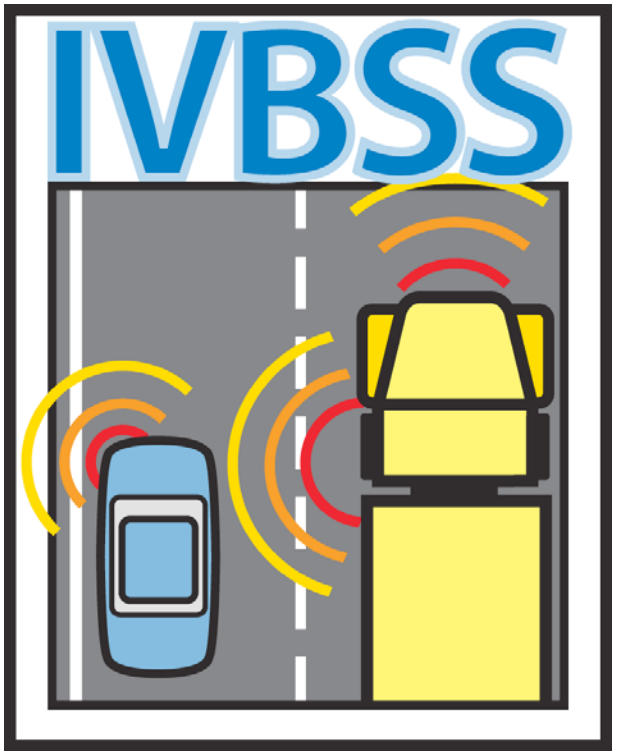

Human Factors and DVI Development Task

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IVBSS 2008 Public Meeting

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Ypsilanti, MI

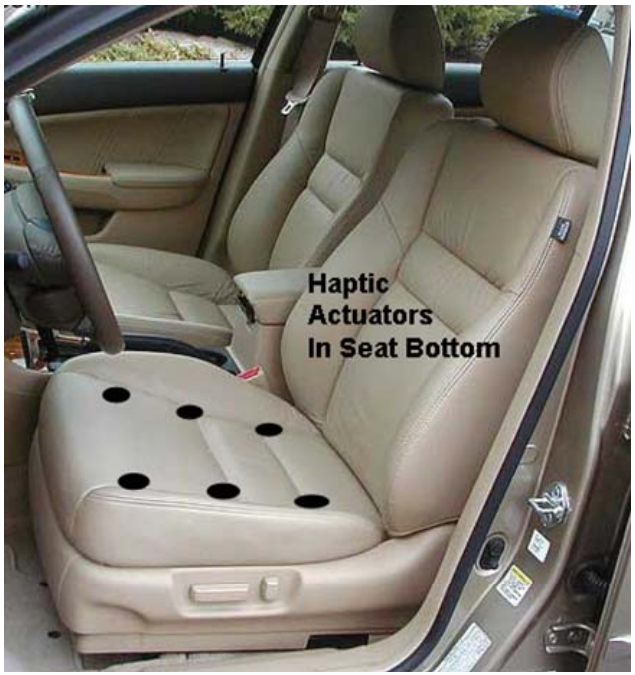
Light Vehicle DVI

	Forward Alerts		Lateral Alerts	
	FCW	CSW	LCM LDW Imminent	LDW Cautionary
Auditory	Tone 1		(L) (R) Tone 2	-----
Haptic	Brake pulse	Brake Pulse	-----	Haptic Seat L/R
Visual			Blind zone: red Closing zone: yellow	
Warning Text	Hazard Ahead	Sharp Curve	Left/Right Hazard	Left/Right Drift

Light Vehicle DVI

Auditory

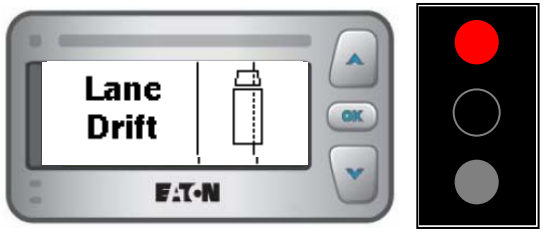
Haptic



Visual

Brake Pulse

Heavy Truck DVI

	Forward Alert	Lateral Alerts	
	FCW	LDW (Unoccupied Space)	LCM or LDW (Occupied Space)
Auditory	Tone 1	(L) (R) Tone 2	(L) (R) Tone 3
Visual			

Experiment 1 – Auditory Warnings

- Objectives
  - Characterize sound environments of vehicles
  - Identify which acoustic properties of sounds are associated with urgency, annoyance, and noticeability
  - Consider that multiple sounds may be required for different warnings
    - How do sounds work together? What is the potential for confusion? How easily are they learned?
  - Can some sound modifications enhance localization of sounds?
  - Are reaction times to warnings affected by pulse characteristics?

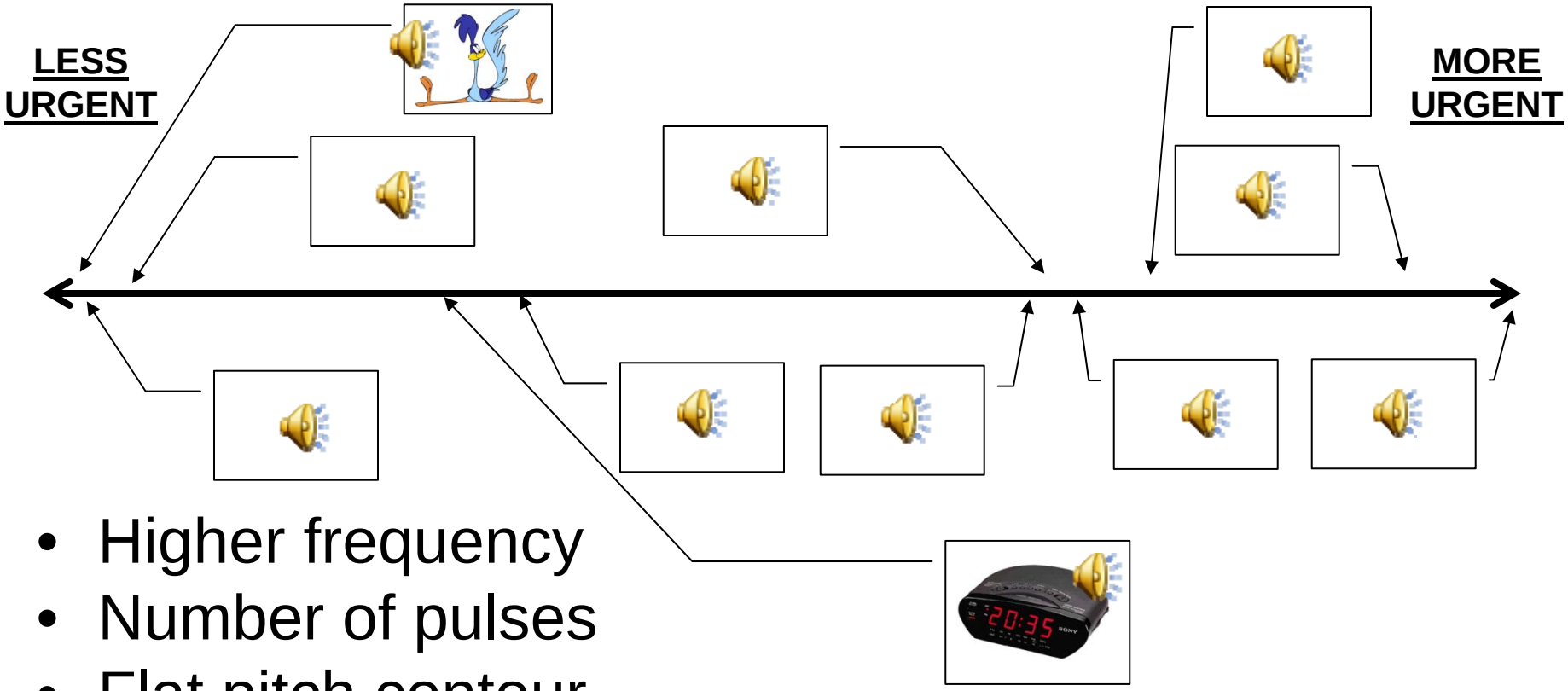
Constraints on Auditory Warnings

- Sounds must be audible in the vehicle
- Must sound “appropriate” in context
  - Urgency
  - Annoyance
  - Past experience can influence sound
- A warning sound must be understood quickly
  - Rare events may be a problem
  - Multiple warnings must be distinguishable from each other and learnable

Study of rated annoyance and urgency of sounds

- Subjects listened to sounds that varied systematically in acoustic attributes
  - Sound rated on urgency, annoyance & noticeability
- All factors were highly correlated—most urgent = most annoying
- The most influential sound characteristics on urgency were:
  - Pitch contour (melodic): decreased rated urgency
  - Pulse number (3, 5, 7): increased rated urgency
  - Pulse speed: increased rated urgency
  - Onset time: short onset increased rated urgency

Perceived urgency is increased with:



- Higher frequency
- Number of pulses
- Flat pitch contour
- Abrupt onsets

Use of different warning sounds for each warning condition

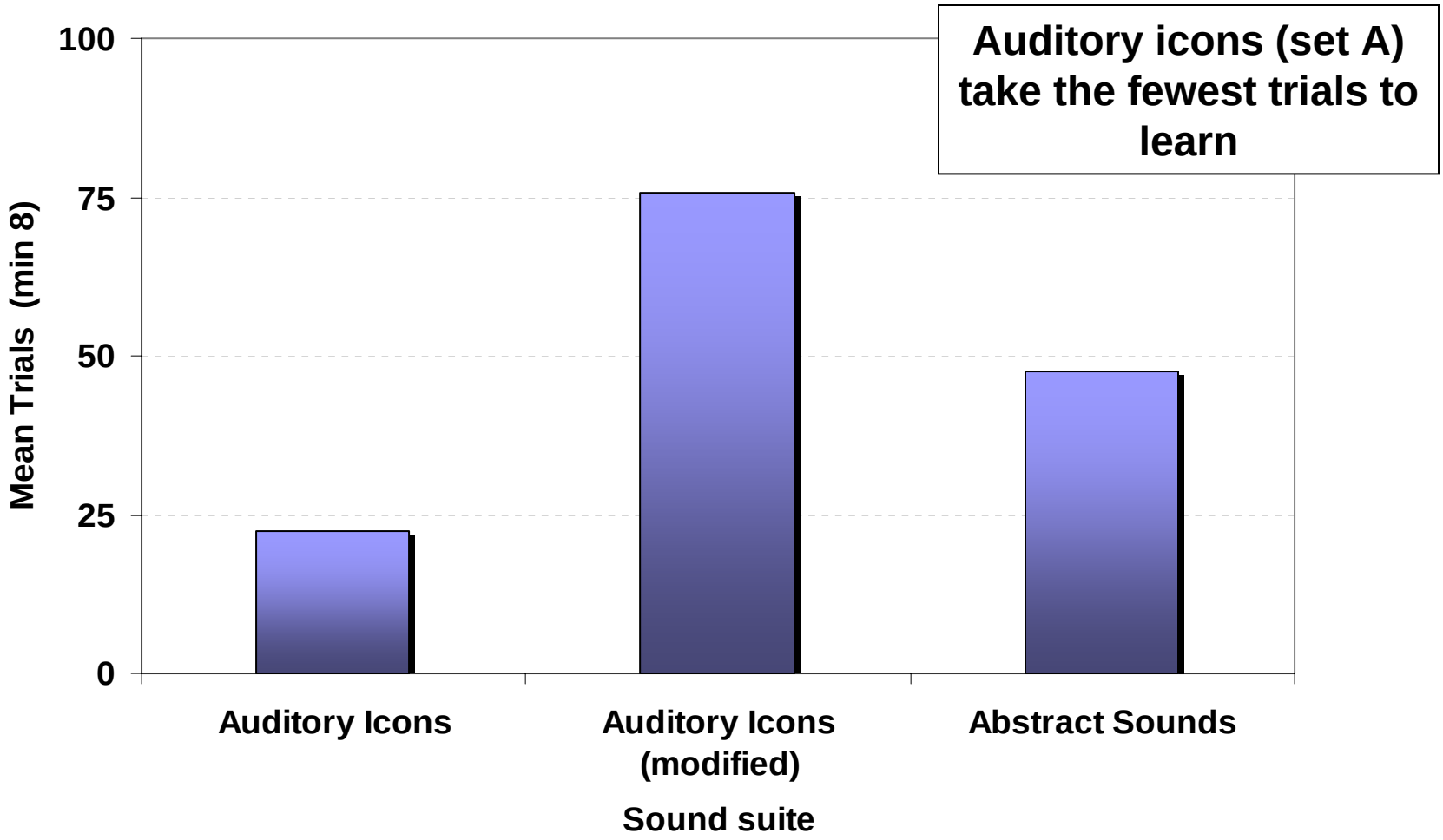
- How will groups of sounds work together?
  - Urgency is not the only criteria
    - If everything is urgent, sounds may not be distinguishable
  - Learnability (trials to acquisition criteria)
  - Confusability (Errors)
  - Response efficiency (RT)

Evaluation of Sound Suites

- Constructed 3 suites containing 4 sounds:
  - FCW, LCM, CSW, and LDM
  - Suite A used auditory icons
  - Suite B used modified auditory icons
  - Suite C used abstract sounds based on urgency measures

Suite	FCW	LCM	CSW	LDW
A				
B				
C				

Trials to Criterion—by sound suite



Conclusions

- Warning sounds that are similar to auditory icons can be:
  - Learned more quickly than abstract sounds
  - Are especially helpful for older drivers
  - Result in shorter choice reaction times
- But…even modest alterations of an auditory icon can result in significant performance differences

Localization enhancements

- Warning sounds were enhanced to improve sound localization
  - Broadband noise
  - Expansion of spatial direction
- Does this improve directional accuracy?
- Does this speed reaction time?
- No evidence that enhancements improve performance

Exp. 1, Subpart 5: LDW Timing (rumble strip-like sound)

Q: How many beeps/burst? Gap duration between bursts?

Bursts	Gap	Beeps/Burst		
		3	4	5
2	Short			
	Medium			
3	Short			
	Medium			

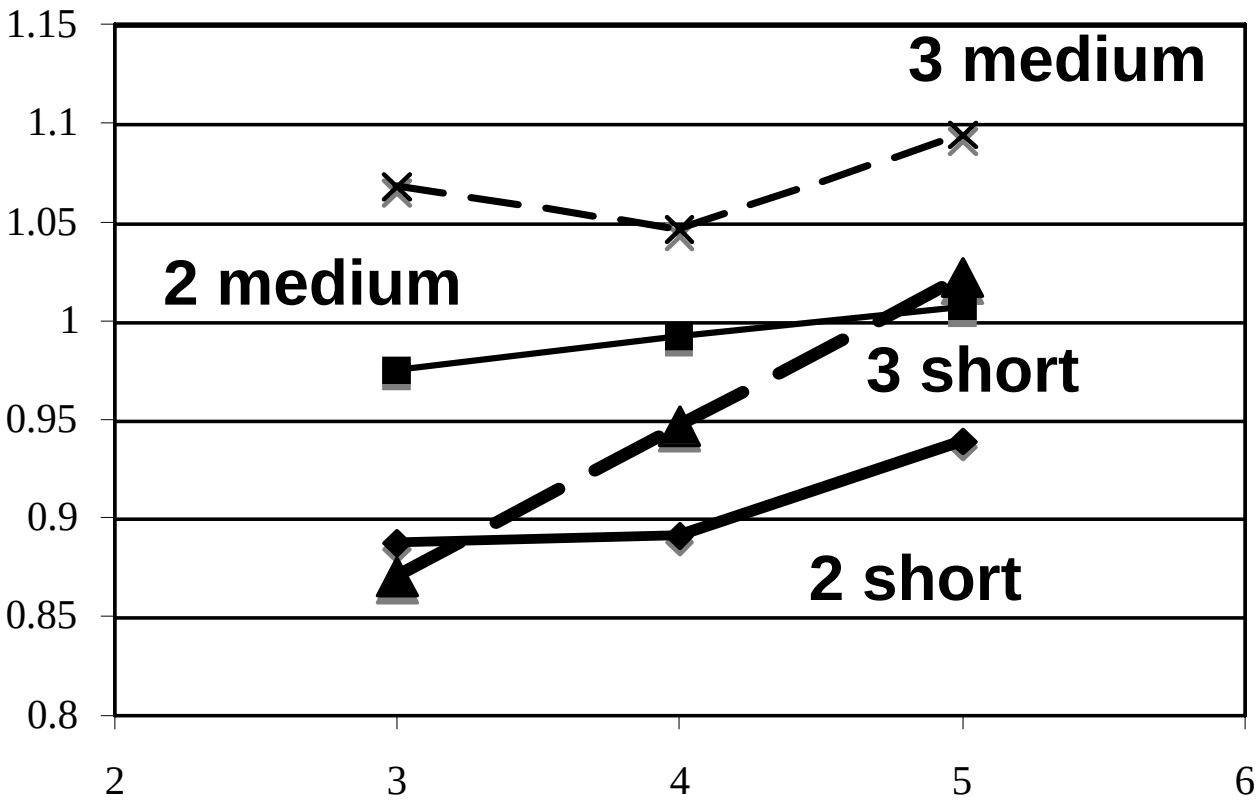
Experiment 1, Subpart 5: Results - LDW Timing

Warning	Correct		Incorrect	
	Mean RT	# of Responses	Mean RT	# of Responses
LDW left	0.991	760	1.800	6
LDW right	0.953	763	1.447	5
FCW	0.724	382	1.150	2
LCM left	0.851	180	1.389	12
LCM right	0.926	171	1.505	21
Mean	0.917	2256	1.491	46

Error rate was 2%, 2 missing

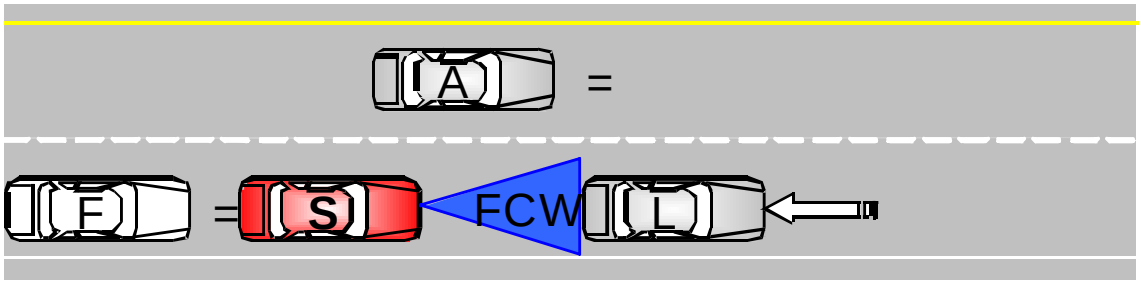
FCW, LCM-left, LCM right were foils (not considered further)

Experiment 1, Subpart 5: Results
Use short gap, 2 or 3 bursts

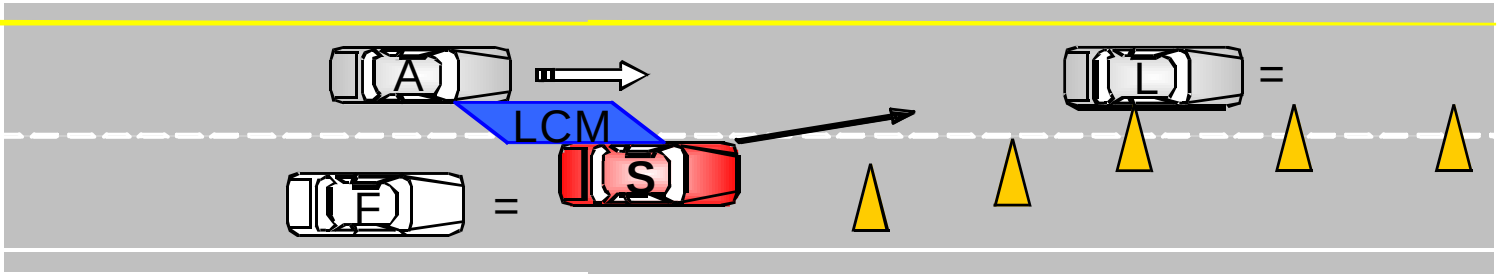


Experiment Design: FCW, LDW Example Scenarios

- FCW triggered when LV (L) suddenly decelerates, Adjacent vehicle (A) block subject (s) from changing lanes



- Construction barrels force subject to change lanes, LDW triggered when subject changes lane with Adjacent vehicle in blind spot



Experiments 2-5: Driving Scenarios

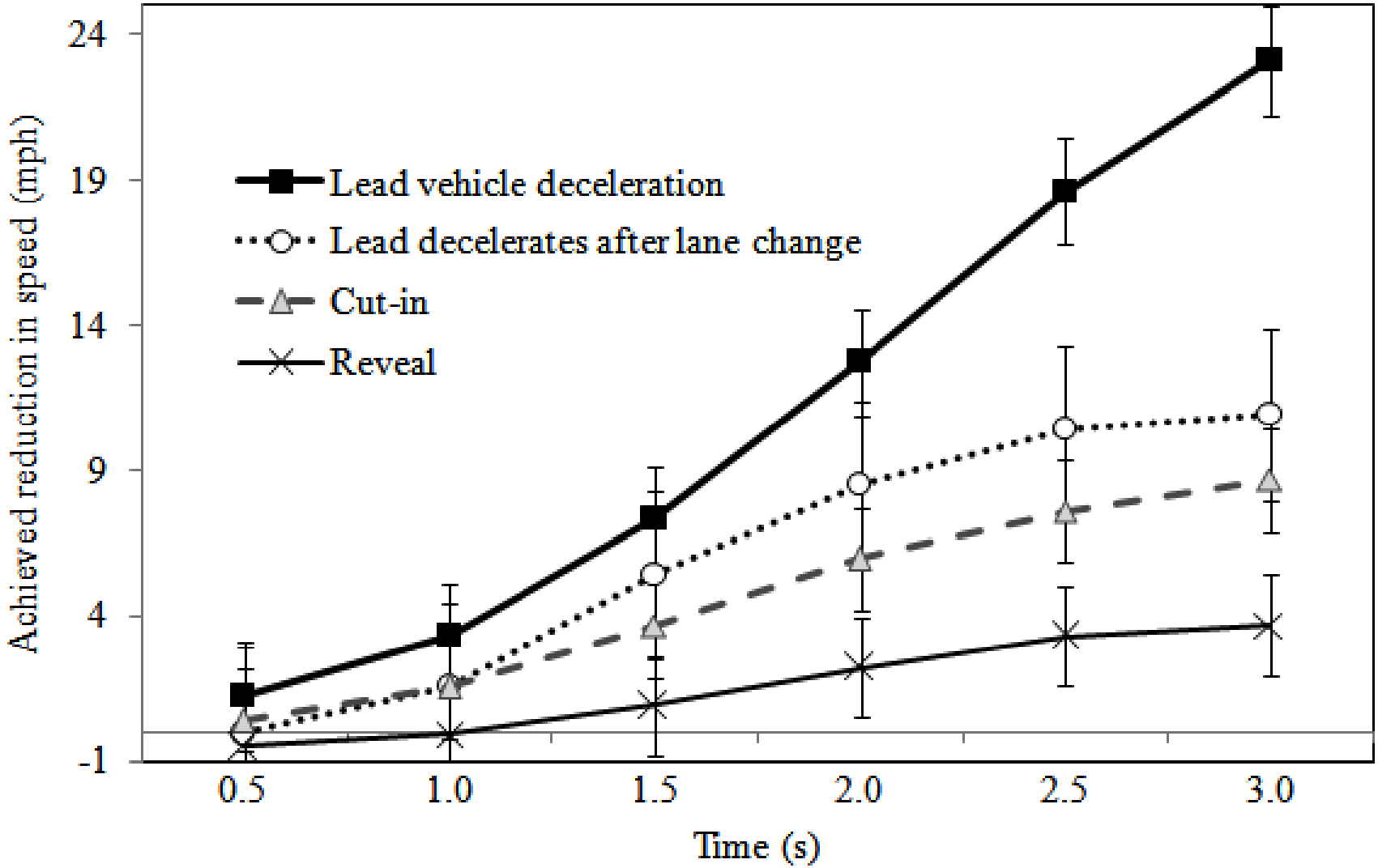
Experiment 2: What normally happens?

Warning Type	Triggering Category	Warning Category		Total (1655)
		Real	FA	
FCW	Triggered As Planned	280	81	361
	Triggered Not As Planned	282	15	297
	Planned But Not Triggered	*9*	*1*	*10*
	TOTAL TRIGGERED	**562**	**96**	**658**
	Triggered as planned: Observed / Expected	*280/96*	*81/96*	
CSW	Triggered As Planned	62	34	96
	Triggered Not As Planned	129	0	129
	Planned But Not Triggered	*1*	*0*	*1*
	TOTAL TRIGGERED	**191**	**34**	**225**

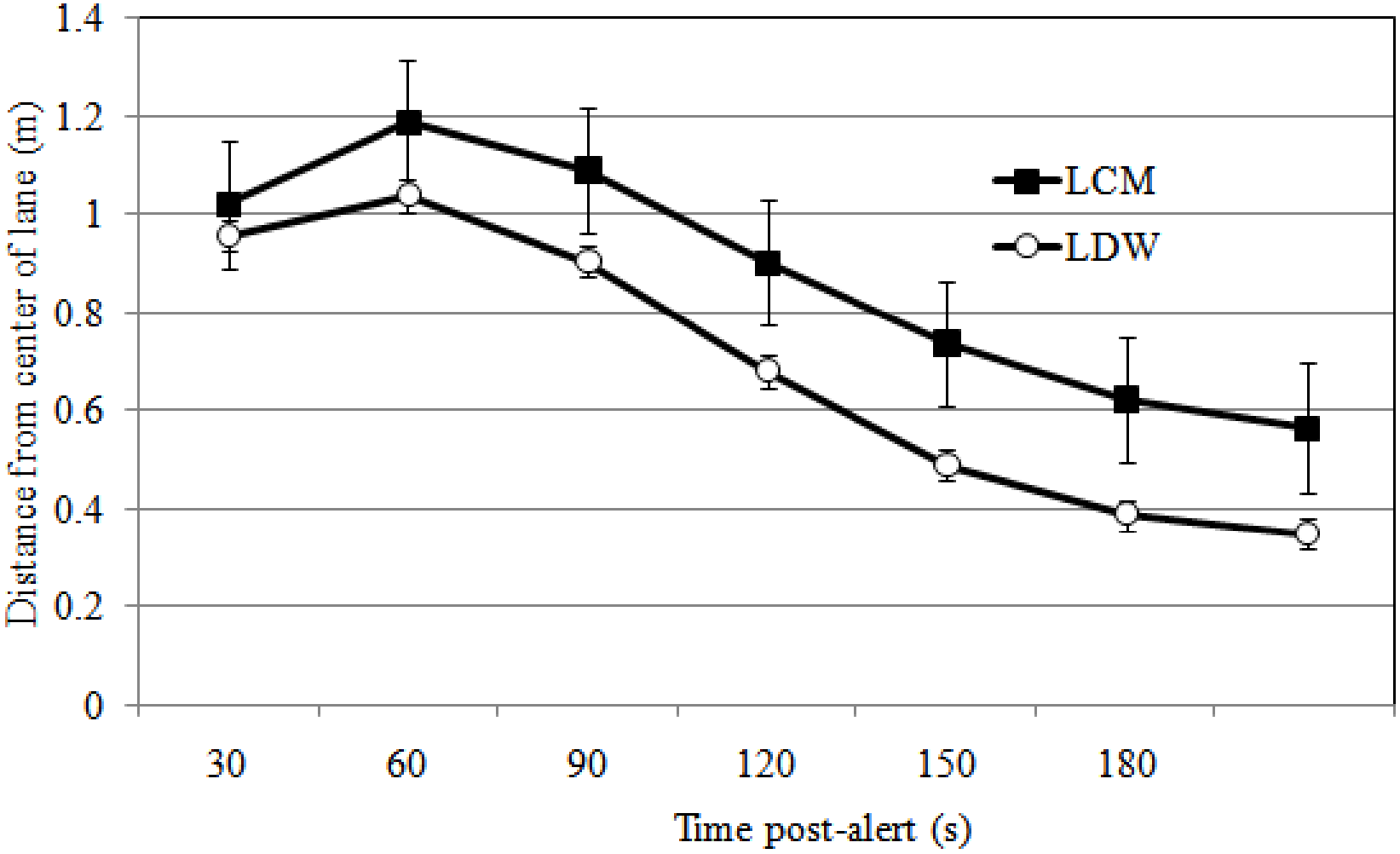
Experiment 2: What normally happens?

Warning Type	Triggering Category	Warning Category		Total (1655)
		Real	FA	
LDW	Triggered As Planned	88	14	102
	Triggered Not As Planned	510	1	511
	Planned But Not Triggered	*16*	*16*	*32*
	TOTAL TRIGGERED	**598**	**15**	**613**
	Triggered as planned: Observed / Expected	*88/64*	*14/32*	
LCM	Triggered As Planned	49	61	110
	Triggered Not As Planned	48	1	49
	Planned But Not Triggered	*79*	*4*	*83*
	TOTAL TRIGGERED	**97**	**62**	**159**
	Triggered as planned: Observed / Expected	*49/128*	*61/64*	

Experiment 2: How did drivers respond to FCW?



Experiment 2: How did drivers respond to LCM & LDW?



Experiment 3.
Shared Warnings

Which is best

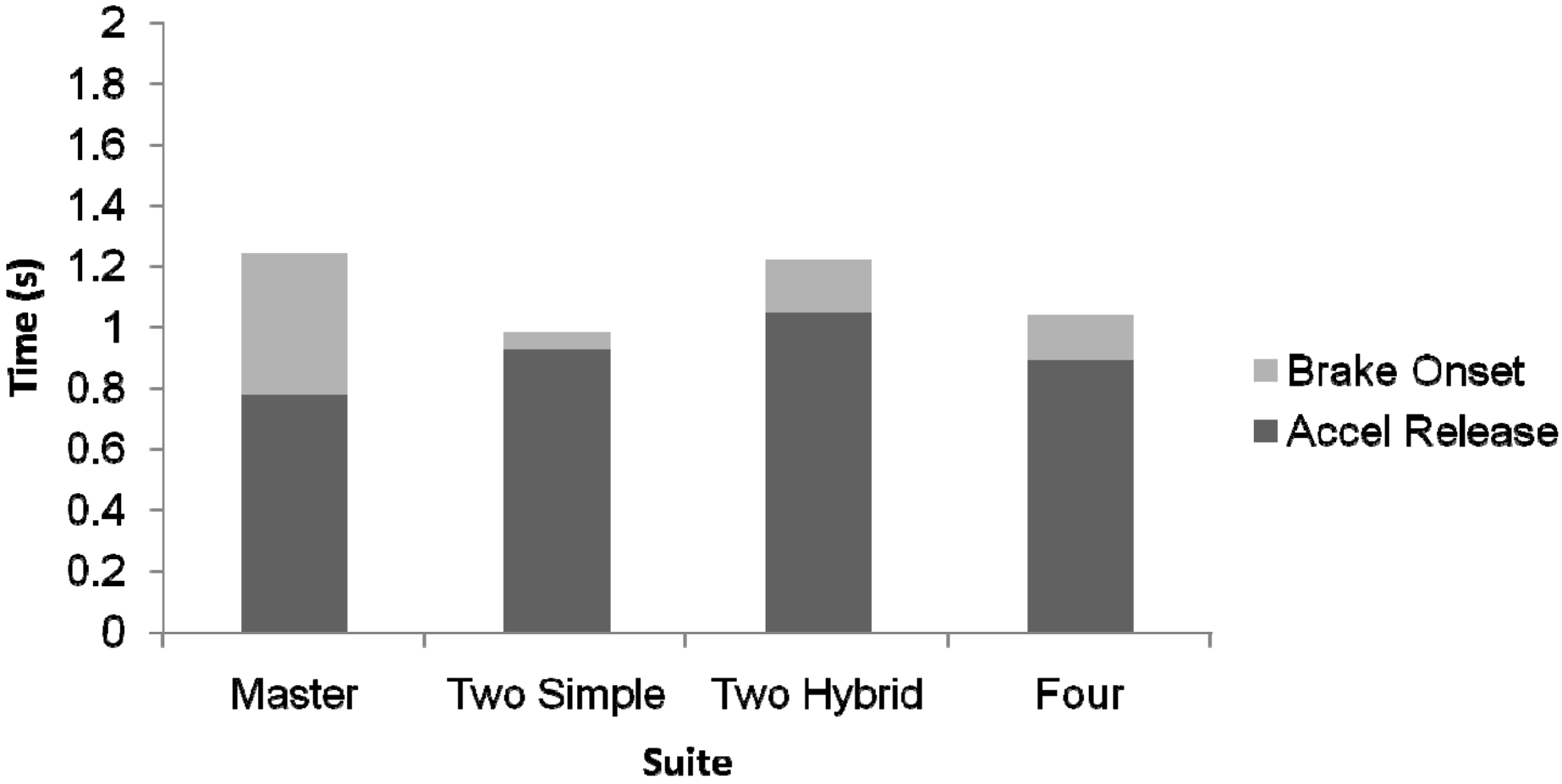
(1) 1 master warning

(2) a warning for each response class (lateral-steer), longitudinal (steer & brake)

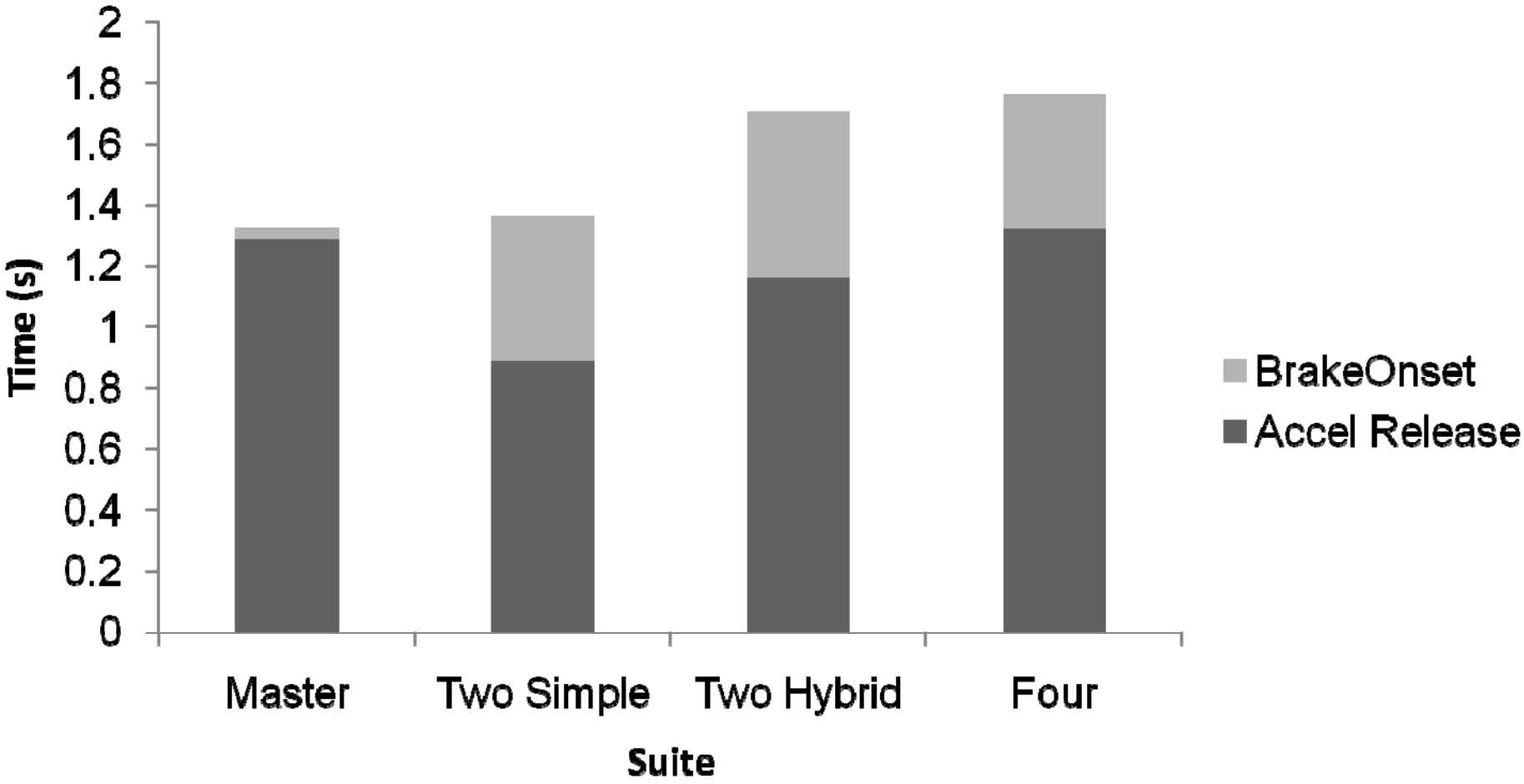
(3) a warning for each hazard

(4) some combination?

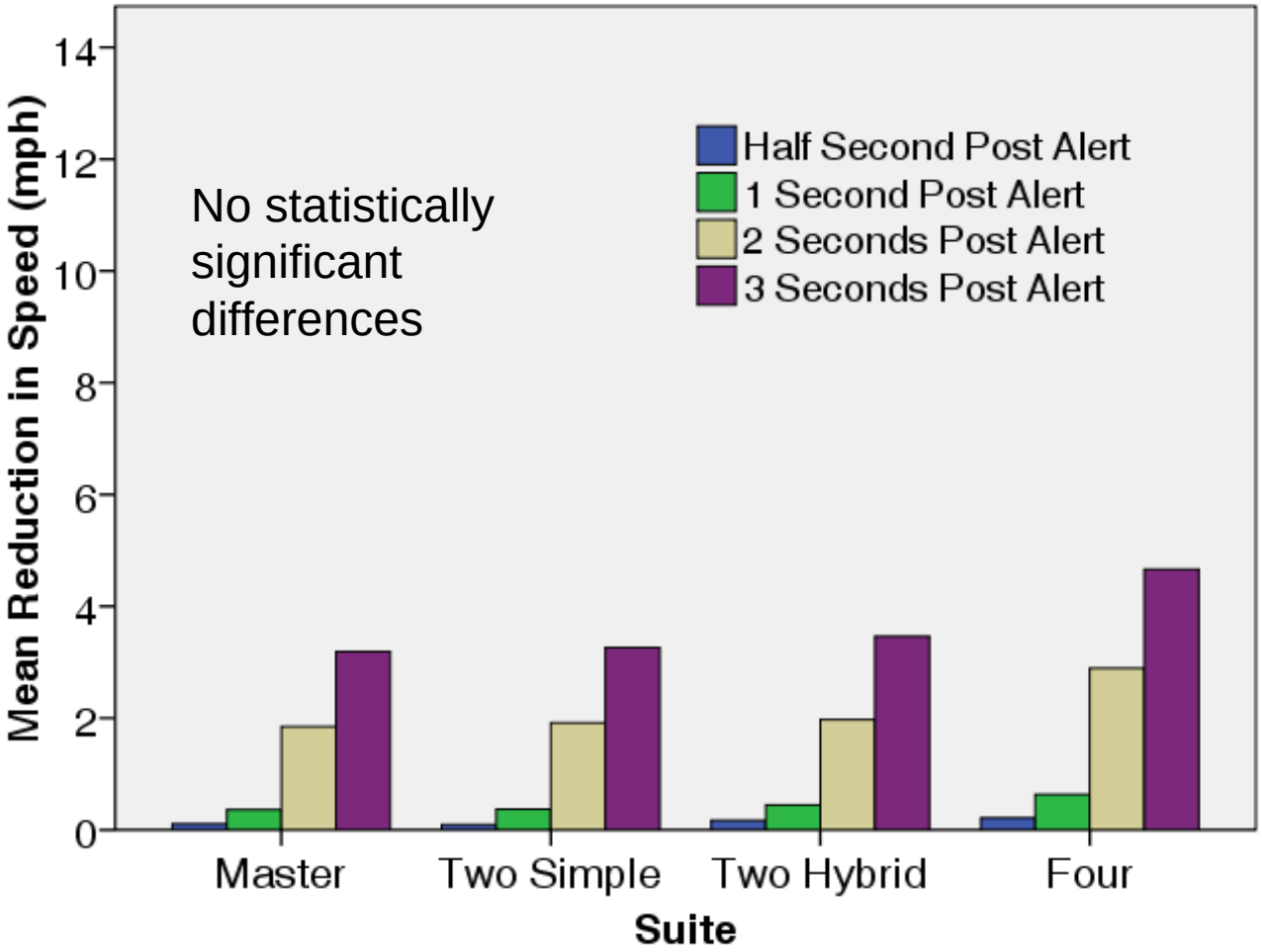
Experiment 3: FCW – Accelerator Release & Brake Onset



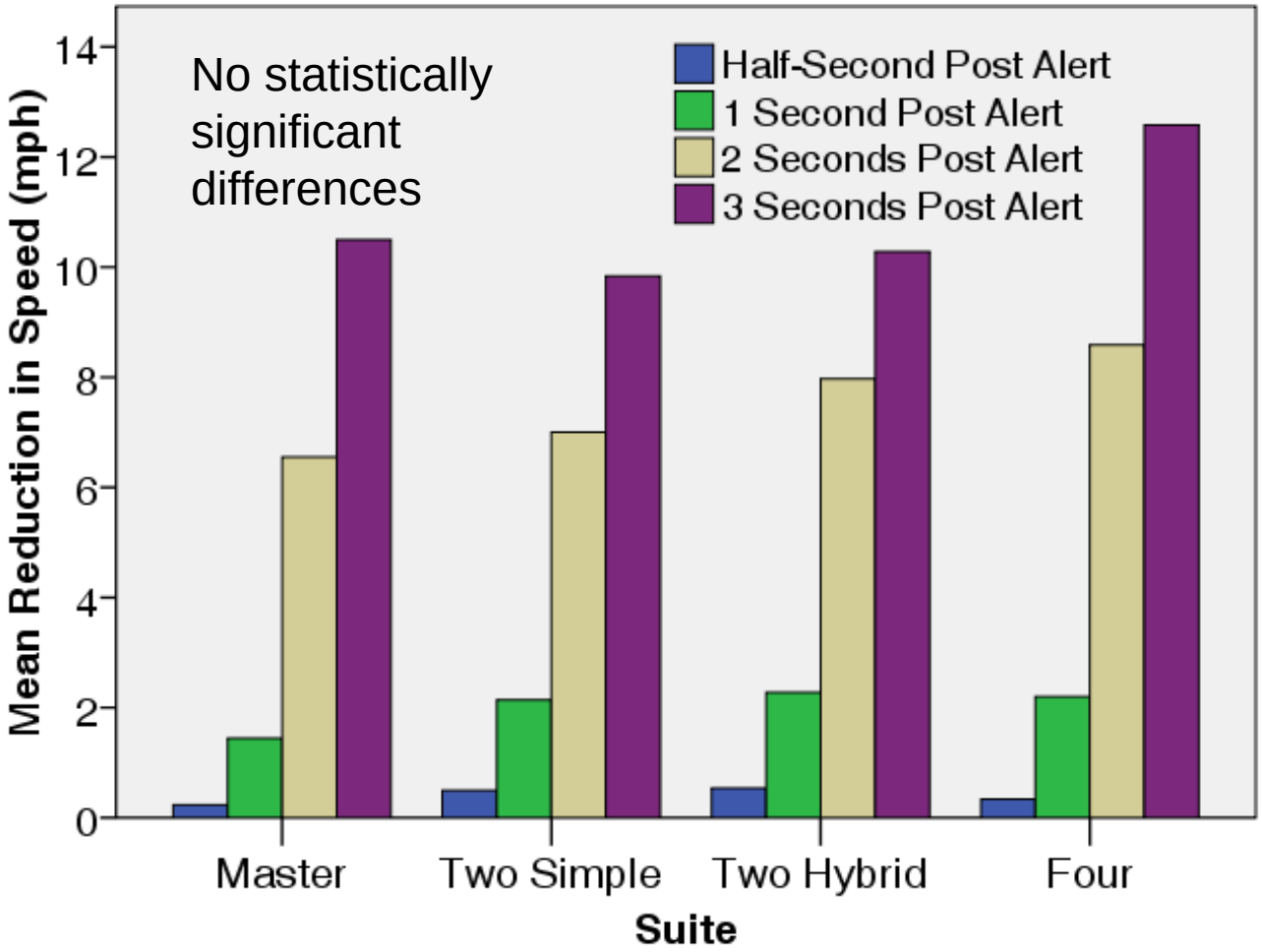
Experiment 3: CSW – Accelerator Release & Brake Onset



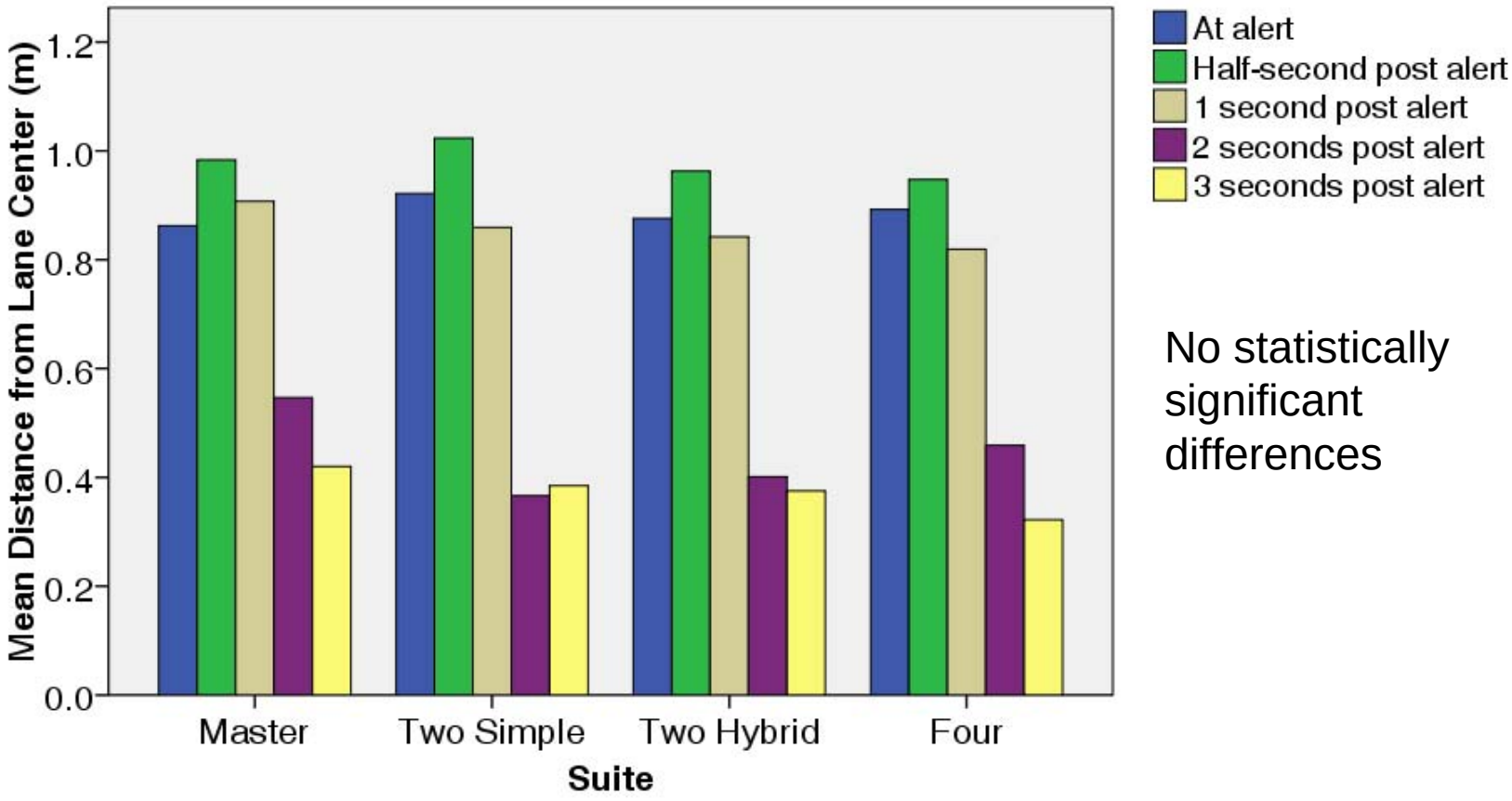
Experiment 3: CSW - Mean Reduction in Speed



Experiment 3: FCW - Mean Reduction in Speed



Experiment 3: LDW - Distance From Lane Center



No statistically significant differences

Experiment 3: Post-drive Survey Which Warning Suite is Preferred?

Suite	Young	Middle-aged	Total
Master	1	5	6
2 Simple	3	1	4
2 Hybrid	3	2	5
Four	1	0	1

Experiment 4 Design (Warning Delay-Accuracy Tradeoff)

Varying delay & accuracy for all 4 warnings led to too many combinations, focus on FCW, LDW (primary warnings)

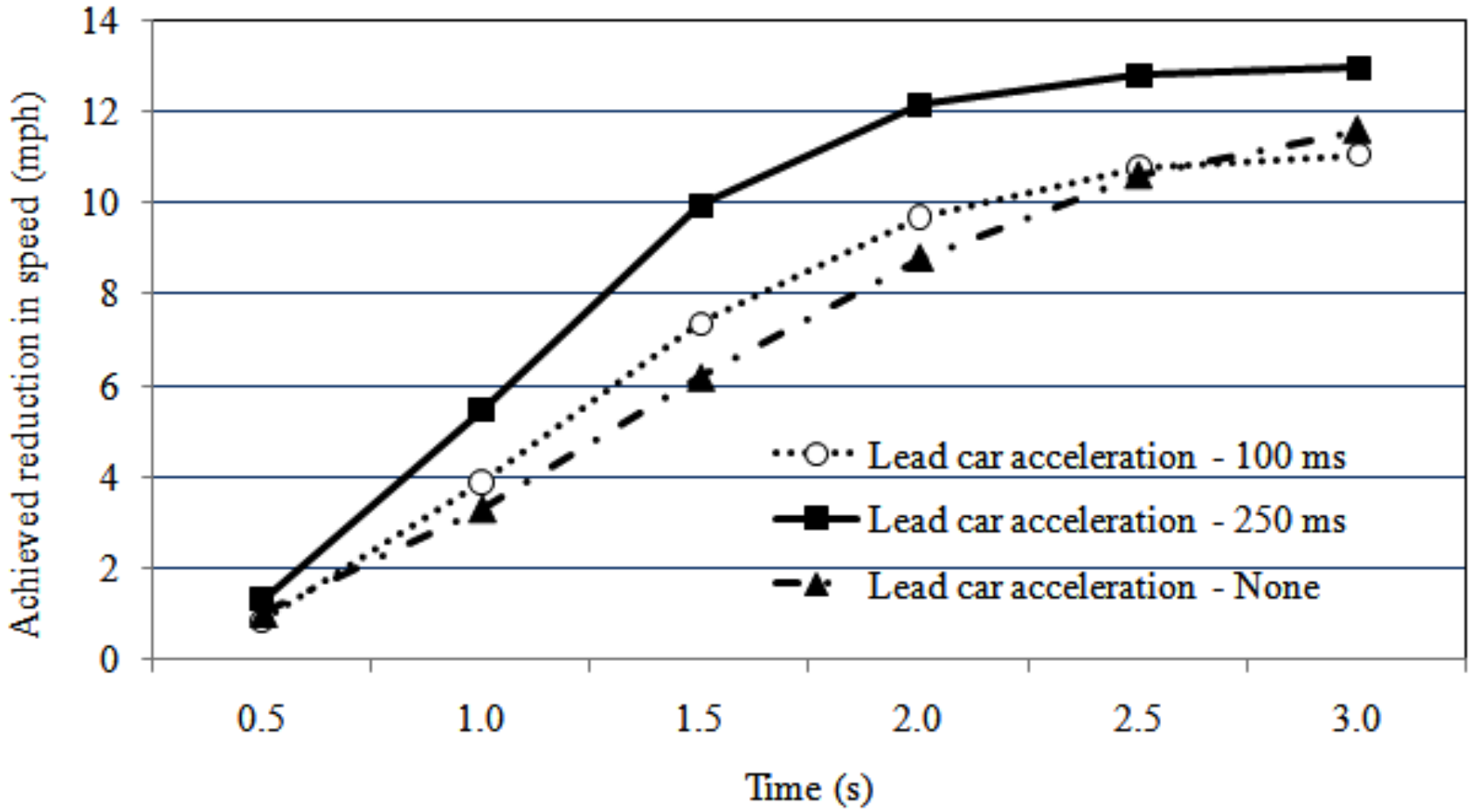
Acceleration Delay	**Warning Delay**		
	none	**150 ms**	**300 ms**
Until end of trial (normal)	warning	warning	warning
250 ms	warning	warning	no warning
100 ms	warning	no warning	no warning

LDW - 2000 N wind gust lasting 1, 2, 3 s

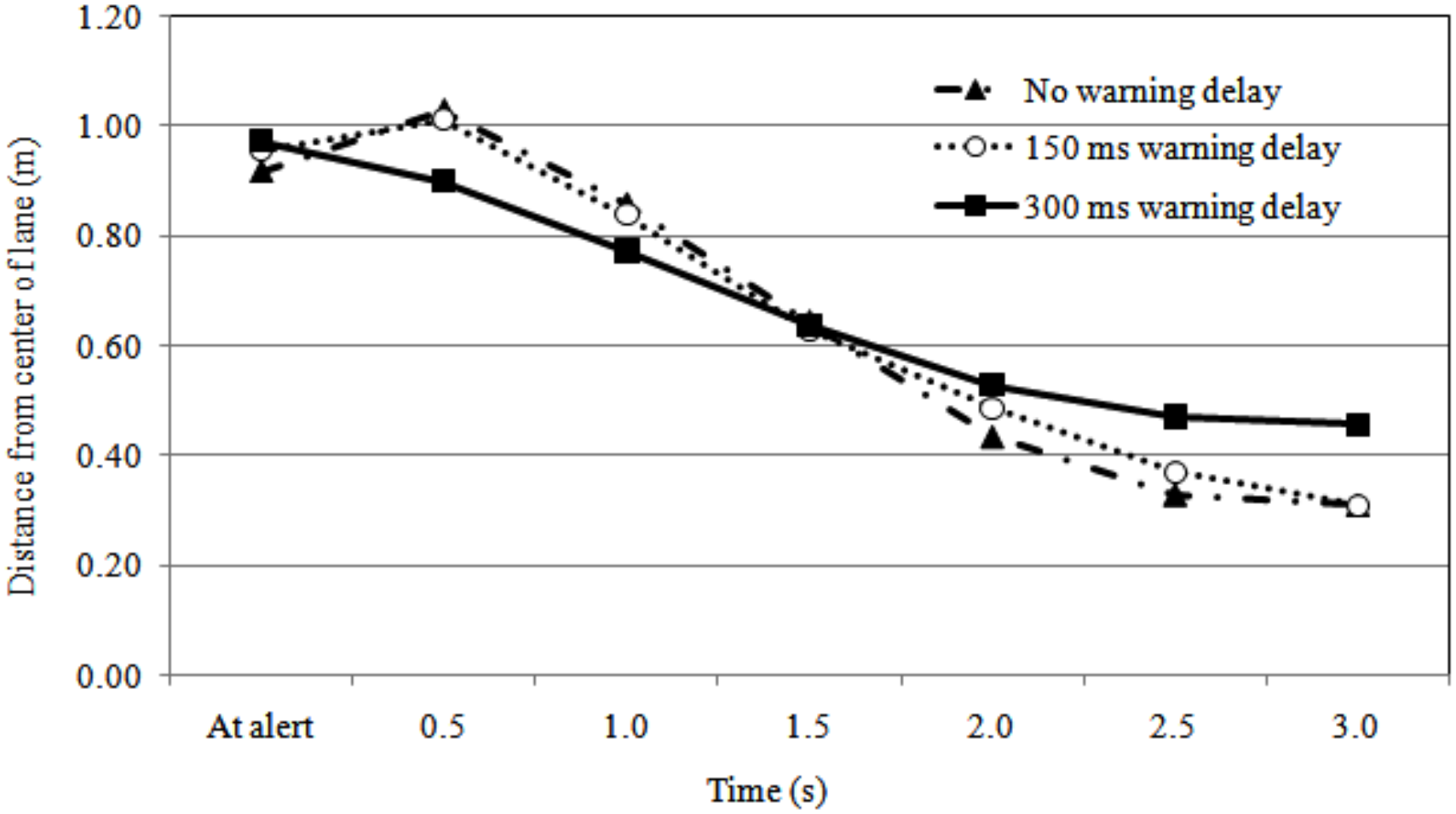
warning delays of 0, 150, 300 ms (vary by block)

(did not vary accuracy)

Experiment 4: FCW deceleration



Experiment 4:
LDW Lateral Position



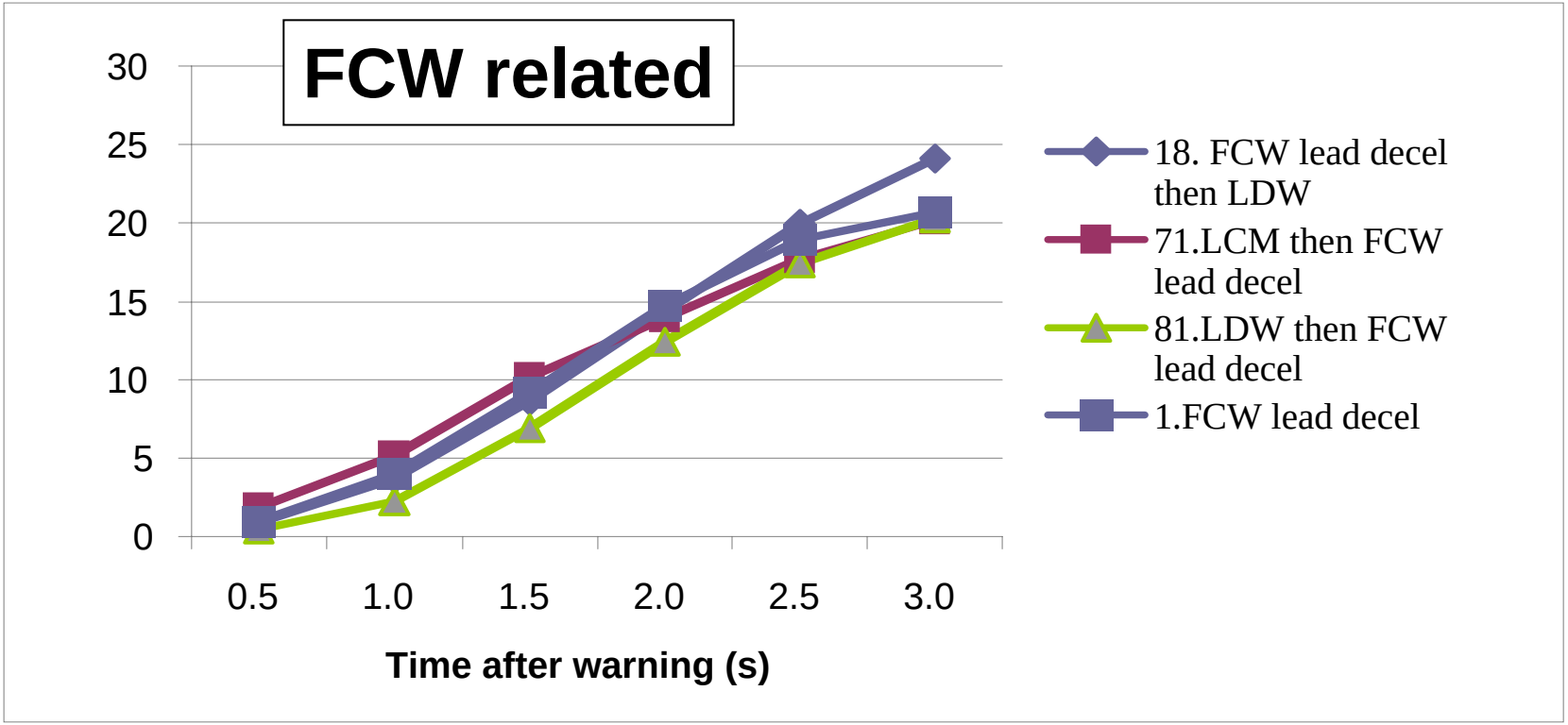
Experiment 5: Warning Co-Occurrence

When 2 warnings occur at the “same” time, how should they be presented?

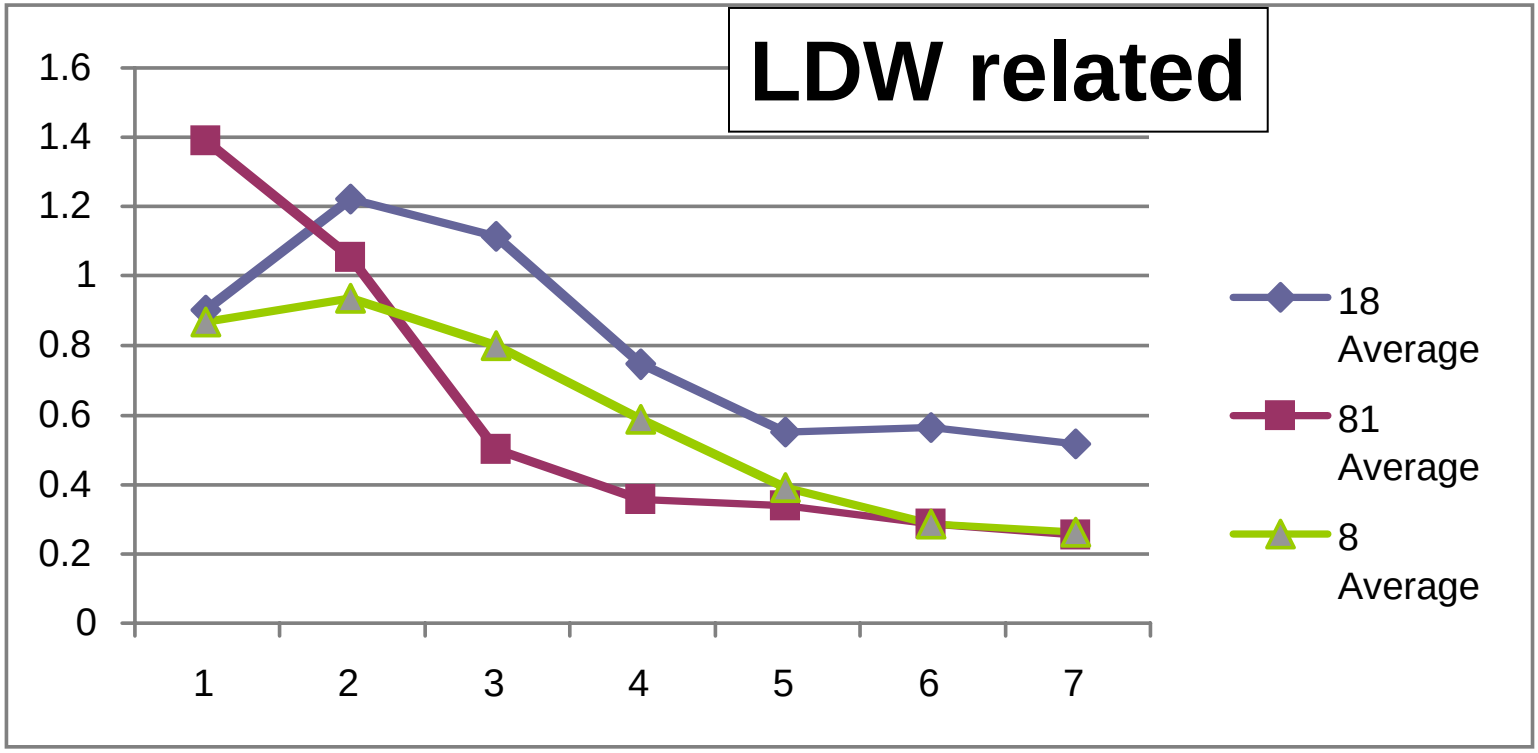
Simultaneous, Preempt, Sequential

- Scheduling “simultaneous warnings was difficult (& uncommon)
- No single rule can be recommended
- For some conditions, but not all, simultaneous warnings led the greatest reductions

First warning	Second warning	n
4. FCW reveal	None	58
4. FCW reveal	6. LCM	34
1. FCW lead decelerates	none	47
1. FCW lead decelerates	8. LDW	20
7. LCM construction zone	1. FCW lead decelerates	6
8. LDW	1. FCW lead decelerates	24



First warning	Second warning	n
8.LDW	none	26
8.LDW	1.FCW lead decel	24
1.FCW lead decel	8.LDW	20
8.LDW	6.LCM	24
6.LCM	8.LDW	1



Influence on Light Vehicle DVI

- Tones (Experiment 1)
  - Guided selection of suite of warning tones that were used in the jury drives
- Number of warnings (Experiment 3)
  - Preference data ruled out four warnings
- Simultaneous warnings (Experiment 5)
  - Guided the length of the warnings

Influence on Heavy Truck DVI

- Threshold for changes to the DVI was high
  - Vorad system subject to several previous evaluations, and years of use
- Tones (Experiment 1)
  - Guided selection of suite of warning tones that were used in the jury drives
- Number of warnings (Experiment 3)
  - Preference data led to dual-hybrid approach
- Simultaneous warnings (Experiment 5)
  - Guided the length of the warnings