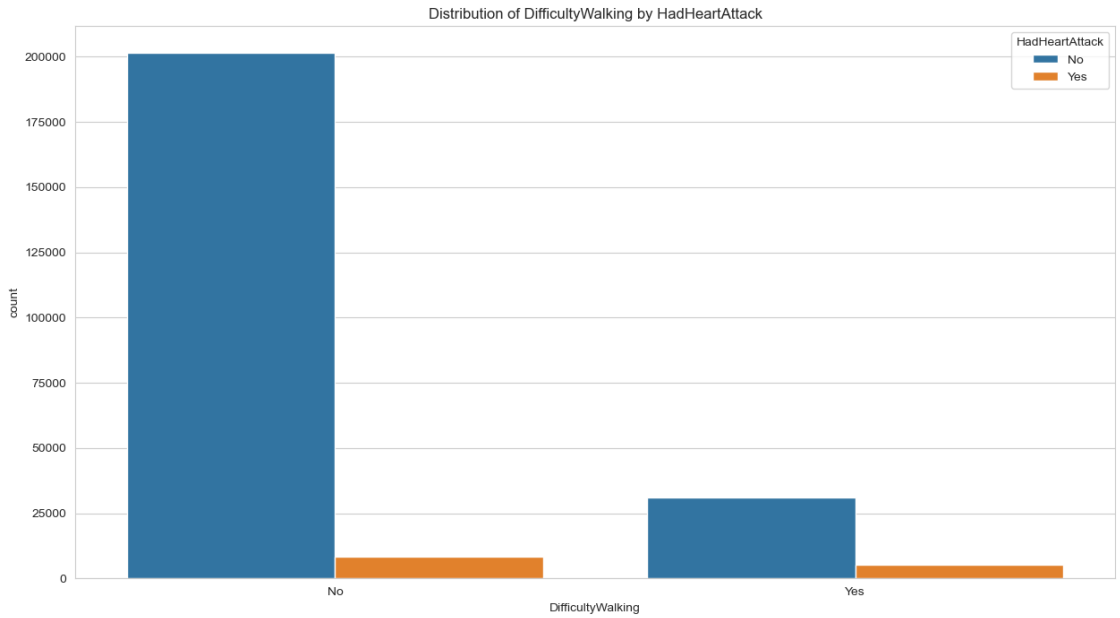

```
HadHeartAttack                No     Yes
BlindOrVisionDifficulty
No                          221906  11881
Yes                          10672   1554
Chi-Squared Test for BlindOrVisionDifficulty and HadHeartAttack
Chi2 value = 1308.1593754891833, p-value = 1.9058085152167356e-286
```



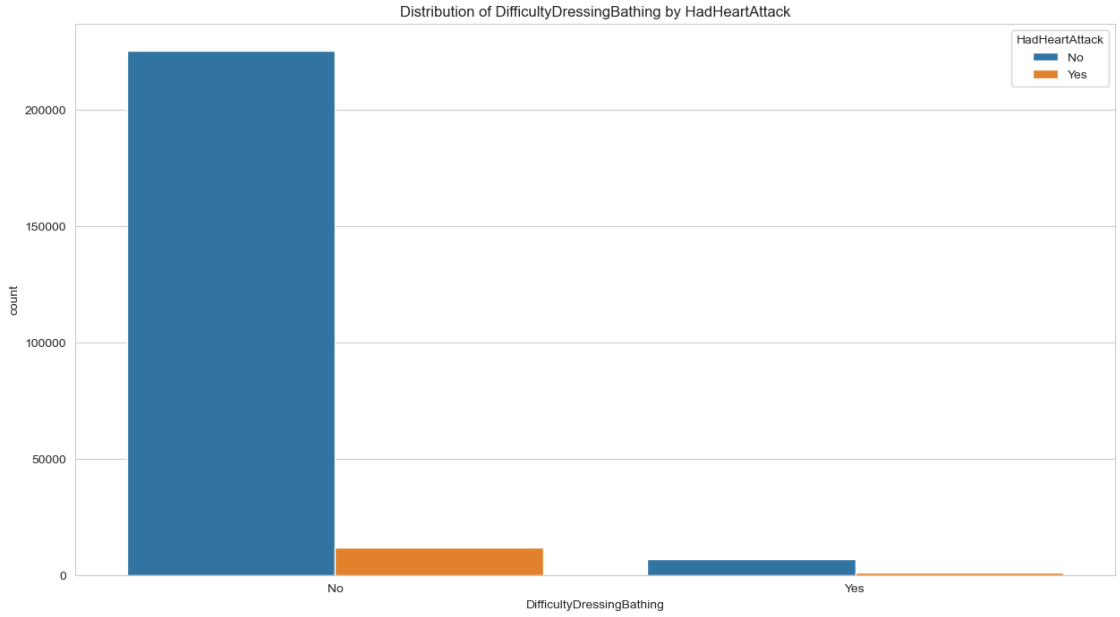
```
HadHeartAttack                No     Yes
DifficultyConcentrating
No                        208681  11112
Yes                        23897   2323
Chi-Squared Test for DifficultyConcentrating and HadHeartAttack
Chi2 value = 655.8249785059869, p-value = 1.2086533205176142e-144
```



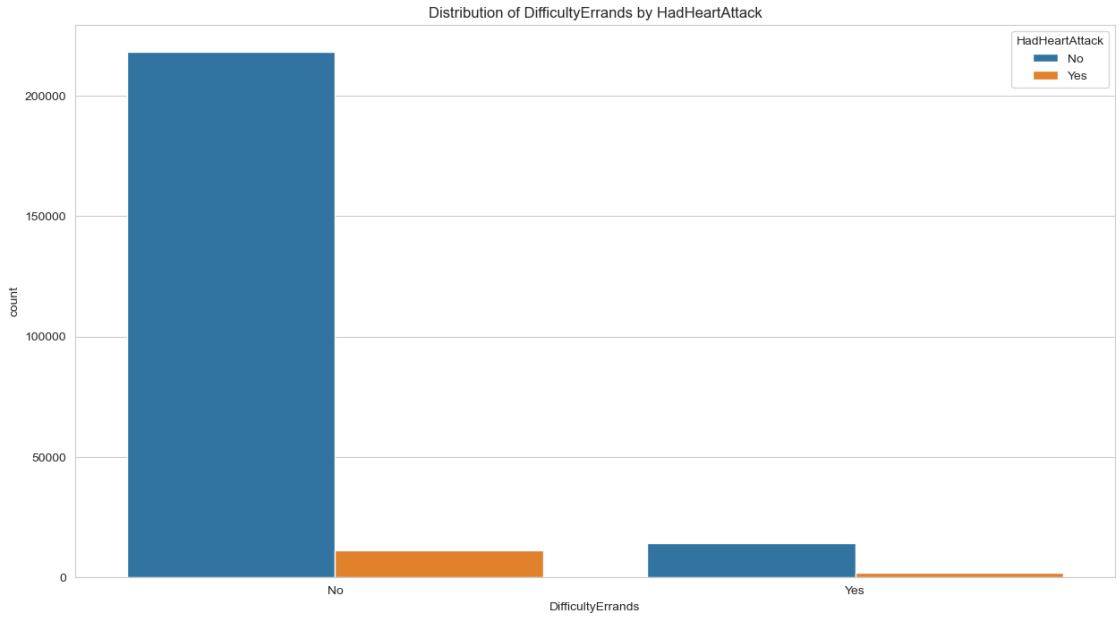

```
HadHeartAttack          No   Yes
DifficultyWalking
No                  201641  8304
Yes                  30937  5131
Chi-Squared Test for DifficultyWalking and HadHeartAttack
Chi2 value = 6286.838781453804, p-value = 0.0
```



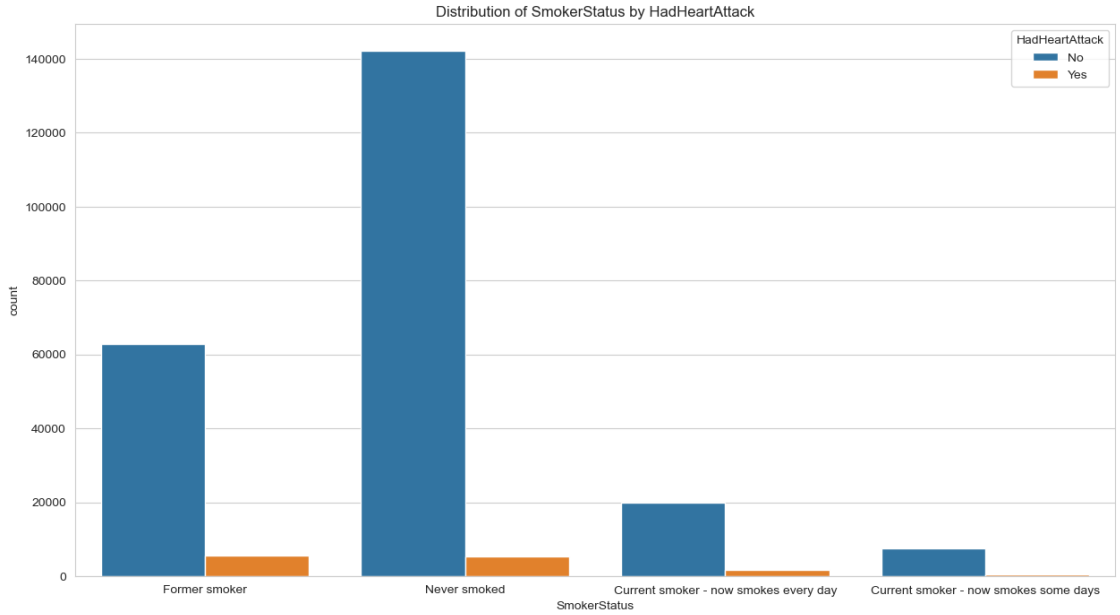

```
HadHeartAttack                 No    Yes
DifficultyDressingBathing
No                         225534  12139
Yes                          7044   1296
Chi-Squared Test for DifficultyDressingBathing and HadHeartAttack
Chi2 value = 1696.394540678655, p-value = 0.0
```



```
HadHeartAttack         No    Yes
DifficultyErrands
No                 218336  11293
Yes                 14242   2142
Chi-Squared Test for DifficultyErrands and HadHeartAttack
Chi2 value = 1968.7158617259954, p-value = 0.0
```

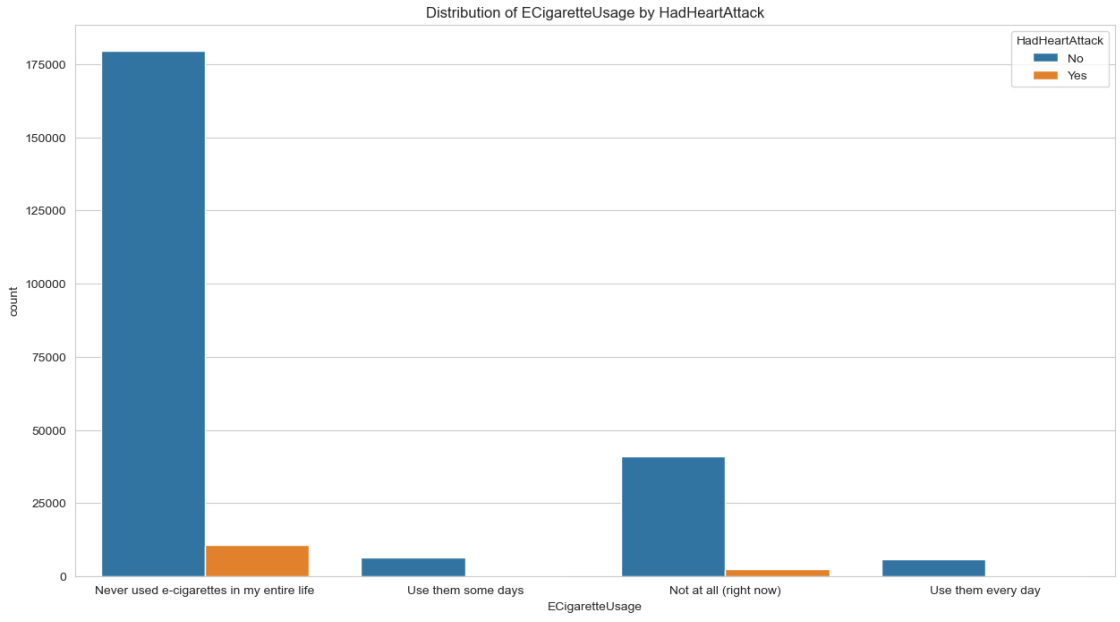



```
HadHeartAttack                              No   Yes
SmokerStatus
Current smoker - now smokes every day   19858  1801
Current smoker - now smokes some days    7546   553
Former smoker                           62914  5610
Never smoked                           142260  5471
Chi-Squared Test for SmokerStatus and HadHeartAttack
Chi2 value = 2241.293874288016, p-value = 0.0
```

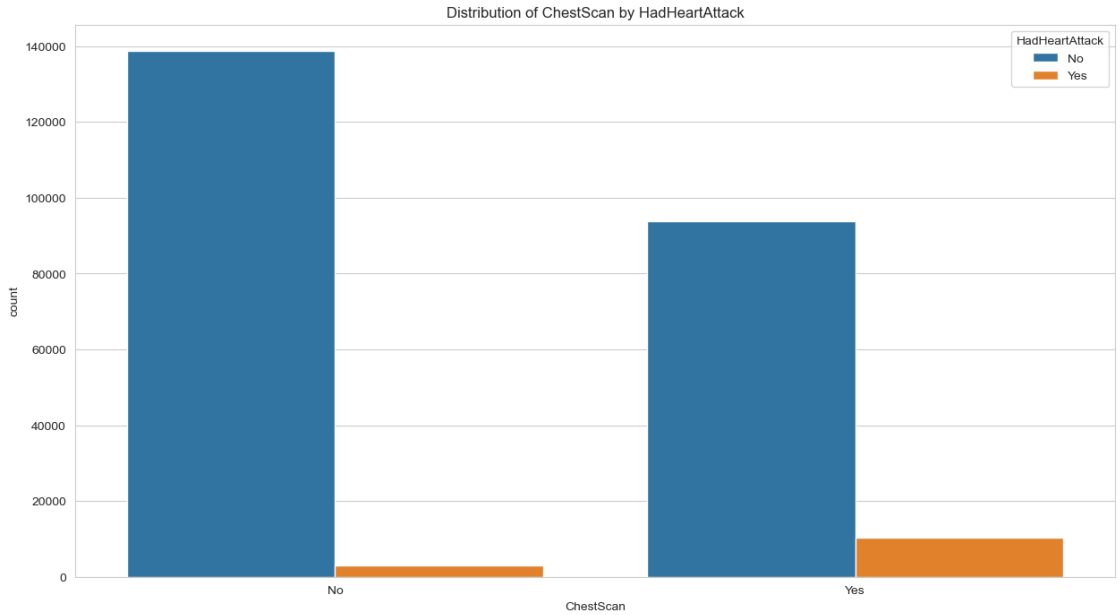


HadHeartAttack	No	Yes
ECigaretteUsage		
Never used e-cigarettes in my entire life	179547	10572
Not at all (right now)	40846	2435
Use them every day	5778	177
Use them some days	6407	251

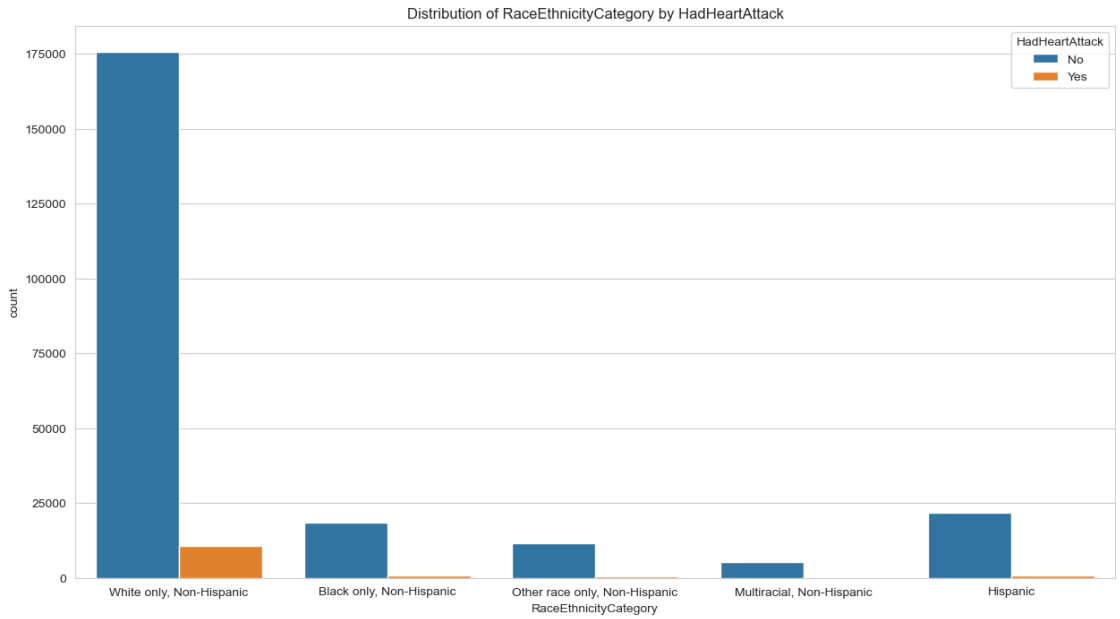
Chi-Squared Test for ECigaretteUsage and HadHeartAttack
Chi2 value = 114.26515381908608, p-value = 1.3252144336233886e-24



```
HadHeartAttack      No    Yes
ChestScan
No              138707   3111
Yes              93871  10324
Chi-Squared Test for ChestScan and HadHeartAttack
Chi2 value = 6922.660386789881, p-value = 0.0
```

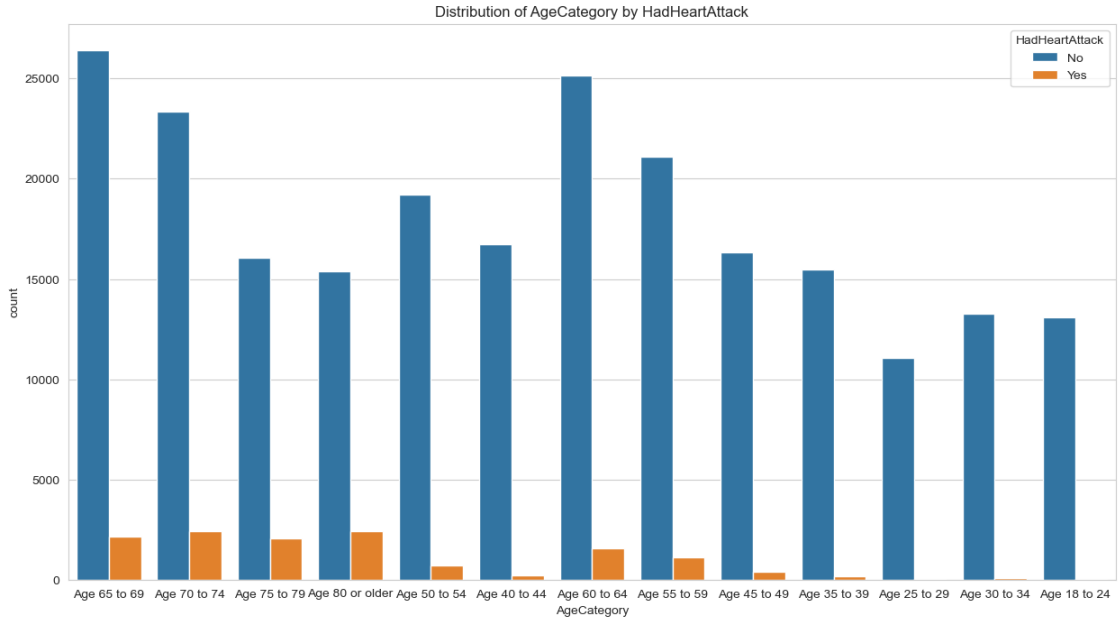



```
HadHeartAttack                     No    Yes
RaceEthnicityCategory
Black only, Non-Hispanic        18441    889
Hispanic                        21711    859
Multiracial, Non-Hispanic        5241    340
Other race only, Non-Hispanic   11614    591
White only, Non-Hispanic       175571  10756
Chi-Squared Test for RaceEthnicityCategory and HadHeartAttack
Chi2 value = 195.9712006643616, p-value = 2.760364866338809e-41
```



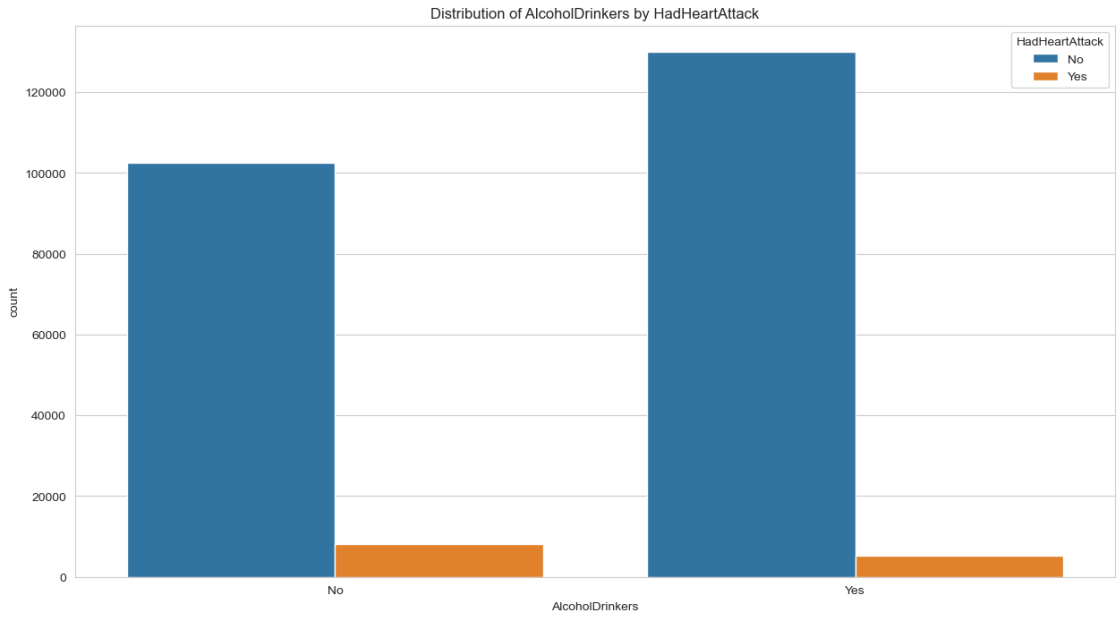
HadHeartAttack	No	Yes
AgeCategory		
Age 18 to 24	13072	50
Age 25 to 29	11062	47
Age 30 to 34	13256	90
Age 35 to 39	15458	156
Age 40 to 44	16745	228
Age 45 to 49	16333	420
Age 50 to 54	19209	703
Age 55 to 59	21112	1112
Age 60 to 64	25144	1575
Age 65 to 69	26400	2155
Age 70 to 74	23329	2408
Age 75 to 79	16068	2065
Age 80 or older	15390	2426

Chi-Squared Test for AgeCategory and HadHeartAttack
Chi2 value = 7925.704390290559, p-value = 0.0

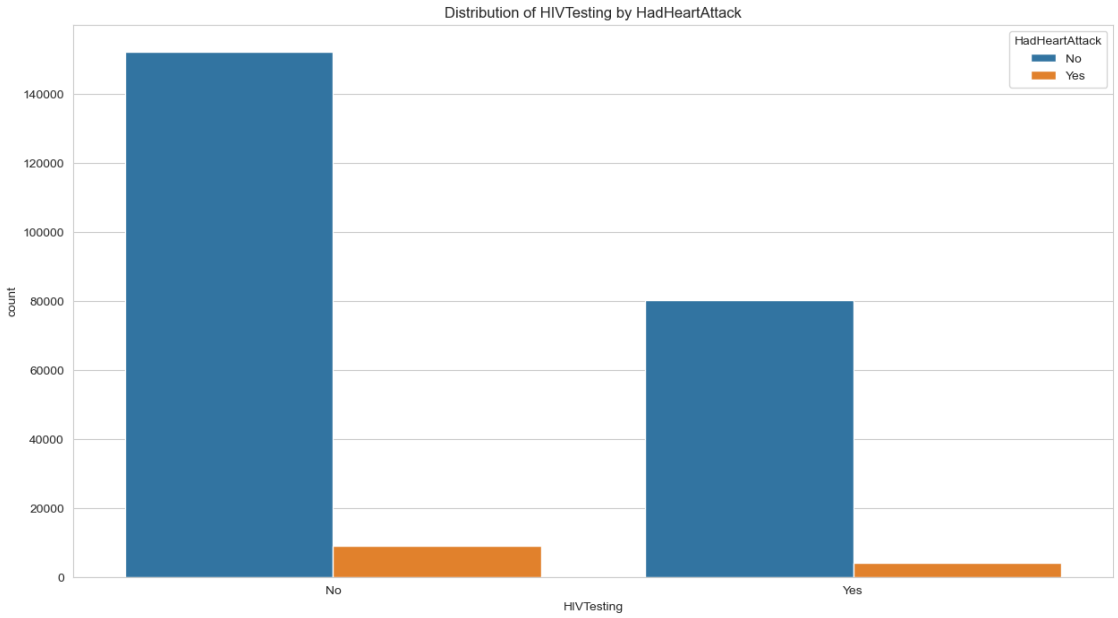


HadHeartAttack	No	Yes
AlcoholDrinkers		
No	102605	8109
Yes	129973	5326

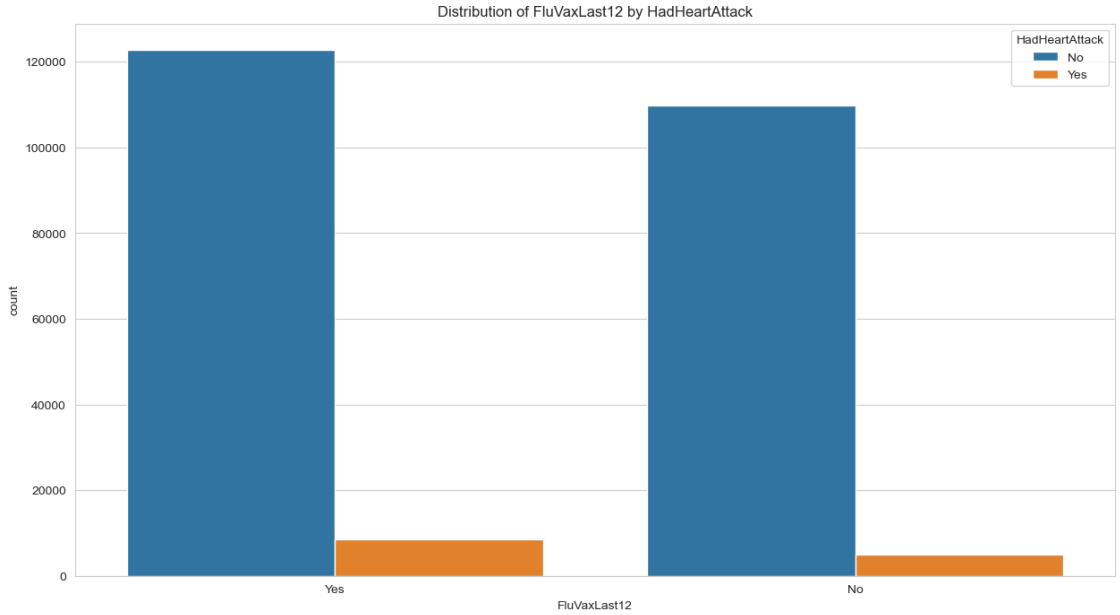
Chi-Squared Test for AlcoholDrinkers and HadHeartAttack
Chi2 value = 1352.9336428746574, p-value = 3.5495529688639013e-296



```
HadHeartAttack      No   Yes
HIVTesting
No              152306  9207
Yes              80272  4228
Chi-Squared Test for HIVTesting and HadHeartAttack
Chi2 value = 52.054385349053376, p-value = 5.398452954756739e-13
```

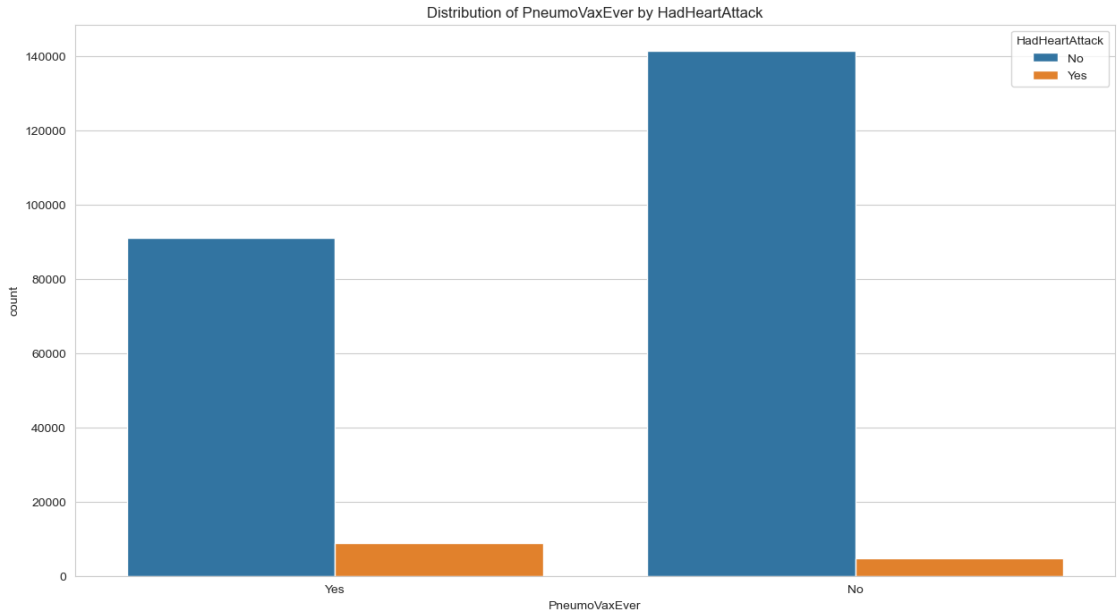



```
HadHeartAttack      No   Yes
FluVaxLast12
No              109816  5009
Yes             122762  8426
Chi-Squared Test for FluVaxLast12 and HadHeartAttack
Chi2 value = 503.1594851068325, p-value = 1.952245327911882e-111
```

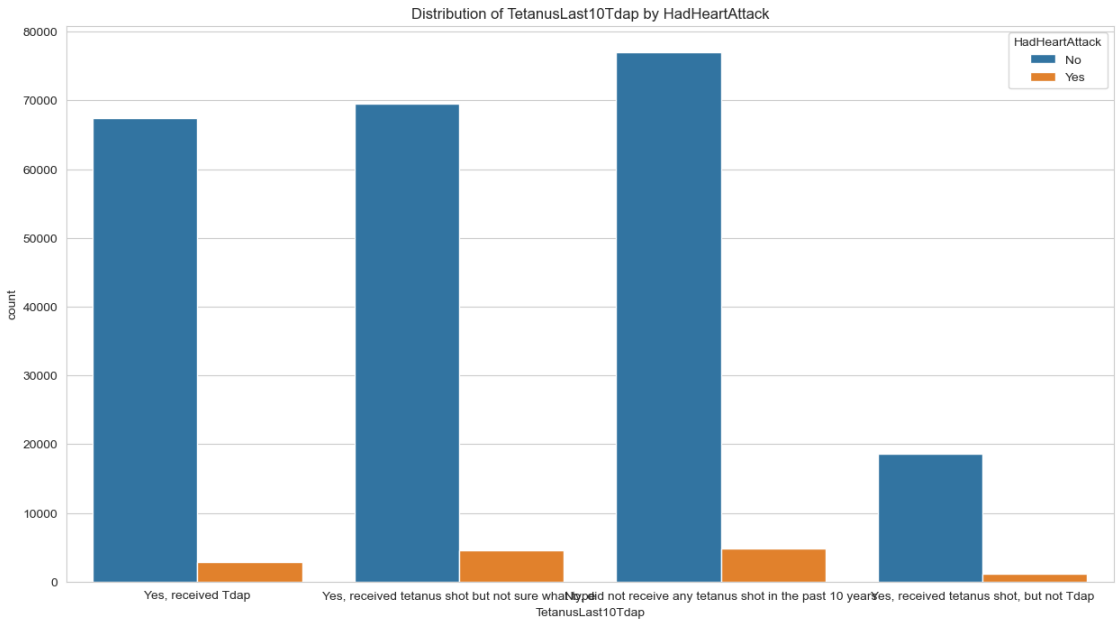


HadHeartAttack	No	Yes
PneumoVaxEver		
No	141441	4687
Yes	91137	8748

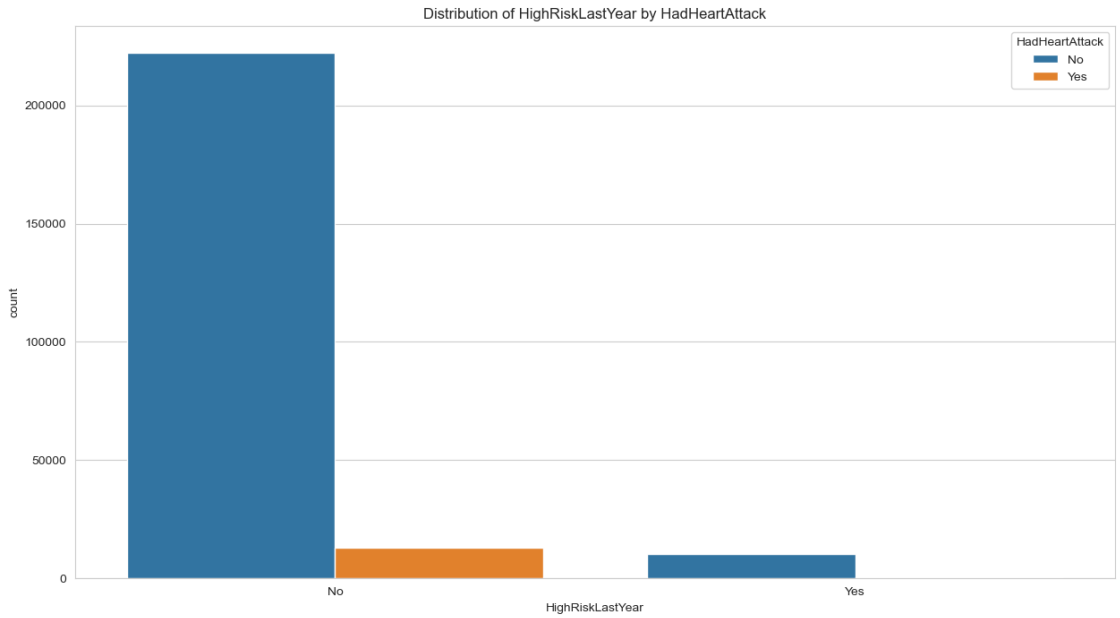
Chi-Squared Test for PneumoVaxEver and HadHeartAttack
Chi2 value = 3539.4434942388366, p-value = 0.0



```
HadHeartAttack                                          No   Yes
TetanusLast10Tdap
No, did not receive any tetanus shot in the pas…  76966  4777
Yes, received Tdap                                67463  2819
Yes, received tetanus shot but not sure what type 69513  4605
Yes, received tetanus shot, but not Tdap          18636  1234
Chi-Squared Test for TetanusLast10Tdap and HadHeartAttack
Chi2 value = 412.2456977489708, p-value = 4.9266526646514085e-89
```

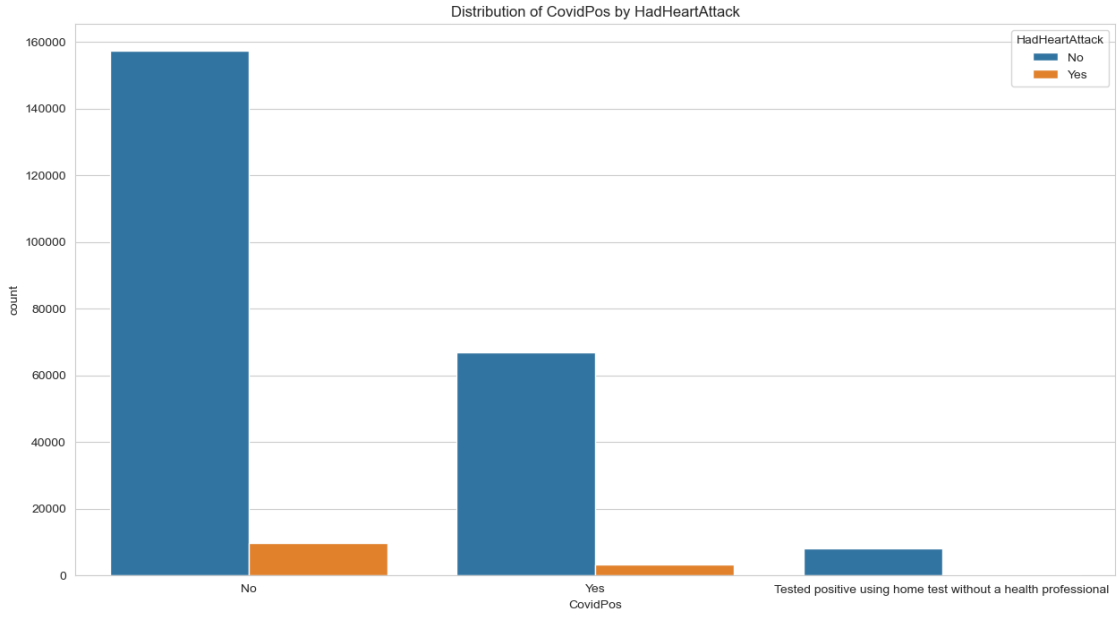



```
HadHeartAttack        No    Yes
HighRiskLastYear
No                222340  13097
Yes                10238    338
Chi-Squared Test for HighRiskLastYear and HadHeartAttack
Chi2 value = 109.3716134286175, p-value = 1.3454258258489073e-25
```



HadHeartAttack	No	Yes
CovidPos		
No	157521	9776
Tested positive using home test without a healt…	8158	234
Yes	66899	3425

Chi-Squared Test for CovidPos and HadHeartAttack
Chi2 value = 211.03994555450967, p-value = 1.490246437343113e-46



[ ]:
```
# Perform t-tests for numerical data
results_df_nums = pd.DataFrame(columns=['Feature', 'Statistic', 'P-Value'])

for var in numerical_vars:
  # Statistical Test (e.g., t-test) for significance
  for category in df[target].unique():
    group1 = df[df[target] == category][var]
    group2 = df[df[target] != category][var]

  stat, p = ttest_ind(group1, group2)

  # Add the results to the DataFrame
  new_row = {'Feature': var, 'Statistic': stat, 'P-Value': p}
  results_df_nums = pd.concat([results_df_nums, pd.DataFrame(new_row,␣
 ↪index=[0])], ignore_index=True)
```

[ ]:
```
# Sort the DataFrame by p-values in ascending order and then by chi2 values in␣
 ↪descending order
results_df_cat = results_df_cat.sort_values(by=['P-Value', 'Chi2'],␣
 ↪ascending=[True, False])

# Display the sorted DataFrame
display(results_df_cat)
```

	Feature	Chi2	P-Value
4	HadAngina	48906.220749	0.000000e+00
1	GeneralHealth	9893.539444	0.000000e+00
23	AgeCategory	7925.704390	0.000000e+00
5	HadStroke	7716.361887	0.000000e+00
3	RemovedTeeth	6996.544849	0.000000e+00
21	ChestScan	6922.660387	0.000000e+00
16	DifficultyWalking	6286.838781	0.000000e+00
12	HadDiabetes	5345.991257	0.000000e+00
8	HadCOPD	4363.963228	0.000000e+00
27	PneumoVaxEver	3539.443494	0.000000e+00
11	HadArthritis	3411.190094	0.000000e+00
10	HadKidneyDisease	2939.567089	0.000000e+00
13	DeafOrHardOfHearing	2344.804201	0.000000e+00
19	SmokerStatus	2241.293874	0.000000e+00
18	DifficultyErrands	1968.715862	0.000000e+00
2	PhysicalActivities	1701.515021	0.000000e+00
17	DifficultyDressingBathing	1696.394541	0.000000e+00
24	AlcoholDrinkers	1352.933643	3.549553e-296
0	Sex	1321.763475	2.107383e-289
14	BlindOrVisionDifficulty	1308.159375	1.905809e-286

```
15    DifficultyConcentrating    655.824979  1.208653e-144
7                HadSkinCancer    599.937749  1.727186e-132
26                FluVaxLast12    503.159485  1.952245e-111
28           TetanusLast10Tdap    412.245698   4.926653e-89
30                     CovidPos    211.039946   1.490246e-46
22       RaceEthnicityCategory    195.971201   2.760365e-41
6                     HadAsthma    138.573175   5.460575e-32
9        HadDepressiveDisorder    137.942355   7.502330e-32
29            HighRiskLastYear    109.371613   1.345426e-25
20             ECigaretteUsage    114.265154   1.325214e-24
25                   HIVTesting     52.054385   5.398453e-13
```

[ ]:
```
# Sort the DataFrame by p-values in ascending order
results_df_nums = results_df_nums.sort_values(by='P-Value', ascending=True)

# Display the sorted DataFrame
display(results_df_nums)
```

```
              Feature  Statistic       P-Value
0  PhysicalHealthDays  66.773602  0.000000e+00
4   WeightInKilograms  19.076335  4.546370e-81
1    MentalHealthDays  12.844421  9.506448e-38
3      HeightInMeters  11.440249  2.678179e-30
2          SleepHours   1.802562  7.145820e-02
```

0.3.1 Null Hypothesis Testing

We're intersted to test the following *null* hypothesis:

H_0: General health and Smoker status don't have effect on the possibility of a heart attack

H_A: General health and Smoker have effect on the possibility of a heart attack

[ ]:
```
hypothesis_df = results_df_cat[results_df_cat['Feature'].isin(['GeneralHealth',␣
↪'SmokerStatus'])]

# Define the significance level (alpha)
alpha = 0.05  # You can choose a different alpha value if needed

# Verify the null hypothesis for each feature
for index, row in hypothesis_df.iterrows():
    feature = row['Feature']
    chi2 = row['Chi2']
    p_value = row['P-Value']

    print(f"Feature: {feature}")
    print(f"Chi-Squared Value: {chi2}")
    print(f"P-Value: {p_value}")
```

```
    if p_value < alpha:
        print("Reject the null hypothesis ( 0)")
        print(f"{feature} has an effect on the possibility of a heart attack.")
    else:
        print("Fail to reject the null hypothesis ( 0)")
        print(f"{feature} does not have an effect on the possibility of a heart␣
 ↪attack.")

    print("\n")
```

```
Feature: GeneralHealth
Chi-Squared Value: 9893.539444125969
P-Value: 0.0
Reject the null hypothesis ( 0)
GeneralHealth has an effect on the possibility of a heart attack.


Feature: SmokerStatus
Chi-Squared Value: 2241.293874288016
P-Value: 0.0
Reject the null hypothesis ( 0)
SmokerStatus has an effect on the possibility of a heart attack.
```

0.3.2 Conclusion

- We have complted chi square test and we able to reject the *null* hypothesis.

0.4 Model Selection

[ ]:
```
# TESTING FOR MULTICOLLINEARITY
# Add a constant term to the predictor variables
X = add_constant(df[['PhysicalHealthDays', 'MentalHealthDays', 'SleepHours',␣
 ↪'HeightInMeters', 'WeightInKilograms']])

vif_data = pd.DataFrame()
vif_data["Variable"] = X.columns
vif_data["VIF"] = [variance_inflation_factor(X.values, i) for i in range(X.
 ↪shape[1])]

print(vif_data)
```

```
             Variable         VIF
0               const  304.683975
1  PhysicalHealthDays    1.115540
2   MentalHealthDays    1.123823
3         SleepHours    1.019942
```

```
4      HeightInMeters    1.306575
5   WeightInKilograms    1.311968
```

[ ]:
```
# HERE WE ADD DUMMIES TO THE CATEGORICAL VARIABLES
heart_df = pd.get_dummies(df, columns=categorical_includes_taget,␣
 ↪drop_first=True, dtype='int32')
heart_df.head(5)
```

[ ]:
```
   PhysicalHealthDays  MentalHealthDays  SleepHours  HeightInMeters  \
0                 4.0               0.0         9.0            1.60
1                 0.0               0.0         6.0            1.78
2                 0.0               0.0         8.0            1.85
3                 5.0               0.0         9.0            1.70
4                 3.0              15.0         5.0            1.55

   WeightInKilograms  Sex_Male  GeneralHealth_Fair  GeneralHealth_Good  \
0              71.67         0                   0                   0
1              95.25         1                   0                   0
2             108.86         1                   0                   0
3              90.72         0                   1                   0
4              79.38         0                   0                   1

   GeneralHealth_Poor  GeneralHealth_Very good  …  HIVTesting_Yes  \
0                   0                        1  …               0
1                   0                        1  …               0
2                   0                        1  …               0
3                   0                        0  …               0
4                   0                        0  …               0

   FluVaxLast12_Yes  PneumoVaxEver_Yes  TetanusLast10Tdap_Yes, received Tdap  \
0                 1                  1                                     1
1                 1                  1                                     0
2                 0                  1                                     0
3                 1                  1                                     0
4                 1                  1                                     0

   TetanusLast10Tdap_Yes, received tetanus shot but not sure what type  \
0                                                  0
1                                                  1
2                                                  0
3                                                  0
4                                                  0

   TetanusLast10Tdap_Yes, received tetanus shot, but not Tdap  \
0                                                  0
1                                                  0
2                                                  0
```

```
3                                                   0
4                                                   0

   HighRiskLastYear_Yes  \
0                     0
1                     0
2                     0
3                     0
4                     0

   CovidPos_Tested positive using home test without a health professional  \
0                                                  0
1                                                  0
2                                                  0
3                                                  0
4                                                  0

   CovidPos_Yes  HadHeartAttack_Yes
0             0                   0
1             0                   0
2             1                   0
3             1                   0
4             0                   0

[5 rows x 65 columns]
```

[ ]:
```
# REMOVE OUR DEPENDENT VARIABLE
target = 'HadHeartAttack_Yes'
X = heart_df.drop(target, axis=1)
y = heart_df[target]
```

Since, the dataset description suggested unbalanced data, we are going to perform model training:

- On the original data
- On the data with oversampling with $SMOTE$ (Synthetic Minority Oversampling Technique)
- On the data with undersampling

[ ]:
```
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2,␣
↪random_state=42)

# GENERATING THE OVERSAMPLE:
smote = SMOTE(random_state=42)
X_ovsampled, y_ovsampled = smote.fit_resample(X_train, y_train)

# GENERATING THE UNDERSAMPLE:
undersampler = RandomUnderSampler(random_state=42)
X_undersampled, y_undersampled = undersampler.fit_resample(X_train, y_train)
```

[ ]:
```
# LOGISTIC REGRESSION
def train_and_evaluate_logit(X_train, X_test, y_train, y_test, random_state=42):
    X_train_ = X_train.copy()
    X_test_ = X_test.copy()

    X_train_ = sm.add_constant(X_train_)
    X_test_ = sm.add_constant(X_test_)
    result = sm.Logit(y_train, X_train_).fit()

    y_pred = result.predict(X_test_)
    y_pred = np.where(y_pred > 0.5, 1, 0)

    report_df = pd.DataFrame(classification_report(y_test, y_pred,␣
 ↪output_dict=True)).transpose()
    return (result, report_df)
```

[ ]:
```
# DECISION TREE MODEL
def train_and_evaluate_decision_tree(X_train, X_test, y_train, y_test,␣
 ↪random_state=42):
    # Create and fit a DecisionTreeClassifier
    classifier = DecisionTreeClassifier(random_state=random_state)
    classifier.fit(X_train, y_train)

    y_pred = classifier.predict(X_test)

    report_df = pd.DataFrame(classification_report(y_test, y_pred,␣
 ↪output_dict=True)).transpose()
    return (classifier, report_df)
```

[ ]:
```
# RESULTS FOR LOGISTIC REGRESSION WITH ORIGINAL DATA
result_log, report_df_log = train_and_evaluate_logit(X_train, X_test, y_train,␣
 ↪y_test)
display(report_df_log)
```

```
Optimization terminated successfully.
         Current function value: 0.145333
         Iterations 10
```

	precision	recall	f1-score	support
0	0.958957	0.988616	0.973561	46558.00000
1	0.560166	0.255198	0.350649	2645.00000
accuracy	0.949190	0.949190	0.949190	0.94919
macro avg	0.759561	0.621907	0.662105	49203.00000
weighted avg	0.937519	0.949190	0.940075	49203.00000

[ ]:
```
# RESULTS FOR LOGISTIC REGRESSION WITH OVERSAMPLE WITH SMOTE
result_log_ov, report_df_log_ov = train_and_evaluate_logit(X_ovsampled, X_test,␣
 ↪y_ovsampled, y_test)
```

```
display(report_df_log_ov)
```

```
Optimization terminated successfully.
         Current function value: 0.210823
         Iterations 9
```

	precision	recall	f1-score	support
0	0.962747	0.926436	0.944243	46558.00000
1	0.221768	0.368998	0.277037	2645.00000
accuracy	0.896470	0.896470	0.896470	0.89647
macro avg	0.592257	0.647717	0.610640	49203.00000
weighted avg	0.922914	0.896470	0.908376	49203.00000

[ ]:
```
# RESULTS FOR LOGISTIC REGRESSION WITH UNDERSAMPLE
result_log_un, report_df_log_un = train_and_evaluate_logit(X_undersampled,␣
 ↪X_test, y_undersampled, y_test)
display(report_df_log_un)
```

```
Optimization terminated successfully.
         Current function value: 0.421748
         Iterations 7
```

	precision	recall	f1-score	support
0	0.984156	0.836505	0.904343	46558.000000
1	0.209553	0.762949	0.328798	2645.000000
accuracy	0.832551	0.832551	0.832551	0.832551
macro avg	0.596855	0.799727	0.616571	49203.000000
weighted avg	0.942516	0.832551	0.873404	49203.000000

[ ]:
```
# RESULTS FOR DECISION TREE (ORIGINAL DATA)
result_tree, report_df_tree = train_and_evaluate_decision_tree(X_train, X_test,␣
 ↪y_train, y_test)
display(report_df_tree)
```

	precision	recall	f1-score	support
0	0.959465	0.949697	0.954556	46558.000000
1	0.249118	0.293762	0.269604	2645.000000
accuracy	0.914436	0.914436	0.914436	0.914436
macro avg	0.604292	0.621729	0.612080	49203.000000
weighted avg	0.921279	0.914436	0.917735	49203.000000

[ ]:
```
# RESULTS FOR DECISION TREE WITH OVERSAMPLE
result_tree_ov, report_df_tree_ov =␣
 ↪train_and_evaluate_decision_tree(X_ovsampled, X_test, y_ovsampled, y_test)
display(report_df_tree_ov)
```

	precision	recall	f1-score	support
0	0.960106	0.922162	0.940751	46558.000000
1	0.191973	0.325520	0.241515	2645.000000
accuracy	0.890088	0.890088	0.890088	0.890088

```
macro avg       0.576039  0.623841  0.591133  49203.000000
weighted avg    0.918813  0.890088  0.903162  49203.000000
```

[ ]:
```
# RESULTS FOR DECISION TREE WITH UNDERSAMPLE
result_tree_un, report_df_tree_un =␣
 ↪train_and_evaluate_decision_tree(X_undersampled, X_test, y_undersampled,␣
 ↪y_test)
display(report_df_tree_un)
```

```
              precision    recall  f1-score       support
0              0.978397  0.721788  0.830727  46558.000000
1              0.128096  0.719471  0.217473   2645.000000
accuracy       0.721663  0.721663  0.721663      0.721663
macro avg      0.553247  0.720629  0.524100  49203.000000
weighted avg   0.932687  0.721663  0.797761  49203.000000
```

0.4.1 Conclusion

- Neither oversampling, nor undersampling produced desired results improving precision, i.e. the accuracy of the positive predictions made by the model
- Compared by the accuracy of the model on the entire dataset, and by mimizing the poor precision performance, **Logistic Regression** trained on the original data performed the best.
- Selected model has recall for **0** class of $\approx 98\%$, meaning low probability of false negatives, which is very important for the health data.

0.5 Model Analysis

[ ]:
```
result_log_sum = result_log.summary()
```

[ ]:
```
result_log_sum_df = pd.DataFrame(result_log_sum.tables[1].data[1:],␣
 ↪columns=result_log_sum.tables[1].data[0])
result_log_sum_sorted = result_log_sum_df.sort_values(by="P>|z|",␣
 ↪ascending=True)
display(result_log_sum_sorted)
```

```
                                                    coef    std err  \
0                                                 const    -5.6427      0.321
63  CovidPos_Tested positive using home test witho…    -0.3420      0.084
33                      SmokerStatus_Former smoker    -0.1972      0.040
34                       SmokerStatus_Never smoked    -0.4333      0.042
57                                FluVaxLast12_Yes    -0.1404      0.026
..                                                …        …          …
37              ECigaretteUsage_Use them some days     0.0449      0.085
60  TetanusLast10Tdap_Yes, received tetanus shot b…    -0.0143      0.029
17                                   HadAsthma_Yes     0.0138      0.033
36              ECigaretteUsage_Use them every day    -0.0210      0.103
32  SmokerStatus_Current smoker - now smokes some …    -0.0045      0.067
```

```
             z   P>|z|     [0.025     0.975]
0      -17.585   0.000     -6.272     -5.014
63      -4.068   0.000     -0.507     -0.177
33      -4.924   0.000     -0.276     -0.119
34     -10.428   0.000     -0.515     -0.352
57      -5.370   0.000     -0.192     -0.089
..         …     …         …          …
37       0.528   0.598     -0.122      0.212
60      -0.502   0.616     -0.070      0.042
17       0.422   0.673     -0.050      0.078
36      -0.204   0.838     -0.222      0.180
32      -0.068   0.946     -0.135      0.126

[65 rows x 7 columns]
```

[ ]:
```
result_log_sum_df_feature_of_interest =␣
↪result_log_sum_sorted[result_log_sum_sorted[''].isin(['SmokerStatus_Former␣
↪smoker', 'SmokerStatus_Never smoked', 'GeneralHealth_Fair',␣
↪'GeneralHealth_Poor', 'GeneralHealth_Good', 'GeneralHealth_Very good',␣
↪'SmokerStatus_Current smoker - now smokes some days'])]
```

[ ]:
```
display(result_log_sum_df_feature_of_interest)
```

```
                                                  coef    std err  \
33                         SmokerStatus_Former smoker    -0.1972      0.040
34                          SmokerStatus_Never smoked    -0.4333      0.042
7                                  GeneralHealth_Fair     0.8915      0.058
8                                  GeneralHealth_Good     0.6649      0.053
9                                  GeneralHealth_Poor     1.0154      0.071
10                           GeneralHealth_Very good     0.3281      0.054
32  SmokerStatus_Current smoker - now smokes some …    -0.0045      0.067

             z   P>|z|     [0.025     0.975]
33      -4.924   0.000     -0.276     -0.119
34     -10.428   0.000     -0.515     -0.352
7       15.372   0.000      0.778      1.005
8       12.550   0.000      0.561      0.769
9       14.360   0.000      0.877      1.154
10       6.054   0.000      0.222      0.434
32      -0.068   0.946     -0.135      0.126
```

0.5.1 Conclusion

- Smoker status related features have the following results:
  - `SmokerStatus_Former smoker` has coefficient -0.1972, `SmokerStatus_Never smoked` has coefficient -0.4333, suggesting negative direction of the effects on the probability of a heart attack. In other words, quitting smoking is associated with reduced probability of having a heart attack

  - `SmokerStatus_Current smoker - now smokes some days` has a small negative coefficient of -0.0045, however the $p-value$ for this feature indicates, that the effect is not statistically significant.

  - All features for `GeneralHealth` have $p-values$ indicating that the effects are statistically significant
- `GeneralHealth_Poor` has the highest magnitude of the coefficient, suggesting an increase in the corresponding independent variable is associated with an increased probability a heart attack