Presentation to Vehicle Dynamics Expo 2007

DRIVER-VEHICLE DYNAMICS
the rôle of the neuromuscular system

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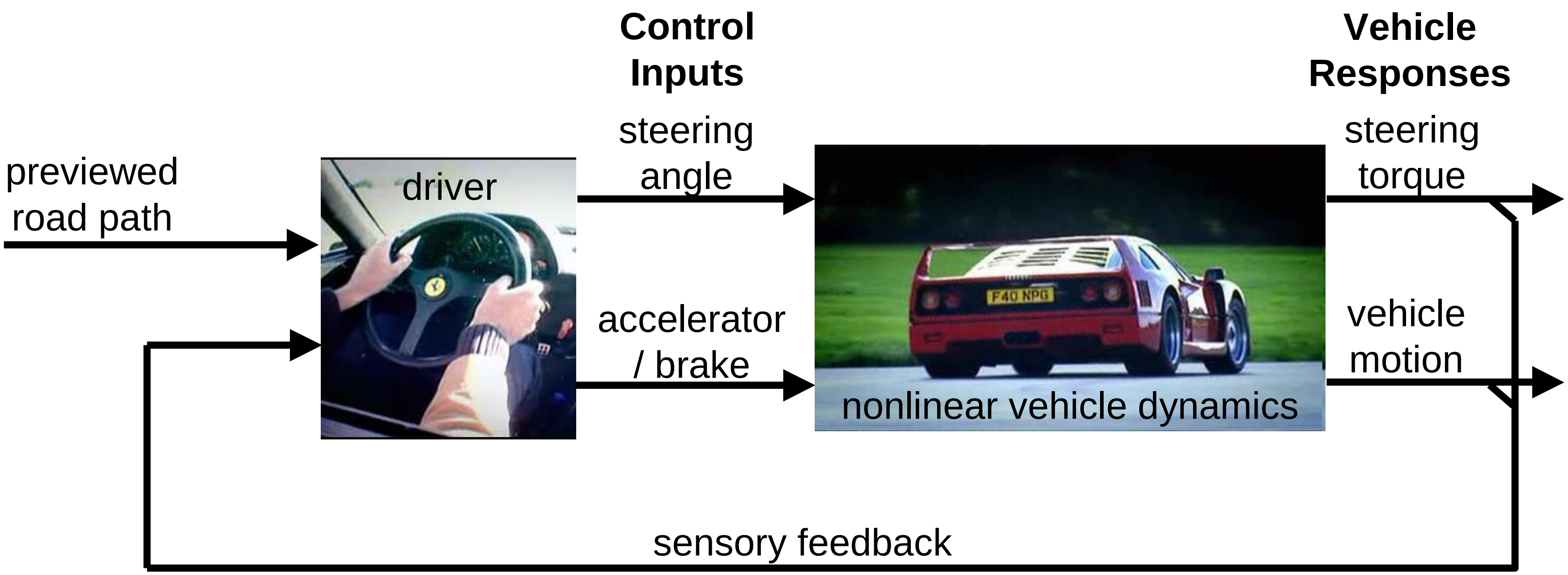
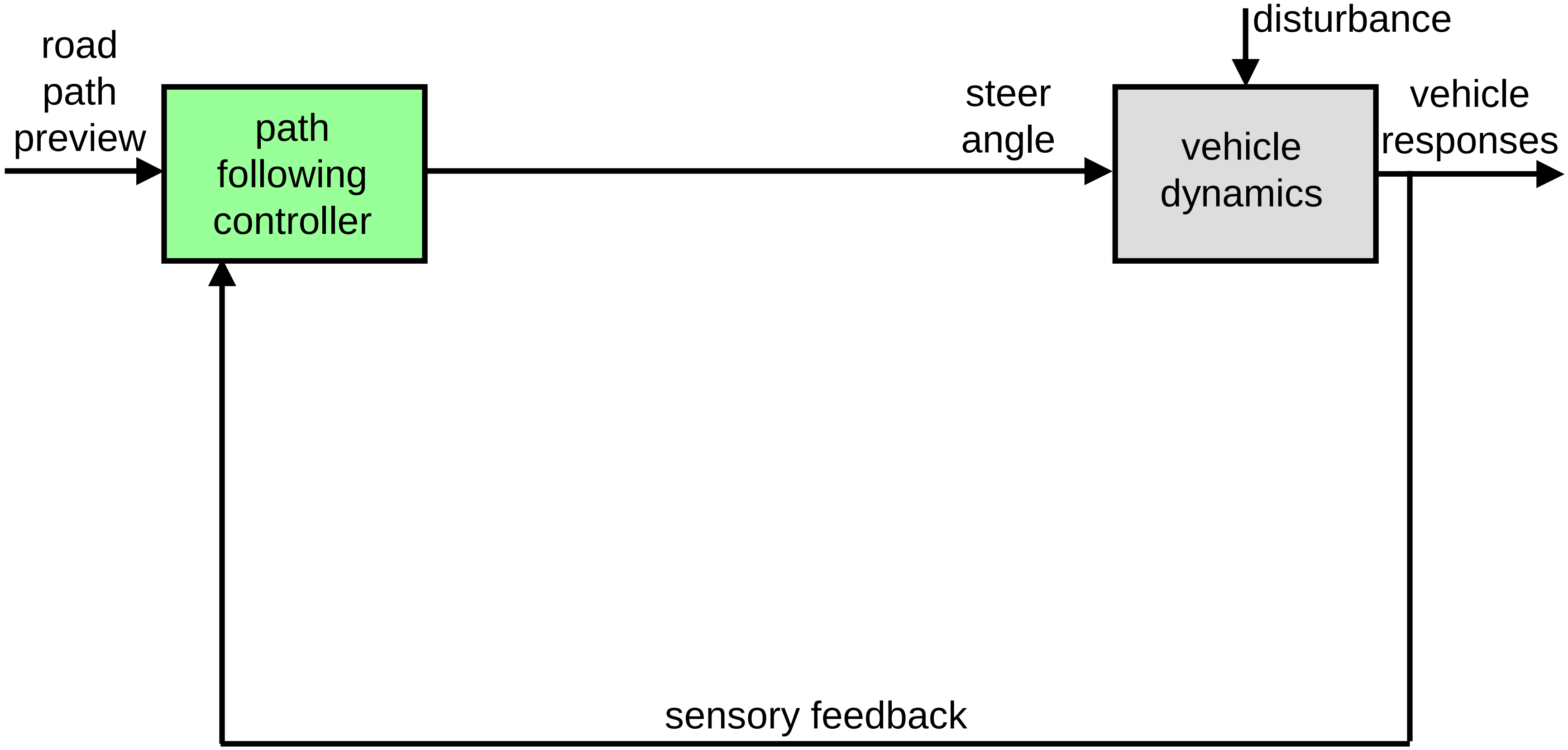
Driver-Vehicle Dynamics



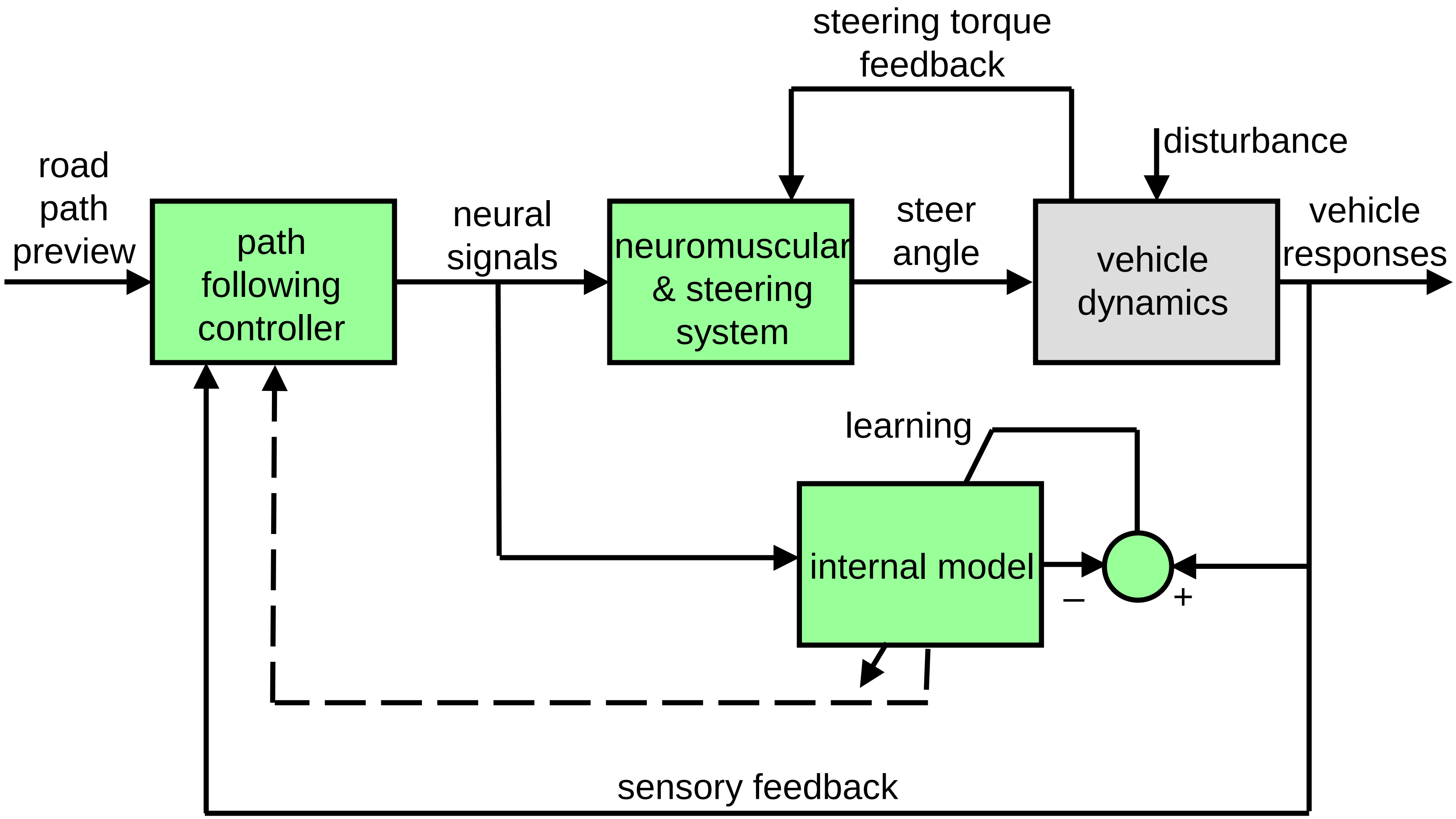
- There is extensive understanding of vehicle response to open-loop inputs
- But vehicle usually operates in closed-loop with the driver
- Much less is known about control behaviour of the driver

Conventional Driver Steering Models



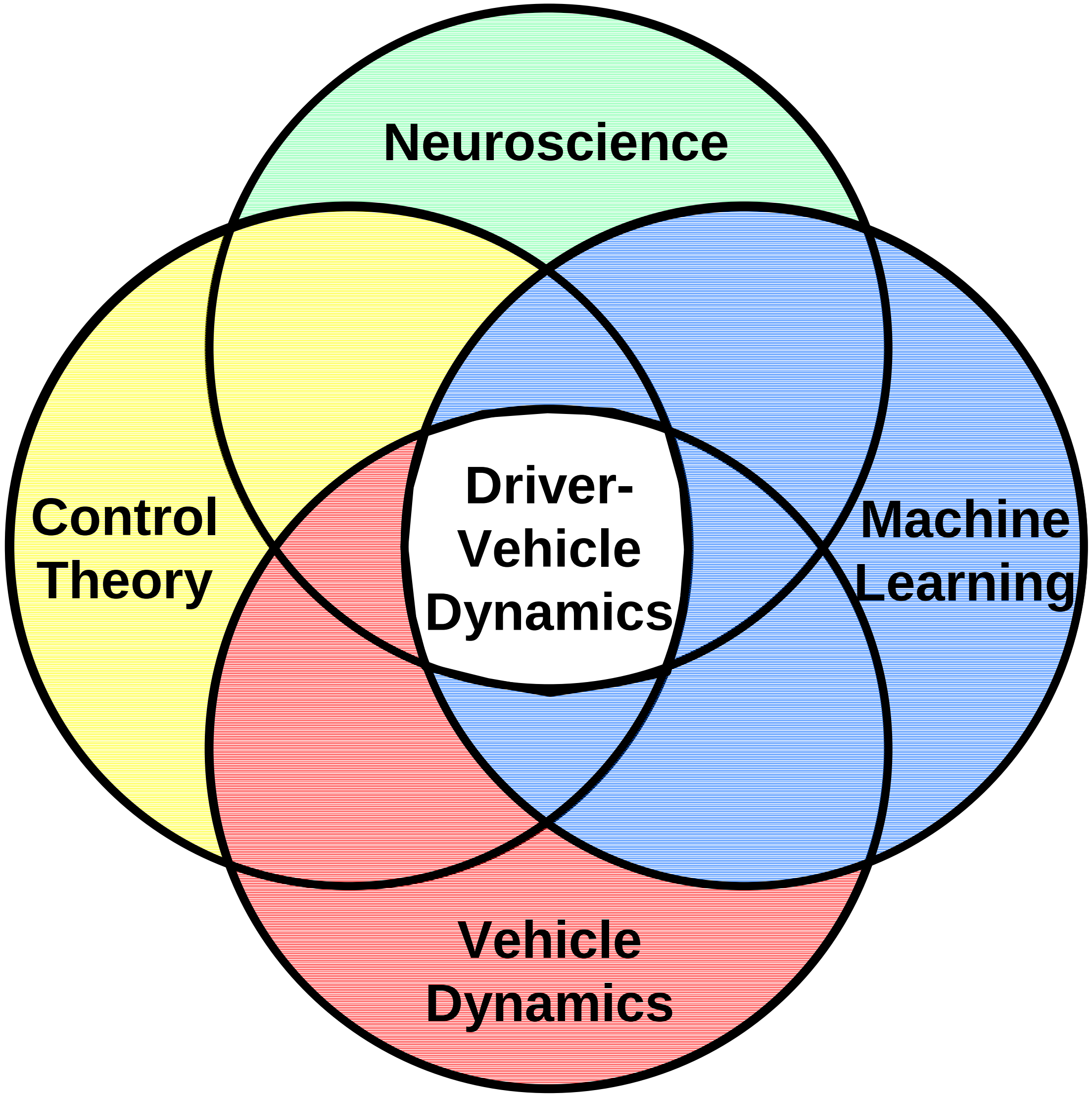
- Conventional driver steering models do not represent human dynamics
- For example, steering torque feedback is not included

Extended Driver Steering Model

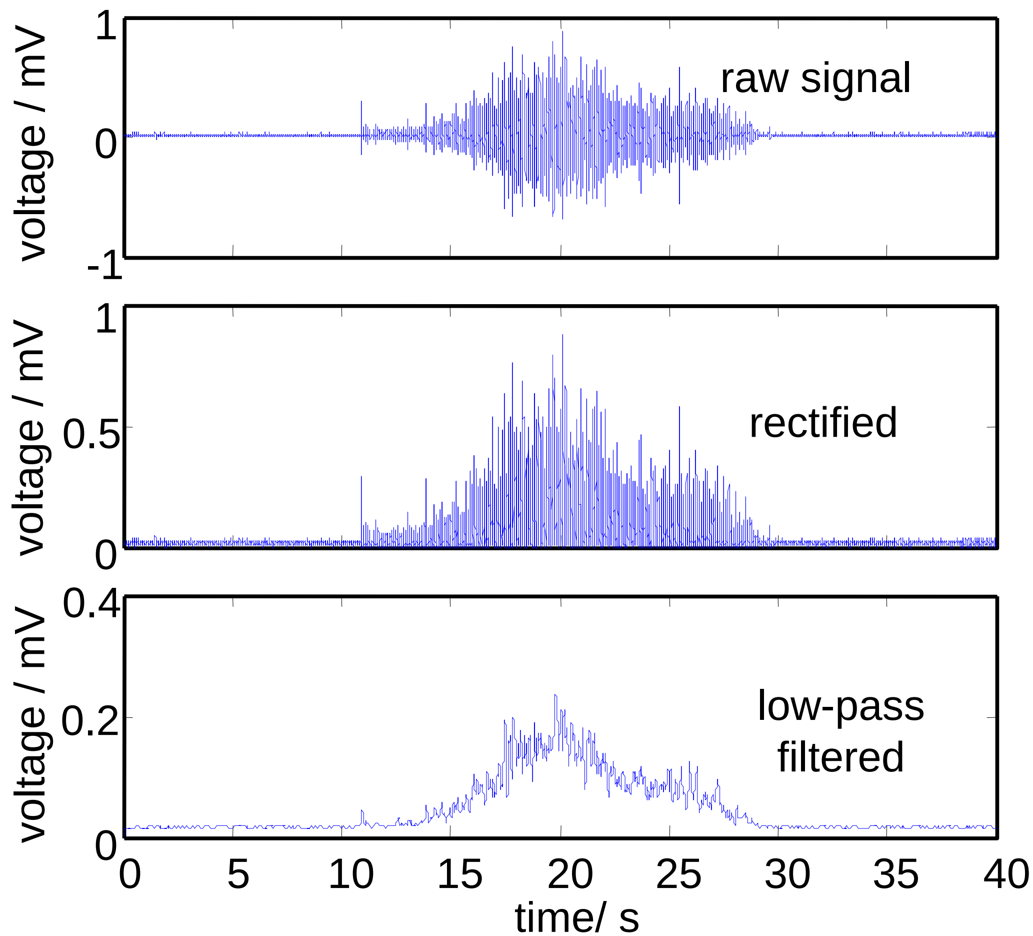


- Extended model includes neuromuscular system and internal model
- Aim is to predict subjective qualities of vehicle dynamics

Multi-Disciplinary

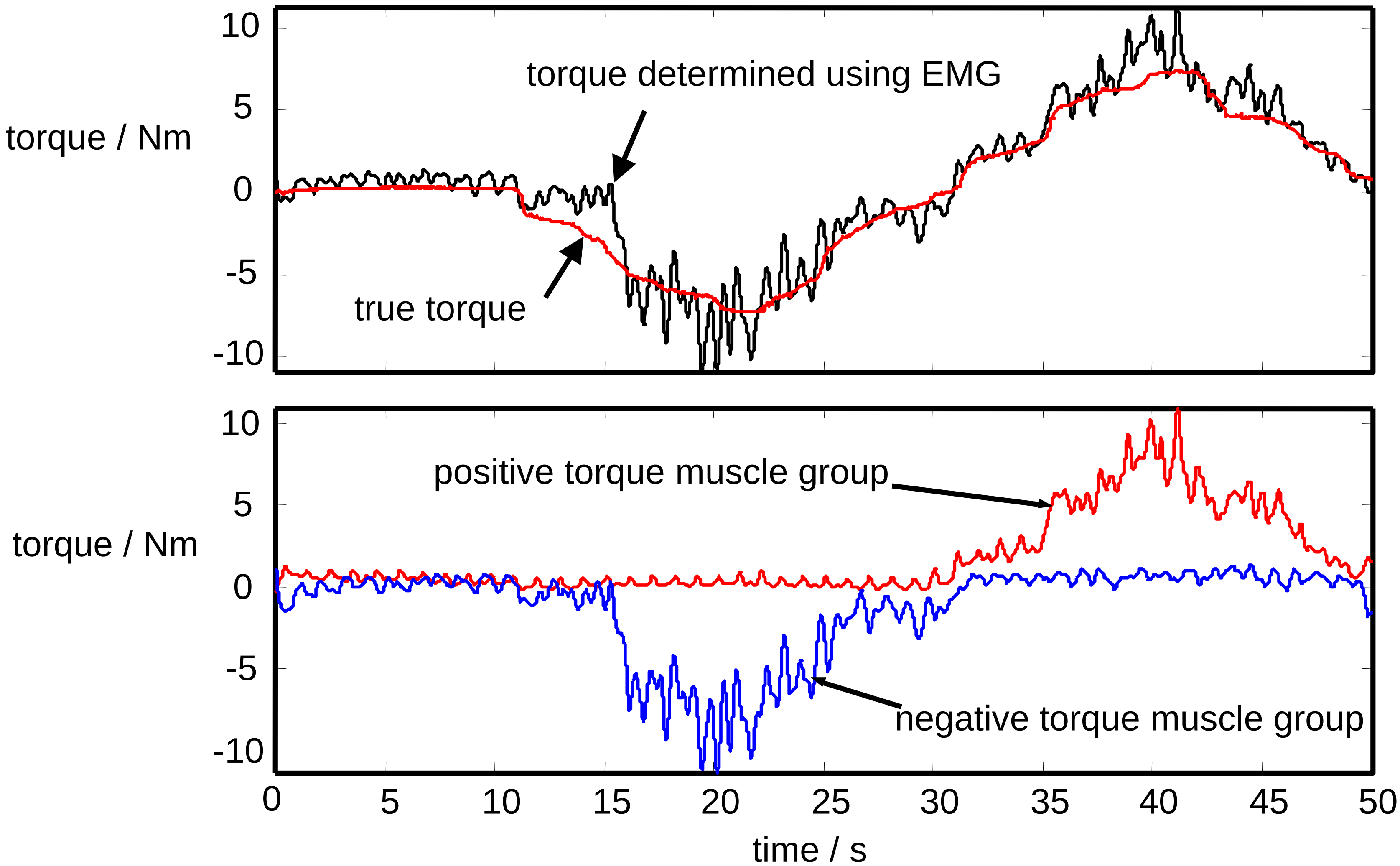


Electromyography (EMG)



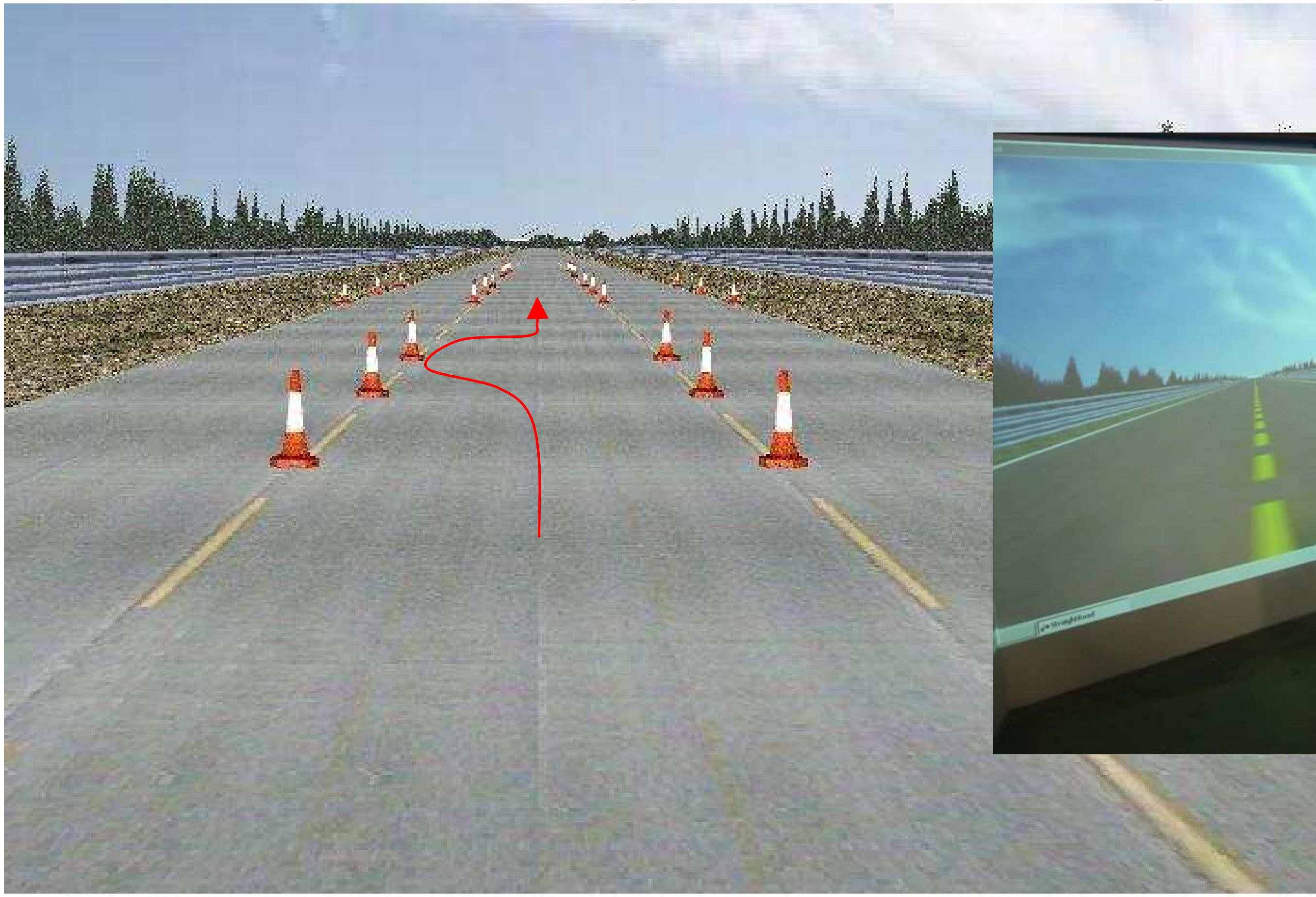
- Driver’s muscle activation voltages are measured using EMG
- Rectified and smoothed voltage is proportional to muscle force

Steering Torque Determined Using EMG



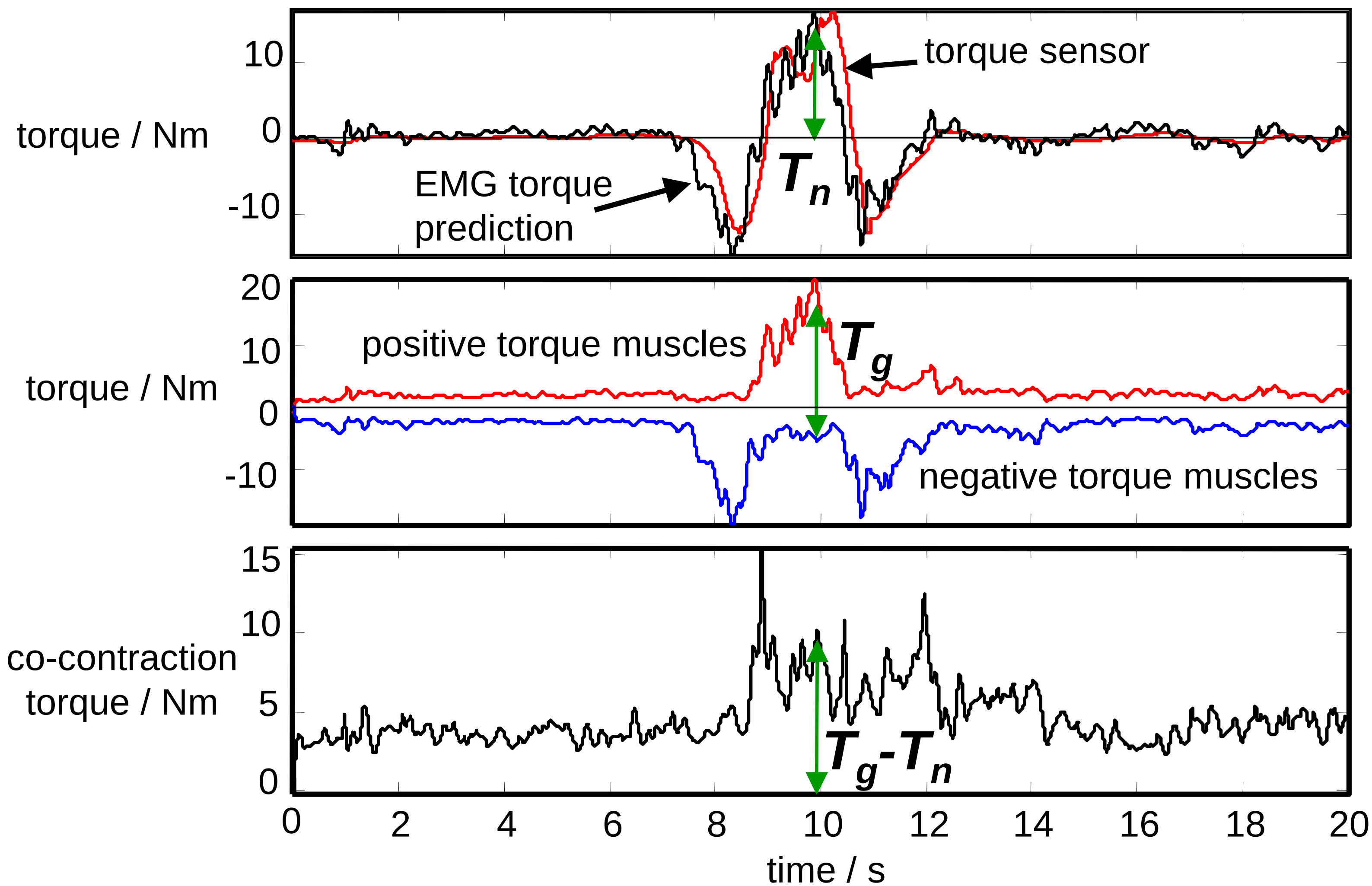
- Steering torque can be determined from the EMG voltages
- Two groups of muscles: one for positive torques; another for negative.

Driving Simulator Experiment



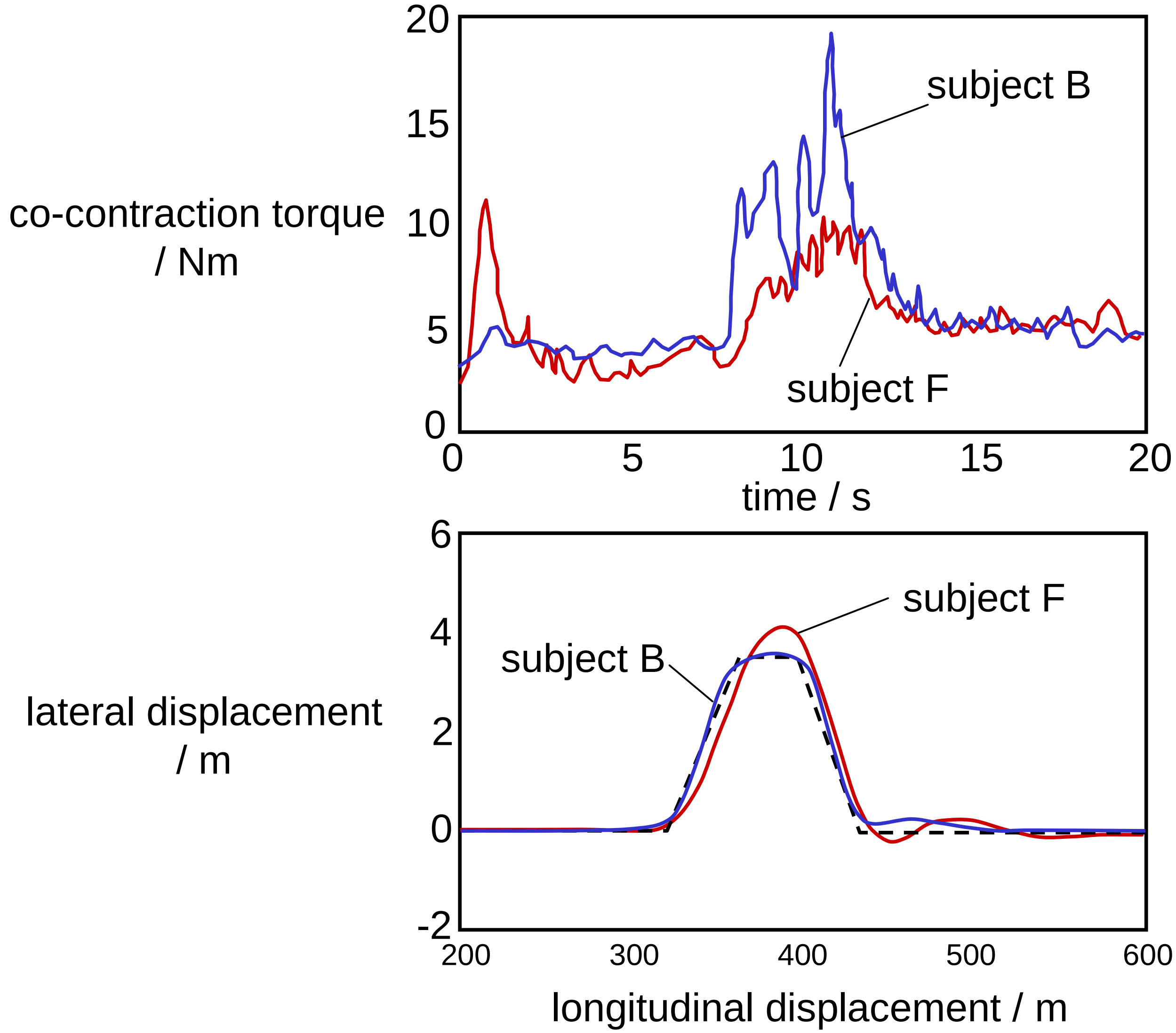
- Double lane change manoeuvre
- Linear vehicle
- Steering wheel has torque feedback
- Driver instrumented with EMG

Muscle Co-Contraction During Lane Change



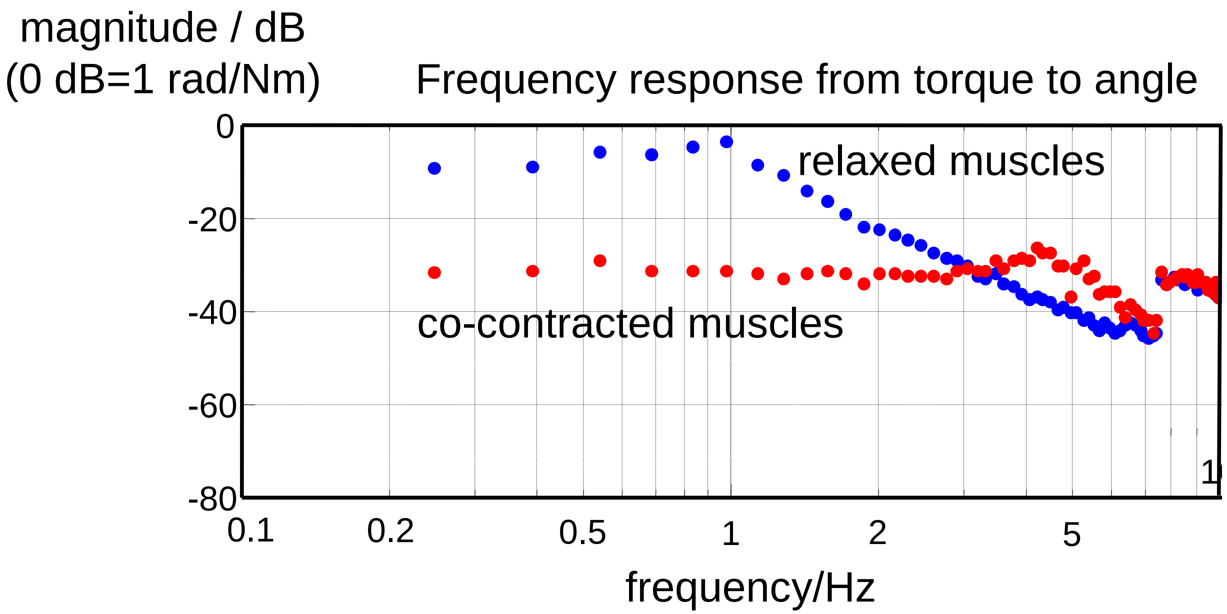
- Co-contraction is the activation of both groups of muscles
- Co-contraction occurs during the lane change manoeuvre

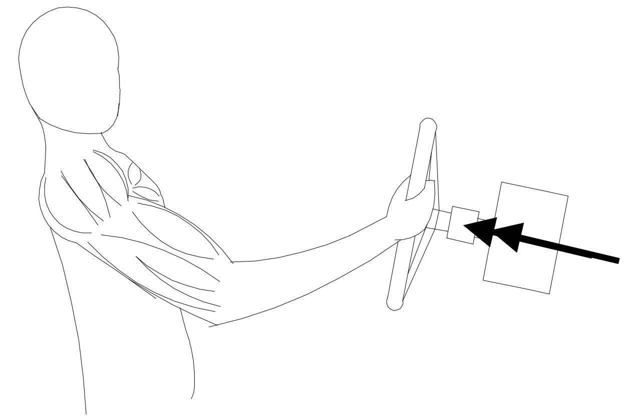
Muscle Co-Contraction During Lane Change

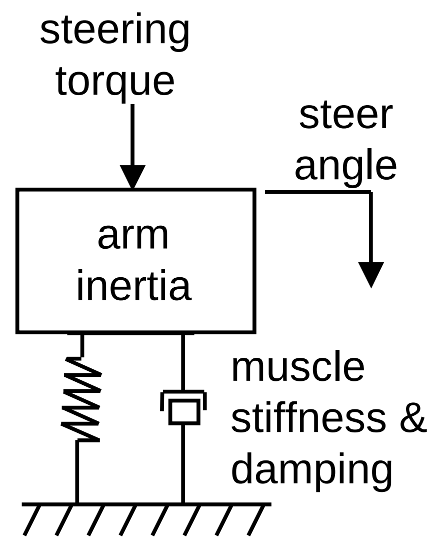


- Two test subjects use different amounts of co-contraction
- More co-contraction gives better path-following (subject B)

Muscle Stiffness

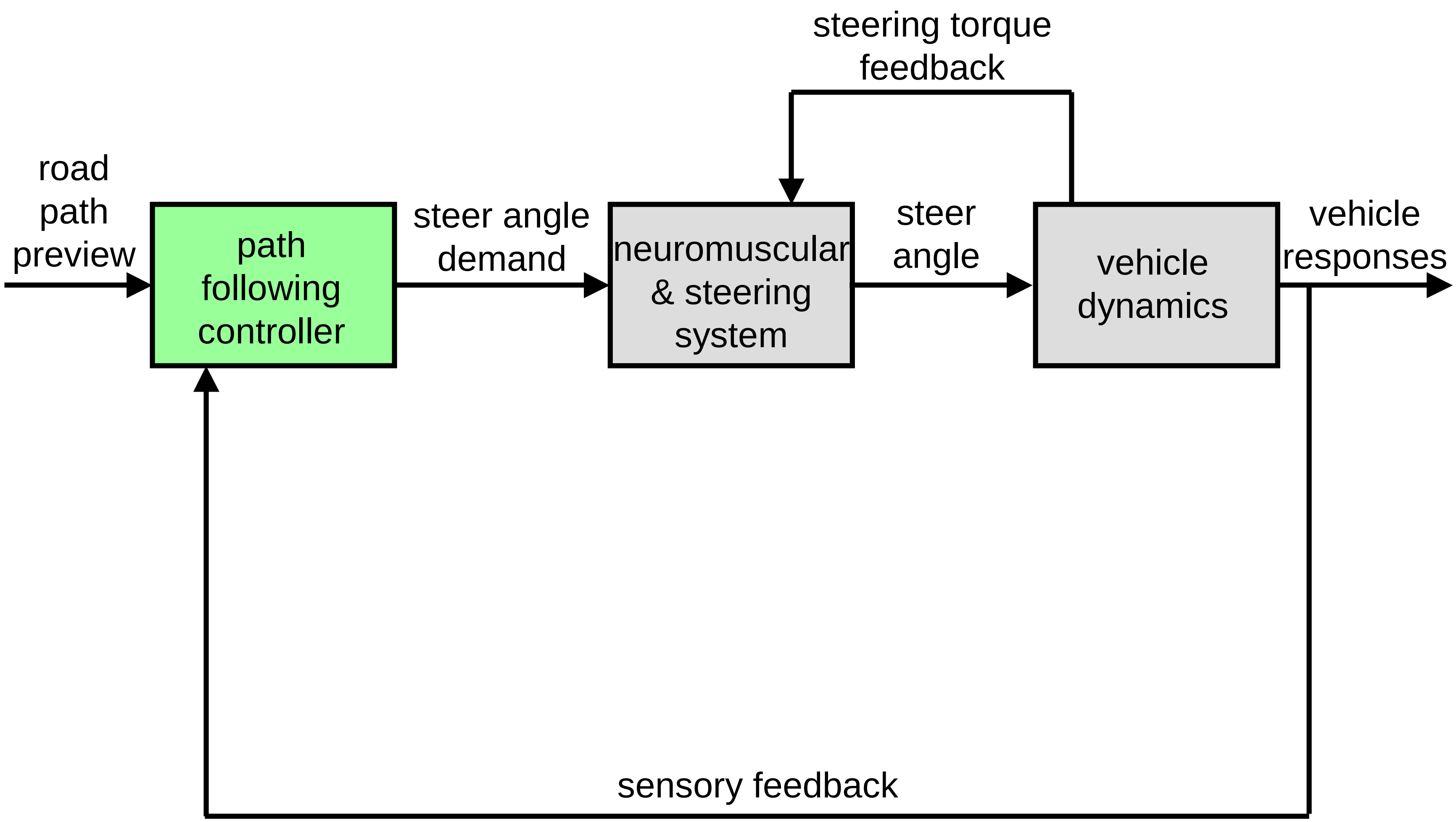






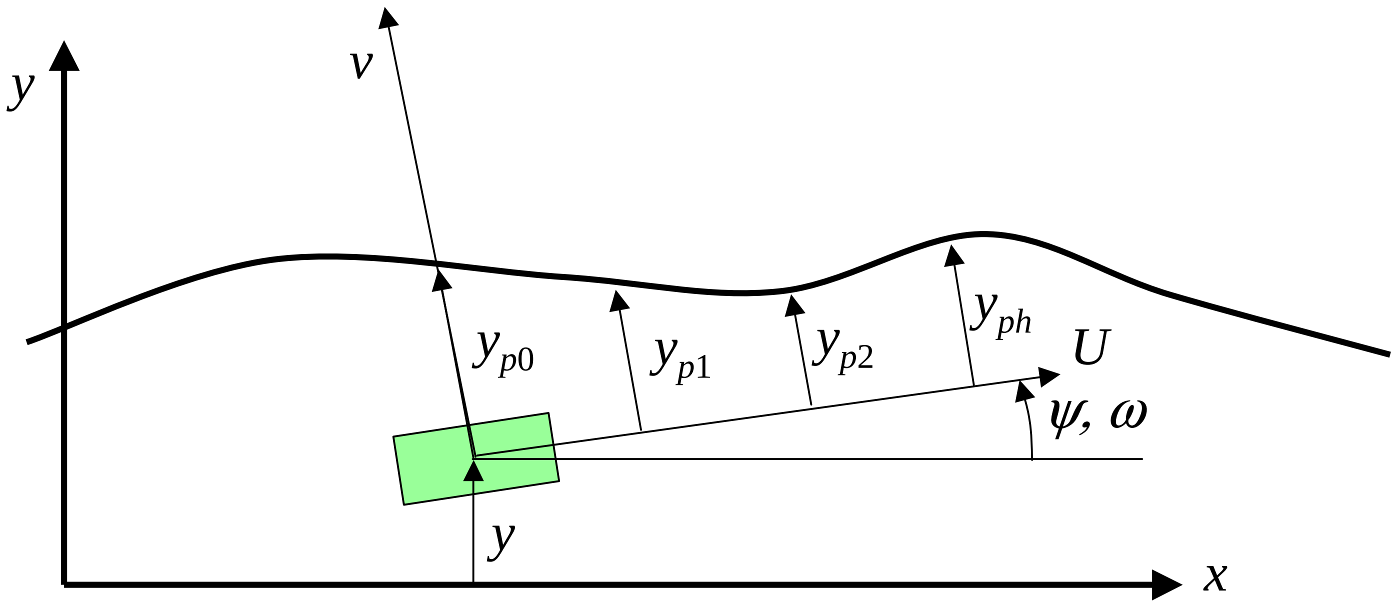
- Put random torque into steering wheel; measure angle response
- Driver's arms can be modelled as a mass/damper/spring
- Co-contraction increases the stiffness of the arms

Path Following Controller



- Use mathematical model to explain why arm stiffness affects path following
- First, consider path following controller

Path Following Controller

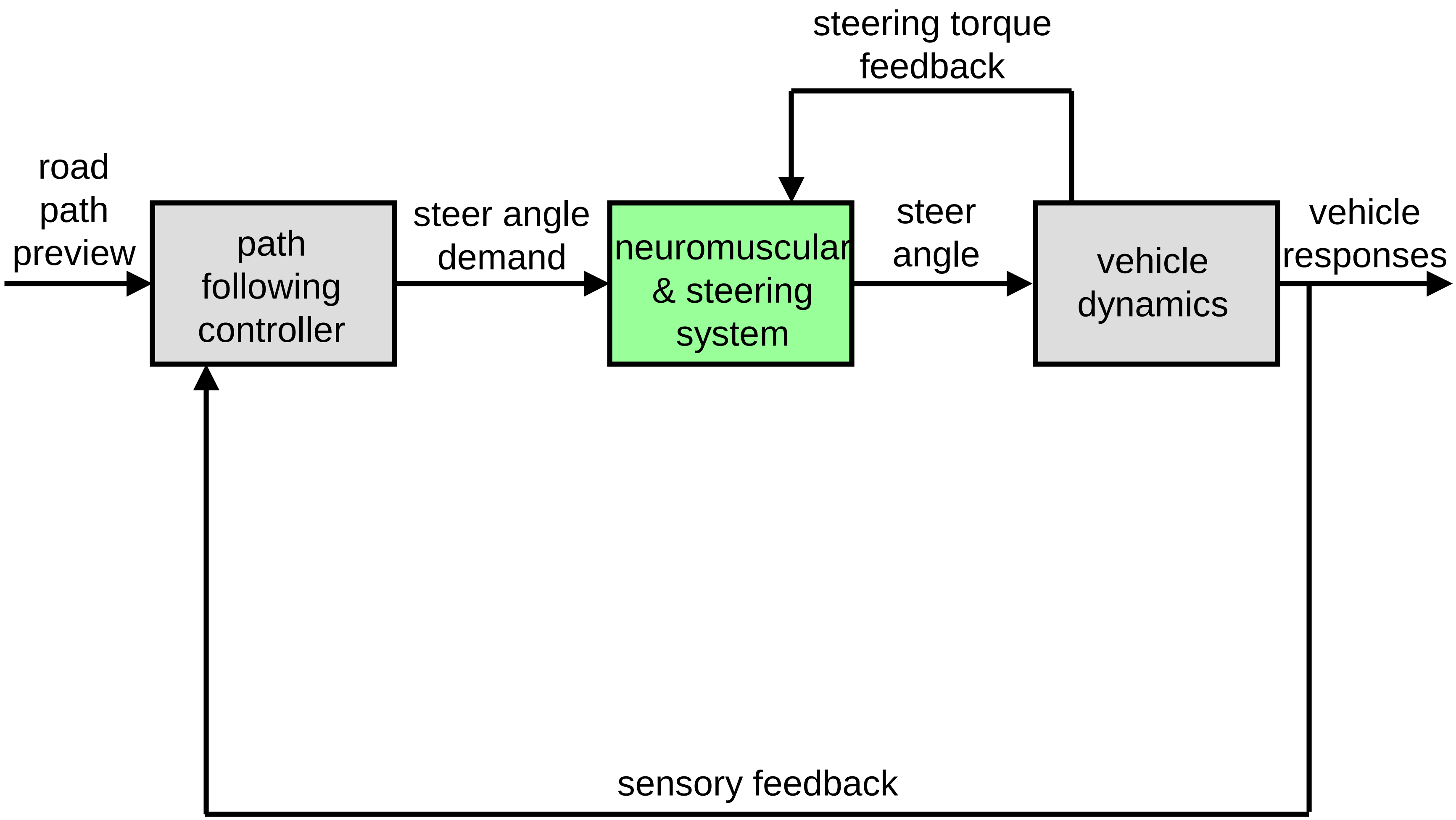


LQR steering control

$$\delta = k_1 v + k_2 \omega + \sum_{i=0}^{h} k_{pi} y_{pi}$$

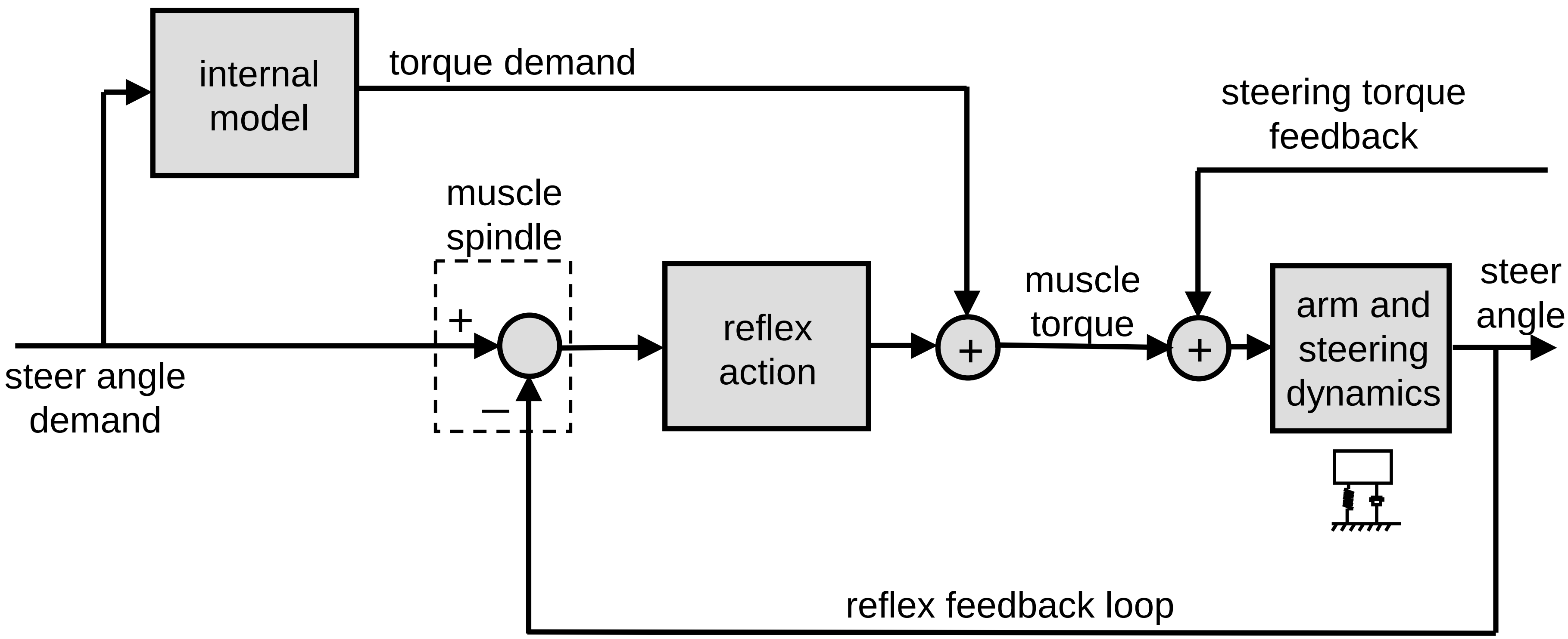
- Use multi-point preview LQR optimal control (following Prof. RS Sharp)
- Demanded steer angle is a function of vehicle states and previewed path

Neuromuscular Dynamics Block



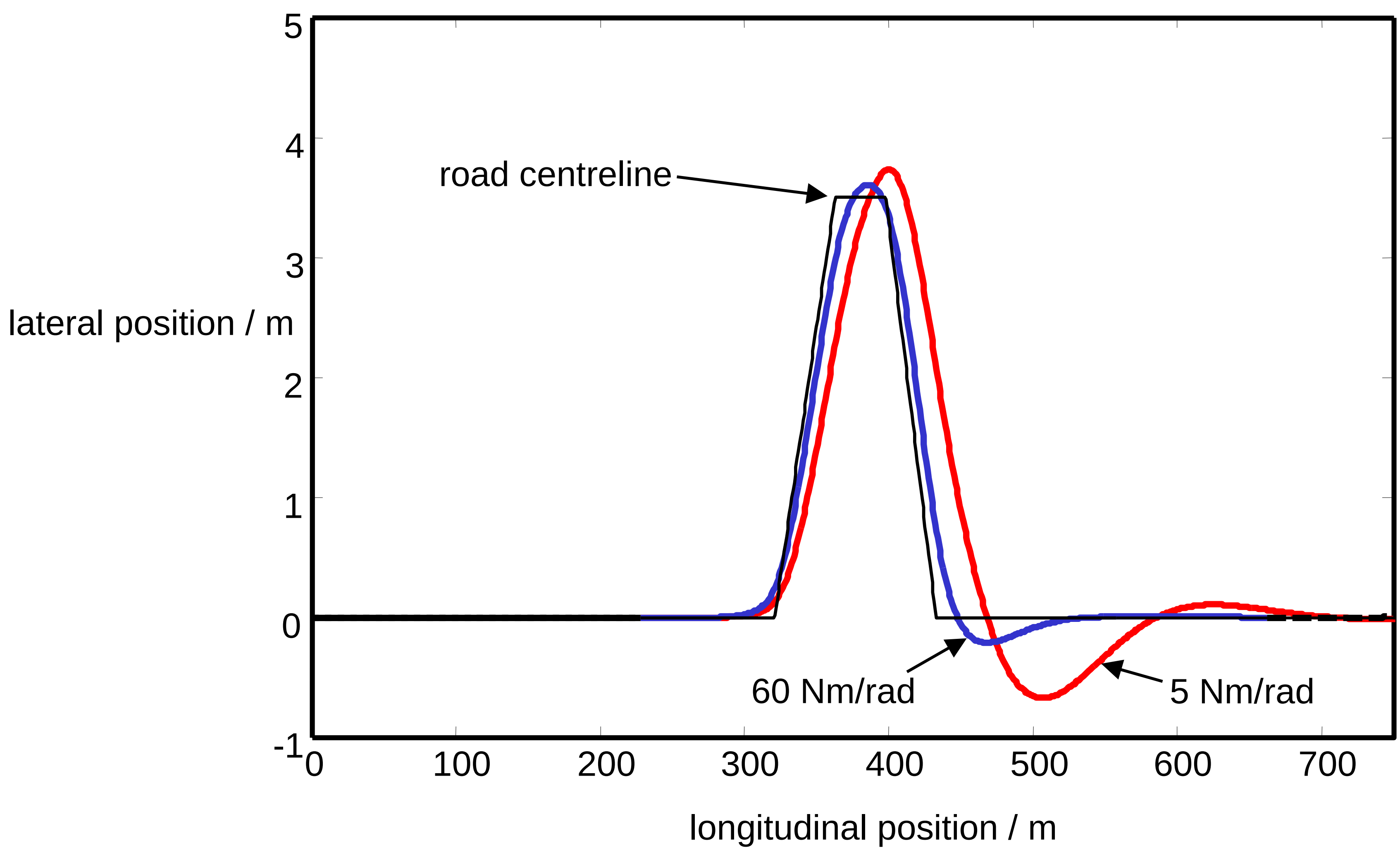
- Use the demand steer angle as the input to the neuromuscular system

Neuromuscular Dynamics Block



- Muscle is activated directly via the driver's internal model of steering torque
- Any subsequent error in steer angle is corrected by reflex action
- Co-contraction increases arm stiffness and bandwidth of angle control

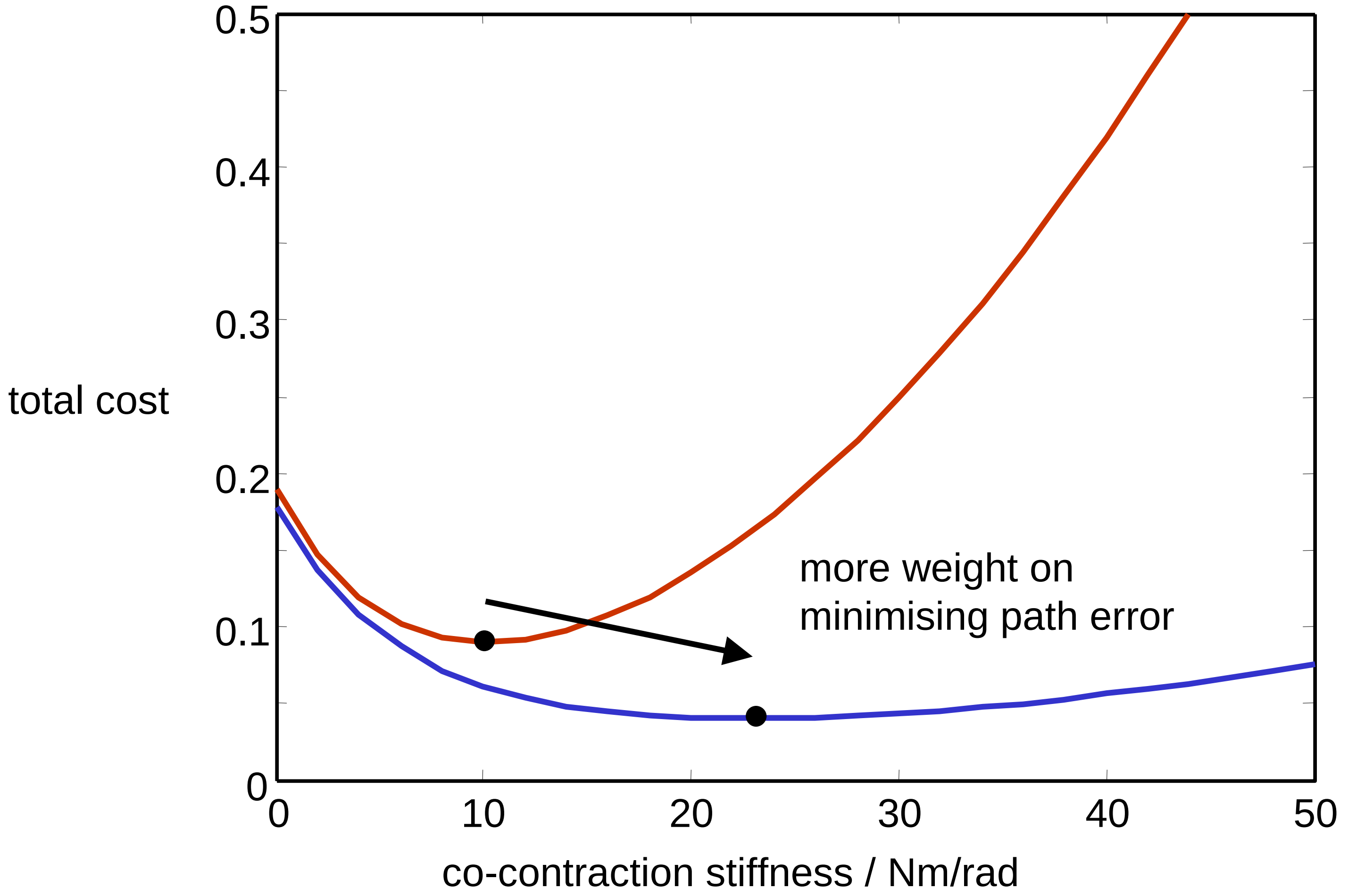
Effect of Co-Contraction Stiffness



- Model shows path following accuracy improves with co-contraction stiffness

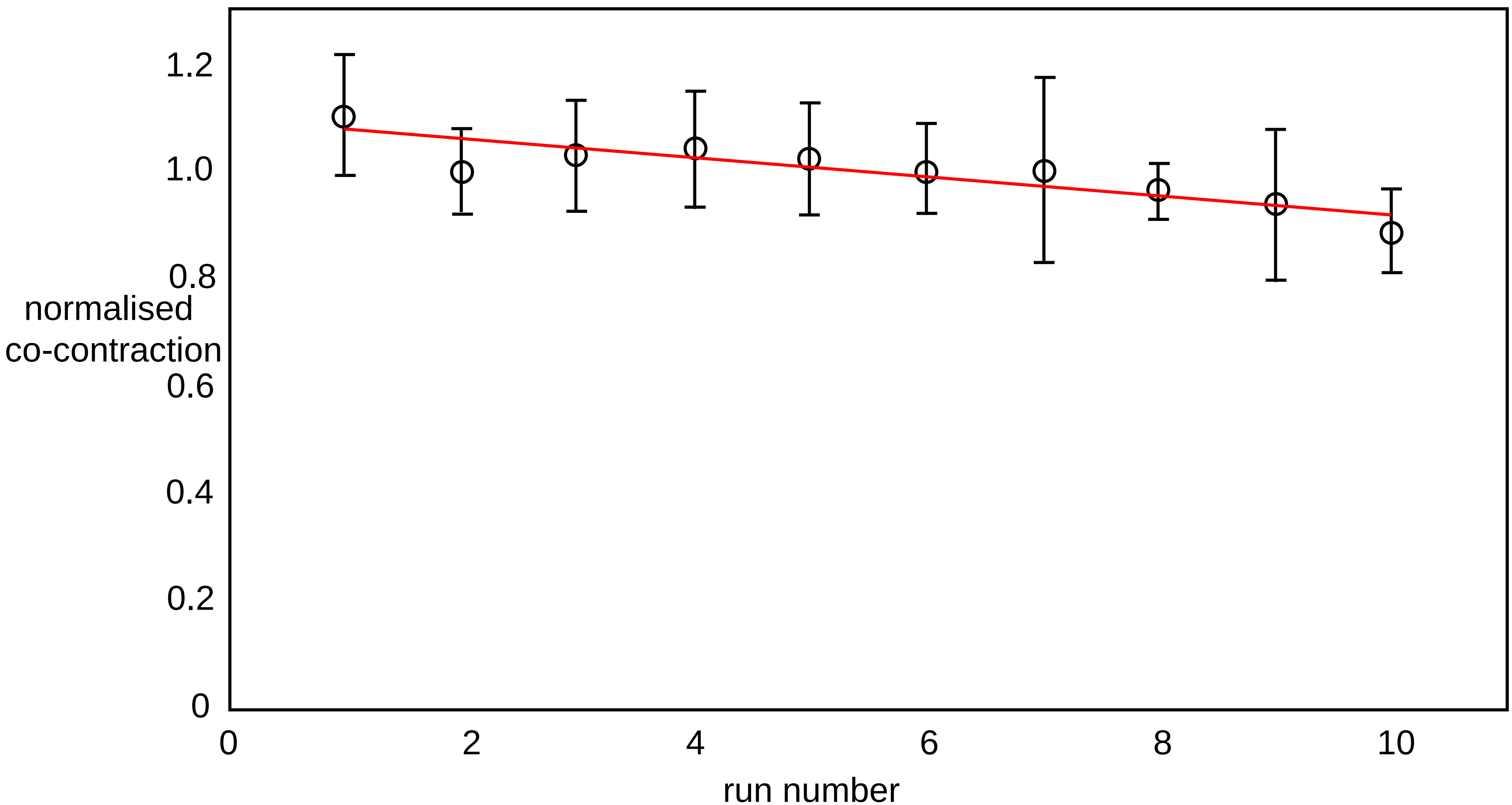
Optimum Co-Contraction Stiffness

total cost = q_m (total muscle torque)^2 + q_p (path following error)^2



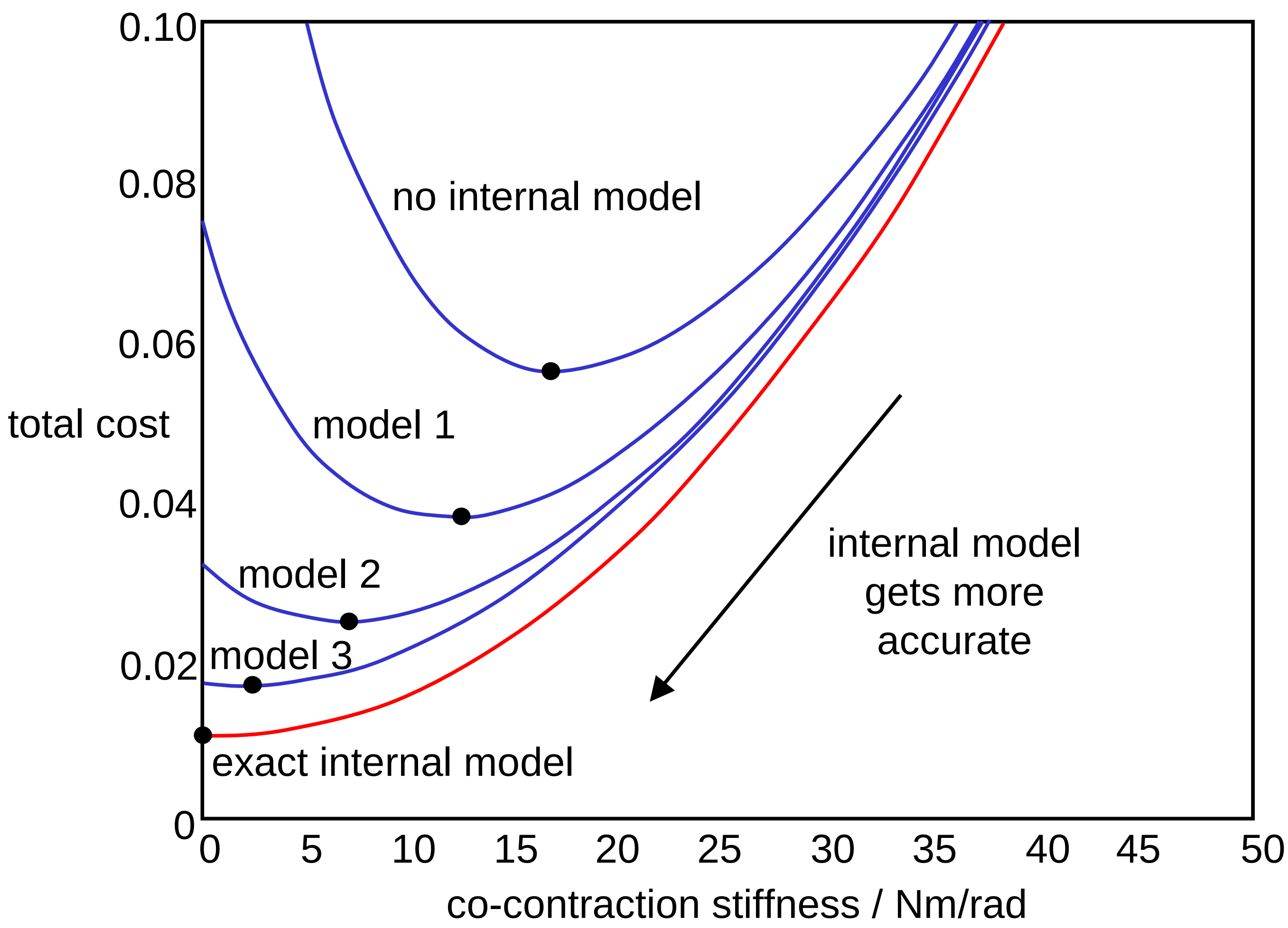
- Optimum level of co-contraction calculated by minimising a cost function
- The cost function weighs muscle torque against path following error

Co-Contraction vs Time



- Successive lane changes give a reduction in muscle co-contraction

Internal Model Accuracy



- Optimum co-contraction reduces as the internal model gets more accurate
- Muscle co-contraction may give insight into the driver's learning process

Conclusion

- Present understanding of driver control behaviour is limited
- Progress requires a multi-disciplinary approach
- Electromyography measures muscle activation & co-contraction
- Drivers employ co-contraction during a lane change manoeuvre
- Co-contraction may give insight into driver learning process
- Mathematical model is consistent with observed behaviour

See www.vehicledynamics.org for list of definitive publications