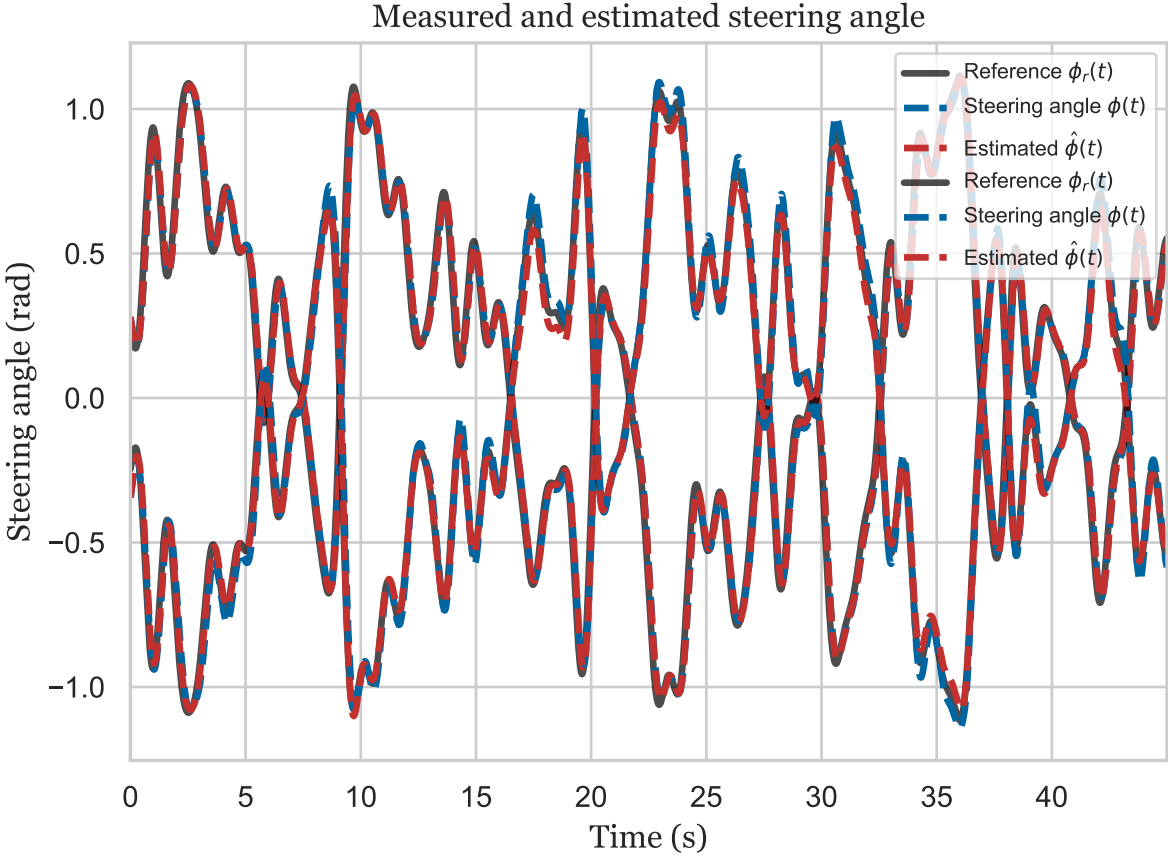
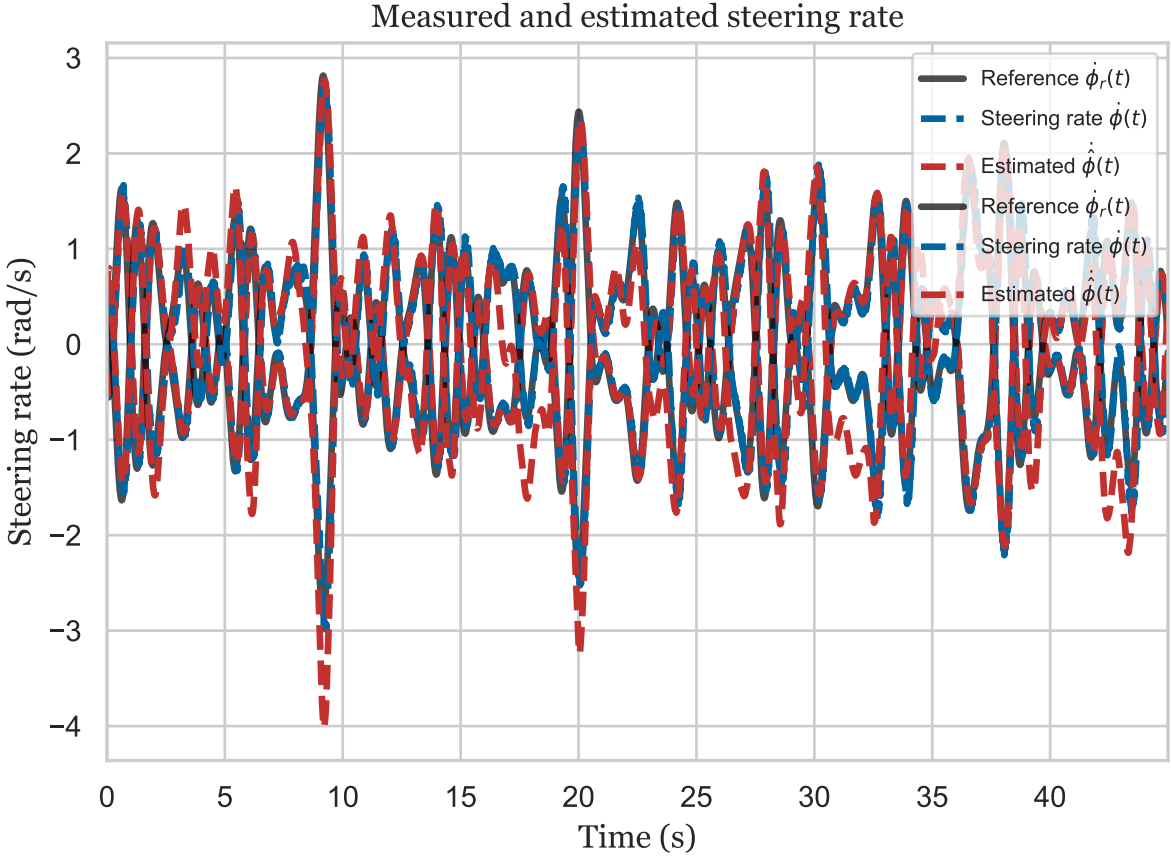
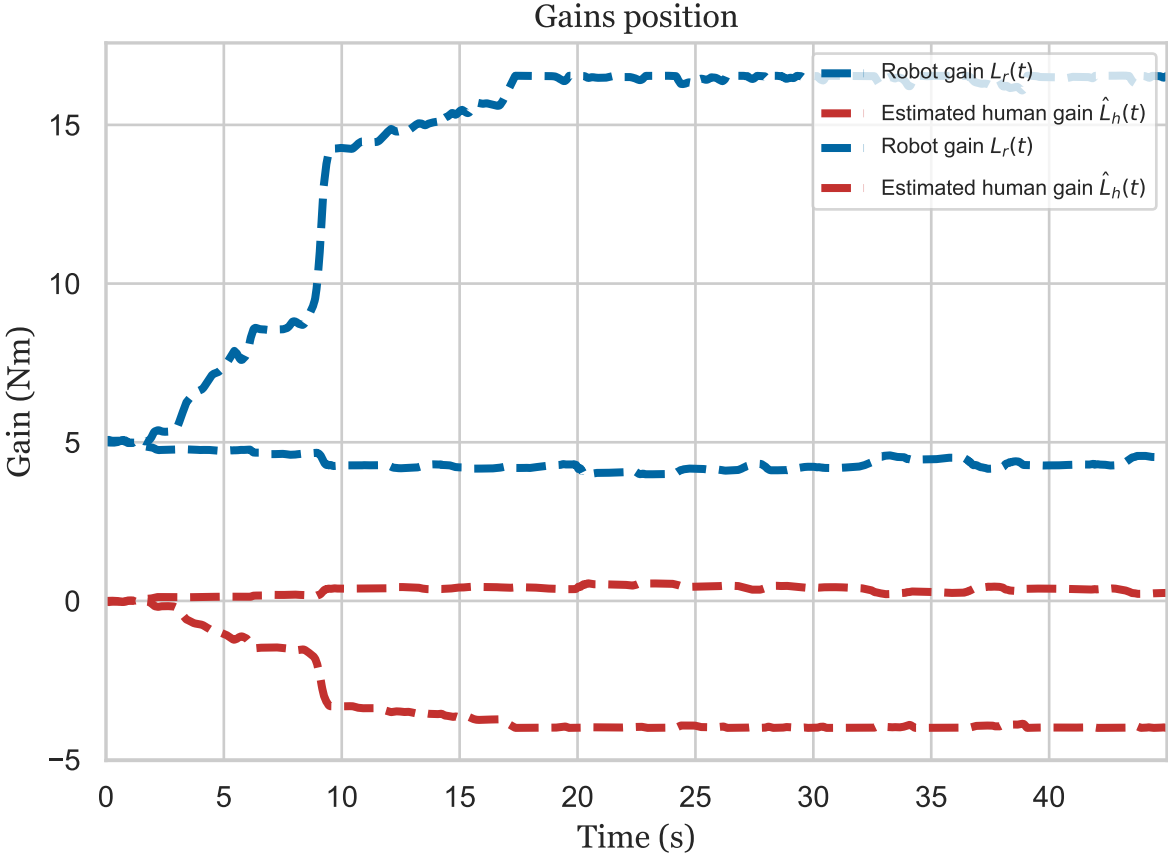
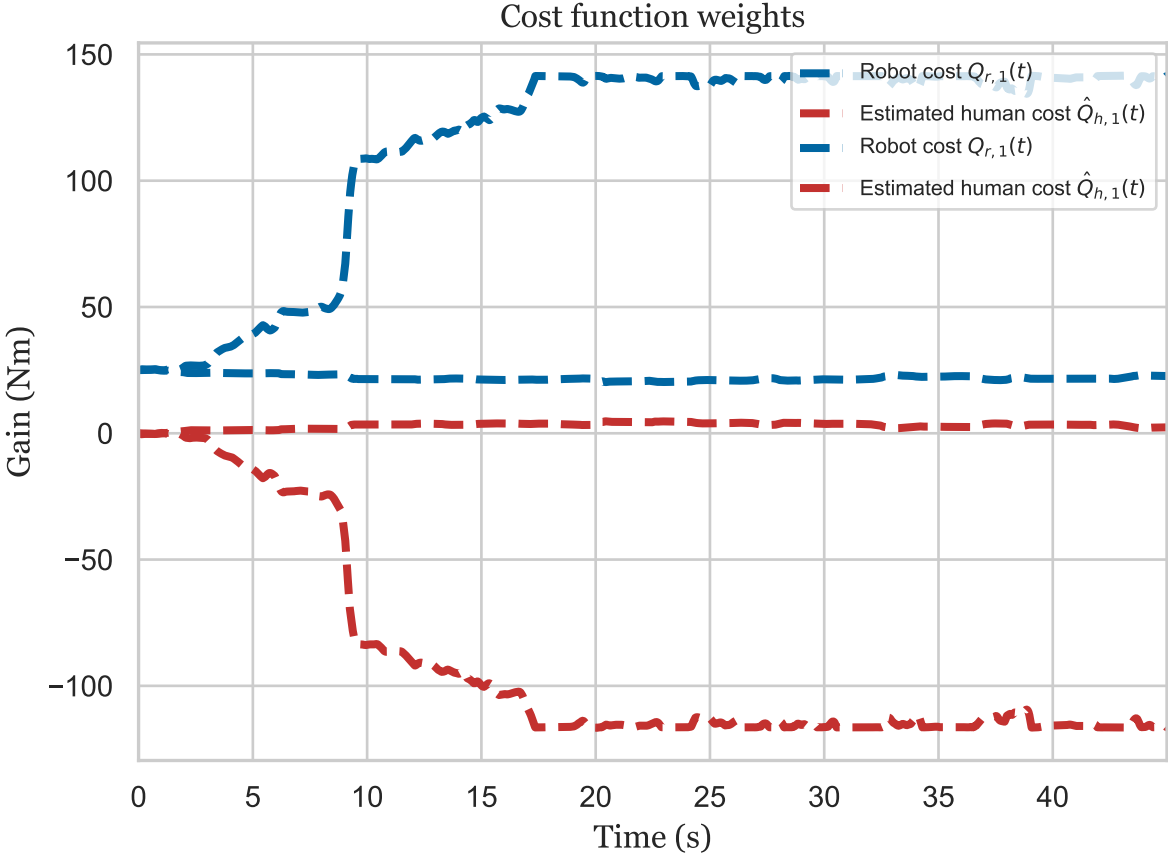
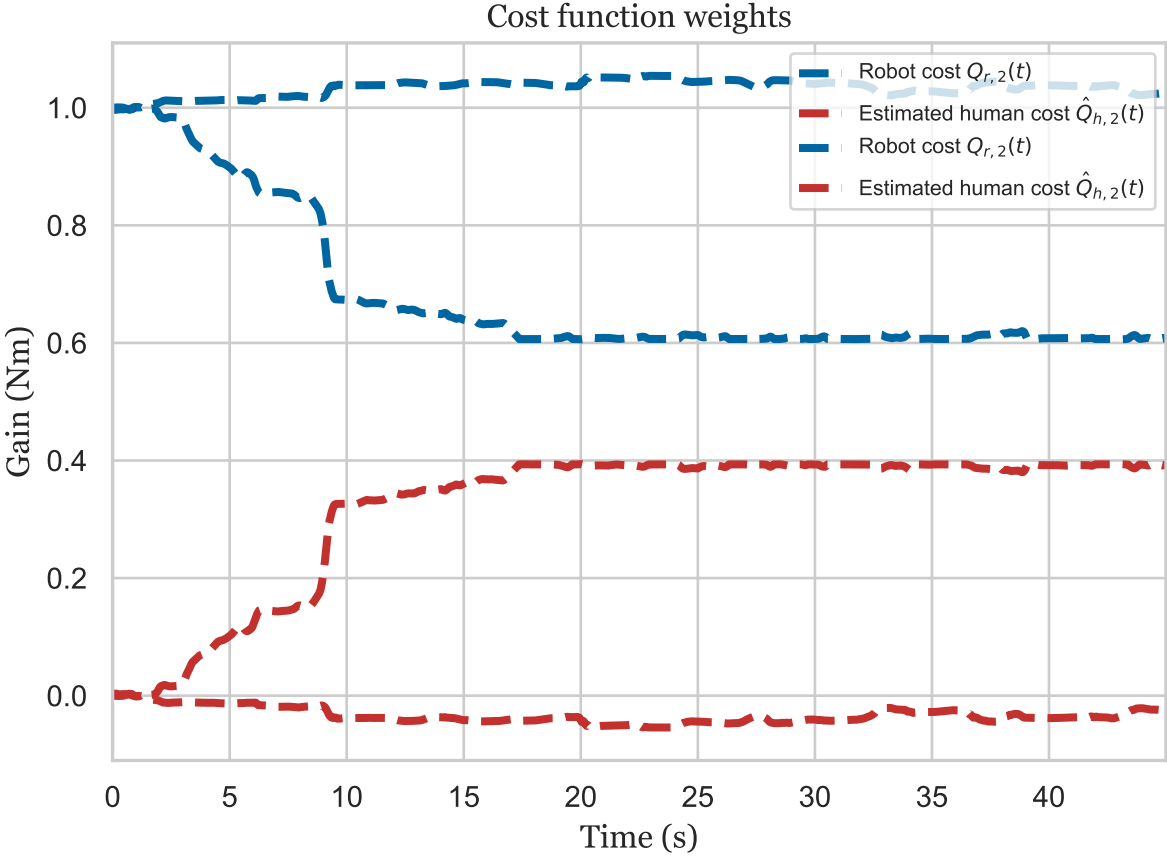
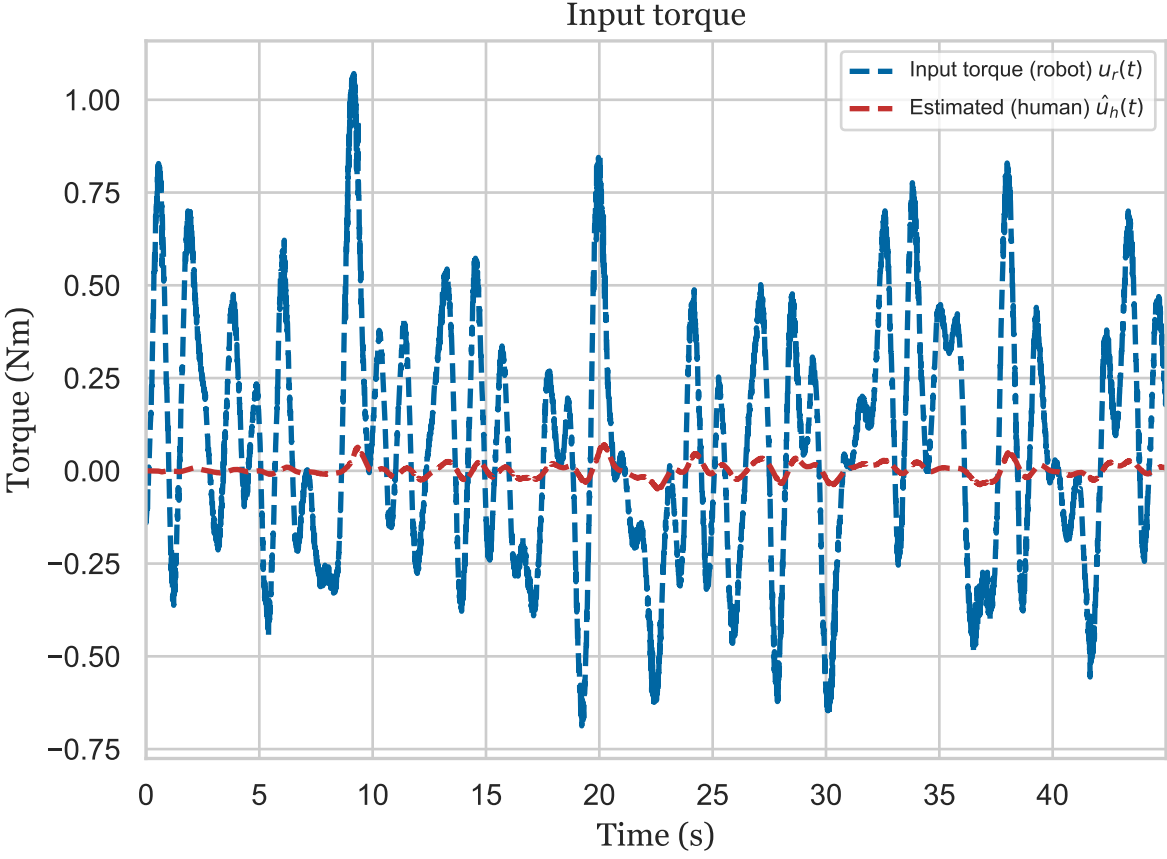

Measured and estimated steering angle
Reference $\phi_r(t)$
Steering angle $\phi(t)$
Estimated $\hat{\phi}(t)$
Reference $\phi_r(t)$
Steering angle $\phi(t)$
Estimated $\hat{\phi}(t)$
Steering angle (rad)
1.0
0.5
0.0
−0.5
−1.0
0
5
10
15
20
25
30
35
40
Time (s)

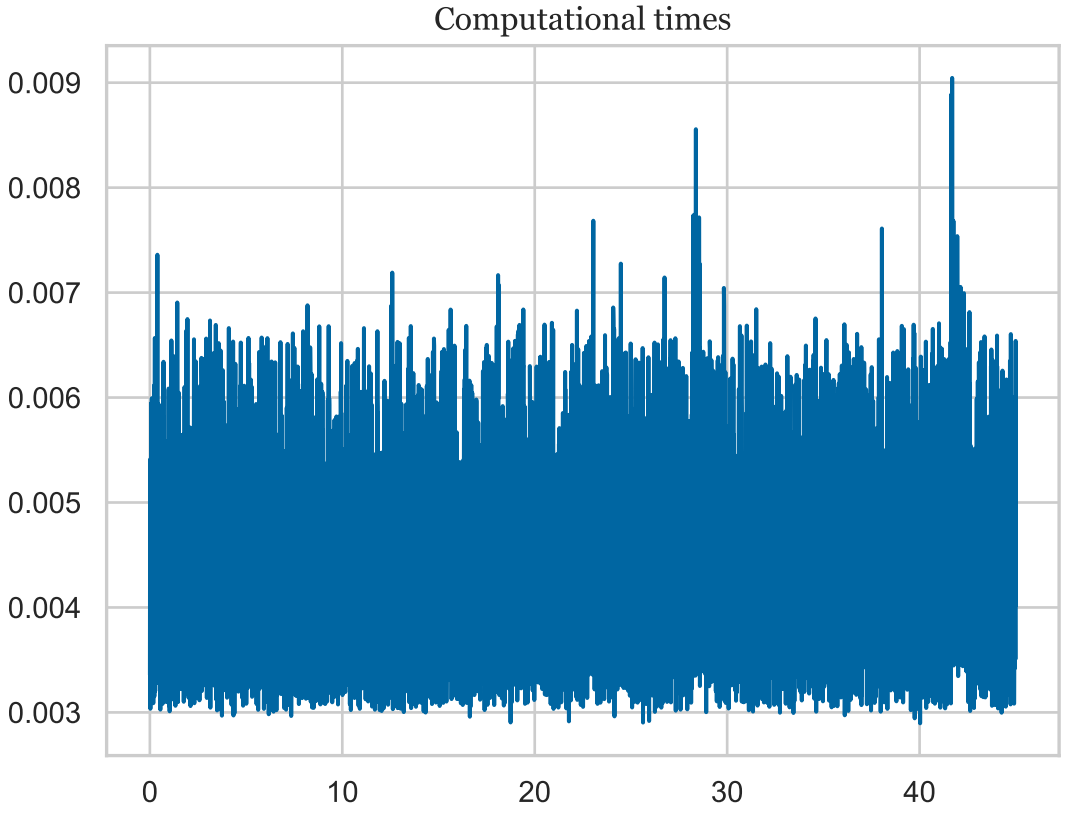

Measured and estimated steering rate
Steering rate (rad/s)
Time (s)
Reference $\dot{\phi}_r(t)$
Steering rate $\dot{\phi}(t)$
Estimated $\hat{\dot{\phi}}(t)$
Reference $\dot{\phi}_r(t)$
Steering rate $\dot{\phi}(t)$
Estimated $\hat{\dot{\phi}}(t)$
3
2
1
0
−1
−2
−3
−4
0
5
10
15
20
25
30
35
40

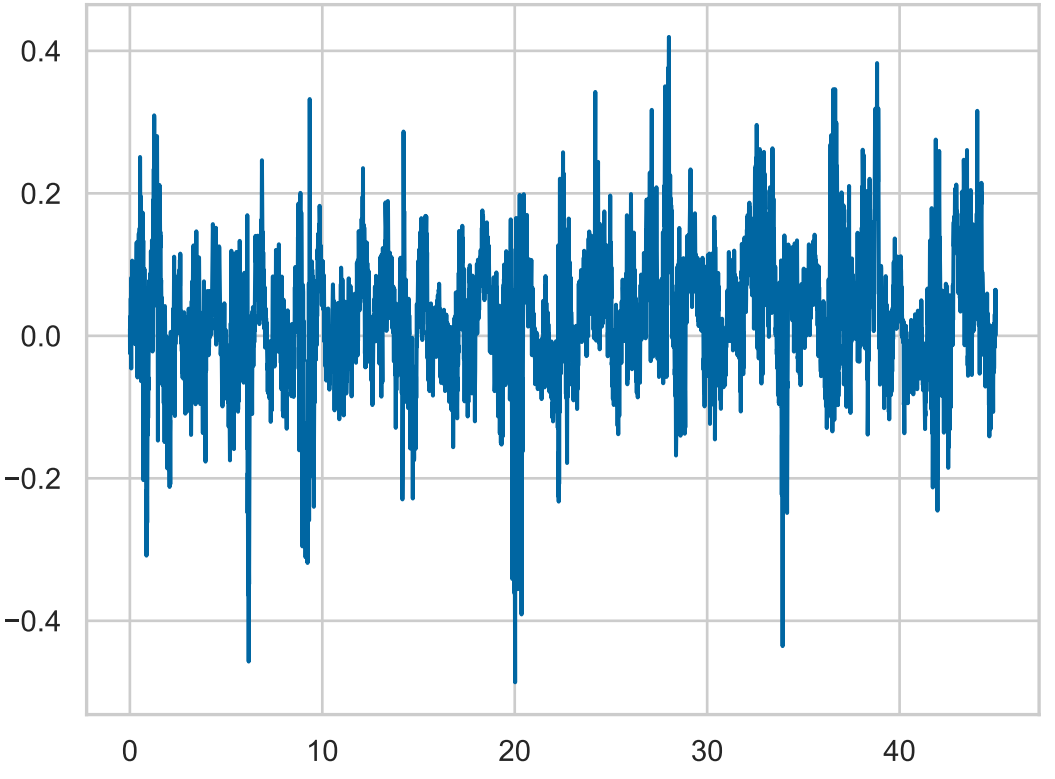

Gains position
Robot gain $L_r(t)$
Estimated human gain $\hat{L}_h(t)$
Robot gain $L_r(t)$
Estimated human gain $\hat{L}_h(t)$
Gain (Nm)
15
10
5
0
−5
0
5
10
15
20
25
30
35
40
Time (s)

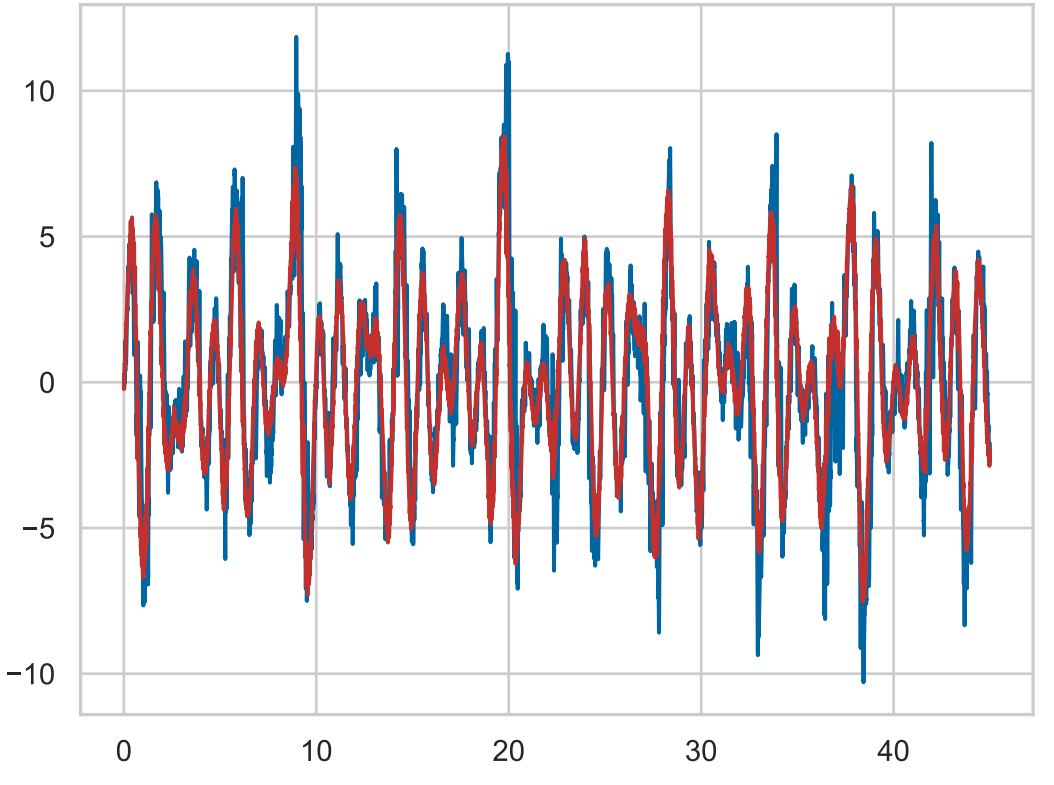

Cost function weights
Robot cost $Q_{r,1}(t)$
Estimated human cost $\hat{Q}_{h,1}(t)$
Robot cost $Q_{r,1}(t)$
Estimated human cost $\hat{Q}_{h,1}(t)$
150
100
50
0
−50
−100
Gain (Nm)
0
5
10
15
20
25
30
35
40
Time (s)

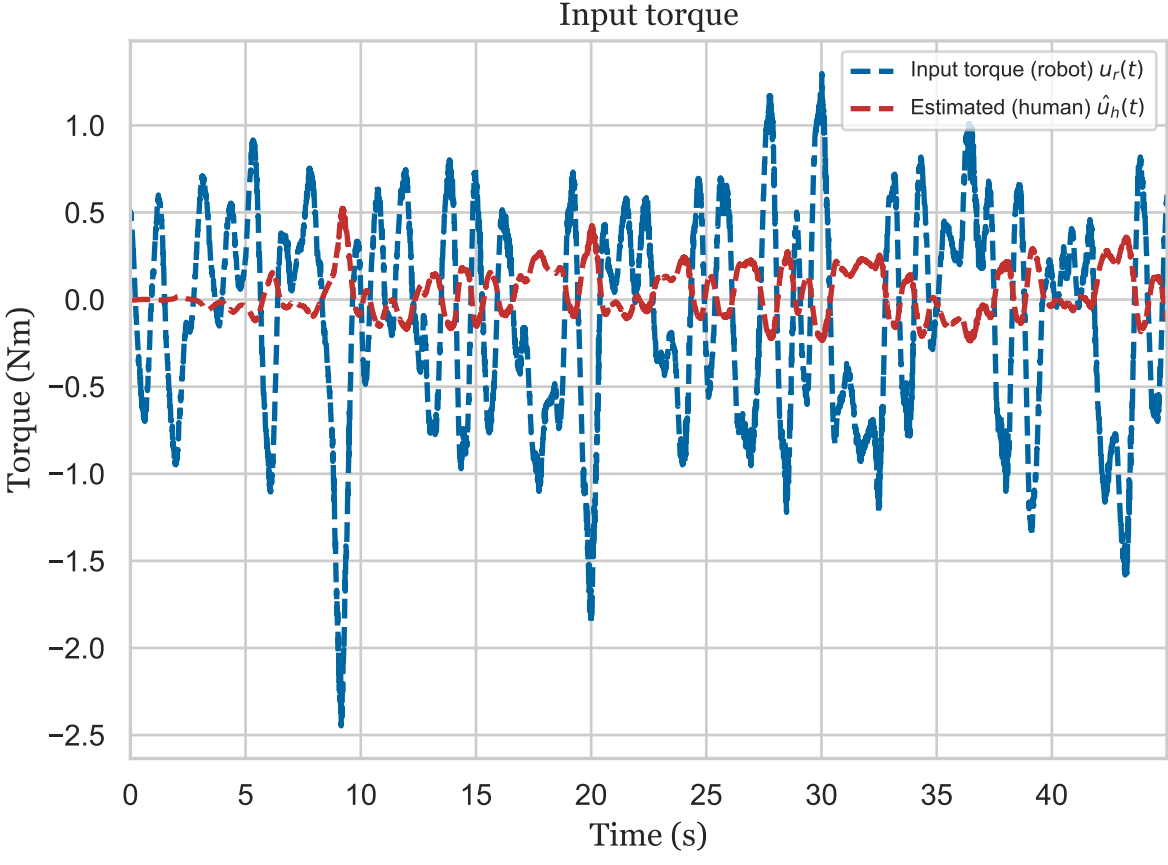

Cost function weights
Robot cost $Q_{r,2}(t)$
Estimated human cost $\hat{Q}_{h,2}(t)$
Robot cost $Q_{r,2}(t)$
Estimated human cost $\hat{Q}_{h,2}(t)$
Gain (Nm)
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
25
30
35
40
Time (s)

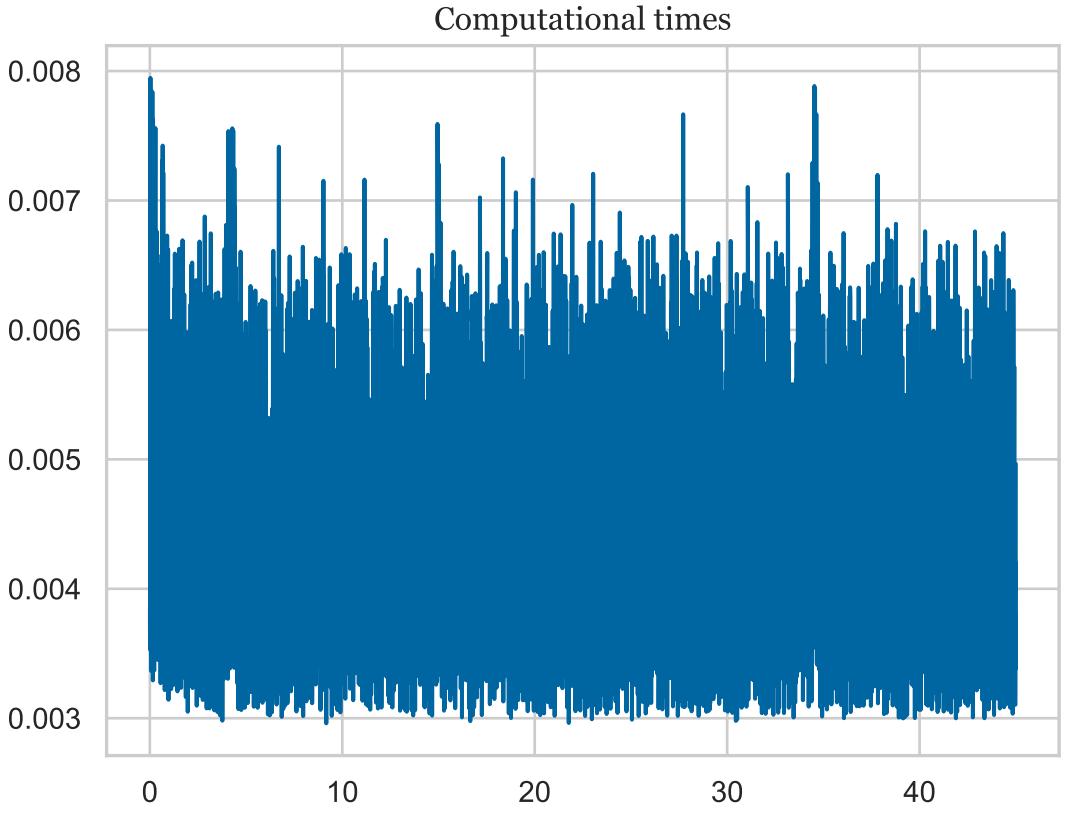

Input torque
Input torque (robot) $u_r(t)$
Estimated (human) $\hat{u}_h(t)$
Torque (Nm)
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
0
5
10
15
20
25
30
35
40
Time (s)

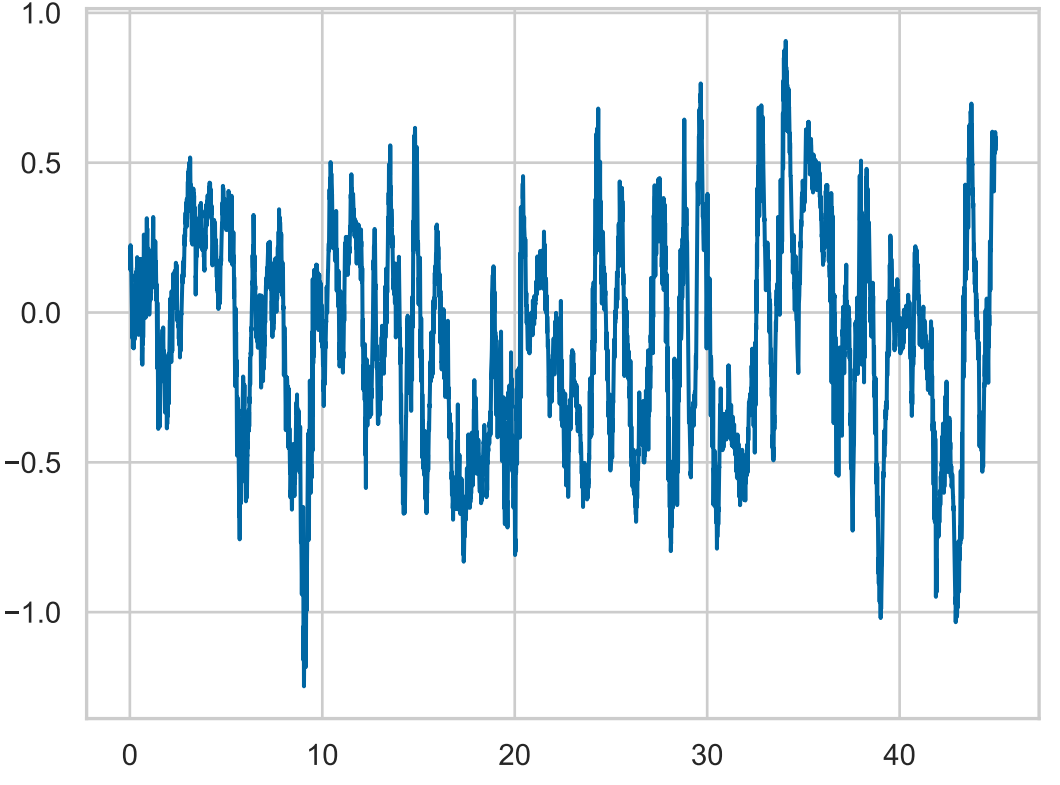

Computational times
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0
10
20
30
40

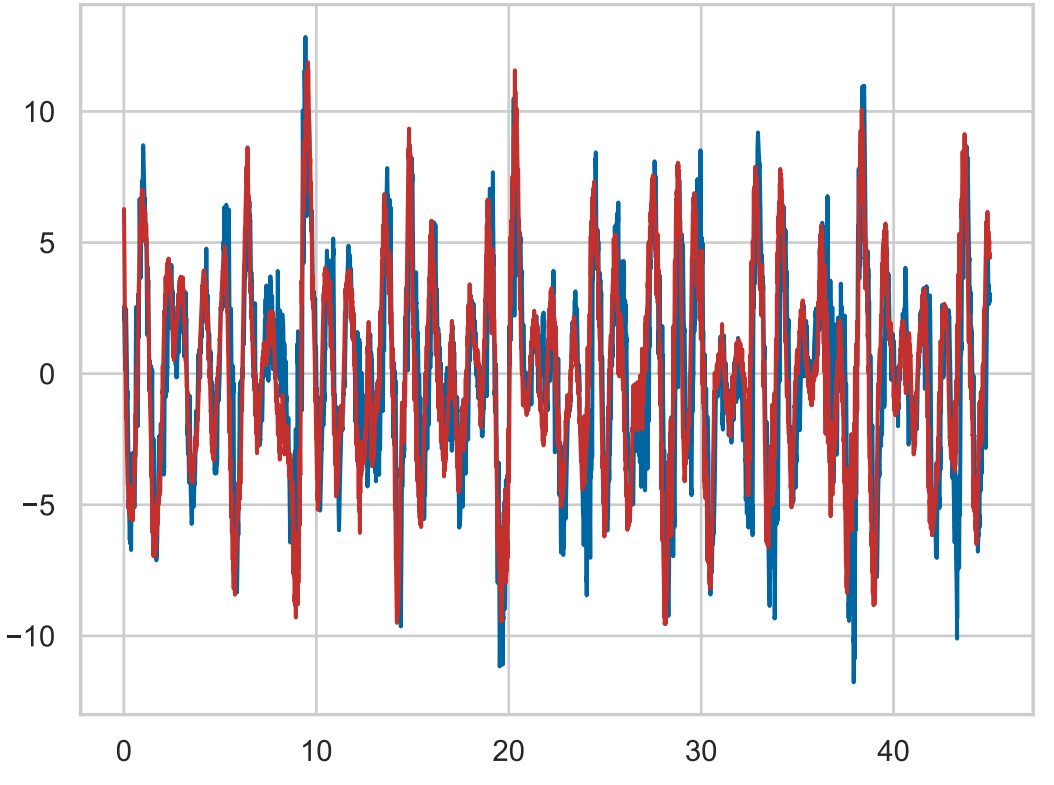

0.4
0.2
0.0
−0.2
−0.4
0
10
20
30
40

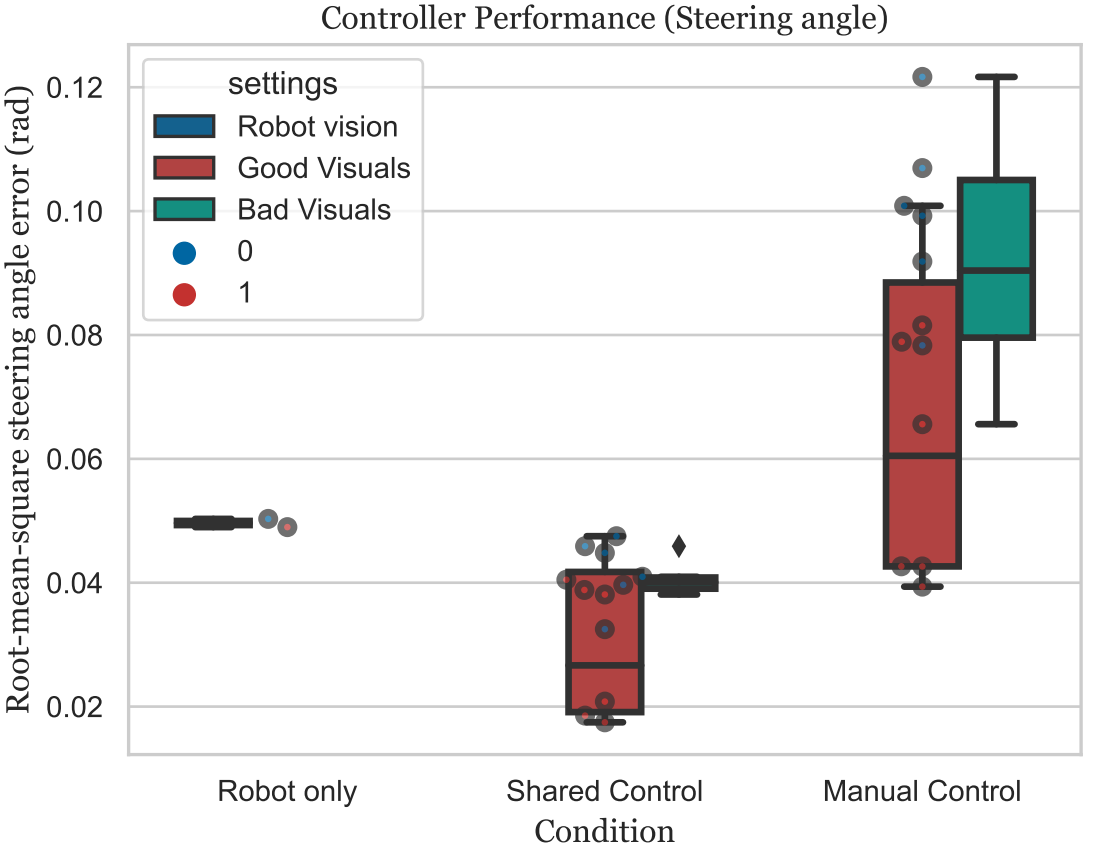

10
5
0
−5
−10
0
10
20
30
40

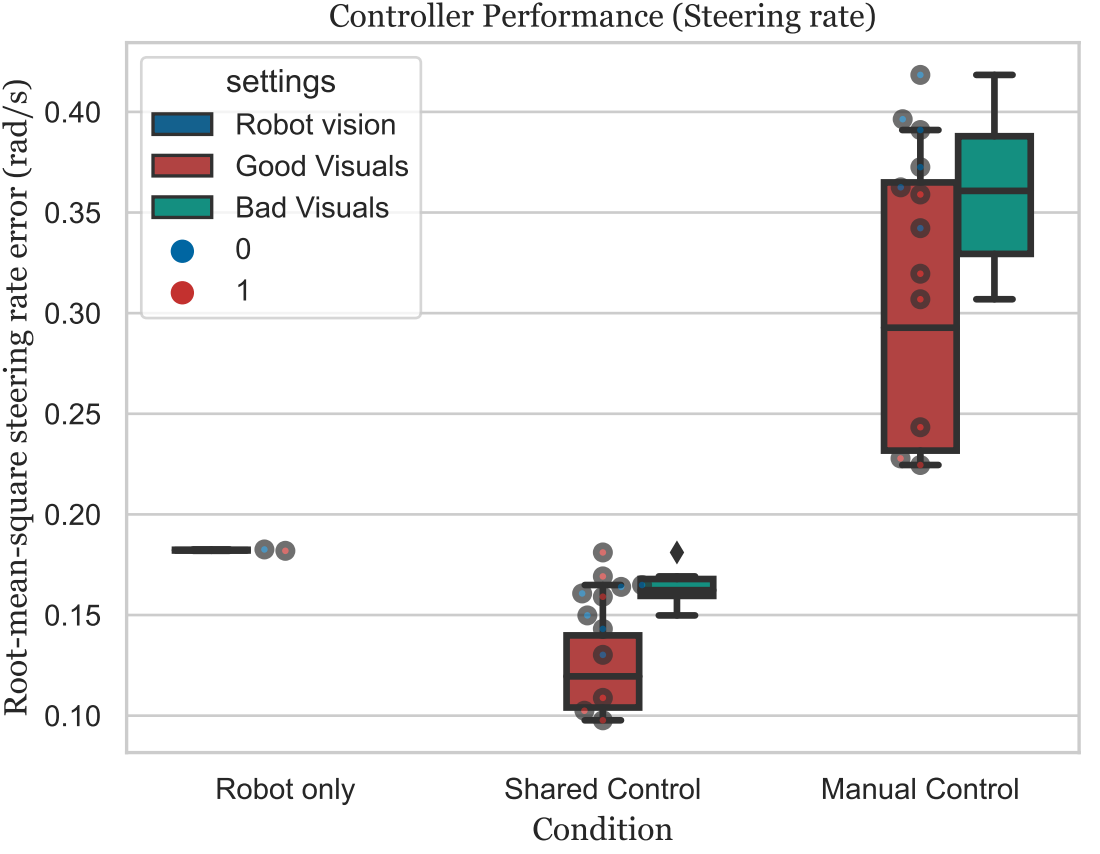

Input torque
Input torque (robot) $u_r(t)$
Estimated (human) $\hat{u}_h(t)$
Torque (Nm)
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
0
5
10
15
20
25
30
35
40
Time (s)

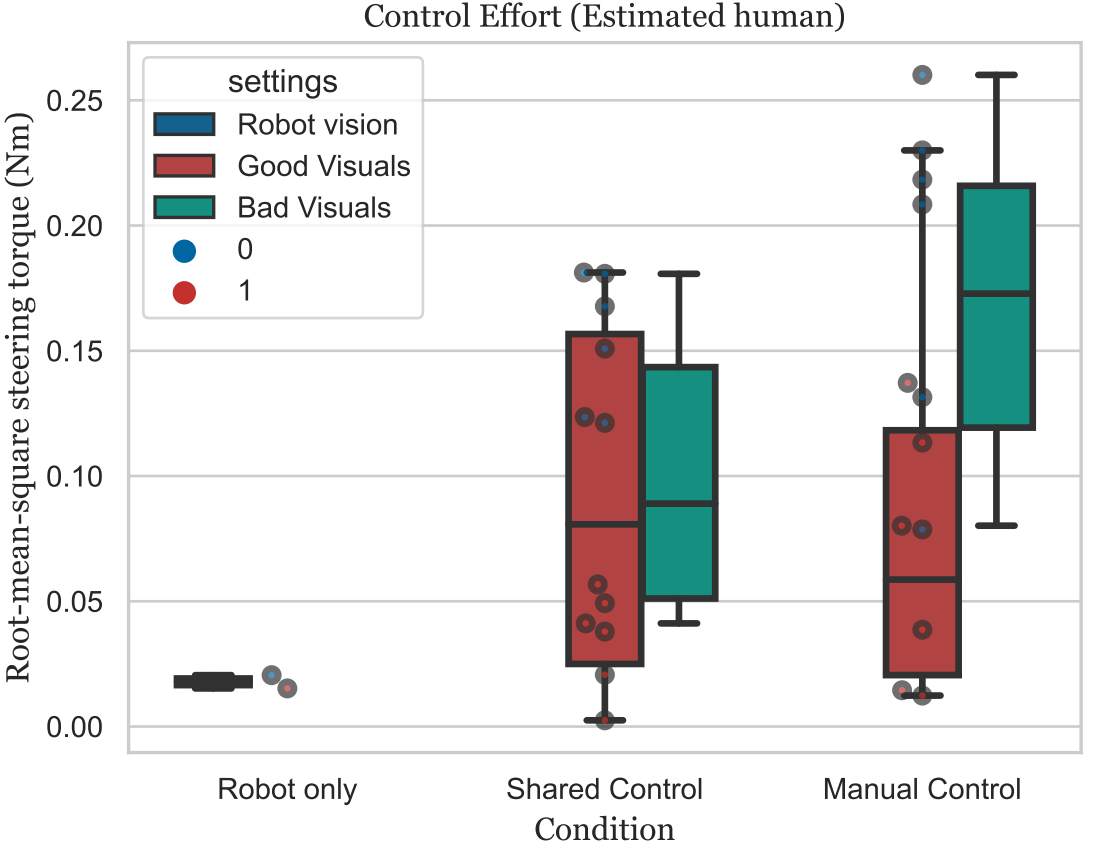

Computational times
0.008
0.007
0.006
0.005
0.004
0.003
0
10
20
30
40

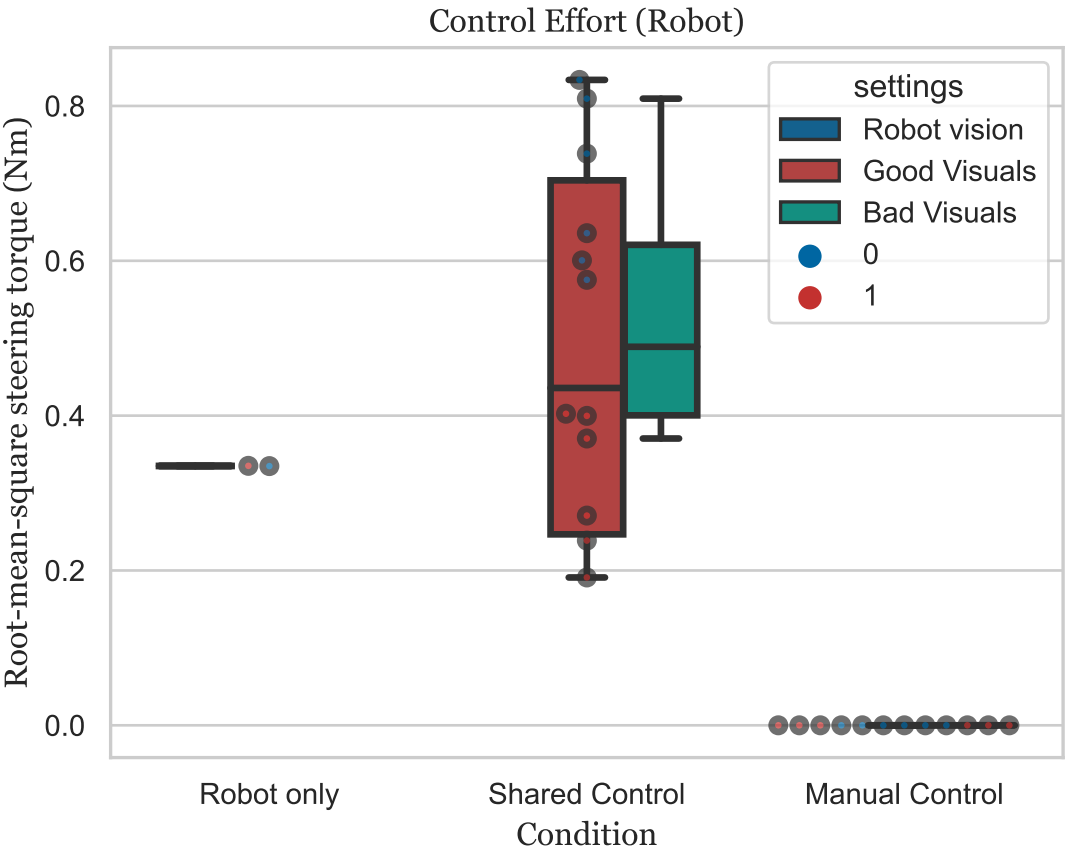

1.0
0.5
0.0
−0.5
−1.0
0
10
20
30
40

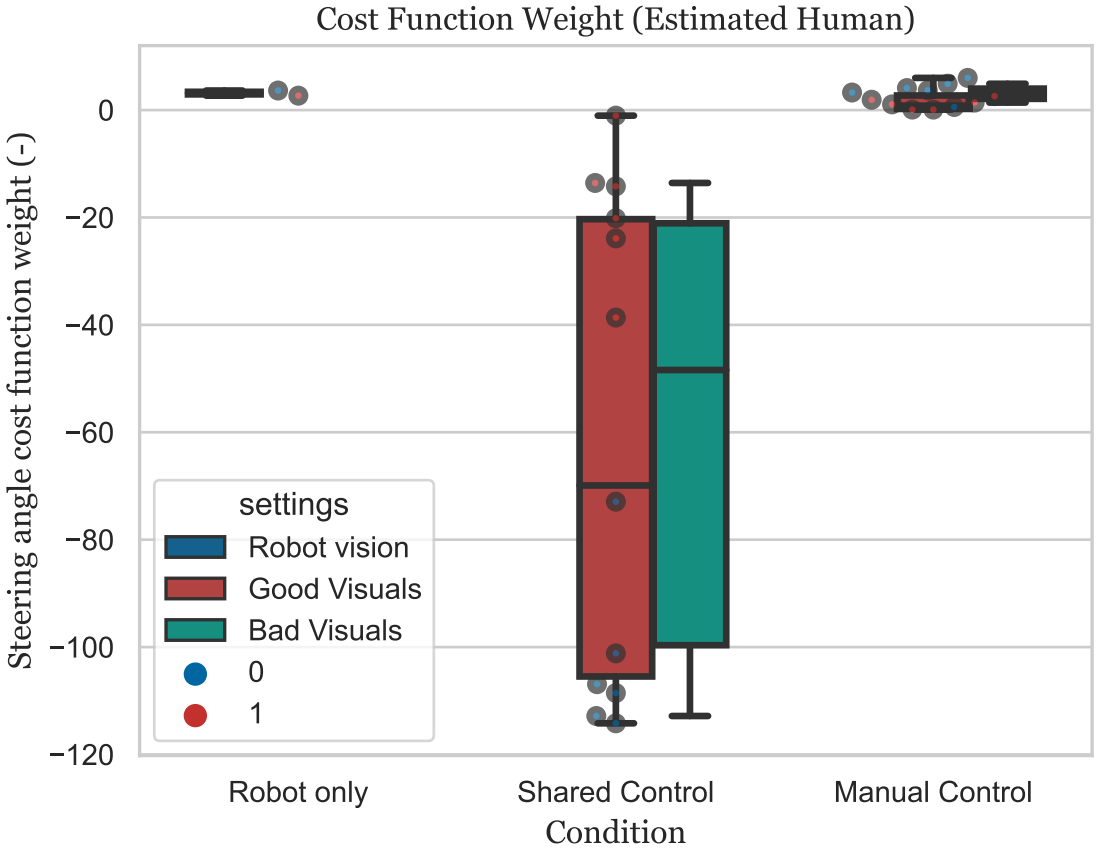

10
5
0
−5
−10
0
10
20
30
40

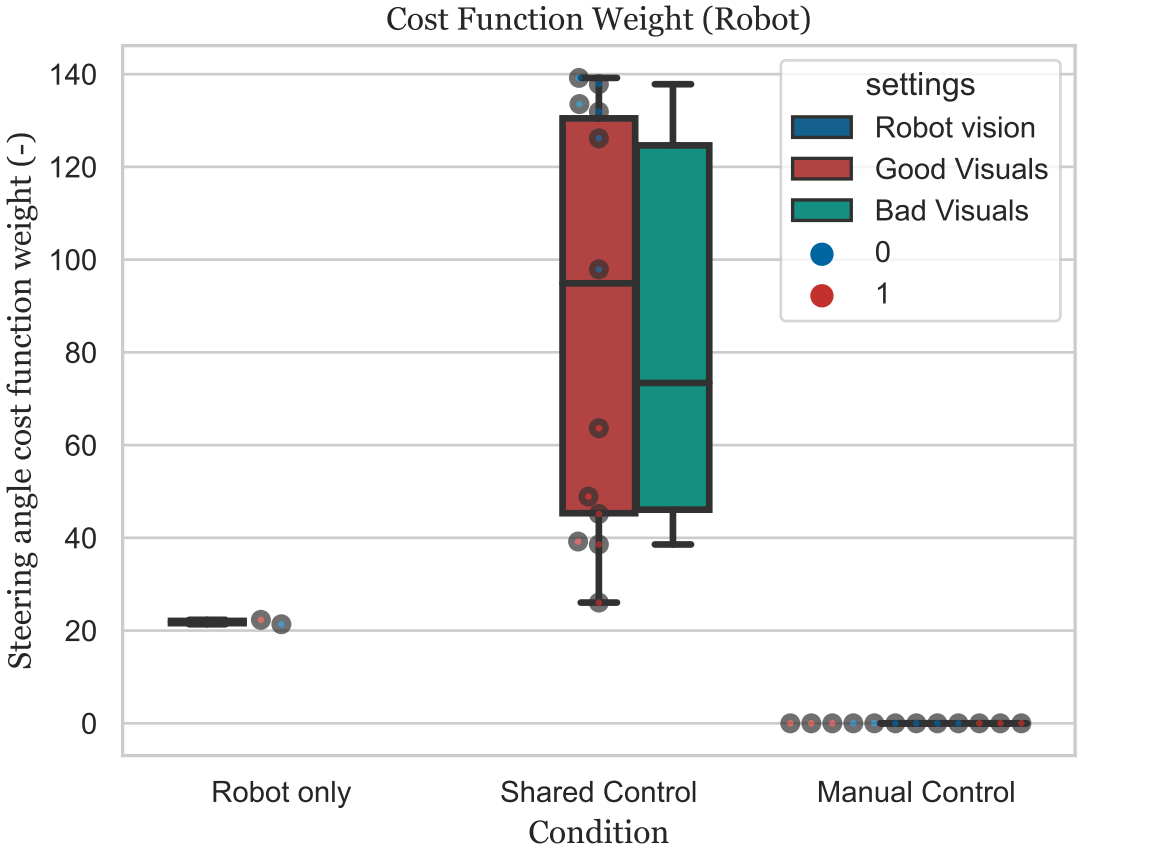

Controller Performance (Steering angle)
settings
Robot vision
Good Visuals
Bad Visuals
0
1
Root-mean-square steering angle error (rad)
0.12
0.10
0.08
0.06
0.04
0.02
Robot only
Shared Control
Manual Control
Condition

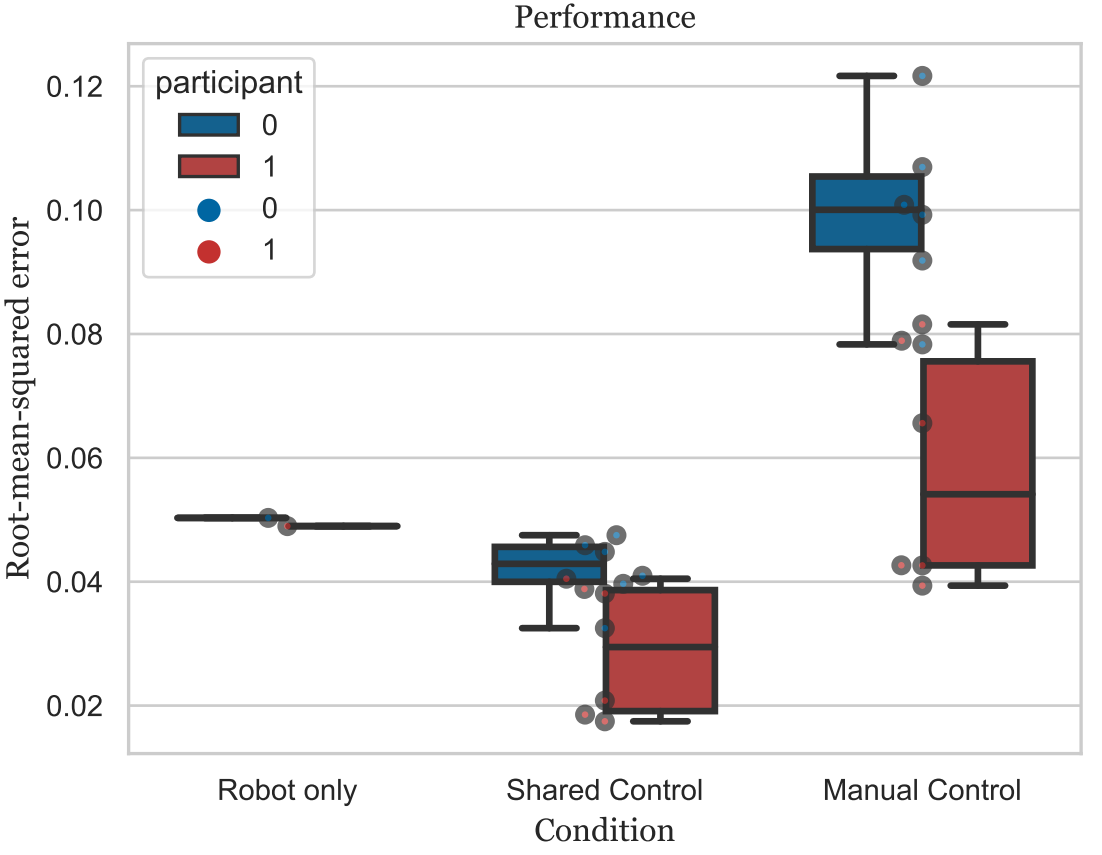

Controller Performance (Steering rate)
settings
Robot vision
Good Visuals
Bad Visuals
0
1
Root-mean-square steering rate error (rad/s)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
Robot only
Shared Control
Manual Control
Condition


Control Effort (Estimated human)
settings
Robot vision
Good Visuals
Bad Visuals
0
1
Root-mean-square steering torque (Nm)
0.25
0.20
0.15
0.10
0.05
0.00
Robot only
Shared Control
Manual Control
Condition


Control Effort (Robot)
Root-mean-square steering torque (Nm)
0.0
0.2
0.4
0.6
0.8
settings
Robot vision
Good Visuals
Bad Visuals
0
1
Robot only
Shared Control
Manual Control
Condition


Cost Function Weight (Estimated Human)
Steering angle cost function weight (-)
0
−20
−40
−60
−80
−100
−120
settings
Robot vision
Good Visuals
Bad Visuals
0
1
Robot only
Shared Control
Manual Control
Condition


Cost Function Weight (Robot)
Steering angle cost function weight (-)
140
120
100
80
60
40
20
0
settings
Robot vision
Good Visuals
Bad Visuals
0
1
Robot only
Shared Control
Manual Control
Condition


Performance
participant
0
1
0
1
0.12
0.10
0.08
0.06
0.04
0.02
Root-mean-squared error
Robot only
Shared Control
Manual Control
Condition