Evaluation of the Visual Demands of Digital Billboards Using a Hybrid Driving Simulator

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The advent of low-cost, high-brightness LED technology has resulted in the proliferation of large-format digital billboards (**DBBs**) in roadside advertising and on-premise signing applications

A Proliferation of Digital Billboards

Critical Characteristics of DBBs

- Continuously updated content (greater information “bandwidth”)
- Attention-capturing dynamic updating (flashing; scrolling text; animation)
- High potential for driver information processing overload that interferes with safe and efficient operation of motor vehicles (increased eyes-off-road time)

Some Noteworthy Findings…

- Beijer (2002)
  Dynamic DBBs associated with glances of excessive duration (2 sec or longer)
- Smiley, et al. (2004)
  Freeway drivers look at DBBs longer and more often than traditional signage
- Beijer, et al. (2004)
  88% of drivers exhibited long duration glances at DBBs with dynamic content (i.e., 750+ msec)

Entry-Level Question:

How much text information can a driver extract from a large-format DBB before driving performance is degraded?

Knowing the answer to this question could help guide the process of deploying sign content that conveys the critical message without imposing an unnecessary risk upon drivers.

Experimental Approach

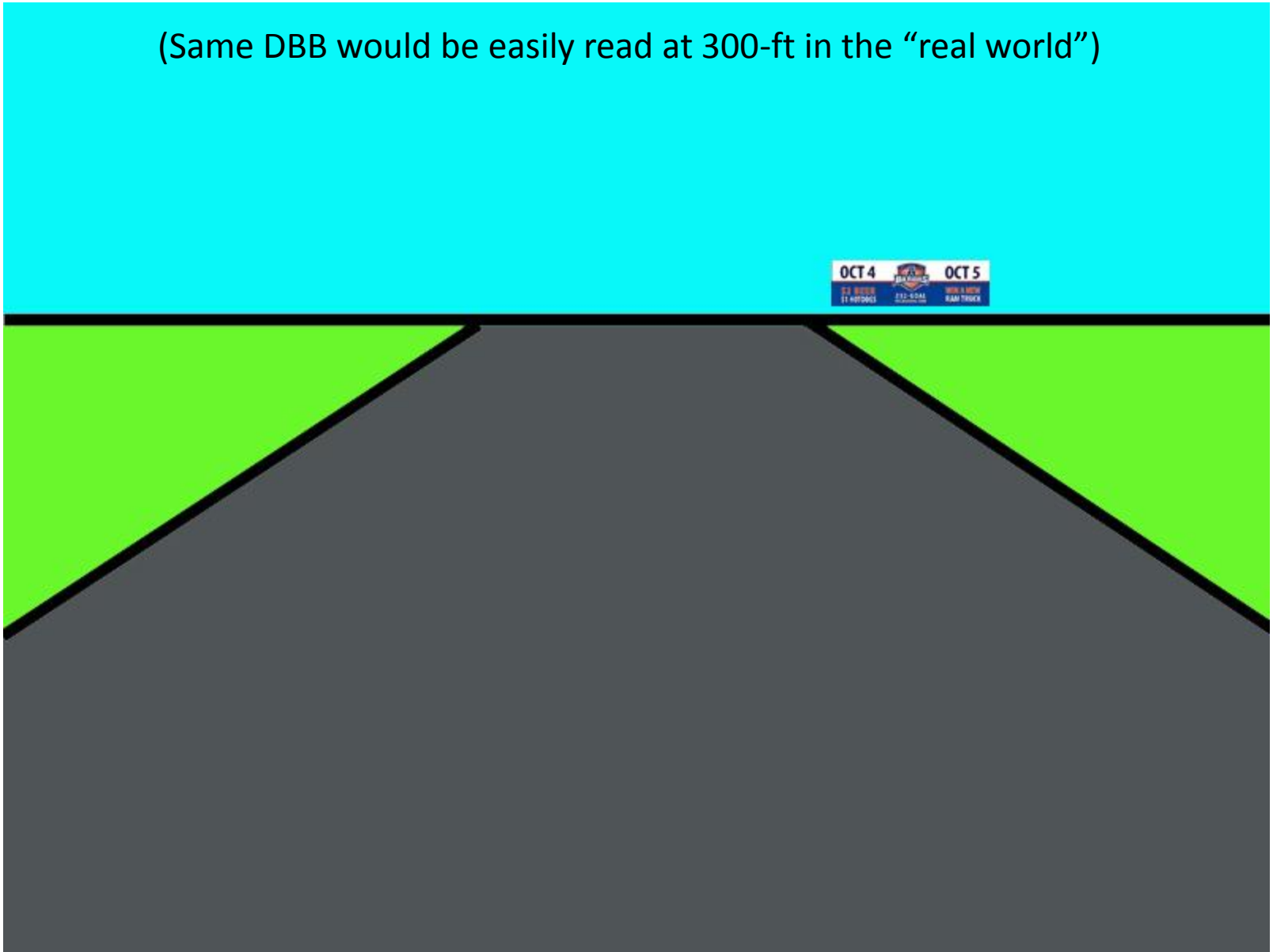
- Increase amount of text information on DBBs until driving performance becomes degraded
- Assess how drivers manage increasing visual demands of signage via reading performance, total glance time and number of glances to signs
- Such a “Push-until-you-Break” strategy demands use of a driving simulator approach

But, there's a big problem…

Driving simulators based upon computer graphic displays are not well suited to studying drivers' sign reading performance.

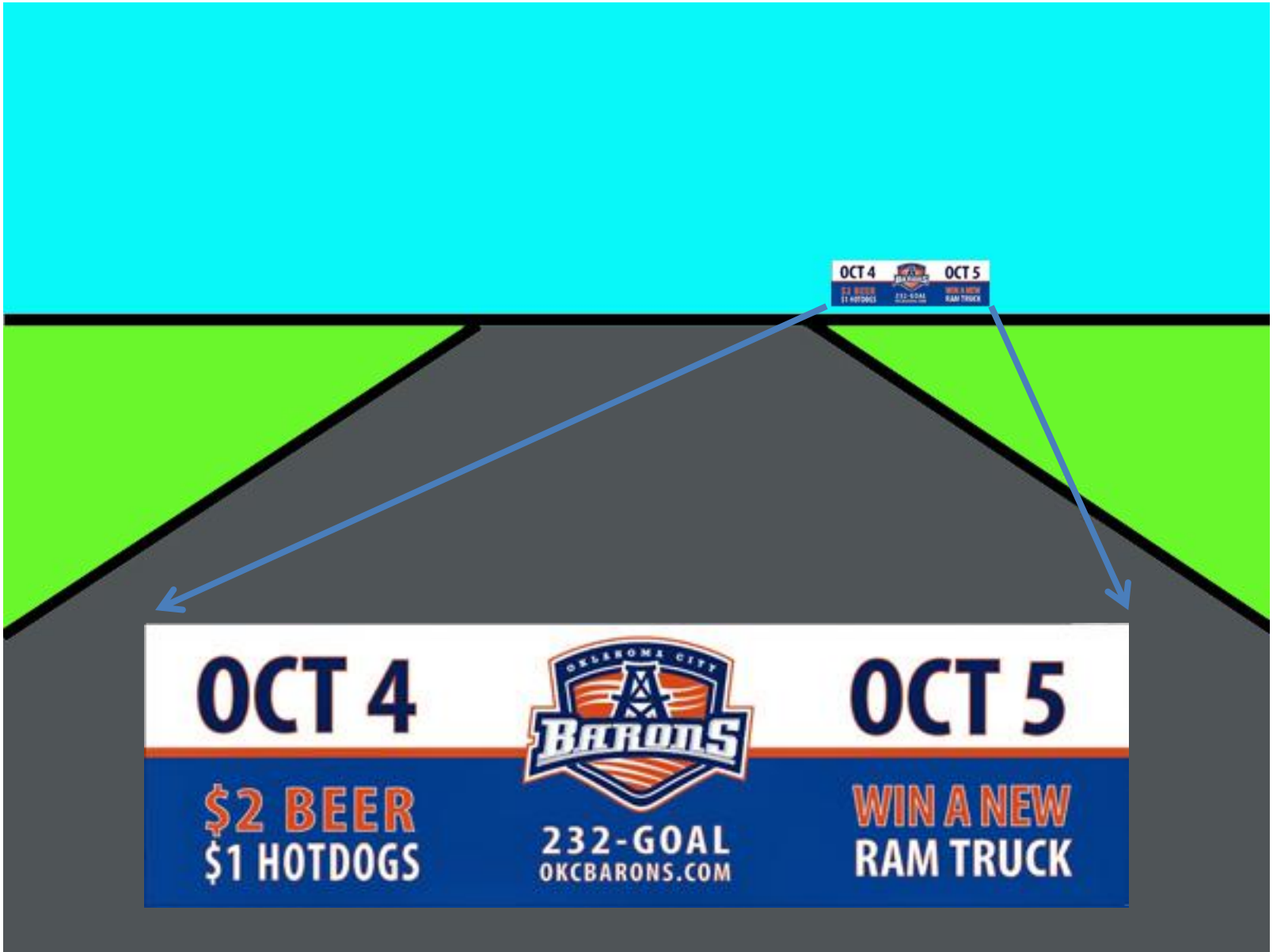
(Illustrated on the followings slides)

A Large-Format DBB Rendered at 300-ft is not Legible in a typical Driving Simulator



Large DBB cannot be properly rendered with 100 x 29 pixel resolution available in this example

Large DBBs can be rendered with sufficient resolution to support real-world legibility distances in a HYBRID simulator



Hybrid DBB Driving Sim Prototype

(Video)

Critical Advantage of Hybrid Approach: Number of pixels used to render text message does not change with simulated viewing distance. Display resolution does not set the limit of legibility performance.

Experimental Protocol

- Read DBB stimulus aloud while maintaining speed and lateral control of vehicle

- Experimental Factors:
  Message Length: 4, 8, or 12 unrelated words (independent linguistic units)
  Driving Speed: 25 vs. 50 MPH (8 vs. 4 sec stimulus exposure time)
  (collapsed across straight vs curved road condition)

- Driving performance, reading behavior and eye glance position data were collected for off-line analysis (N=18; 20/28 or better acuity)

Simulated DBB Display

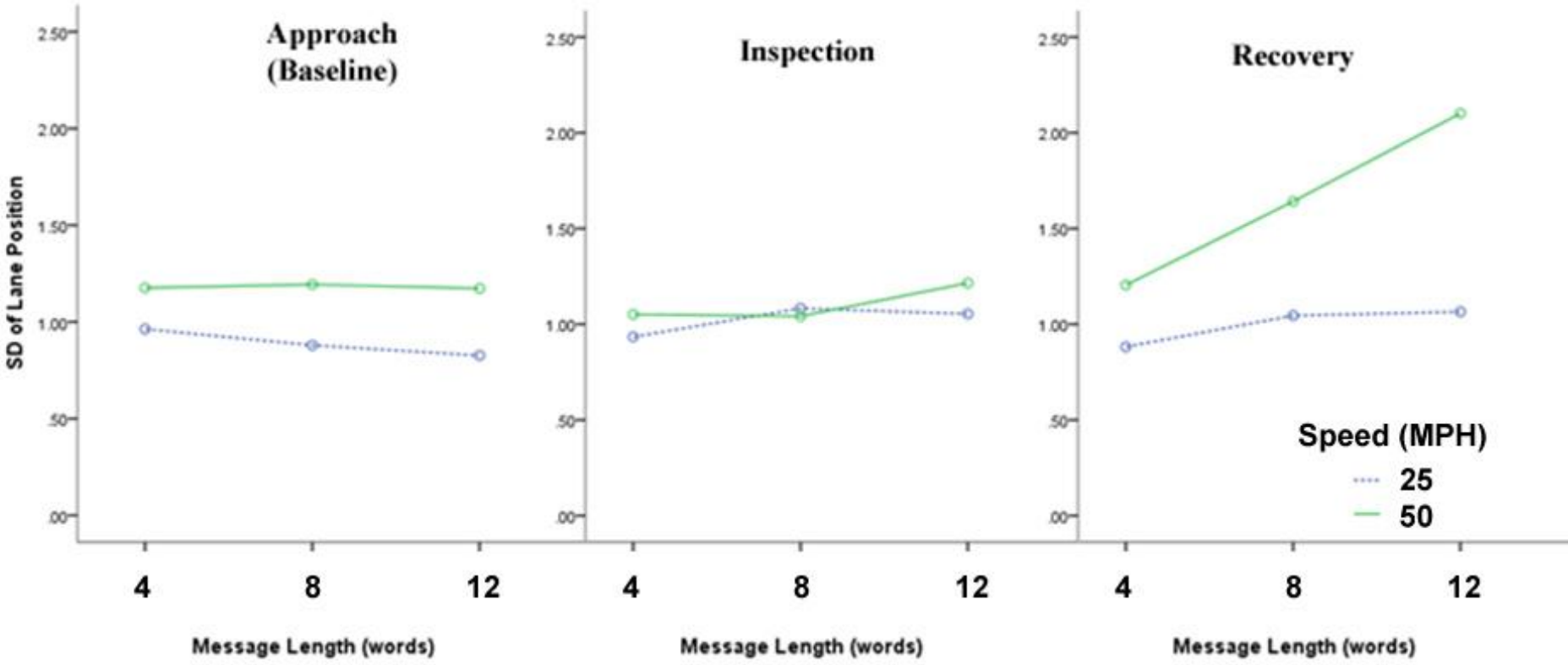
- **800 x 600 LCD panel**
  - 0.5-inch tall letters
    - (i.e., 10-inch tall or 10 minarc at 300-ft)
  - white-on-black format
  - 85% contrast; 85 cd/m^2 luminance
- **20-ft motorized linear actuator**
  - 300-ft of travel; scale = 1:20
  - computer controlled stepper motor

Results

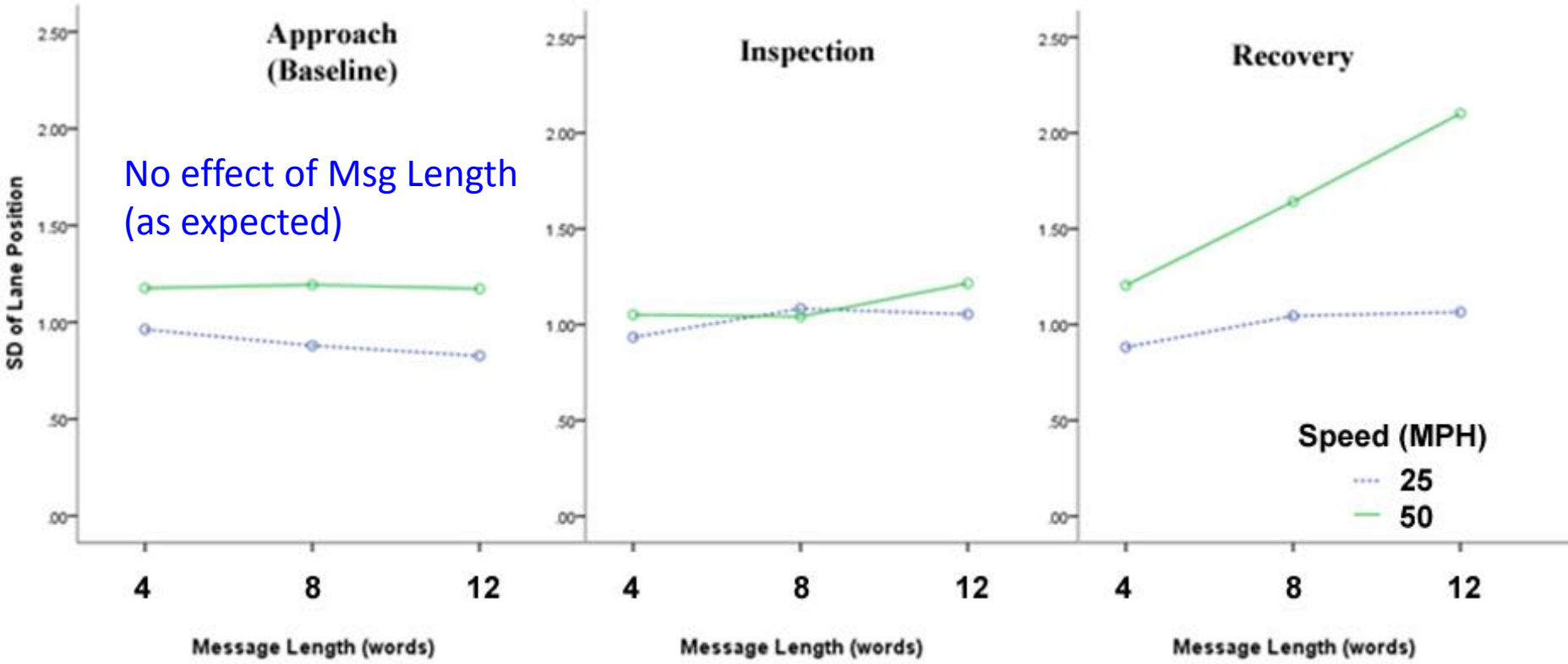
- Vehicular Control
  - **SD Lane Position** (across 3 Epochs)
    - Baseline (8 sec before sign reading)
    - Inspection (during sign encounter)
    - Recovery (8 sec after sign reading)
- **Reading Performance**
- **Eye Glance Behavior**
    - Total eyes-off-road time
    - Number of glances

SD Lane Position

(2) Speed x (3) Message Length x (3) Epoch Interaction

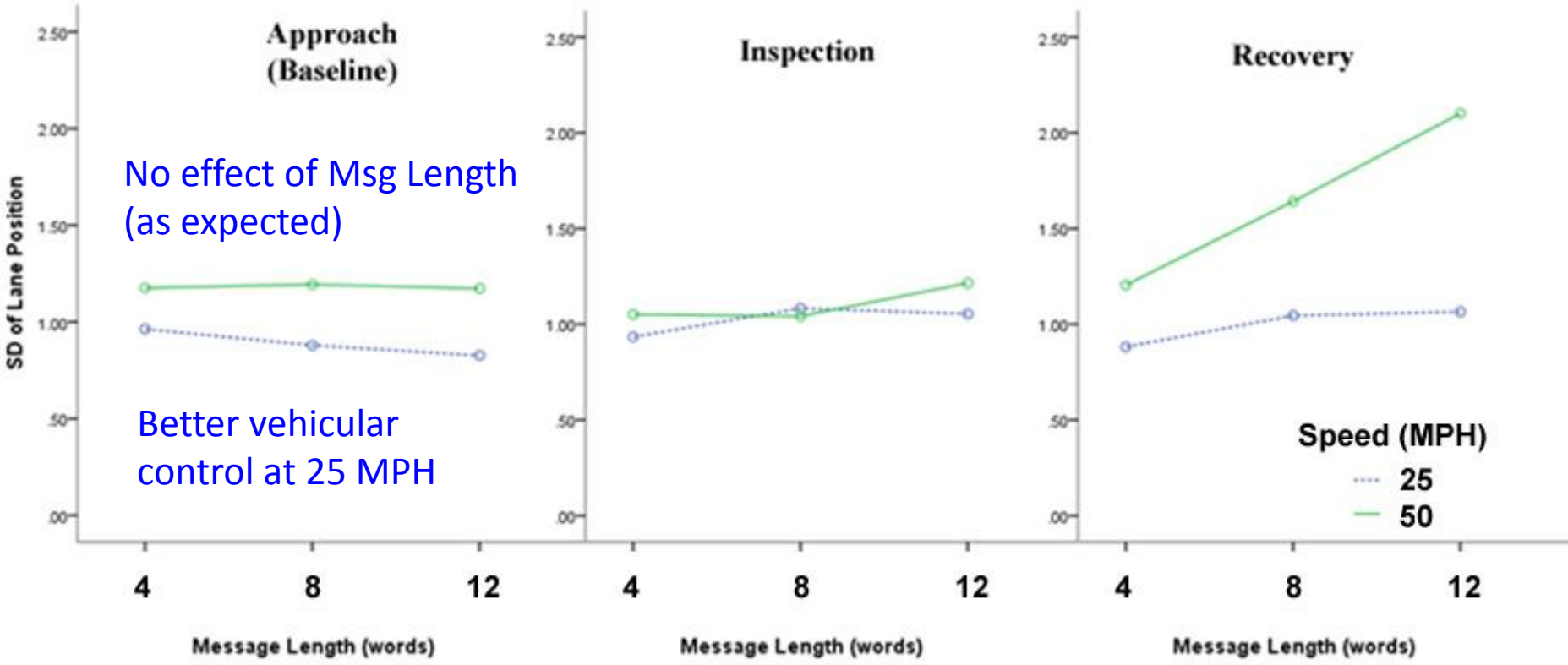


Vehicular Control

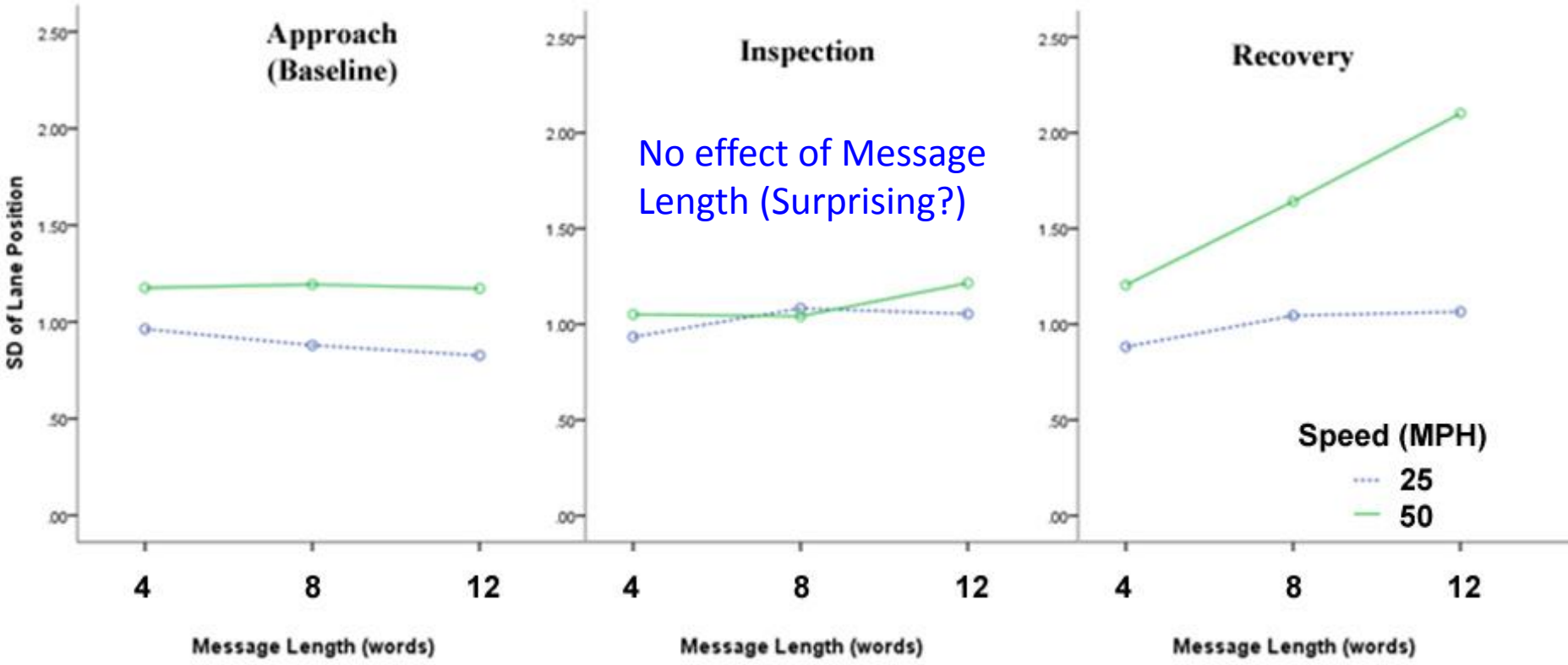


No effect of Msg Length (as expected)

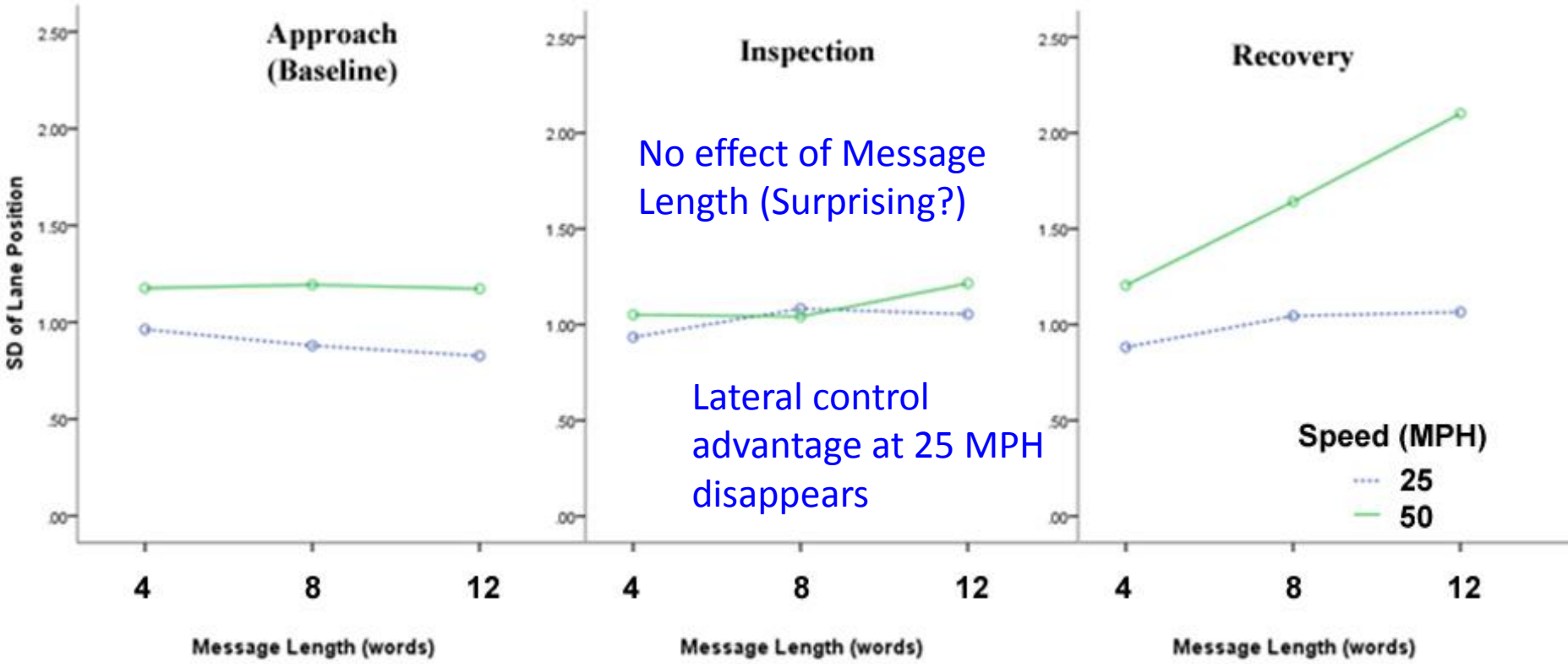
Vehicular Control



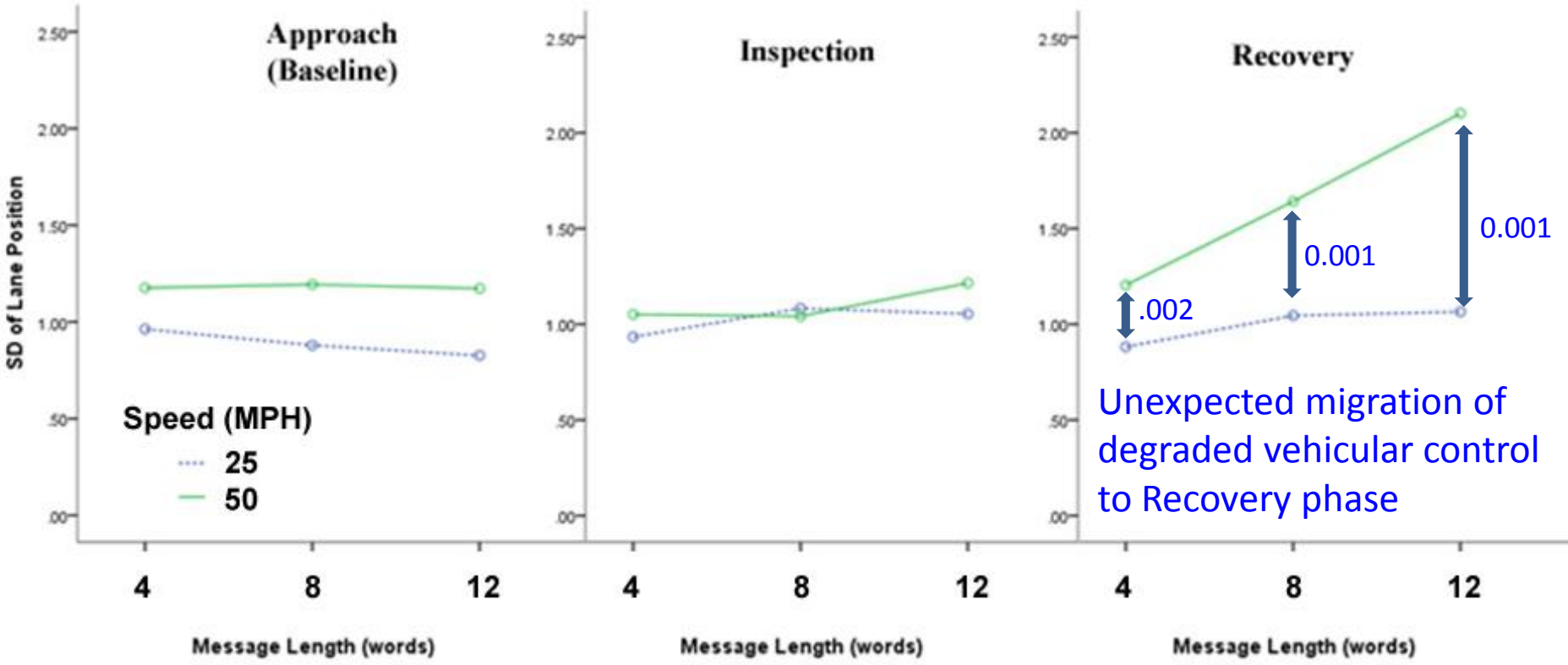
Vehicular Control



Vehicular Control

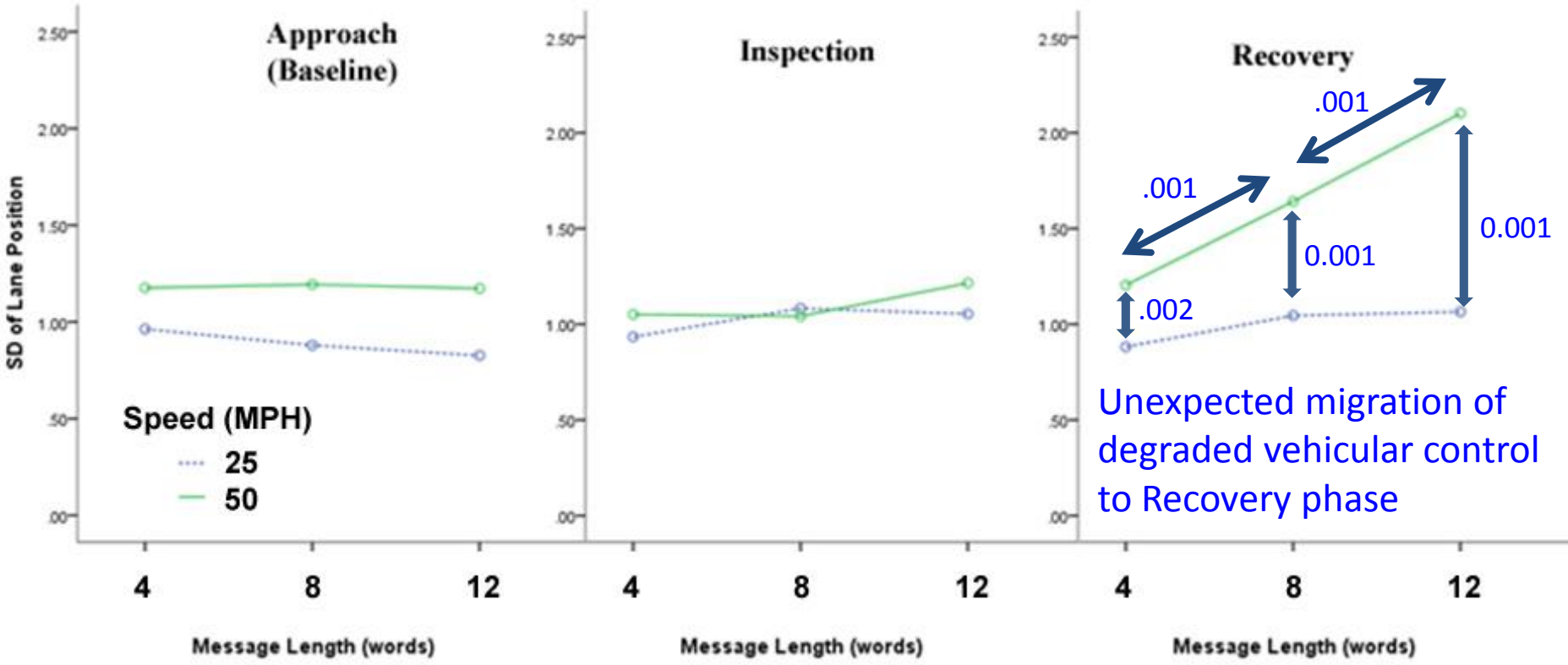


Vehicular Control



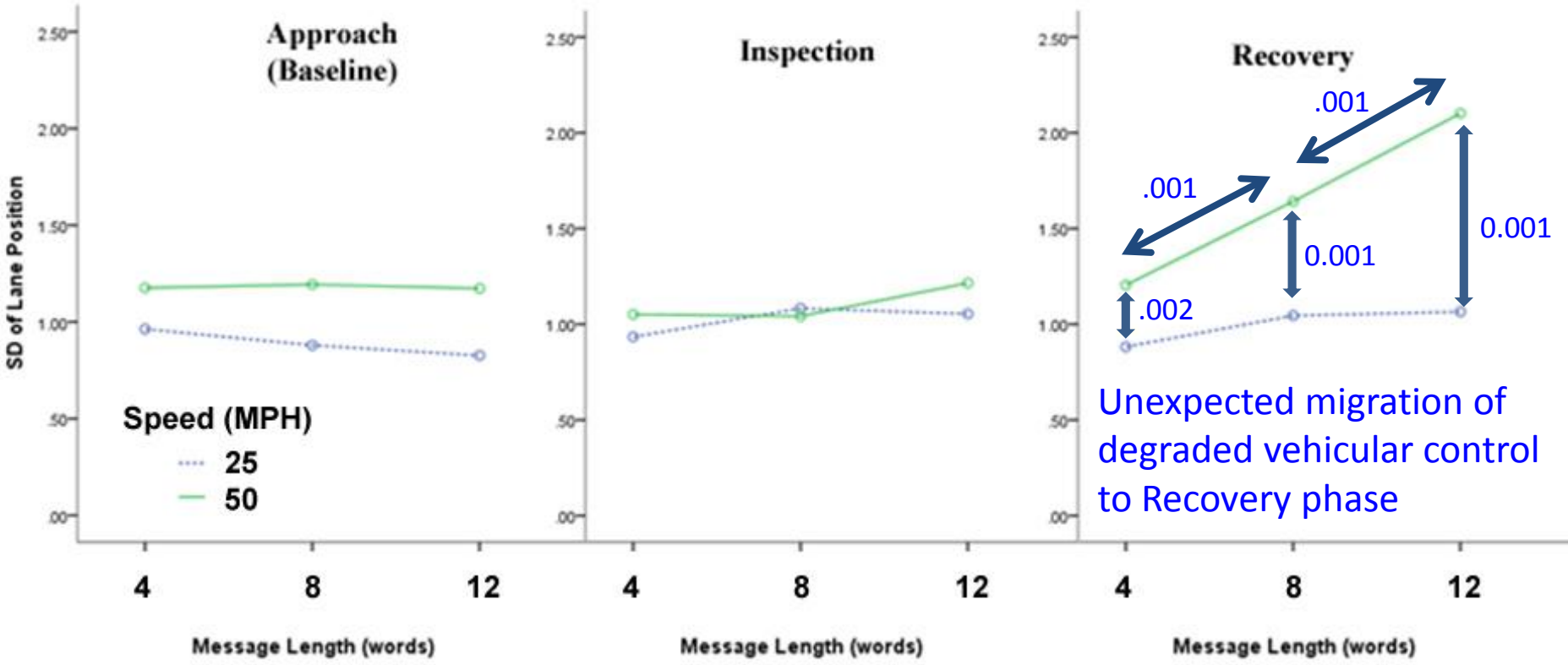
Unexpected migration of degraded vehicular control to Recovery phase

Vehicular Control



Unexpected migration of degraded vehicular control to Recovery phase

Vehicular Control



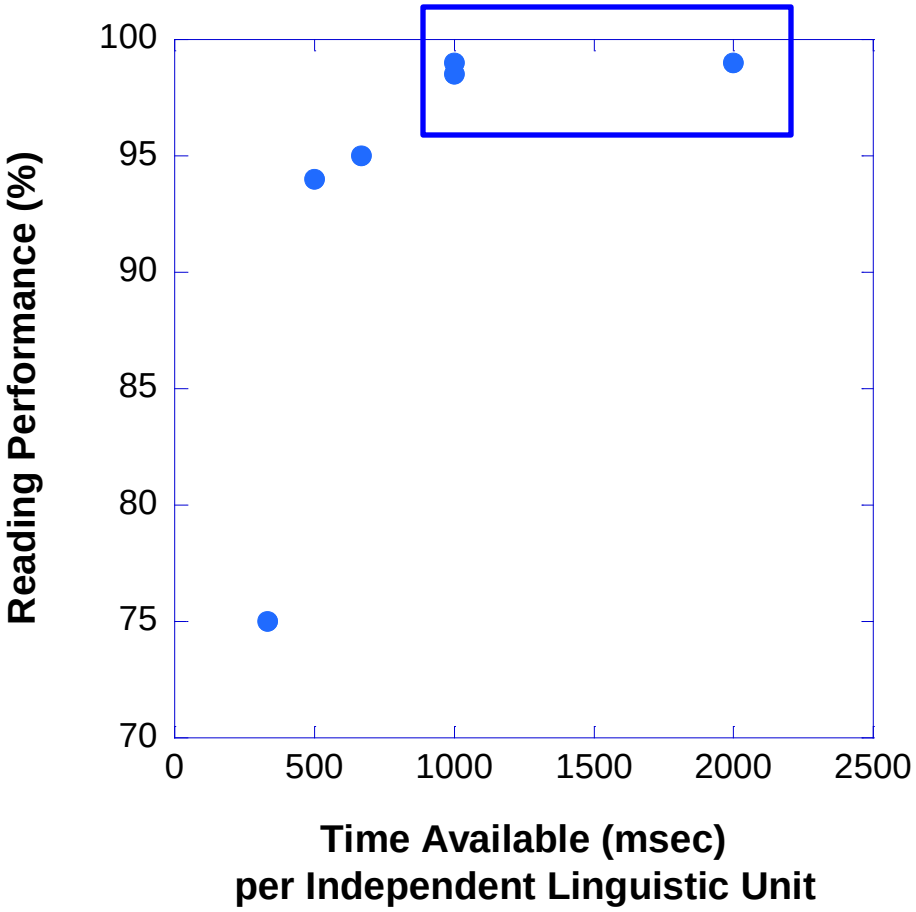
Unexpected migration of degraded vehicular control to Recovery phase

Analysis of first derivative of lane position revealed that a slow, unidirectional "drift" occurred during sign reading followed by a high-amplitude "correction" after the encounter with the DBB

Reading Performance and Gaze Management

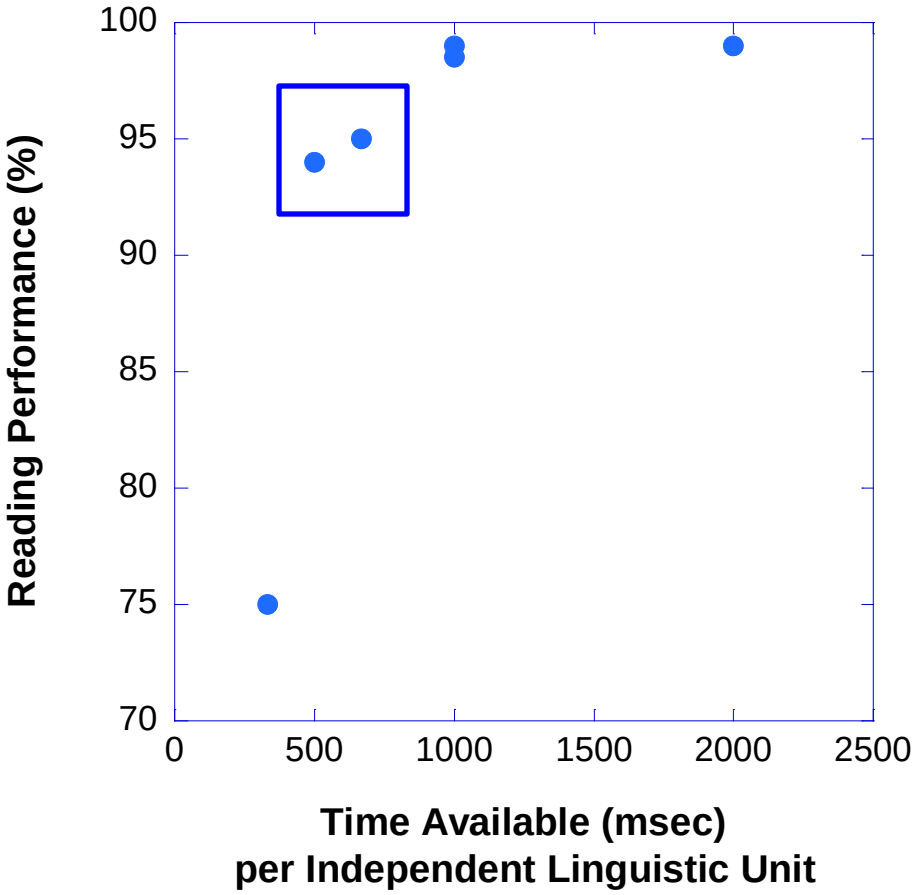
Speed (MPH)	Message Length	Reading %Correct	msec per word	EoRT	EoRT Duty Cycle
	4	99	2000	2346	29%
25	8	98.5	1000	3676	46%
	12	95	667	4803	60%
	4	99	1000	1861	46%
50	8	94	500	2902	73%
	12	75	333	3484	87%

Effects of Diminishing Time Availability upon Reading Performance



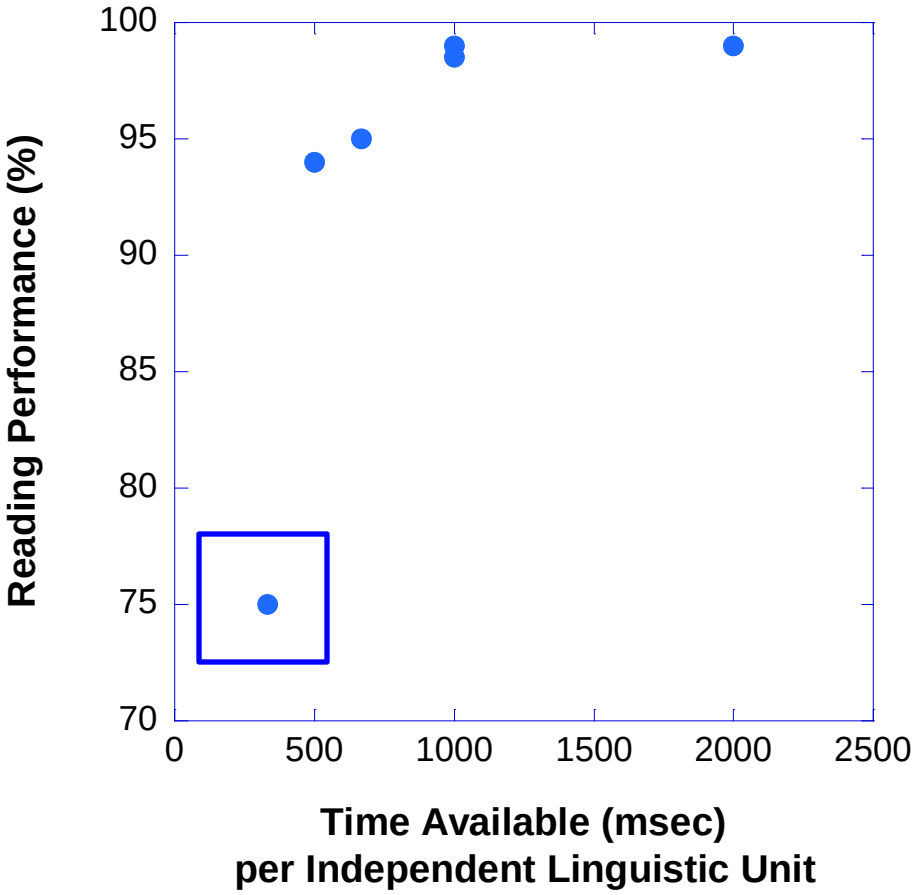
Asymptotic reading performance when time availability exceeded 1000 msec per word

Effects of Diminishing Time Availability upon Reading Perfomance



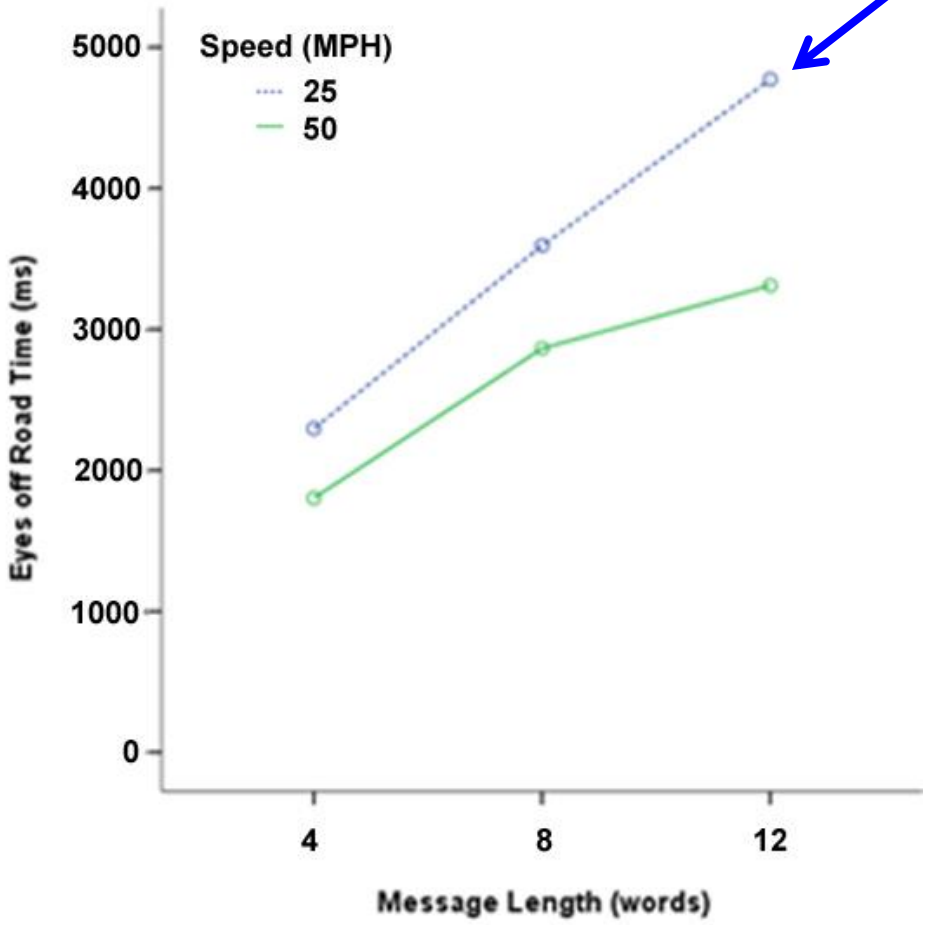
Reading performance began to suffer a bit when time availability dropped to 500-700 msec per word.

Effects of Diminishing Time Availability upon Reading Performance



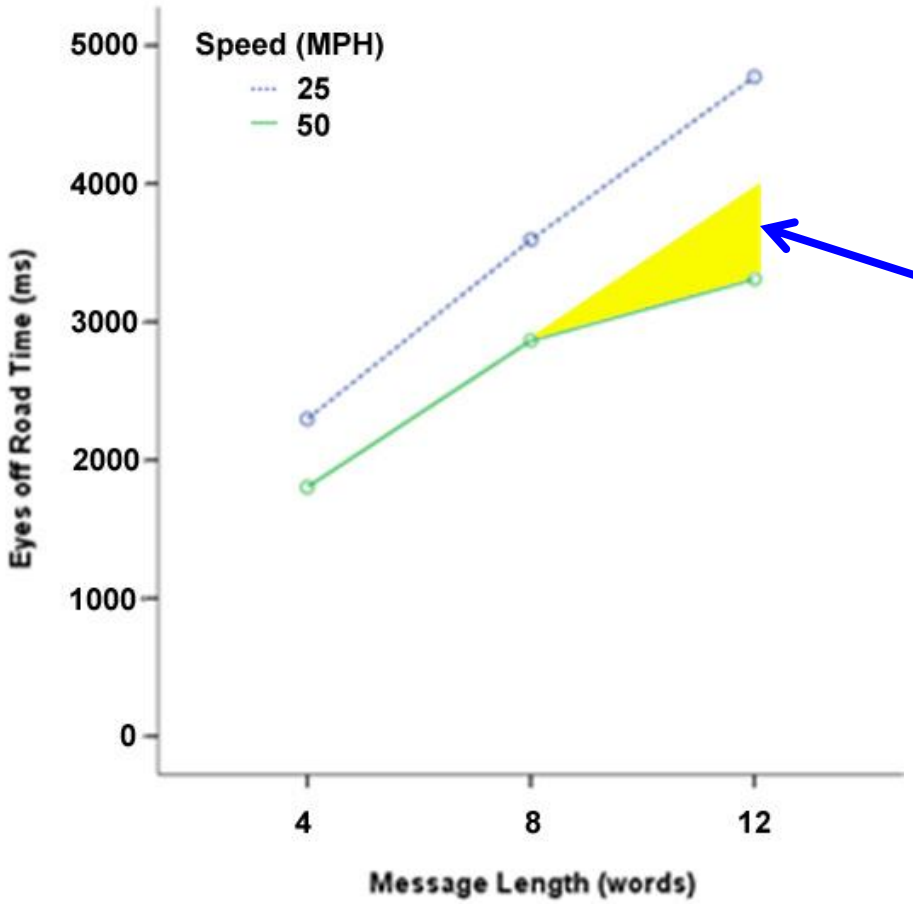
Reading performance was significantly degraded when time availability dropped below 500 msec per word.

Total Eyes-Off-Road-Time



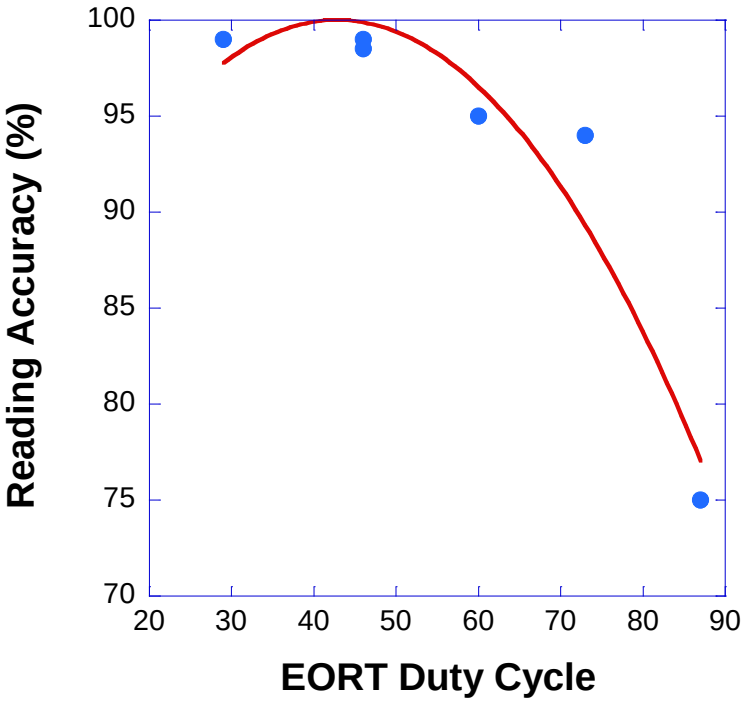
Visual information processing capacity was able to keep up with demand as message length increased (25 MPH)

Total Eyes-Off-Road-Time



Visual information processing capacity shortfall was observed as available processing time fell to 500 ms per linguistic unit or less (4000 ms/8 words = 500 ms/word)

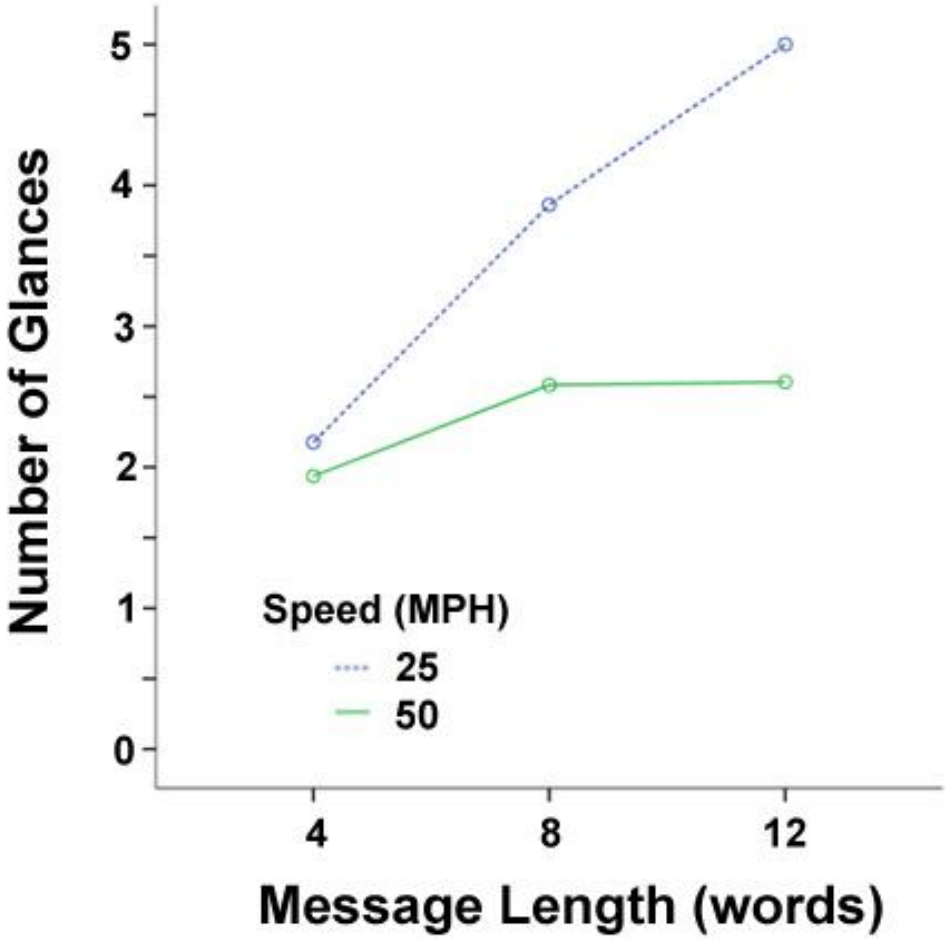
Eyes-Off-Road-Time Duty Cycle



$$\text{EORT Duty Cycle} = \frac{\text{Total EORT}}{\text{Stimulus Presentation Time}}$$

Reading performance was degraded when glance time exceeded 50% of the total time available to read the DBB

Glance Frequency



Glance frequency data depicts the same visual information processing “overload” scenario seen for the EoRT data

Summary of Findings

- Little evidence for visual processing bottleneck or loss of vehicular control at 25 MPH

- Significant visual information processing overload and interference with vehicular control was observed at higher speed (where available sign reading time was reduced to 4 sec)

Summary of Findings

- Both reading performance and vehicular control were degraded when available processing time dropped below 500 msec per independent linguistic unit (i.e., unrelated word) and/or where EoRT Duty Cycle exceeded 50%

- Negative impact on vehicular control was characterized by unidirectional drift (“ lane neglect”) instead of increased oscillation

Summary of Findings

- Lane neglect accrued during sign reading was accompanied by a large amplitude corrective maneuver AFTER reading was finished

- "Max change in lane position"
  or
  "First derivative of lane position" (or yaw rate) may be better suited to quantifying vehicular control during sign reading than traditional RMS measures

Summary of Findings

- The hybrid simulator approach appears to be well suited to the study of sign reading behavior while driving

- The hybrid simulator can support more comprehensive studies aimed at optimizing the design of complex/dynamic elements of DBBs such as text scrolling, page update rates and animation


"THANK YOU!"

Contact Information:

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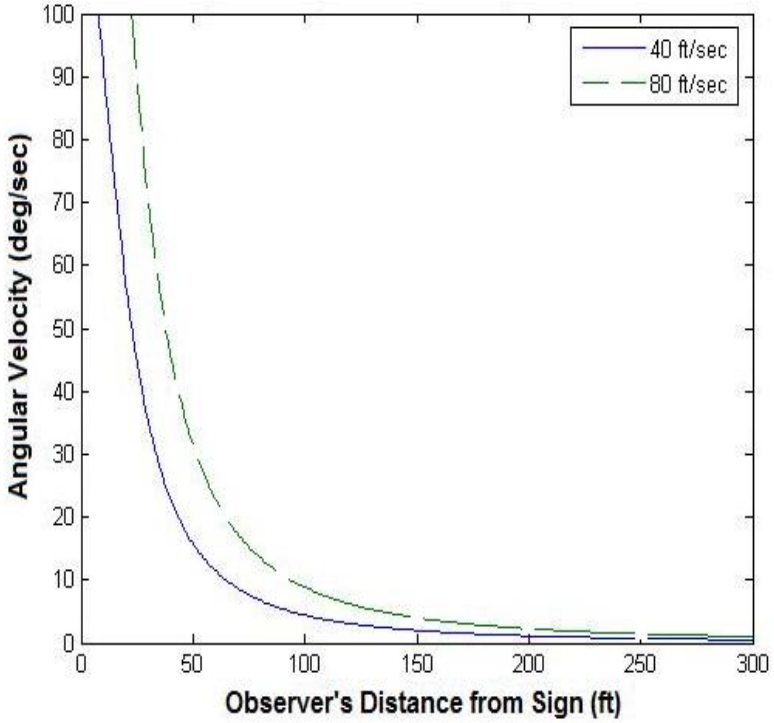
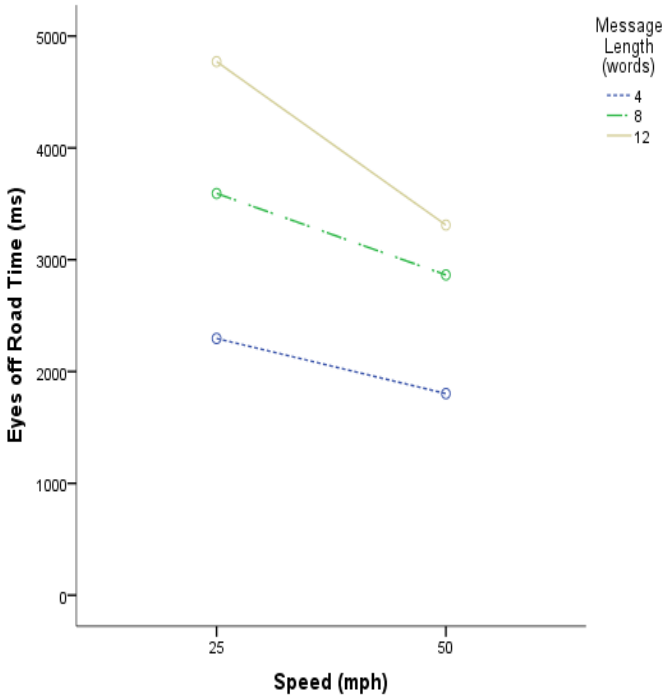
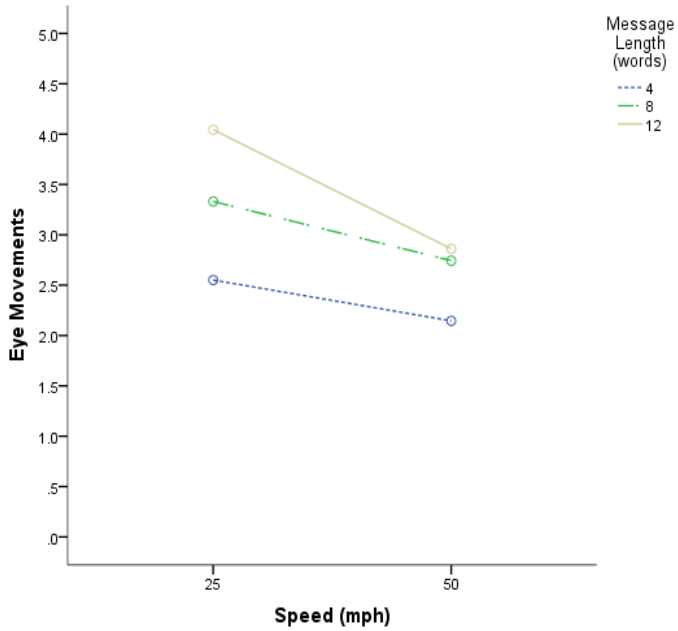
Appendix

- Angular velocity as a function of distance
- More detailed EoRT plots
- Picture of stepper motor/transport cart
- Oscillation vs continuous drift (SD Position)

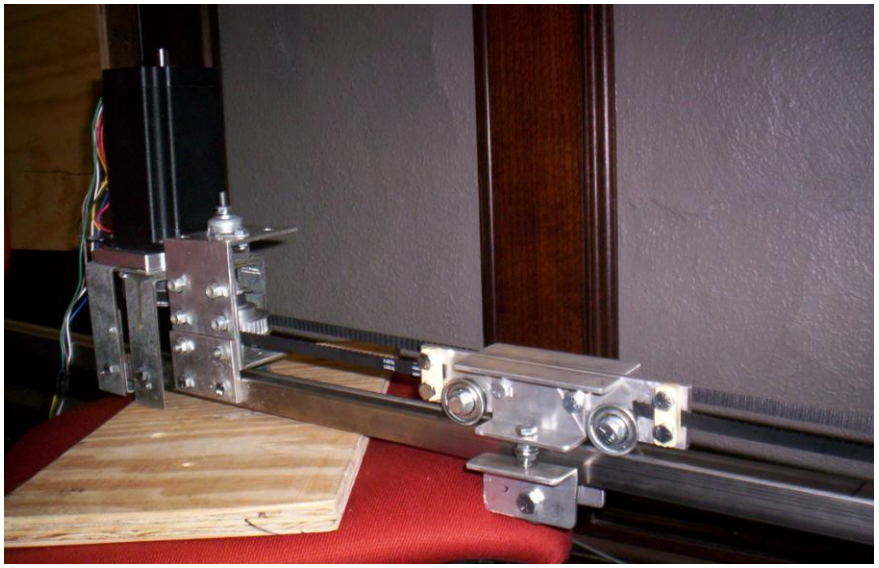
Appendix


40 ft/sec
80 ft/sec
Angular Velocity (deg/sec)
Observer's Distance from Sign (ft)
0
10
20
30
40
50
60
70
80
90
100
0
50
100
150
200
250
300


Eyes off Road Time (ms)
5000
4000
3000
2000
1000
0
25
50
Speed (mph)
Message Length (words)
4
8
12


Eye Movements
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
.0
25
50
Speed (mph)
Message Length (words)
4
8
12

Stepping Motor, Actuator Rail and Transport Cart



Sine Oscillation vs Linear Drift