In [22]:
```
import numpy as np
import time
from nilearn.connectome import ConnectivityMeasure
from nilearn.datasets import fetch_abide_pcp
from nilearn.image import load_img
from sklearn.svm import SVC
from sklearn.model_selection import GridSearchCV, StratifiedKFold
from sklearn.metrics import accuracy_score, f1_score, confusion_matrix
import warnings
warnings.filterwarnings('ignore')

# Download ABIDE dataset with CC400 ROIs
print("Downloading ABIDE dataset with CC400 ROIs...")
abide_data = fetch_abide_pcp(
    derivatives=["rois_cc400"],
    pipeline="cpac",
    band_pass_filtering=True,
    global_signal_regression=True
)
```

```
Downloading ABIDE dataset with CC400 ROIs...
[fetch_abide_pcp] Dataset found in /Users/xinyang/nilearn_data/ABIDE_p
```

In [25]:
```
print("\nExtracting functional connectivity features...")

# 1. Create a functional connectivity estimator (correlation-based)
connectivity_measure = ConnectivityMeasure(kind='correlation')

# 2. Look at the first subject to infer number of ROIs
first_ts = np.asarray(abide_data.rois_cc400[0])
n_time_first, n_rois = first_ts.shape

print(f"Every subject has number of ROIs : {n_rois}")
# Every subject will have shape: (time_points, n_rois)

X = []
y = []

total_subjects = len(abide_data.rois_cc400)
successful = 0

for idx, (ts_obj, label) in enumerate(
    zip(abide_data.rois_cc400, abide_data.phenotypic['DX_GROUP']), 1
):

    # Convert time series to numpy array
    time_series = np.asarray(ts_obj)

    # 4. Compute correlation-based functional connectivity (n_rois × n_rois)
    conn_matrix = connectivity_measure.fit_transform([time_series])[0]

    # 5. Vectorize upper triangle
    upper_triangle = conn_matrix[np.triu_indices_from(conn_matrix, k=1)]
    X.append(upper_triangle)
```

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    # 6. Convert label to: autism=1, control=0
    y_val = 1 if label == 1 else 0
    y.append(y_val)

    # Convert label to text
    label_name = "autism" if y_val == 1 else "control"

    successful += 1

    # 7. One-line progress message (with label)
    print(f"Subject {idx} | {label_name} | shape: {time_series.shape}
    | Connectivity OK | Done")

# ---- Summary ----
print(f"\nSuccessfully processed {successful}/{total_subjects} subjects")

X = np.array(X)
y = np.array(y)

print(f"Number of samples: {len(X)}")
if len(X) > 0:
    print(f"Feature dimension (length of each feature vector): {X.shape[1]}"
print(f"Class distribution (counts of [control, autism]): {np.bincount(y)}")
```

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Extracting functional connectivity features...
Every subject has number of ROIs : 392
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Subject 764 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 765 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 766 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 767 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 768 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 769 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 770 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 771 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 772 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 773 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 774 | autism | shape: (116, 392) | Connectivity OK | Done
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Subject 777 | control | shape: (116, 392) | Connectivity OK | Done
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Subject 780 | control | shape: (116, 392) | Connectivity OK | Done
Subject 781 | control | shape: (116, 392) | Connectivity OK | Done
Subject 782 | control | shape: (116, 392) | Connectivity OK | Done

Subject 783 | control | shape: (116, 392) | Connectivity OK | Done
Subject 784 | control | shape: (116, 392) | Connectivity OK | Done
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Subject 793 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 794 | autism | shape: (116, 392) | Connectivity OK | Done
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Subject 796 | autism | shape: (196, 392) | Connectivity OK | Done
Subject 797 | autism | shape: (196, 392) | Connectivity OK | Done
Subject 798 | control | shape: (116, 392) | Connectivity OK | Done
Subject 799 | control | shape: (116, 392) | Connectivity OK | Done
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Subject 812 | control | shape: (116, 392) | Connectivity OK | Done
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Subject 815 | autism | shape: (196, 392) | Connectivity OK | Done
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Subject 820 | control | shape: (196, 392) | Connectivity OK | Done
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Subject 826 | control | shape: (116, 392) | Connectivity OK | Done
Subject 827 | control | shape: (116, 392) | Connectivity OK | Done
Subject 828 | control | shape: (116, 392) | Connectivity OK | Done
Subject 829 | autism | shape: (146, 392) | Connectivity OK | Done
Subject 830 | autism | shape: (146, 392) | Connectivity OK | Done
Subject 831 | autism | shape: (146, 392) | Connectivity OK | Done
Subject 832 | autism | shape: (146, 392) | Connectivity OK | Done
Subject 833 | autism | shape: (146, 392) | Connectivity OK | Done
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Subject 838 | control | shape: (146, 392) | Connectivity OK | Done

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Subject 839 | control | shape: (146, 392) | Connectivity OK | Done
Subject 840 | control | shape: (146, 392) | Connectivity OK | Done
Subject 841 | control | shape: (146, 392) | Connectivity OK | Done
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Subject 844 | control | shape: (196, 392) | Connectivity OK | Done
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Subject 850 | control | shape: (196, 392) | Connectivity OK | Done
Subject 851 | control | shape: (196, 392) | Connectivity OK | Done
Subject 852 | control | shape: (196, 392) | Connectivity OK | Done
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Subject 857 | control | shape: (196, 392) | Connectivity OK | Done
Subject 858 | autism | shape: (196, 392) | Connectivity OK | Done
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Subject 862 | autism | shape: (196, 392) | Connectivity OK | Done
Subject 863 | autism | shape: (196, 392) | Connectivity OK | Done
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Subject 867 | autism | shape: (196, 392) | Connectivity OK | Done
Subject 868 | autism | shape: (196, 392) | Connectivity OK | Done
Subject 869 | autism | shape: (196, 392) | Connectivity OK | Done
Subject 870 | autism | shape: (116, 392) | Connectivity OK | Done
Subject 871 | autism | shape: (116, 392) | Connectivity OK | Done

Successfully processed 871/871 subjects
Number of samples: 871
Feature dimension (length of each feature vector): 76636
Class distribution (counts of [control, autism]): [468 403]
```

In [26]:

```python
# Grid search for optimal SVM parameters
print("\n" + "="*60)
print("Grid Search for Optimal SVM Parameters")
print("="*60)

# Define parameter grid
param_grid = {
    'C': [0.01, 1, 10, 100],
    'kernel': ['rbf', 'linear']
}

# Define 5-fold cross-validation
skf = StratifiedKFold(n_splits=5, shuffle=True, random_state=42)

# Initialize GridSearchCV
svm = SVC(random_state=42)
```

```
# Grid Search
grid_search = GridSearchCV(
    svm,
    param_grid,
    cv=skf,
    scoring='accuracy',
    n_jobs=-1,
    verbose=1
)

# Fit grid search
print("\nPerforming grid search...")
start_time_grid = time.time()
grid_search.fit(X, y)
total_time_grid = time.time() - start_time_grid

# Print best parameters and best score
print(f"\nBest parameters: {grid_search.best_params_}")
print(f"Best cross-validation score: {grid_search.best_score_:.4f}")
print(f"Total time for grid search: {total_time_grid/60:.2f} minutes ({total

# Get best model
best_svm = grid_search.best_estimator_
```

```
============================================================
Grid Search for Optimal SVM Parameters
============================================================

Performing grid search...
Fitting 5 folds for each of 8 candidates, totalling 40 fits

Best parameters: {'C': 10, 'kernel': 'rbf'}
Best cross-validation score: 0.6911
Total time for grid search: 3.09 minutes (185.36s)
```

In [27]:
```
# Store metrics for each fold using best model
print("\n" + "="*60)
print("5-Fold Cross-Validation Results with Best Model")
print("="*60)

accuracies = []
sensitivities = []
specificities = []
f1_scores = []
fold_times = []

fold = 1
total_cv_time = 0  # track total time for CV

for train_idx, test_idx in skf.split(X, y):
    fold_start = time.time()   # start timing this fold

    X_train, X_test = X[train_idx], X[test_idx]
    y_train, y_test = y[train_idx], y[test_idx]
```

```
    # Train best SVM model
    best_svm.fit(X_train, y_train)

    # Predict
    y_pred = best_svm.predict(X_test)

    # Calculate metrics
    acc = accuracy_score(y_test, y_pred)
    f1 = f1_score(y_test, y_pred, average='binary')

    # Sensitivity & Specificity
    tn, fp, fn, tp = confusion_matrix(y_test, y_pred).ravel()
    sens = tp / (tp + fn)
    spec = tn / (tn + fp)

    fold_time = time.time() - fold_start   # calculate fold time
    total_cv_time += fold_time

    # Store metrics
    accuracies.append(acc)
    sensitivities.append(sens)
    specificities.append(spec)
    f1_scores.append(f1)
    fold_times.append(fold_time)

    fold += 1

# ---- Print table for each fold ----
print("\nFold   Accuracy  Sensitivity  Specificity  F1 Score  Time (s)")
for i in range(5):
    print(f"{i+1:<5}  {accuracies[i]:.4f}    {sensitivities[i]:.4f}       "
          f"{specificities[i]:.4f}       {f1_scores[i]:.4f}   {fold_times[i]

# Calculate and display mean and std
print("\n" + "="*60)
print("Mean Results Across 5 Folds")
print("="*60)
print(f"Accuracy:    {np.mean(accuracies):.4f} ± {np.std(accuracies):.4f}")
print(f"Sensitivity: {np.mean(sensitivities):.4f} ± {np.std(sensitivities):.
print(f"Specificity: {np.mean(specificities):.4f} ± {np.std(specificities):.
print(f"F1 Score:    {np.mean(f1_scores):.4f} ± {np.std(f1_scores):.4f}")
print("="*60)

# Print total CV time
print(f"\nTotal time for 5-fold evaluation: {total_cv_time/60:.2f} minutes (
print("="*60)
```

```
============================================================
5-Fold Cross-Validation Results with Best Model
============================================================

Fold   Accuracy  Sensitivity  Specificity  F1 Score  Time (s)
1      0.7086    0.6914       0.7234       0.6871   6.74
2      0.7011    0.5926       0.7957       0.6486   6.71
3      0.6954    0.5679       0.8065       0.6345   6.74
4      0.6897    0.6125       0.7553       0.6447   6.70
5      0.6609    0.6125       0.7021       0.6242   6.81

============================================================
Mean Results Across 5 Folds
============================================================
Accuracy:    0.6911 ± 0.0164
Sensitivity: 0.6154 ± 0.0414
Specificity: 0.7566 ± 0.0402
F1 Score:    0.6478 ± 0.0214
============================================================

Total time for 5-fold evaluation: 0.56 minutes (33.71 seconds)
============================================================
```

In [ ]: