```
In [1]:   from simplified_bio_cnn import run_experiment

          # Run the experiment
          results = run_experiment()
```

Using device: cuda
CUDA available: True

Running biologically-inspired CNN experiment

Training Control model...
Epoch 1/5: 100%|████████| 782/782 [00:30<00:00, 25.30it/s, loss=0.231, acc=
83.85%]
Epoch 1 Summary:
  Train Acc: 83.85%
  Val Acc: 91.05%
Epoch 2/5: 100%|████████| 782/782 [00:27<00:00, 28.32it/s, loss=0.272, acc=
93.10%]
Epoch 2 Summary:
  Train Acc: 93.10%
  Val Acc: 93.26%
Epoch 3/5: 100%|████████| 782/782 [00:26<00:00, 29.05it/s, loss=0.091, acc=
95.29%]
Epoch 3 Summary:
  Train Acc: 95.29%
  Val Acc: 93.42%
Epoch 4/5: 100%|████████| 782/782 [00:27<00:00, 28.42it/s, loss=0.034, acc=
96.60%]
Epoch 4 Summary:
  Train Acc: 96.60%
  Val Acc: 94.05%
Epoch 5/5: 100%|████████| 782/782 [00:27<00:00, 28.36it/s, loss=0.240, acc=
97.41%]
Epoch 5 Summary:
  Train Acc: 97.41%
  Val Acc: 93.62%

Test results for Control:
  clean: 93.62%
  noisy: 14.72%
  occluded: 92.16%

Training Bio_Combined model...
Epoch 1/5: 100%|████████| 782/782 [00:28<00:00, 27.52it/s, loss=0.366, acc=
83.82%]
Epoch 1 Summary:
  Train Acc: 83.82%
  Val Acc: 90.83%
  mixing: 0.619
  inhibition_alpha: 1.008
  attention_gamma: 0.982
Epoch 2/5: 100%|████████| 782/782 [00:28<00:00, 27.84it/s, loss=0.092, acc=
93.05%]
```

```
Epoch 2 Summary:
  Train Acc: 93.05%
  Val Acc: 93.25%
  mixing: 0.618
  inhibition_alpha: 1.008
  attention_gamma: 0.973
Epoch 3/5: 100%|████████████| 782/782 [00:28<00:00, 27.55it/s, loss=0.027, acc=
95.33%]
Epoch 3 Summary:
  Train Acc: 95.33%
  Val Acc: 93.15%
  mixing: 0.617
  inhibition_alpha: 1.010
  attention_gamma: 0.964
Epoch 4/5: 100%|████████████| 782/782 [00:28<00:00, 27.27it/s, loss=0.331, acc=
96.67%]
Epoch 4 Summary:
  Train Acc: 96.67%
  Val Acc: 93.71%
  mixing: 0.616
  inhibition_alpha: 1.011
  attention_gamma: 0.958
Epoch 5/5: 100%|████████████| 782/782 [00:28<00:00, 27.46it/s, loss=0.109, acc=
97.69%]
Epoch 5 Summary:
  Train Acc: 97.69%
  Val Acc: 93.68%
  mixing: 0.615
  inhibition_alpha: 1.010
  attention_gamma: 0.950

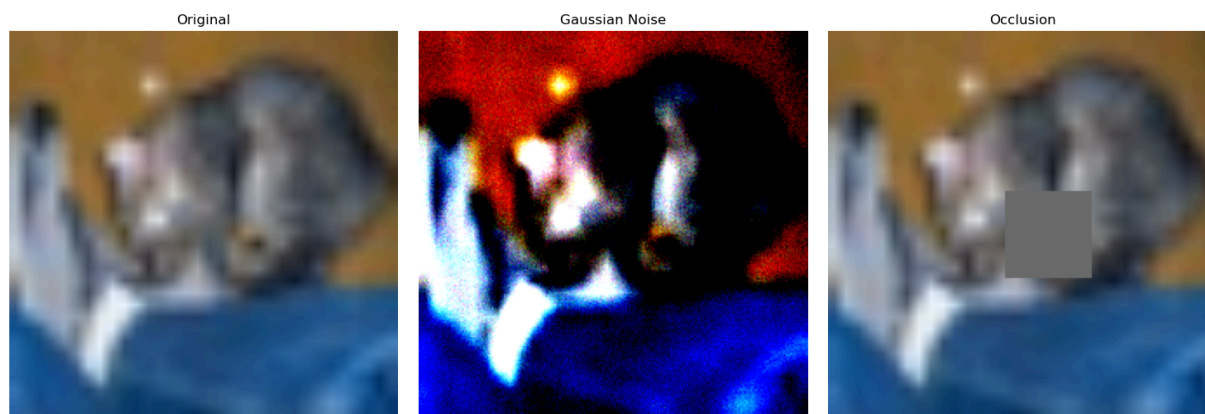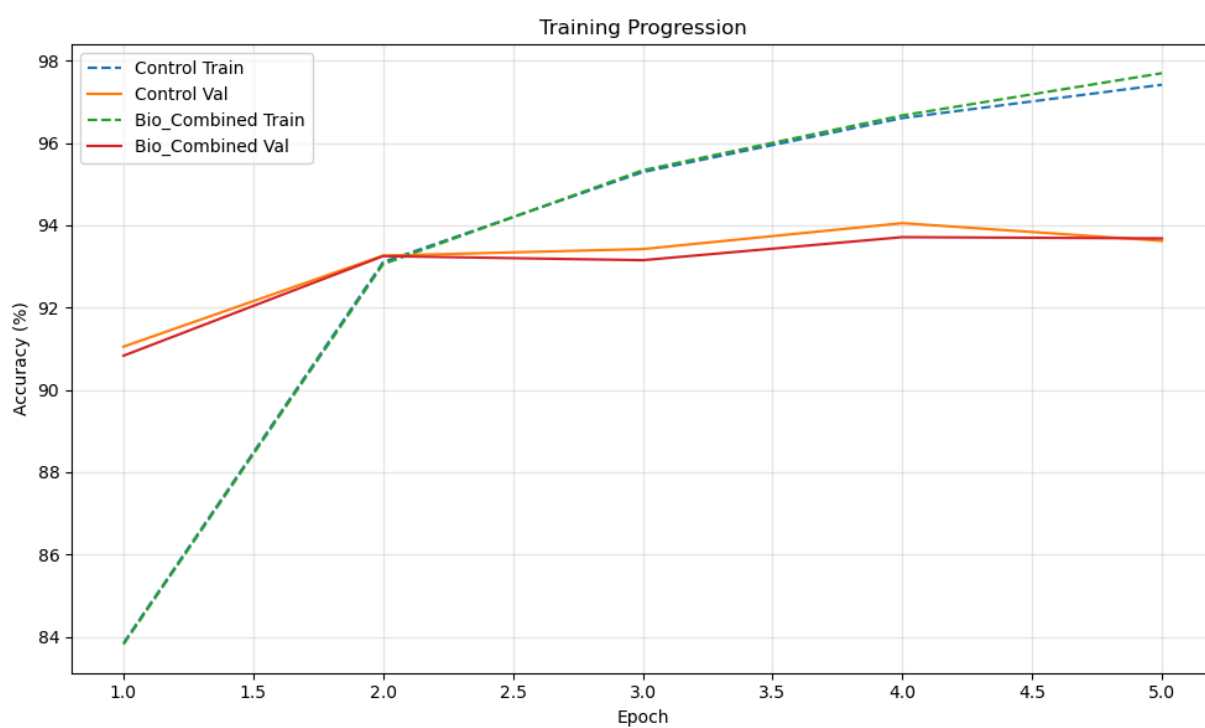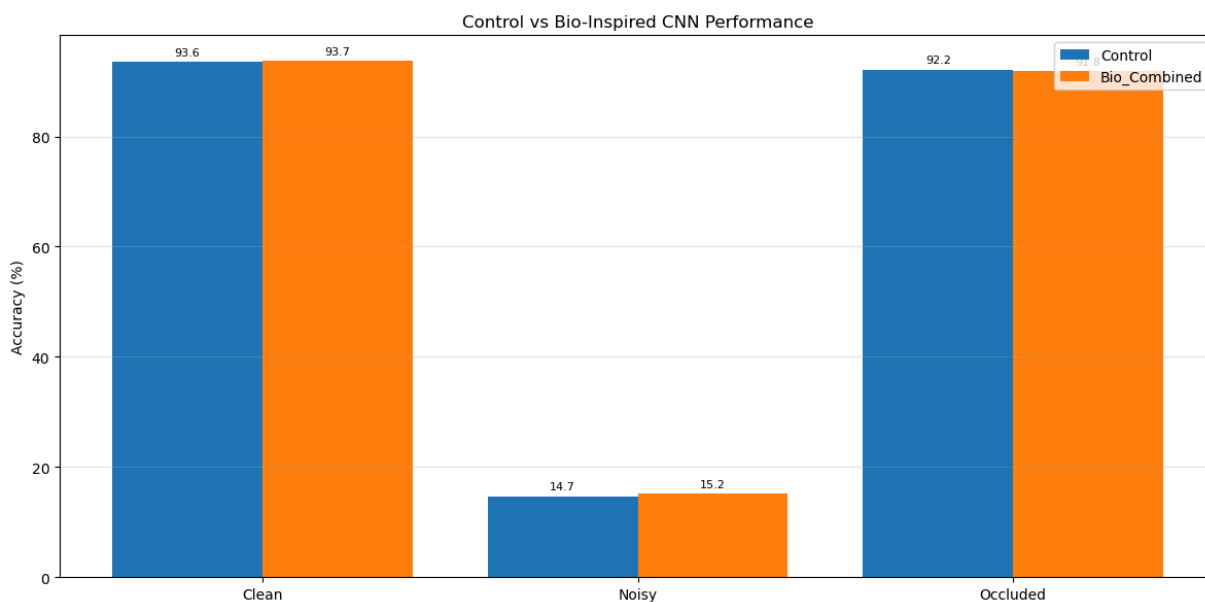Test results for Bio_Combined:
  clean: 93.68%
  noisy: 15.23%
  occluded: 91.82%

Improvement over control model:
  clean: +0.06%
  noisy: +3.46%
  occluded: −0.37%
```

Control vs Bio-Inspired CNN Performance

Training Progression

| Original | Gaussian Noise | Occlusion |

```
In [2]: from bio_cnn import run_experiment
```

```python
# Run the experiment
results = run_experiment()
```

Using device: cuda
CUDA available: True

Running biologically-inspired CNN experiment with ablation study

Training Control model...
Epoch 1/5: 100%|████████| 782/782 [00:27<00:00, 28.43it/s, loss=0.386, acc=84.32%]
Epoch 1 Summary:
  Train Acc: 84.32%
  Val Acc: 91.38%
Epoch 2/5: 100%|████████| 782/782 [00:28<00:00, 27.90it/s, loss=0.097, acc=93.29%]
Epoch 2 Summary:
  Train Acc: 93.29%
  Val Acc: 93.16%
Epoch 3/5: 100%|████████| 782/782 [00:27<00:00, 28.76it/s, loss=0.632, acc=95.34%]
Epoch 3 Summary:
  Train Acc: 95.34%
  Val Acc: 93.68%
Epoch 4/5: 100%|████████| 782/782 [00:27<00:00, 28.36it/s, loss=0.069, acc=96.55%]
Epoch 4 Summary:
  Train Acc: 96.55%
  Val Acc: 93.77%
Epoch 5/5: 100%|████████| 782/782 [00:27<00:00, 28.93it/s, loss=0.035, acc=97.47%]
Epoch 5 Summary:
  Train Acc: 97.47%
  Val Acc: 93.84%

Test results for Control:
  clean: 93.84%
  noisy: 16.10%
  occluded: 92.20%

Training Bio_Combined model...
Epoch 1/5: 100%|████████| 782/782 [00:28<00:00, 27.87it/s, loss=0.469, acc=84.23%]
Epoch 1 Summary:
  Train Acc: 84.23%
  Val Acc: 91.84%
  mixing: 0.619
  inhibition_alpha: 1.008
  attention_gamma: 0.981
Epoch 2/5: 100%|████████| 782/782 [00:28<00:00, 27.78it/s, loss=0.301, acc=93.18%]
```

```
Epoch 2 Summary:
  Train Acc: 93.18%
  Val Acc: 93.07%
  mixing: 0.617
  inhibition_alpha: 1.010
  attention_gamma: 0.970
Epoch 3/5: 100%|████████| 782/782 [00:28<00:00, 27.68it/s, loss=0.818, acc=
95.37%]
Epoch 3 Summary:
  Train Acc: 95.37%
  Val Acc: 93.79%
  mixing: 0.616
  inhibition_alpha: 1.012
  attention_gamma: 0.959
Epoch 4/5: 100%|████████| 782/782 [00:28<00:00, 27.87it/s, loss=0.049, acc=
96.78%]
Epoch 4 Summary:
  Train Acc: 96.78%
  Val Acc: 94.07%
  mixing: 0.614
  inhibition_alpha: 1.016
  attention_gamma: 0.952
Epoch 5/5: 100%|████████| 782/782 [00:28<00:00, 27.76it/s, loss=0.378, acc=
97.74%]
Epoch 5 Summary:
  Train Acc: 97.74%
  Val Acc: 93.99%
  mixing: 0.614
  inhibition_alpha: 1.013
  attention_gamma: 0.947

Test results for Bio_Combined:
  clean: 93.99%
  noisy: 16.73%
  occluded: 92.43%

Training Bio_Inhibition_Only model...
Epoch 1/5: 100%|████████| 782/782 [00:28<00:00, 27.23it/s, loss=0.348, acc=
83.74%]
Epoch 1 Summary:
  Train Acc: 83.74%
  Val Acc: 91.67%
  inhibition_alpha: 0.984
Epoch 2/5: 100%|████████| 782/782 [00:28<00:00, 27.30it/s, loss=0.365, acc=
93.09%]
Epoch 2 Summary:
  Train Acc: 93.09%
  Val Acc: 93.02%
  inhibition_alpha: 0.977
Epoch 3/5: 100%|████████| 782/782 [00:28<00:00, 27.54it/s, loss=0.120, acc=
95.35%]
Epoch 3 Summary:
  Train Acc: 95.35%
  Val Acc: 93.73%
  inhibition_alpha: 0.974
```

```
Epoch 4/5: 100%|███████████| 782/782 [00:28<00:00, 27.74it/s, loss=0.188, acc=
96.70%]
Epoch 4 Summary:
  Train Acc: 96.70%
  Val Acc: 93.82%
  inhibition_alpha: 0.974
Epoch 5/5: 100%|███████████| 782/782 [00:28<00:00, 27.79it/s, loss=0.027, acc=
97.66%]
Epoch 5 Summary:
  Train Acc: 97.66%
  Val Acc: 93.62%
  inhibition_alpha: 0.972

Test results for Bio_Inhibition_Only:
  clean: 93.62%
  noisy: 16.21%
  occluded: 91.78%

Training Bio_Attention_Only model...
Epoch 1/5: 100%|███████████| 782/782 [00:28<00:00, 27.76it/s, loss=0.219, acc=
83.96%]
Epoch 1 Summary:
  Train Acc: 83.96%
  Val Acc: 90.74%
  attention_gamma: 0.990
Epoch 2/5: 100%|███████████| 782/782 [00:28<00:00, 27.63it/s, loss=0.340, acc=
93.06%]
Epoch 2 Summary:
  Train Acc: 93.06%
  Val Acc: 93.05%
  attention_gamma: 0.981
Epoch 3/5: 100%|███████████| 782/782 [00:28<00:00, 27.68it/s, loss=0.232, acc=
95.33%]
Epoch 3 Summary:
  Train Acc: 95.33%
  Val Acc: 93.71%
  attention_gamma: 0.972
Epoch 4/5: 100%|███████████| 782/782 [00:28<00:00, 27.81it/s, loss=0.185, acc=
96.51%]
Epoch 4 Summary:
  Train Acc: 96.51%
  Val Acc: 93.89%
  attention_gamma: 0.966
Epoch 5/5: 100%|███████████| 782/782 [00:28<00:00, 27.76it/s, loss=0.259, acc=
97.59%]
```

```
Epoch 5 Summary:
  Train Acc: 97.59%
  Val Acc: 93.28%
  attention_gamma: 0.968

Test results for Bio_Attention_Only:
  clean: 93.28%
  noisy: 16.40%
  occluded: 91.74%

Improvement over control model:

Bio_Combined:
  clean: +0.16%
  noisy: +3.91%
  occluded: +0.25%

Bio_Inhibition_Only:
  clean: −0.23%
  noisy: +0.68%
  occluded: −0.46%

Bio_Attention_Only:
  clean: −0.60%
  noisy: +1.86%
  occluded: −0.50%

Ablation comparison (relative to combined model):

Bio_Inhibition_Only:
  clean: −0.71% points
  noisy: −0.33% points
  occluded: −0.69% points

Bio_Attention_Only:
  clean: −0.71% points
  noisy: −0.33% points
  occluded: −0.69% points
```
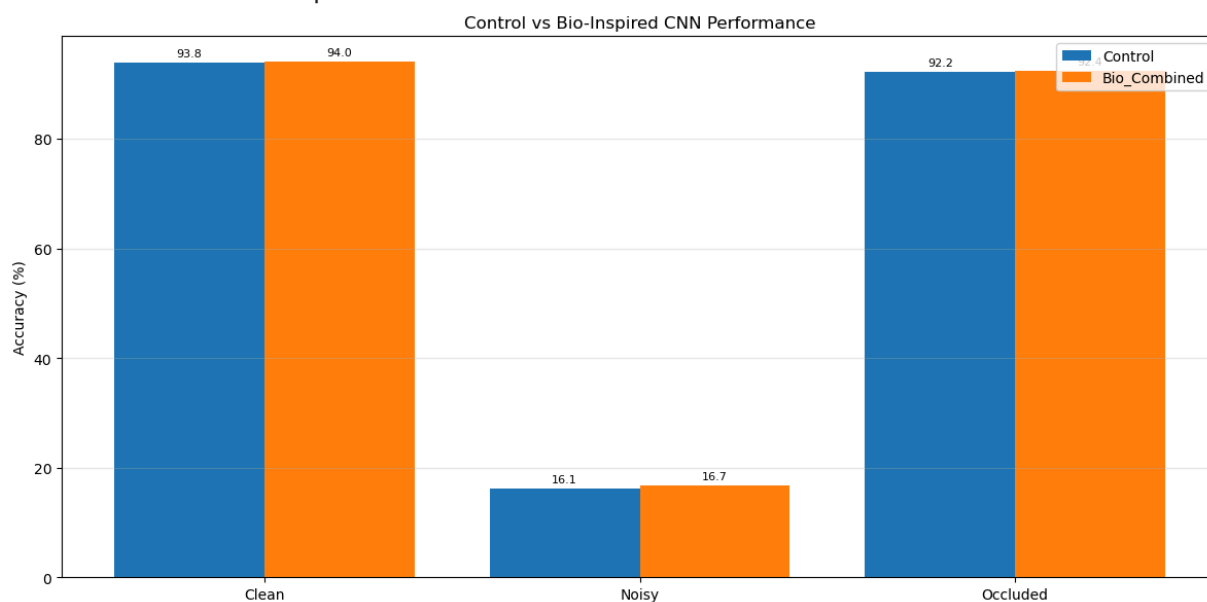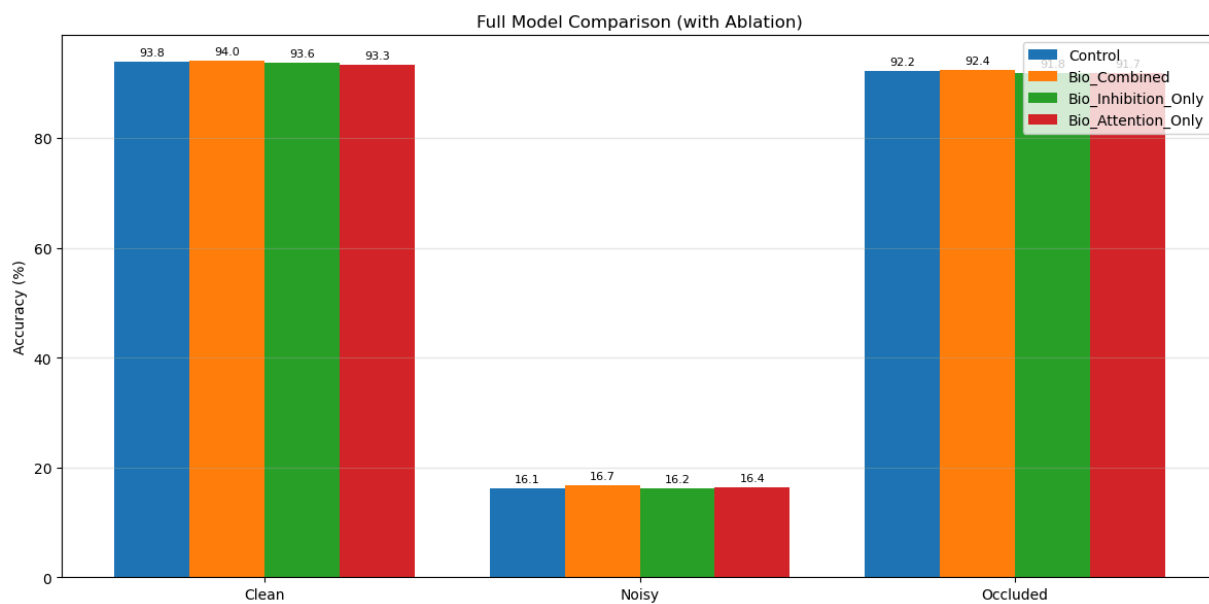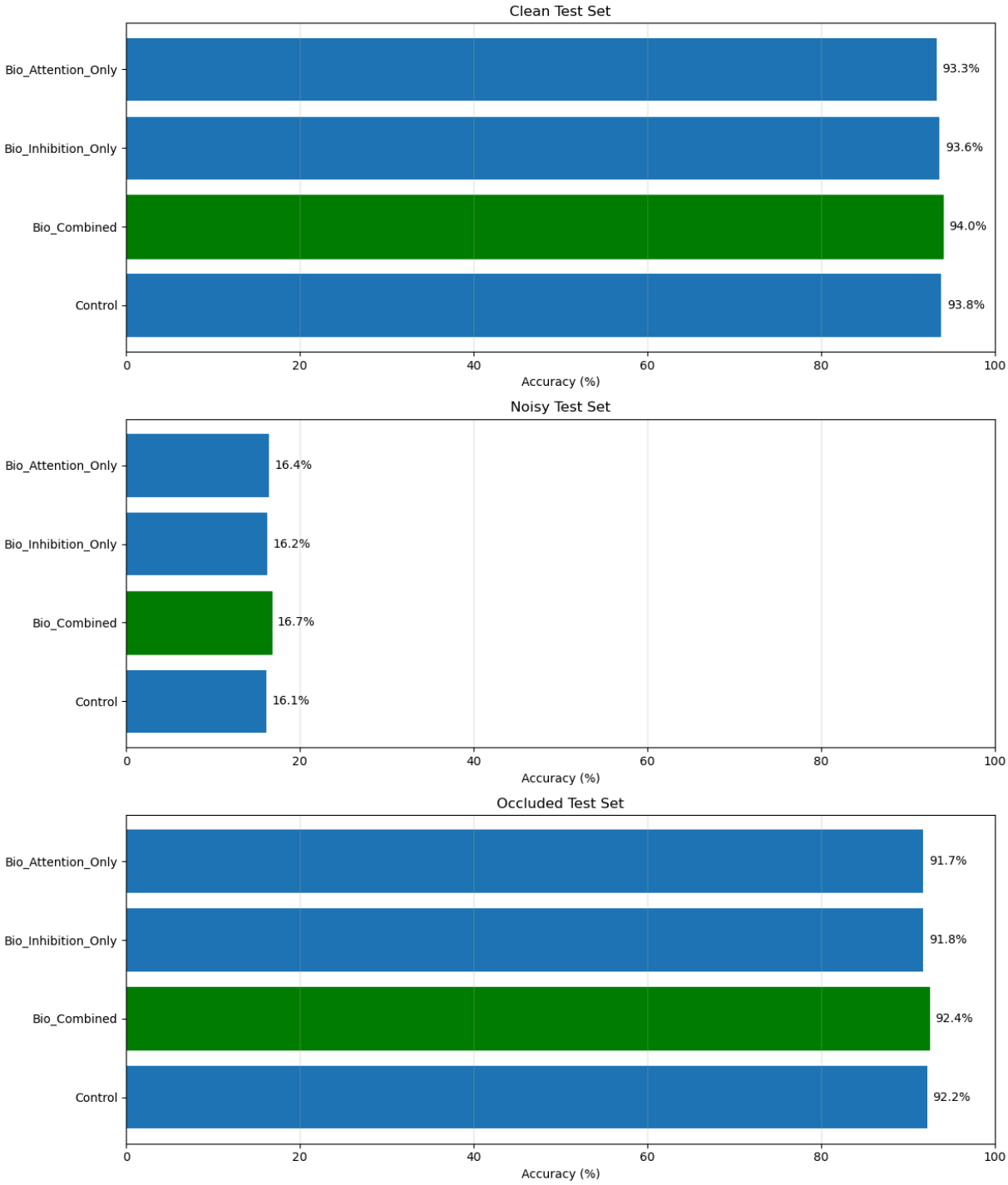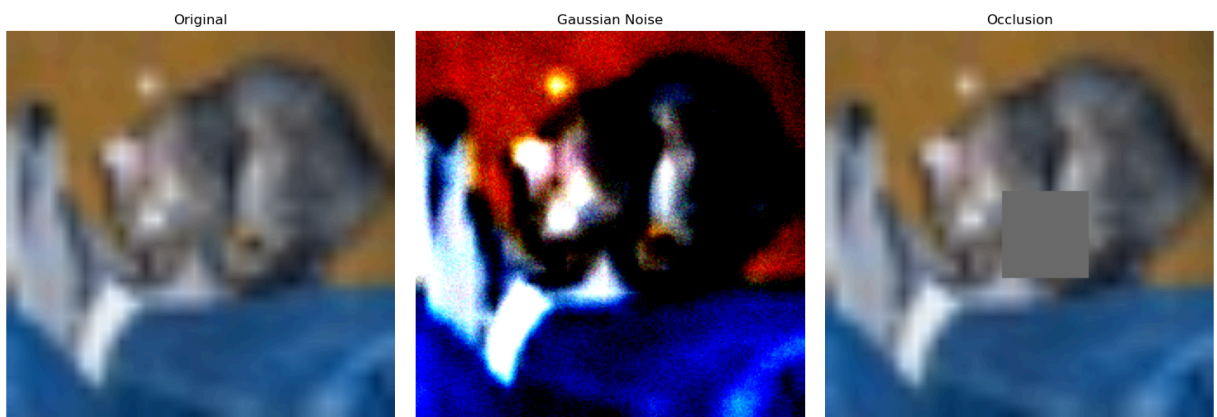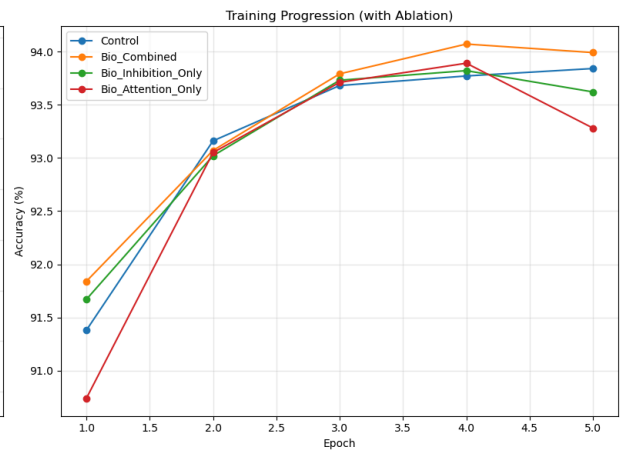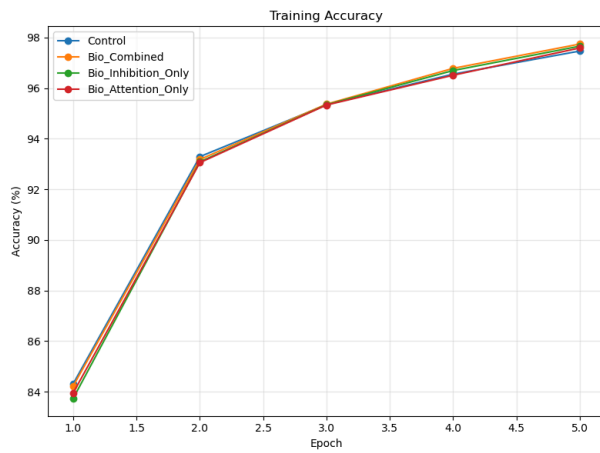

Control vs Bio-Inspired CNN Performance

Full Model Comparison (with Ablation)

Ablation Study: Model Performance Comparison

Clean Test Set

- Bio_Attention_Only: 93.3%
- Bio_Inhibition_Only: 93.6%
- Bio_Combined: 94.0%
- Control: 93.8%

Noisy Test Set

- Bio_Attention_Only: 16.4%
- Bio_Inhibition_Only: 16.2%
- Bio_Combined: 16.7%
- Control: 16.1%

Occluded Test Set

- Bio_Attention_Only: 91.7%
- Bio_Inhibition_Only: 91.8%
- Bio_Combined: 92.4%
- Control: 92.2%

Training Progression (Original)

Training Accuracy

Training Progression (with Ablation)

Original

Gaussian Noise

Occlusion

In [ ]: