Automobile Steering

Land & Lee (1994)

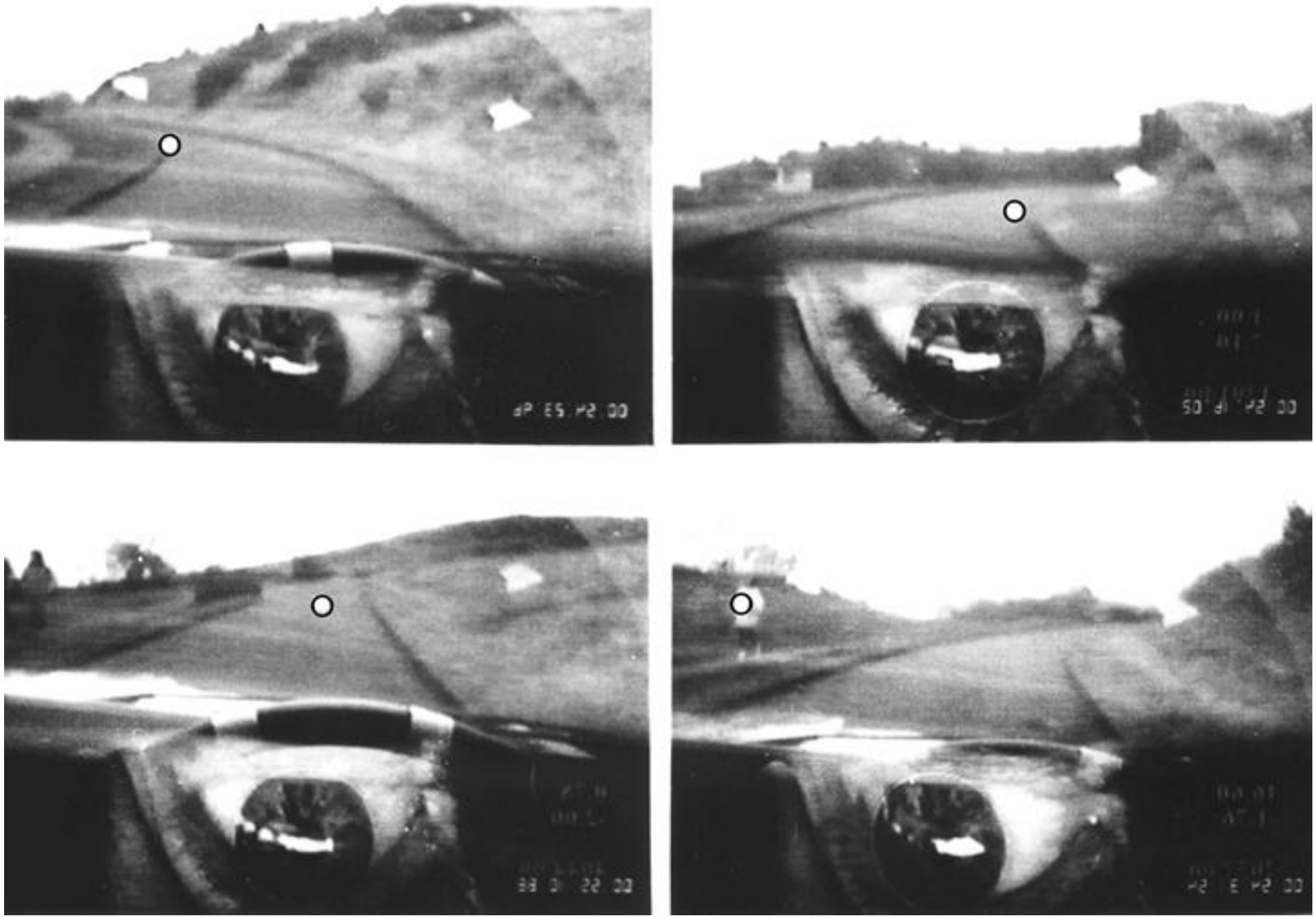
Where do we look when we steer

Eye movements of three subjects while driving a narrow dirt road with tortuous curves around Edinburgh Scotland.

Geometry demanded almost continuous visual guidance and very slow driving speeds.

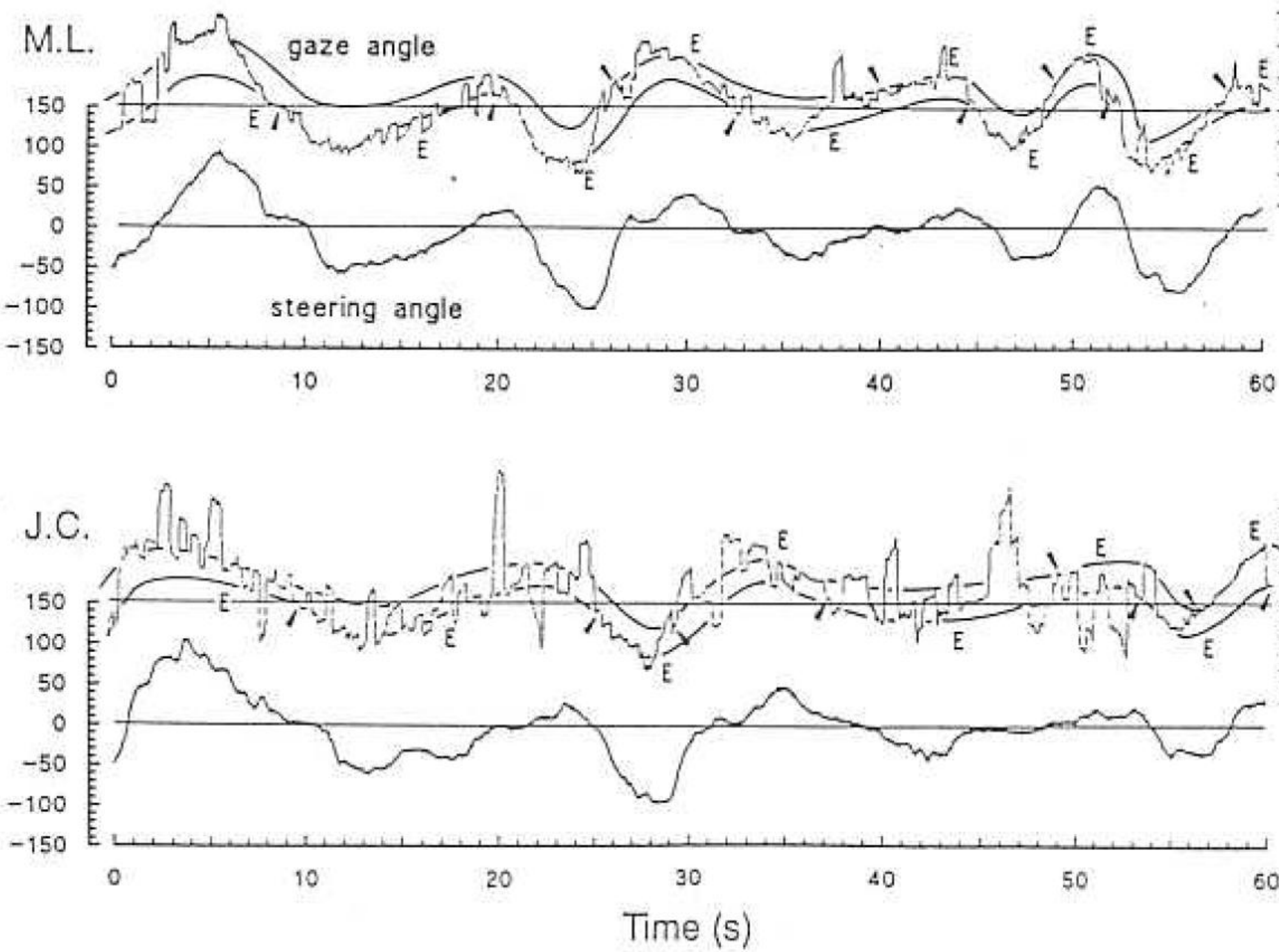
Very special case
Interesting…but how generalizable?

Frame-by-frame Video Analysis



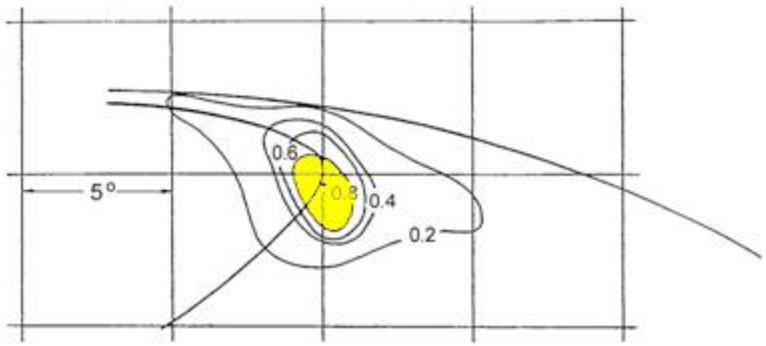
Note inverted image of eye in lower-third of video; and, two reference "tape marks" on windshield to allow head tracking computation.

Land & Lee (1994) video clip

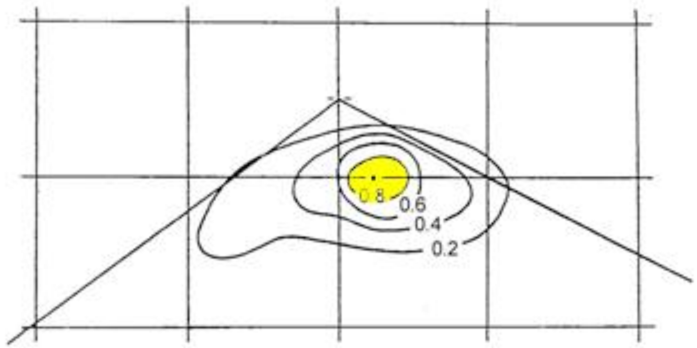


M.L.
gaze angle
steering angle
J.C.
E
150
100
50
0
−50
−100
−150
30
20
10
0
−10
−20
−30
0
10
20
30
40
50
60
Time (s)

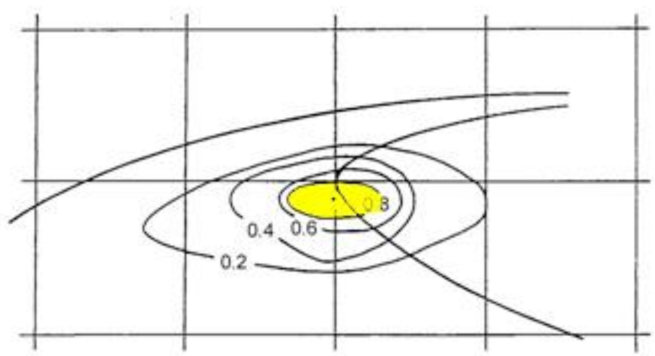
Fixation Density Distributions



Fixations cluster around the near “tangent point” on left curves

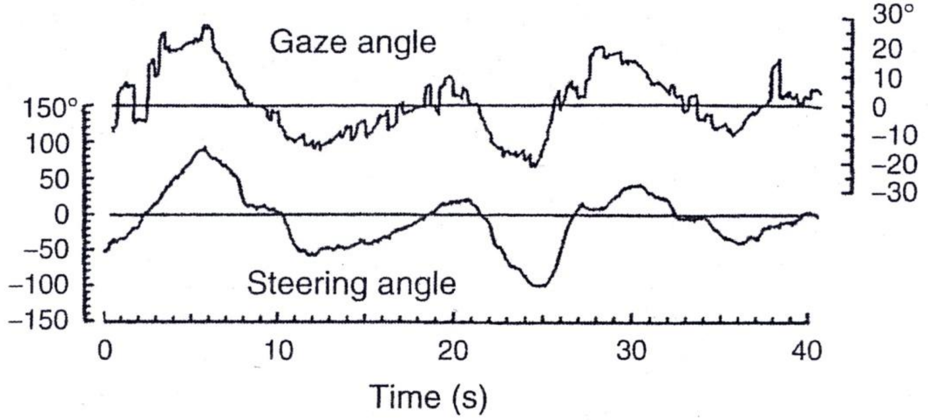


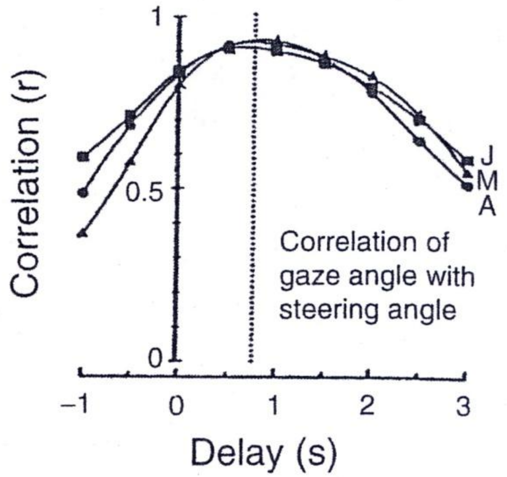
Fixations cluster around a fixed “preview distance” on straight roadway segments



Oversampling of “tangent point”
Replicated for right curves

Gaze and Steering Angle Correlation





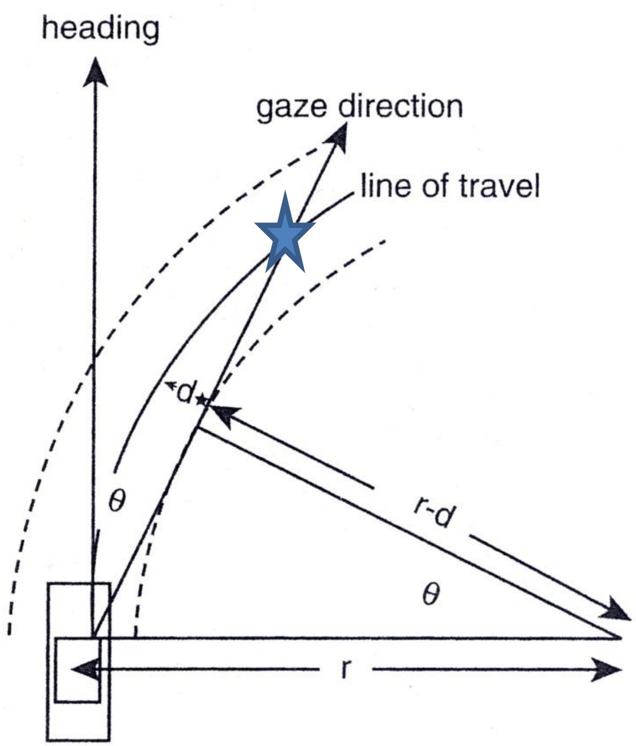
Drivers tend to look to the future path of travel
Gaze angle correlates with steering wheel angle
when "lag time" is adjusted (i.e., gaze leads motor control)

Land & Lee (1994) conclusions…

- “tangent point” provides reliable information about the curvature of upcoming bend
  curvature = 1/radius = $\theta^2/2d$
  θ=angle from current heading
  d=distance of driver’s head from inner lane edge

- Drivers monitor both θ and d cues (parameters) simultaneously (see Land & Horwood, 1995)

Tangent Point Geometry



<u>Recovering roadway "curvature"</u>

Curvature = 1 / r

r = radius of curved path of travel

θ = heading-to-tangent angle

d = distance to near edge line

$\cos(\theta) = (r-d)/r$

and since $\cos(\theta) \approx \theta^2/2$

the equation above becomes

$\theta^2/2 = (r-d)/r$

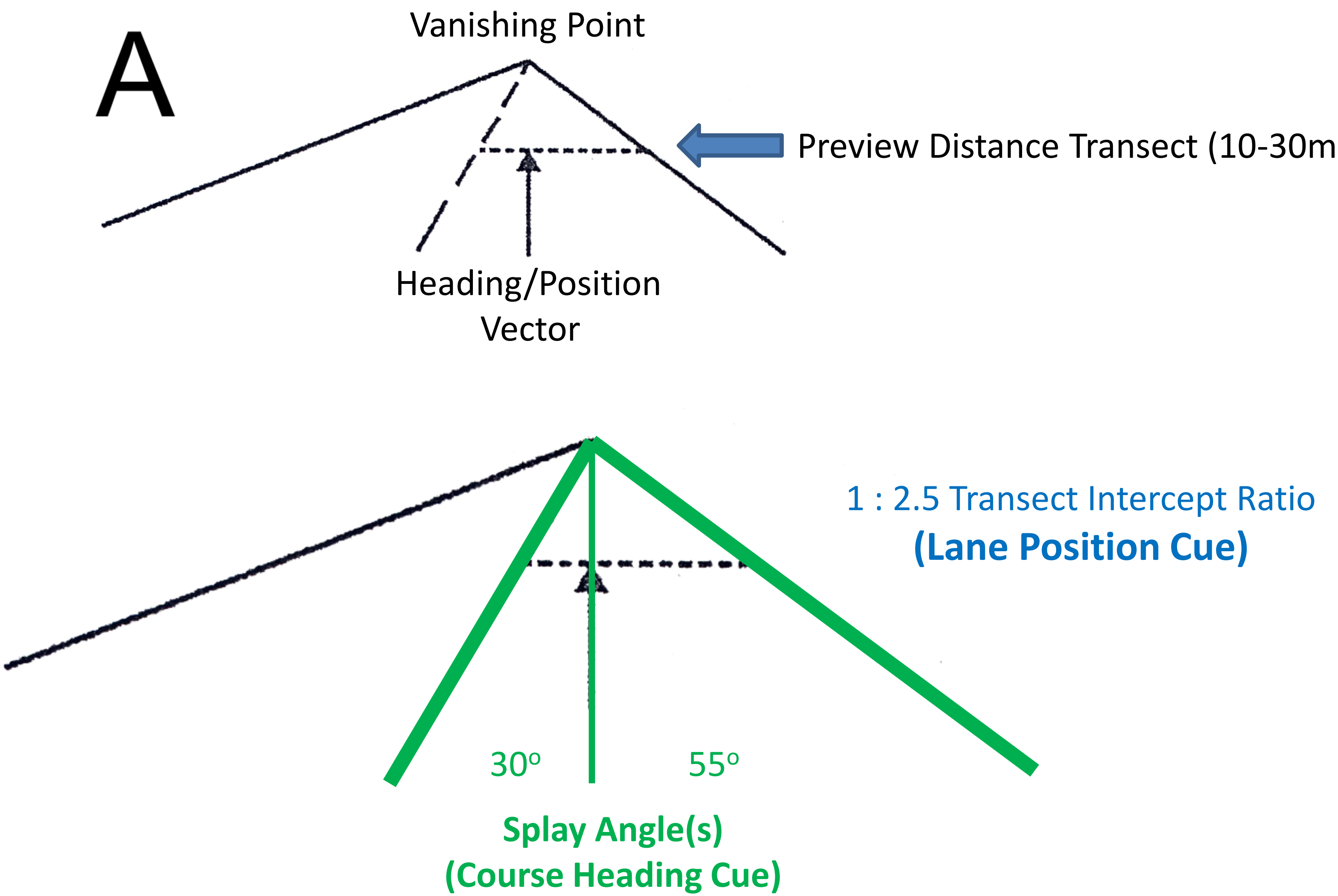
which reduces to

$\theta^2/2d = 1/r$ = roadway curvature

Q: Where would you look if you wanted to obtain the farthest possible preview time (or distance) of the future path of travel   A: see ★

Land’s Dual-Cue Approach

(Optimal Straight Road Steering)



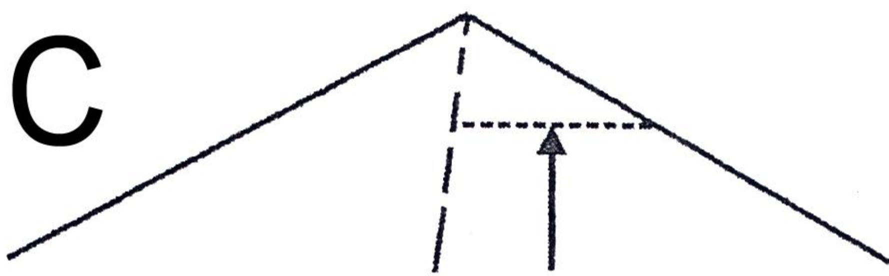
Land's Dual-Cue Approach

(Departure from Optimal Heading)

B

<u>Veering to Right (Scenario B)</u>
Heading diverges from vanishing point; Intersect of preview distance transect is now highly biased to the left; Encroachment into oncoming lane is imminent

C



<u>Veering to Left (Scenario C)</u>
Lane departure into shoulder is imminent.

What other cues are available here?

Optical flow information?

TLC?

Land's Dual-Cue Approach

(Correct Heading but Improper Lane Position)

D

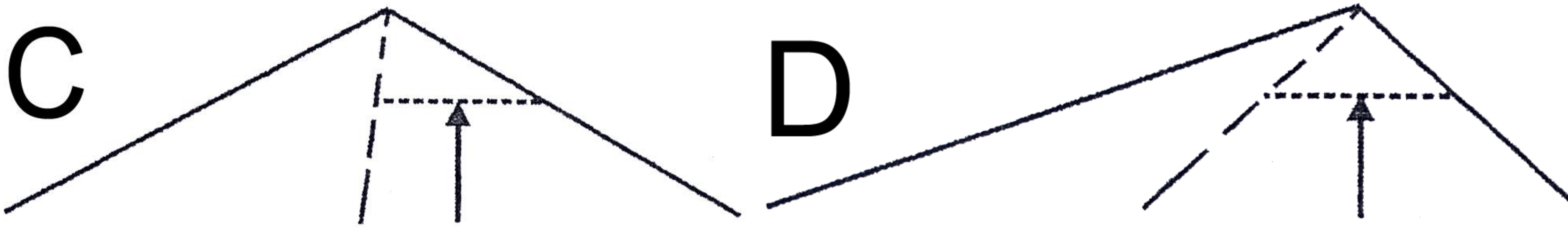
Lane position is biased to the right.

E

Lane position is biased to the left.

Land's Cues are Ambiguous in Isolation

(but not in combination)



Bisection of the preview distance transect is an ambiguous indicator of lane keeping maintenance until considered together with long-range heading information

Land and Horwood (1995) demonstrate the separate roles for **near-range** lane position information and **far-range** heading angle cues using their selective visual sampling paradigm.

Land & Horwood (1995)

(Selective Visual Preview Paradigm)

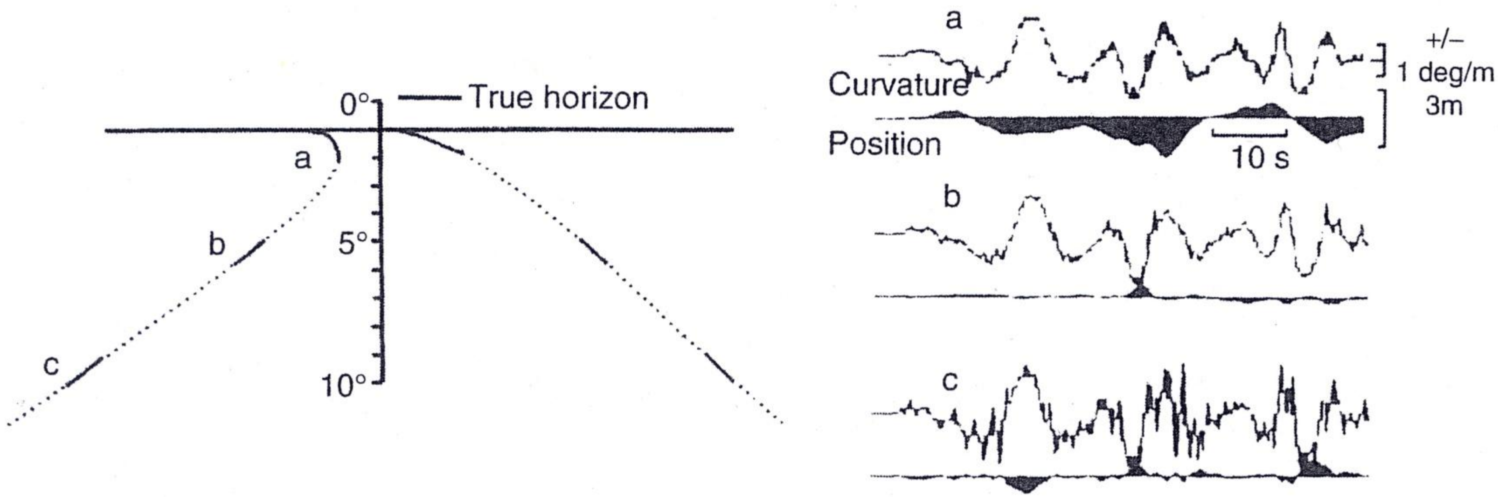
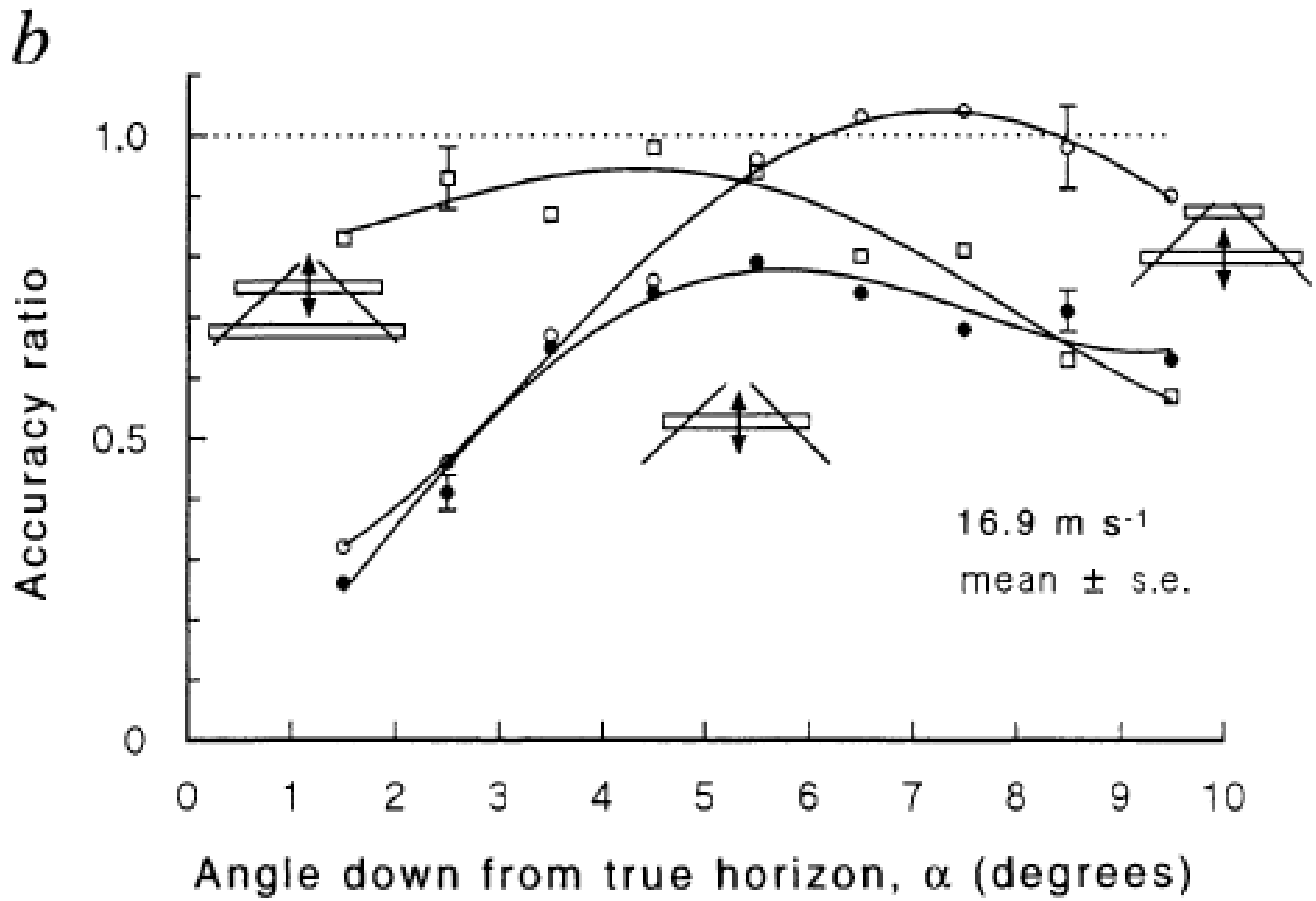


Fig. 7.9 Performance on a simulator when different 1° vertical segments of a winding road were visible (a-c, top). Records show curvature of road and car's track, and position of car relative to the midline of the road. Inaccuracies – discrepancies between the road and car track – show up in black. More distant parts of the road (a) allow road curvature to be matched accurately but are very poor at keeping the car in lane. Near regions (c) are better for maintaining lane position but cause the steering to go into 'bang-bang' mode. From Land and Horwood (1995).

Land & Horwood (1995)



Donges (1978) Two-Level Model

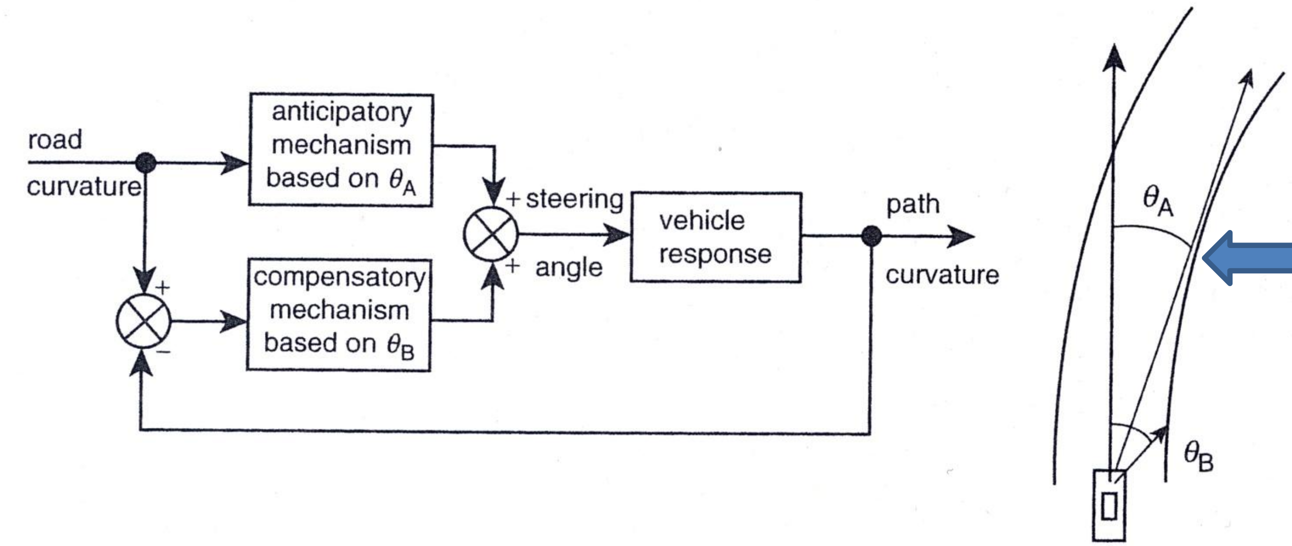


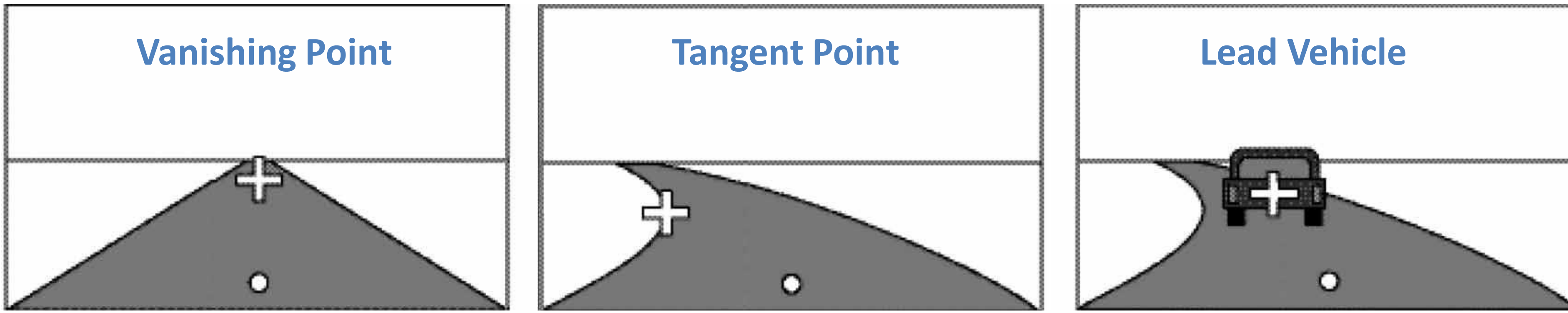
Fig. 7.8 Control diagram of steering incorporating feed-forward information from distant parts of the road (θ_A) and feedback information from the near lane edges (θ_B). Based on Donges (1978).

Tangent Point
(Land & Lee, 1994)

Perceived road curvature estimated from **far** distance visual information using **open-loop** decision-making processes versus current lane position maintenance via **closed-loop** nulling of error signals based upon **near** distance visual information

Salvucci & Gray (2004)

Two-Point Model of Steering



Rather than estimating curvature or other complex entities, the 2-point model relies solely upon directly perceivable visual input.

The **near point** is the center of the lane at some nearby distance and is used to monitor both lateral position and stability (central or peripheral vision).

Far point can be ANY salient point that provides predictive steering angle information about upcoming changes in roadway geometry (anticipatory; smoothness; minimizes “lag” effects).

Potential FAR POINTS: vanishing point; tangent point; lead vehicle

Salvucci & Gray (2004)

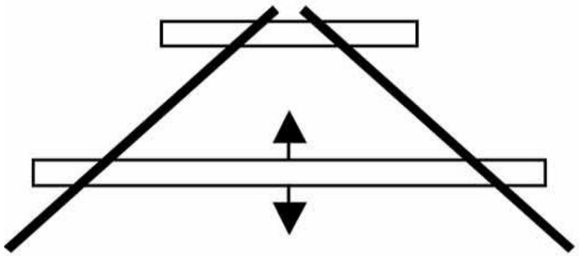
Two-Point Computational Model of Steering

$$\Delta\varphi = k_{\mathrm{f}}\,\Delta\theta_{\mathrm{f}} + k_{\mathrm{n}}\,\Delta\theta_{\mathrm{n}} + k_{\mathrm{I}}\,\theta_{\mathrm{n}}\,\Delta t$$

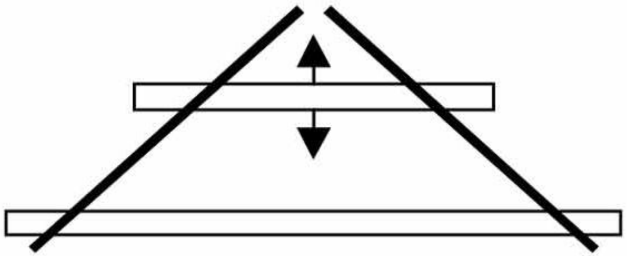
Steering Angle	=	Far point stability	+	Near point stability	+	Near point centering

Simulating Land & Horwood (1995)

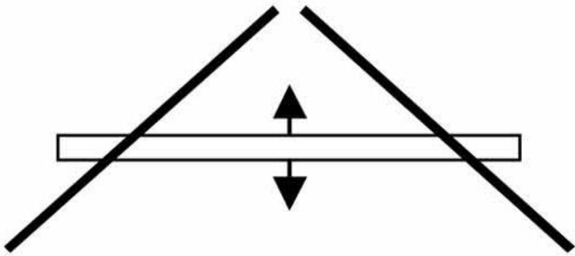
Experimental Viewing Conditions



Move-Near



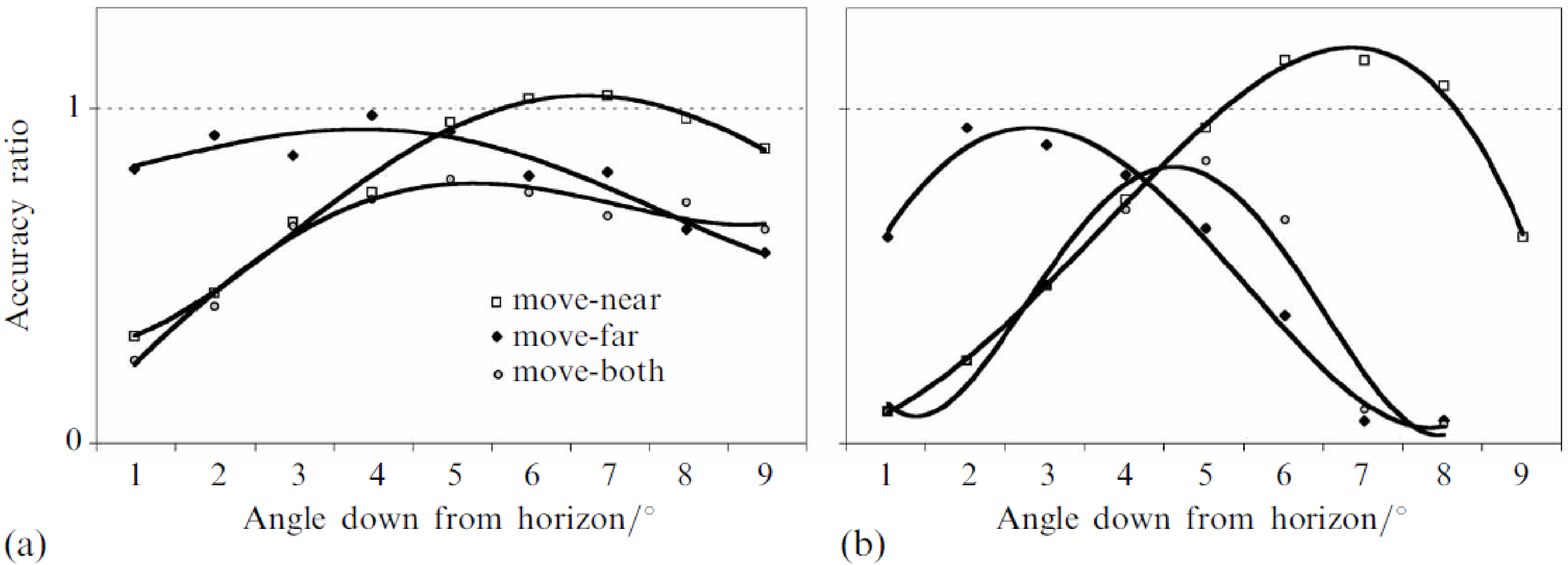
Move-Far



Move-Both

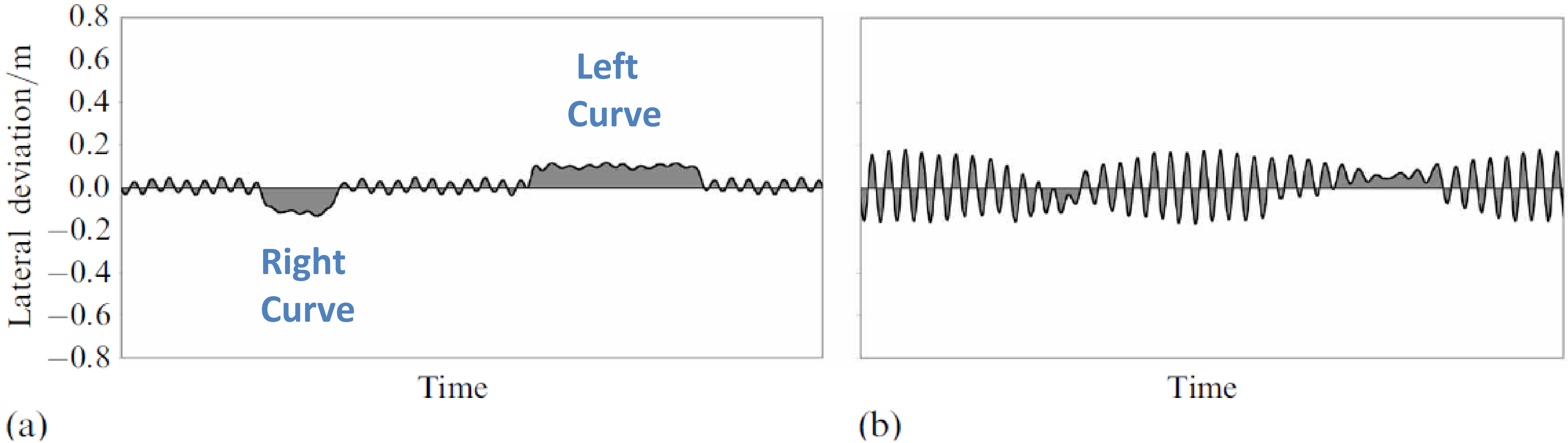
Salvucci & Gray (2004)

Two-Point Model of Steering



Human Data **Model Simulations**

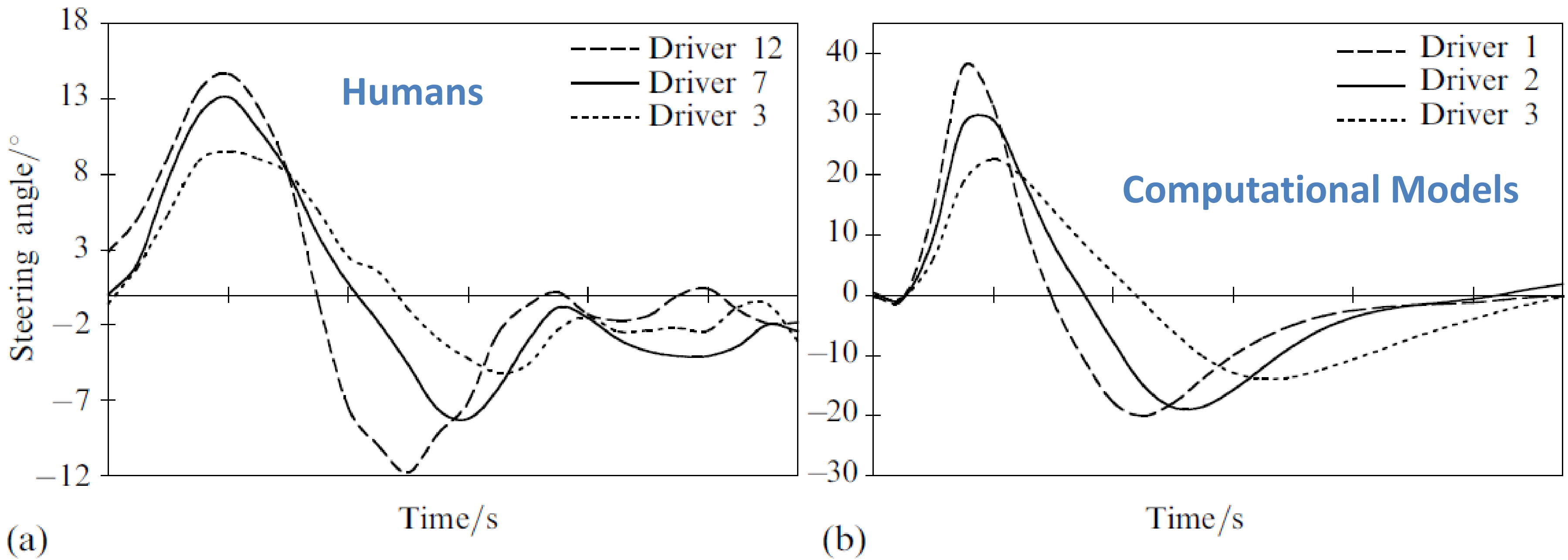
Model Mimics Human Behavior in Far-Only vs. Near-Only Viewing



<u>Far-Only Vision</u>
Lane keeping highly biased while negotiating curves

<u>Near-Only Vision</u>
Good average lane position but “Bang-bang” instability

Lane Change Behavior



Gaze scanning moves to destination lane prior to lane change (Salvucci & Liu, 2002).

Large initial movement followed by shallow movement "return phase".

Model (like humans) switches from using near/far points of current lane to near/far points in the destination lane.

Wallis et al. (2002) failure to execute "return phase" after lane change in no visual Feedback condition (Just-in-Time visual cognition rather than open loop?)

Pure Open-Loop Steering

(A Thought Experiment)

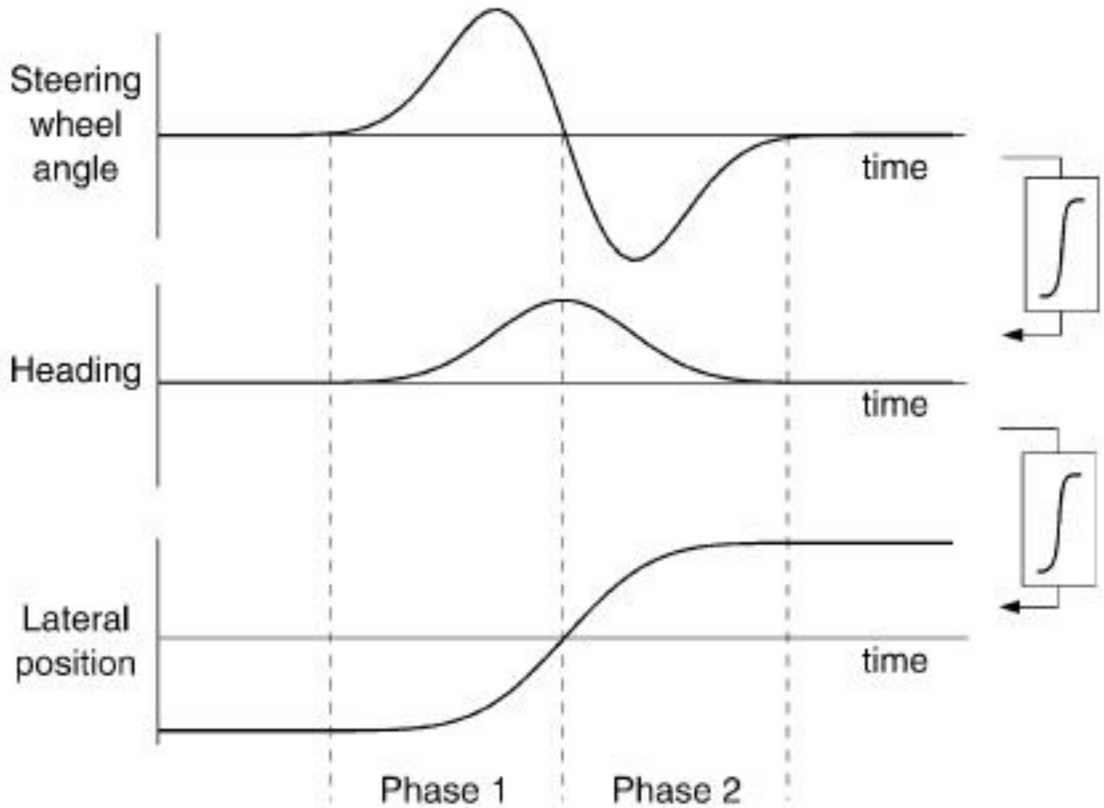
- Image that your driving down the right lane of a freeway with your hands fixed to an imaginary steering wheel
- Now, execute an imaginary lane change into the adjacent left lane…complete with your steering inputs to the imaginary steering wheel
- Describe your inputs to the steering wheel

Wallis, et al. (2002)

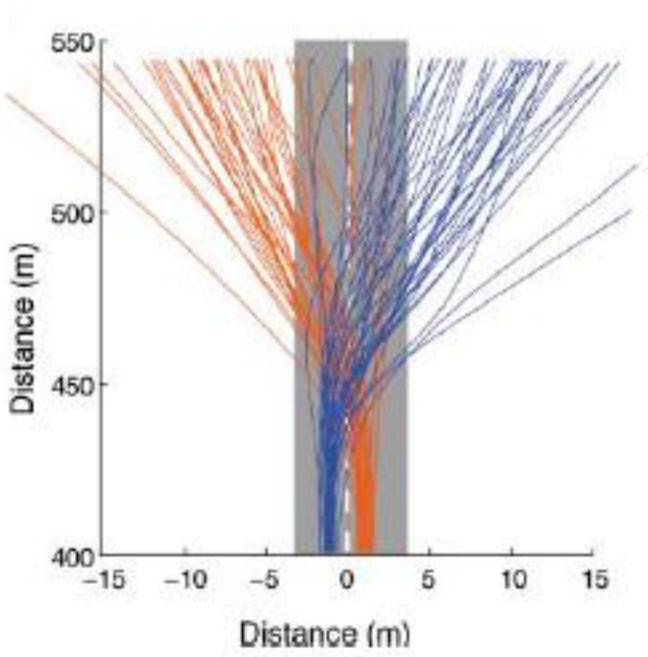
Steering Maneuver
With Visual Feedback

Steering Maneuver
Imagined or Without
Visual Feedback

Normal Steering Profile



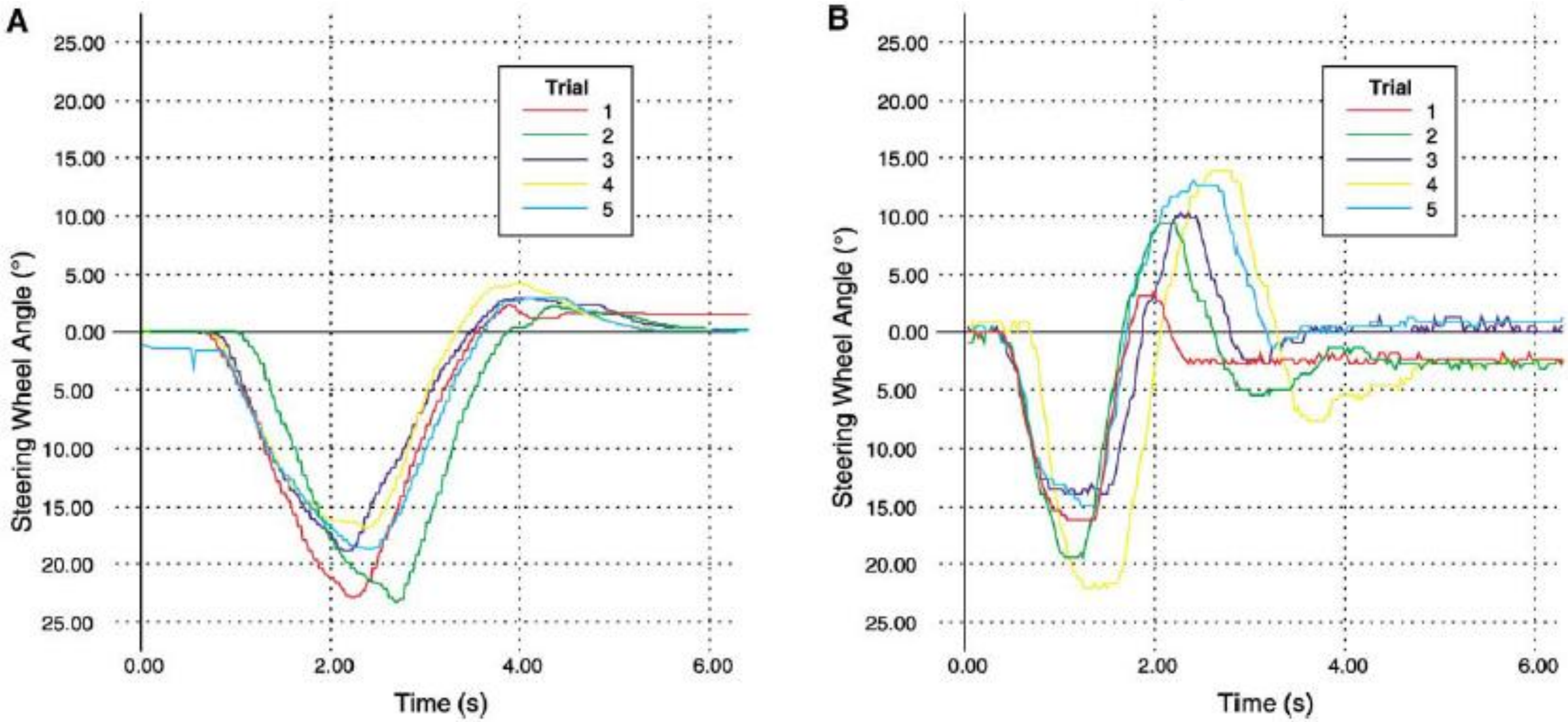
Steering Paths without Visual Feedback



Plots of lane change maneuvers completed in the dark (i.e., after entering a tunnel)

Participants consistently fail to execute the "return" input to the steering wheel.

Effects of Providing Post-Maneuver Visual Feedback of Heading Error



Single subject repeatedly omits "return phase" steering response in the dark condition with no end-of-maneuver feedback

Single subject quickly learns to correct omission error when terminal heading error is provided

Myers' USD Thesis Project

- Modified visual occlusion paradigm (near-only; far-only; full vision baseline)
- Prediction:
  Time-to-line-crossing (TLC) unchanged in FAR condition but degraded in NEAR condition

  SD Lane Position unchanged in NEAR but degraded in FAR condition
- TLC = far process; SD Lane Pos. = near process