```
In [42]: import pandas as pd
         import numpy as np
         import matplotlib.pyplot as plt
         import seaborn as sns
         import shap
         import os
         from sklearn.model_selection import train_test_split
         from sklearn.preprocessing import StandardScaler
         from imblearn.over sampling import SMOTE
         from sklearn.linear model import LogisticRegression
         from sklearn.ensemble import RandomForestClassifier
         from sklearn.svm import SVC
         from sklearn.neural network import MLPClassifier
         from xgboost import XGBClassifier
         from sklearn.model_selection import GridSearchCV, StratifiedKFold
         from sklearn.metrics import classification report, confusion matrix, roc aud
```

In [2]: df = pd.read_csv("clean.csv")
 df.head()

Out[2]: SEQN RIAGENDR RIDAGEYR RIDRETH3 DMDBORN4 DMDEDUC2 INDFMPIR 0 109290.0 2.0 68.0 4.0 1.0 5.0 5.0 1 109290.0 2.0 68.0 4.0 1.0 5.0 5.0 2 109290.0 2.0 68.0 4.0 1.0 5.0 5.0 3 109290.0 2.0 68.0 4.0 1.0 5.0 5.0 2.0 6.0 5.0 4 109300.0 54.0 2.0 5.0

5 rows × 65 columns

In [3]: df.columns

```
Out[3]: Index(['SEQN', 'RIAGENDR', 'RIDAGEYR', 'RIDRETH3', 'DMDBORN4', 'DMDEDUC2',
                 'INDFMPIR', 'DR1TKCAL', 'DR1TPROT', 'DR1TCARB', 'DR1TSUGR', 'DR1TFIB
         Е',
                 'DR1TTFAT', 'DR1TSFAT', 'DR1TCHOL', 'DR1TALCO', 'DR1TCAFF', 'DR1TSOD
         Ι',
                 'DR1TPOTA', 'DR2TKCAL', 'DR2TPROT', 'DR2TCARB', 'DR2TSUGR', 'DR2TFIB
         Ε',
                 'DR2TTFAT', 'DR2TSFAT', 'DR2TCHOL', 'DR2TALCO', 'DR2TCAFF', 'DR2TSOD
         Ι',
                 'DR2TPOTA', 'BPXOSY1', 'BPXODI1', 'BPXOSY2', 'BPXODI2', 'BPXOSY3', 'BPXODI3', 'BPXOPLS1', 'BPXOPLS2', 'BPXOPLS3', 'BMXWT', 'BMXHT',
                 'BMXBMI', 'BMXWAIST', 'LBXIN', 'LBXGLU', 'LBXTR', 'LBDLDL', 'LBDHD
         DΊ,
                 'LBXHSCRP', 'PHAFSTHR', 'PAQ605', 'PAQ620', 'PAQ635', 'PAQ650',
                 'PAQ665', 'RXDUSE', 'RXDDRUG', 'RXDDRGID', 'RXDRSC1', 'BPQ020',
                 'DIQ010', 'DBQ700', 'DBQ197', 'HIQ011'],
                dtype='object')
```

```
In [4]: columns to drop = [
            # Day 1 dietary variables
            'DR1TPROT', 'DR1TCARB', 'DR1TCHOL', 'DR1TALCO',
            'DR1TCAFF', 'DR1TSODI', 'DR1TPOTA',
            # Day 2 dietary variables
            'DR2TPROT', 'DR2TCARB', 'DR2TCHOL', 'DR2TALCO',
            'DR2TCAFF', 'DR2TSODI', 'DR2TPOTA',
            # Weight and height
            'BMXWT', 'BMXHT',
            # Blood pressure pulse readings
            'BPXOPLS1', 'BPXOPLS2', 'BPXOPLS3',
            # Drug metadata
            'RXDDRGID', 'RXDRSC1',
            'SEQN', 'LBDLDL', 'RIDAGEYR', 'RIDRETH3', 'DMDBORN4', 'DMDEDUC2', 'PHAFS
            'PAQ665', 'BPQ020', 'DIQ010', 'HIQ011'
        df.drop(columns=columns_to_drop, inplace=True)
```

Feature Engineering

Clinical Risk Indicators (Metabolic Syndrome Flags)

```
In [5]: # Obesity based on waist circumference (gender-specific)
        df['flag\ obese'] = ((df['RIAGENDR'] == 1) & (df['BMXWAIST'] > 102)) | \setminus
                            ((df['RIAGENDR'] == 2) \& (df['BMXWAIST'] > 88))
        # Elevated blood pressure
        df['avg_sys'] = df[['BPXOSY1', 'BPXOSY2', 'BPXOSY3']].mean(axis=1)
        df['avg_dia'] = df[['BPXODI1', 'BPXODI2', 'BPXODI3']].mean(axis=1)
        df['flag\ high\ bp'] = (df['avg\ sys'] >= 130) \mid (df['avg\ dia'] >= 85)
        # Elevated fasting glucose
        df['flag high glucose'] = df['LBXGLU'] >= 100
        # Elevated triglycerides
        df['flag high triglycerides'] = df['LBXTR'] >= 150
        # Low HDL cholesterol (gender-specific)
        df['flag_low_hdl'] = ((df['RIAGENDR'] == 1) & (df['LBDHDD'] < 40)) | 
                              ((df['RIAGENDR'] == 2) \& (df['LBDHDD'] < 50))
        # HOMA-IR
        df['HOMA_IR'] = (df['LBXIN'] * df['LBXGLU']) / 405
        df['flag_homa_ir'] = df['HOMA_IR'] > 2.5
```

Derived Metabolic Syndrome Target

Lifestyle Feature Engineering

```
In [7]: # Average Daily Intake
        df['avg_kcal'] = df[['DR1TKCAL', 'DR2TKCAL']].mean(axis=1)
        df['avg_sugar'] = df[['DR1TSUGR', 'DR2TSUGR']].mean(axis=1)
        df['avg_fat'] = df[['DR1TTFAT', 'DR2TTFAT']].mean(axis=1)
        df['avg fiber'] = df[['DR1TFIBE', 'DR2TFIBE']].mean(axis=1)
        # Change in Intake
        df['delta_kcal'] = df['DR2TKCAL'] - df['DR1TKCAL']
        df['delta sugar'] = df['DR2TSUGR'] - df['DR1TSUGR']
        df['delta fat'] = df['DR2TTFAT'] - df['DR1TTFAT']
        # Binary Flags for Intake Reduction
        df['reduced_calories'] = df['delta_kcal'] < -100</pre>
        df['reduced_sugar'] = df['delta_sugar'] < -10</pre>
        # Likely Dieting (Overweight + trying to lose weight + reduced intake)
        df['likely_dieting'] = (
            (df['BMXBMI'] >= 25) &
            df['reduced calories'] &
            df['DBQ700'].eq(1)
        # Eating Out Behavior
        df['eats_out_often'] = df['DBQ197'].isin([1, 2]) # every day / most days
        df['eats_out_rarely'] = df['DBQ197'].isin([4, 5]) # 1-2x/week or never
        # Physical Activity
        df['physically active'] = (
            df[['PAQ605', 'PAQ620', 'PAQ635', 'PAQ650']].isin([1]).any(axis=1)
        df['activity_score'] = df[['PAQ605', 'PAQ620', 'PAQ635', 'PAQ650']].applymar
        # Lifestyle Effort Score
        df['lifestyle effort'] = (
            df['likely_dieting'].astype(int)
            + df['eats_out_rarely'].astype(int)
            + df['delta_kcal'].apply(lambda x: 1 if x < 0 else 0) # decreased calor
            + df['delta sugar'].apply(lambda x: 1 if x < 0 else 0) # decreased sugar
            + df['physically_active'].astype(int) # NEW: physical activity
        )
       /var/folders/z1/w_njtpr52ss65yn2_5wp9xfm0000gn/T/ipykernel_49326/814351403.p
```

```
/var/folders/z1/w_njtpr52ss65yn2_5wp9xfm0000gn/T/ipykernel_49326/814351403.p
y:31: FutureWarning: DataFrame.applymap has been deprecated. Use DataFrame.m
ap instead.
   df['activity_score'] = df[['PAQ605', 'PAQ620', 'PAQ635', 'PAQ650']].applym
ap(lambda x: 1 if x == 1 else 0).sum(axis=1)
```

Med_Class Variable

```
In [8]: met_syn_drugs = [
            # Diabetes-related
            'METFORMIN', 'INSULIN', 'GLIPIZIDE', 'GLYBURIDE', 'PIOGLITAZONE', 'SITAC
            'EMPAGLIFLOZIN', 'DAPAGLIFLOZIN', 'CANAGLIFLOZIN', 'LINAGLIPTIN', 'LIRAG
            'EXENATIDE', 'SEMAGLUTIDE', 'GLIMEPIRIDE',
            # Hypertension
            'LISINOPRIL', 'LOSARTAN', 'AMLODIPINE', 'METOPROLOL', 'RAMIPRIL', 'FUROS
            'HYDROCHLOROTHIAZIDE', 'VALSARTAN', 'BISOPROLOL', 'SPIRONOLACTONE', 'DIL
            # Cholesterol
            'ATORVASTATIN', 'ROSUVASTATIN', 'SIMVASTATIN', 'PRAVASTATIN', 'PITAVASTA
            'EZETIMIBE', 'FENOFIBRATE', 'GEMFIBROZIL', 'FENOFIBRIC ACID', 'NIACIN',
        # Clean and classify each record
        def classify_meds(drug_str):
            if pd.isna(drug_str) or drug_str.strip().upper() in ['NONE', 'NO MEDICAT
                return 'None'
            # Clean and split into list
            drugs = [d.strip().upper() for d in drug str.split(';')]
            has_met_syn = any(any(med in drug for med in met_syn_drugs) for drug in
            has non met syn = any(not any(med in drug for med in met syn drugs) for
            if has_met_syn and has_non_met_syn:
                return 'Both MetSyn + Other'
            elif has met syn:
                return 'MetSyn-related'
            elif has non met syn:
                return 'Other'
            else:
                return 'None'
        # Apply to your column
        df['med class'] = df['RXDDRUG'].astype(str).apply(classify meds)
In [9]: # 1 corresponds to using medication
```

```
In [9]: # 1 corresponds to using medication
# 2 corresponds to not using medication
```

Income_Level Variable

```
Out[11]: Index(['RIAGENDR', 'INDFMPIR', 'DR1TKCAL', 'DR1TSUGR', 'DR1TFIBE', 'DR1TTFA
          Т',
                  'DR1TSFAT', 'DR2TKCAL', 'DR2TSUGR', 'DR2TFIBE', 'DR2TTFAT', 'DR2TSFA
          Т',
                  'BPXOSY1', 'BPXODI1', 'BPXOSY2', 'BPXODI2', 'BPXOSY3', 'BPXODI3',
                  'BMXBMI', 'BMXWAIST', 'LBXIN', 'LBXGLU', 'LBXTR', 'LBDHDD', 'LBXHSCR
           Ρ',
                  'PAQ605', 'PAQ620', 'PAQ635', 'PAQ650', 'RXDUSE', 'RXDDRUG', 'DBQ70
          0',
                  'DBQ197', 'flag_obese', 'avg_sys', 'avg_dia', 'flag_high_bp',
                  'flag_high_glucose', 'flag_high_triglycerides', 'flag_low_hdl',
                  'HOMA_IR', 'flag_homa_ir', 'met_syndrome_count',
                  'has_metabolic_syndrome', 'avg_kcal', 'avg_sugar', 'avg_fat', 'avg_fiber', 'delta_kcal', 'delta_sugar', 'delta_fat',
                  'reduced_calories', 'reduced_sugar', 'likely_dieting', 'eats_out_oft
          en',
                  'eats_out_rarely', 'physically_active', 'activity_score',
'lifestyle_effort', 'med_class', 'income_level',
                  'likely dieting numeric'],
                 dtype='object')
In [12]: df.dtypes[df.dtypes == 'object']
Out[12]: RXDDRUG
                         object
                         object
          med class
          dtype: object
In [13]: df.dtypes[df.dtypes == 'category']
Out[13]: income level
                            category
          dtype: object
In [14]: df.dtypes[df.dtypes == 'int64']
Out[14]: met_syndrome_count
                                       int64
          activity score
                                       int64
          lifestyle effort
                                       int64
          likely_dieting_numeric
                                       int64
          dtype: object
In [15]: df.dtypes[df.dtypes == 'float64']
```

Out[15]: RIAGENDR

INDFMPIR

DR1TKCAL

float64

float64

float64

```
DR1TSUGR
                           float64
          DR1TFIBE
                           float64
                           float64
          DR1TTFAT
          DR1TSFAT
                           float64
                           float64
          DR2TKCAL
                           float64
          DR2TSUGR
          DR2TFIBE
                           float64
                           float64
          DR2TTFAT
          DR2TSFAT
                           float64
          BPX0SY1
                           float64
                           float64
          BPX0DI1
          BPX0SY2
                           float64
          BPX0DI2
                           float64
          BPX0SY3
                           float64
                           float64
          BPX0DI3
                           float64
          BMXBMI
                           float64
          BMXWAIST
          LBXIN
                           float64
          LBXGLU
                           float64
                           float64
          LBXTR
          LBDHDD
                           float64
          LBXHSCRP
                           float64
          PAQ605
                           float64
          PAQ620
                           float64
          PAQ635
                           float64
                           float64
          PAQ650
                           float64
          RXDUSE
                           float64
          DBQ700
          DBQ197
                           float64
                           float64
          avg_sys
          avg_dia
                           float64
                           float64
          HOMA_IR
                           float64
          avg_kcal
          avg_sugar
                           float64
          avg_fat
                           float64
          avg_fiber
                           float64
          delta_kcal
                           float64
          delta_sugar
                           float64
          delta_fat
                           float64
          dtype: object
In [16]:
          predictors_lifestyle = [
              # Lifestyle and Behavior
              'avg_kcal', 'avg_sugar', 'avg_fat', 'avg_fiber',
'reduced_calories', 'reduced_sugar', 'likely_dieting',
               'eats_out_often', 'eats_out_rarely',
               'physically_active', 'lifestyle_effort',
              # Income
               'income_level'
          ]
```

```
predictors_with_meds = predictors_lifestyle + ['med_class']
```

In [17]: df['has_metabolic_syndrome'].value_counts()

Out[17]: has_metabolic_syndrome

True 3941 False 2219

Name: count, dtype: int64

In [18]: df[predictors_lifestyle]

-		Г -	- 7	
()	п÷	[1	$Q \mid$	
U	uч	1 1	O_{J}	

		avg_kcal	avg_sugar	avg_fat	avg_fiber	reduced_calories	reduced_sugar	like
	0	1333.0	54.360	53.120	10.30	False	False	
	1	1333.0	54.360	53.120	10.30	False	False	
	2	1333.0	54.360	53.120	10.30	False	False	
	3	1333.0	54.360	53.120	10.30	False	False	
	4	784.5	31.170	40.805	6.65	False	False	
	•••	•••					•••	
	6155	1972.0	70.765	91.960	12.55	True	True	
	6156	1972.0	70.765	91.960	12.55	True	True	
	6157	1972.0	70.765	91.960	12.55	True	True	
6158	6158	1783.5	136.995	60.405	8.45	False	False	
	6159	1618.5	39.905	63.375	7.05	True	False	

6160 rows × 12 columns

In [19]: df_subset = df[predictors_with_meds + ['has_metabolic_syndrome']]
 df_subset.head()

Out[19]:

:	avg_kcal	avg_sugar	avg_fat	avg_fiber	reduced_calories	reduced_sugar	likely_c
C	1333.0	54.36	53.120	10.30	False	False	
1	1 1333.0	54.36	53.120	10.30	False	False	
2	2 1333.0	54.36	53.120	10.30	False	False	
3	1333.0	54.36	53.120	10.30	False	False	
4	784.5	31.17	40.805	6.65	False	False	

```
df['income_level'].value_counts()
In [20]:
Out[20]: income level
          Middle Income
                            2480
          High Income
                            2013
          Low Income
                            1667
          Name: count, dtype: int64
In [21]: # variables that need categorical encoding:
          # reduced_calories, reduced_sugar, likely_dieting, eats_out_often, eats_out_
          # income_level, med_class, has_metabolic
          income mapping = {
              'Low Income': 0,
              'Middle Income': 1,
              'High Income': 2
          }
          df_encoded = pd.get_dummies(df_subset, columns=['med_class'], drop_first=Tru
          df_encoded['income_level'] = df['income_level'].map(income_mapping).astype(i
          df encoded.head()
Out[21]:
             avg_kcal avg_sugar avg_fat avg_fiber reduced_calories reduced_sugar likely_c
          0
               1333.0
                           54.36
                                  53.120
                                              10.30
                                                               False
                                                                              False
          1
               1333.0
                           54.36
                                  53.120
                                              10.30
                                                               False
                                                                              False
          2
                           54.36
                                             10.30
                                                               False
                                                                              False
               1333.0
                                  53.120
          3
               1333.0
                           54.36
                                  53.120
                                              10.30
                                                               False
                                                                              False
          4
                784.5
                           31.17
                                  40.805
                                              6.65
                                                               False
                                                                              False
In [22]: df_encoded.isnull().sum()
Out[22]: avg kcal
                                       0
                                        0
          avg sugar
          avg_fat
                                        0
          avg fiber
                                        0
          reduced_calories
                                        0
          reduced sugar
                                        0
          likely dieting
                                        0
          eats_out_often
                                        0
          eats_out_rarely
                                        0
          physically_active
                                        0
          lifestyle_effort
                                        0
          income_level
          has_metabolic_syndrome
                                        0
          med class MetSyn-related
                                        0
          med_class_None
                                        0
          med_class_Other
                                        0
          dtype: int64
In [23]: df_encoded.columns.tolist()
```

```
Out[23]: ['avg kcal',
           'avg_sugar',
           'avg fat',
           'avg_fiber',
           'reduced calories',
           'reduced_sugar',
           'likely dieting',
           'eats_out_often',
           'eats_out_rarely',
           'physically_active',
           'lifestyle_effort',
           'income level',
           'has metabolic syndrome',
           'med_class_MetSyn-related',
           'med_class_None',
           'med class Other']
In [24]: all_columns = df_encoded.columns.tolist()
         med_class_columns = all_columns[-3:]
         predictors_lifestyle_only = all_columns[0:12]
         predictors_with_meds = predictors_lifestyle_only + med_class_columns
         numeric_cols = ['avg_kcal', 'avg_sugar', 'avg_fat', 'avg_fiber']
In [25]: from sklearn.feature selection import VarianceThreshold
         def prepare_data(df, predictors, scale=True):
             X = df[predictors]
             y = df['has_metabolic_syndrome'].astype(int)
             # Train/Test Split (stratified)
             X_train, X_test, y_train, y_test = train_test_split(
                  X, y, test_size=0.3, stratify=y, random_state=42
             # Remove zero-variance columns
             vt = VarianceThreshold(threshold=0.0)
             X train = pd.DataFrame(vt.fit transform(X train), columns=X train.column
             X_{\text{test}} = X_{\text{test}}[X_{\text{train}}] # Keep only the columns from X_{\text{train}} if
             if scale:
                  scaler = StandardScaler()
                  X_train[numeric_cols] = scaler.fit_transform(X_train[numeric_cols])
                  X_test[numeric_cols] = scaler.transform(X_test[numeric_cols])
             else:
                  scaler = None
             # SMOTE on training data only
             smote = SMOTE(random state=42)
             X_train_resampled, y_train_resampled = smote.fit_resample(X_train, y_train)
              return X_train_resampled, X_test, y_train_resampled, y_test
In [26]: # Model A: Lifestyle + Medications
         X_train_A, X_test_A, y_train_A, y_test_A = prepare_data(df_encoded, predictor)
```

```
# Model B: Lifestyele Only
X_train_B, X_test_B, y_train_B, y_test_B = prepare_data(df_encoded, predictor)
```

```
In [27]: # Define models and parameter grids
         model_params = {
             "Logistic Regression": {
                  "model": LogisticRegression(max iter=1000),
                  "params": {
                      "C": [0.01, 0.1, 1, 10],
                      "penalty": ['l2'], # 'l1' requires solver='liblinear'
                      "solver": ['lbfqs']
             },
             "Random Forest": {
                  "model": RandomForestClassifier(),
                  "params": {
                      "n estimators": [100, 200],
                      "max_depth": [None, 10, 20],
                      "min_samples_split": [2, 5],
                  }
             },
             "XGBoost": {
                  "model": XGBClassifier(use label encoder=False, eval metric='logloss
                  "params": {
                      "n_estimators": [100, 200],
                      "max_depth": [3, 5, 7],
                      "learning rate": [0.01, 0.1, 0.2],
                 }
             },
             "SVM": {
                  "model": SVC(probability=True),
                  "params": {
                      "C": [0.1, 1, 10],
                      "kernel": ['rbf', 'linear']
                  }
             },
             "MLP": {
                  "model": MLPClassifier(max_iter=1000),
                  "params": {
                      "hidden_layer_sizes": [(50,), (100,), (100, 50)],
                      "activation": ['relu', 'tanh'],
                      "alpha": [0.0001, 0.001],
                 }
             }
```

```
In [28]: def train_and_tune_models(X_train, y_train, X_test, y_test):
    results = {}

    for name, mp in model_params.items():
        print(f"\n Training {name}...")
        model = mp["model"]
        param_grid = mp["params"]

        grid = GridSearchCV(
```

```
model,
        param_grid,
        cv=StratifiedKFold(n splits=5, shuffle=True, random state=42),
        scoring='f1',
        n_{jobs}=-1
    grid.fit(X_train, y_train)
   best_model = grid.best_estimator_
   y_pred = best_model.predict(X_test)
   y prob = best model.predict proba(X test)[:, 1] if hasattr(best model
    print(" Best Parameters:", grid.best_params_)
   print("II Classification Report:\n", classification report(y test, y
    if y prob is not None:
        print(" ROC AUC Score:", roc_auc_score(y_test, y_prob))
    # Store results
    results[name] = {
        "model": best_model,
        "best params": grid.best params,
        "y_pred": y_pred,
        "y_prob": y_prob,
        "report": classification_report(y_test, y_pred, output_dict=True
        "roc auc": roc auc score(y test, y prob) if y prob is not None e
    }
return results
```

Training Logistic Regression...

■ Best Parameters: {'C': 10, 'penalty': 'l2', 'solver': 'lbfgs'}

■ Classification Report:

	precision	recall	f1-score	support
0 1	0.48 0.72	0.55 0.66	0.51 0.69	666 1182
accuracy macro avg weighted avg	0.60 0.63	0.61 0.62	0.62 0.60 0.63	1848 1848 1848

ROC AUC Score: 0.6498503579721853

Training Random Forest...

☑ Best Parameters: {'max_depth': 20, 'min_samples_split': 2, 'n_estimator
s': 100}

■ Classification Report:

	precision	recall	f1-score	support
0	0.82	0.80	0.81	666
1	0.89	0.90	0.90	1182
accuracy			0.87	1848
macro avg	0.85	0.85	0.85	1848
weighted avg	0.86	0.87	0.86	1848

ROC AUC Score: 0.9507254716645581

Training XGBoost...

```
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWarnin
g: [09:54:41] WARNING: /Users/runner/work/xgboost/xgboost/src/learner.cc:74
0:
Parameters: { "use_label_encoder" } are not used.
  warnings.warn(smsg, UserWarning)
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWarnin
g: [09:54:41] WARNING: /Users/runner/work/xgboost/xgboost/src/learner.cc:74
Parameters: { "use_label_encoder" } are not used.
  warnings.warn(smsg, UserWarning)
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWarnin
g: [09:54:41] WARNING: /Users/runner/work/xgboost/xgboost/src/learner.cc:74
Parameters: { "use_label_encoder" } are not used.
  warnings.warn(smsg, UserWarning)
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWarnin
g: [09:54:41] WARNING: /Users/runner/work/xgboost/xgboost/src/learner.cc:74
0:
Parameters: { "use_label_encoder" } are not used.
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/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWarnin
q: [09:54:42] WARNING: /Users/runner/work/xqboost/xqboost/src/learner.cc:74
Parameters: { "use_label_encoder" } are not used.
  warnings.warn(smsg, UserWarning)
```

☑ Best Parameters: {'learning_rate': 0.2, 'max_depth': 7, 'n_estimators': 2
00}

■ Classification Report:

		precision	recall	f1-score	support
	0	0.86	0.85	0.86	666
	1	0.92	0.92	0.92	1182
accui	racy			0.90	1848
macro	avg	0.89	0.89	0.89	1848
weighted	avg	0.90	0.90	0.90	1848

[●] ROC AUC Score: 0.9590643943435823

Training SVM...

☑ Best Parameters: {'C': 10, 'kernel': 'rbf'}

■ Classification Report:

	precision	recall	f1-score	support
0	0.64	0.67	0.65	666
1	0.81	0.79	0.80	1182
accuracy			0.75	1848
macro avg weighted avg	0.72 0.75	0.73 0.75	0.73 0.75	1848 1848

[●] ROC AUC Score: 0.7925323800958319

Training MLP...

```
/opt/anaconda3/lib/python3.11/site-packages/sklearn/neural network/ multilay
er_perceptron.py:686: ConvergenceWarning: Stochastic Optimizer: Maximum iter
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warnings.warn(

☑ Best Parameters: {'activation': 'tanh', 'alpha': 0.001, 'hidden_layer_siz es': (100, 50)} ■ Classification Report: precision recall f1-score support 0 0.83 0.82 0.83 666 0.90 0.91 0.90 1182 1 0.88 1848 accuracy 0.86 1848 macro avg 0.87 0.86 weighted avg 0.87 0.88 0.87 1848

● ROC AUC Score: 0.9097384186216674

Training Logistic Regression...

Best Parameters: {'C': 0.1, 'penalty': 'l2', 'solver': 'lbfgs'}

■ Classification Report:

	precision	recall	f1-score	support	
0	0.42	0.53	0.47	666	
1	0.69	0.59	0.64	1182	
accuracy			0.57	1848	
macro avg	0.56	0.56	0.56	1848	
weighted avg	0.60	0.57	0.58	1848	

ROC AUC Score: 0.6025352763931444

Training Random Forest...

■ Best Parameters: {'max_depth': 20, 'min_samples_split': 2, 'n_estimator s': 200}

■ Classification Report:

	precision	recall	f1-score	support
0 1	0.86 0.92	0.85 0.92	0.85 0.92	666 1182
accuracy macro avg weighted avg	0.89 0.90	0.89 0.90	0.90 0.89 0.90	1848 1848 1848

ROC AUC Score: 0.9728783351879798

Training XGBoost...

```
/opt/anaconda3/lib/python3.11/site-packages/xgboost/core.py:158: UserWarnin
g: [09:55:55] WARNING: /Users/runner/work/xgboost/xgboost/src/learner.cc:74
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```

■ Best Parameters: {'learning_rate': 0.2, 'max_depth': 7, 'n_estimators': 2
00}

■ Classification Report:

	precision	recall	f1-score	support
0	0.85	0.84	0.85	666
1	0.91	0.92	0.91	1182
accuracy	,		0.89	1848
macro avo	0.88	0.88	0.88	1848
weighted avo	0.89	0.89	0.89	1848

ROC AUC Score: 0.9566901927308019

Training SVM...

☑ Best Parameters: {'C': 10, 'kernel': 'rbf'}

■ Classification Report:

	precision	recall	f1-score	support
0	0.61	0.66	0.64	666
1	0.80	0.77	0.78	1182
accuracy			0.73	1848
macro avg weighted avg	0.71 0.73	0.71 0.73	0.71 0.73	1848 1848

[●] ROC AUC Score: 0.7659918802050782

Training MLP...

```
/opt/anaconda3/lib/python3.11/site-packages/sklearn/neural network/ multilay
er_perceptron.py:686: ConvergenceWarning: Stochastic Optimizer: Maximum iter
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          warnings.warn(
        ☑ Best Parameters: {'activation': 'tanh', 'alpha': 0.0001, 'hidden_layer_si
        zes': (100, 50)}
        Classification Report:
                       precision
                                    recall f1-score
                                                       support
                   0
                                     0.83
                                                          666
                           0.87
                                               0.85
                   1
                           0.91
                                     0.93
                                               0.92
                                                         1182
                                               0.90
                                                         1848
            accuracy
           macro avg
                           0.89
                                     0.88
                                               0.89
                                                         1848
                                               0.90
        weighted avg
                           0.89
                                     0.90
                                                         1848
        ROC AUC Score: 0.9036104632551333
In [30]: # extract and plot feature importances
In [40]: def plot_shap_bar(model, X_test, title, save_path=None):
             explainer = shap.TreeExplainer(model)
             X for shap = X test[model.feature names in ]
             shap_values = explainer.shap_values(X_for_shap)
             if isinstance(shap_values, list):
                 shap values class1 = shap values[1]
             elif shap values.ndim == 3:
```

```
shap_values_class1 = shap_values[:, :, 1]
else:
    shap_values_class1 = shap_values

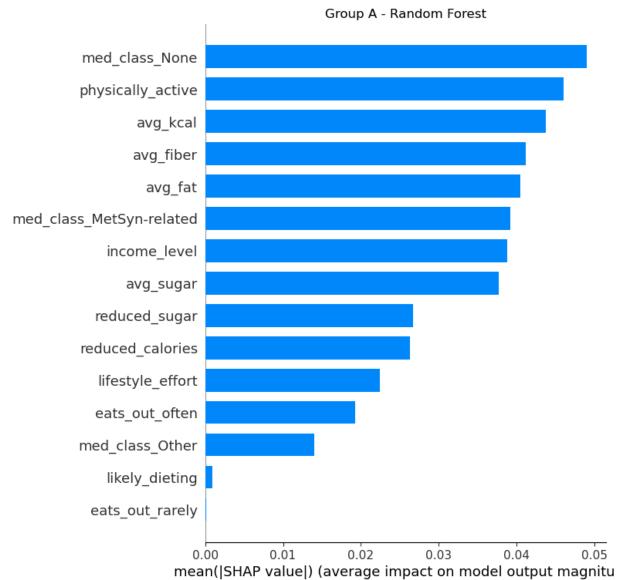
plt.figure()
shap.summary_plot(shap_values_class1, X_for_shap, plot_type="bar", show=
plt.title(title)

if save_path:
    os.makedirs(os.path.dirname(save_path), exist_ok=True)
    plt.savefig(save_path, dpi=300, bbox_inches='tight')
    print(f"Saved: {save_path}")

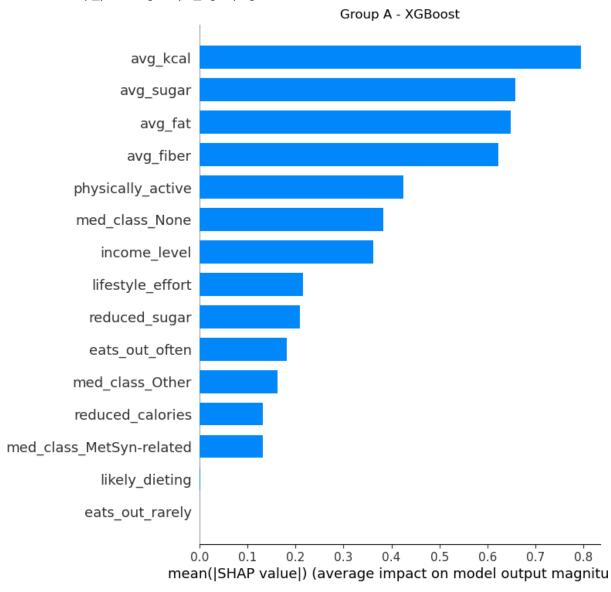
plt.show()
```

In [43]: plot_shap_bar(results_A["Random Forest"]["model"], X_test_A, "Group A - Random plot_shap_bar(results_A["XGBoost"]["model"], X_test_A, "Group A - XGBoost", plot_shap_bar(results_B["Random Forest"]["model"], X_test_B, "Group B - Random plot_shap_bar(results_B["XGBoost"]["model"], X_test_B, "Group B - XGBoost",



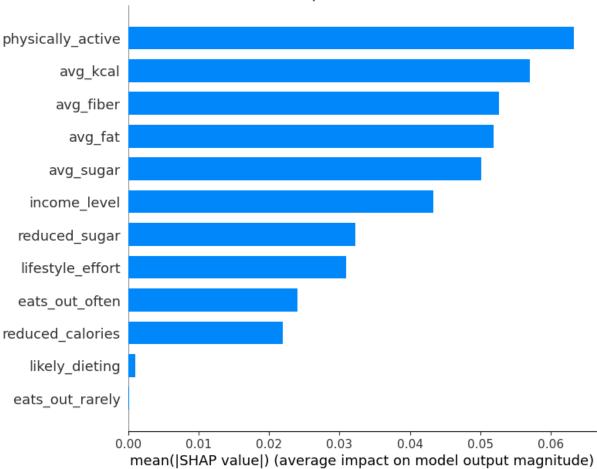


Saved: shap_plots/groupA_xgb.png

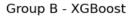


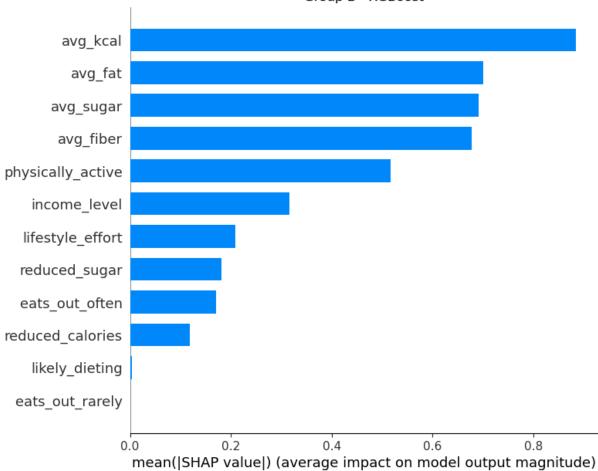
Saved: shap_plots/groupB_rf.png





Saved: shap_plots/groupB_xgb.png





In []: