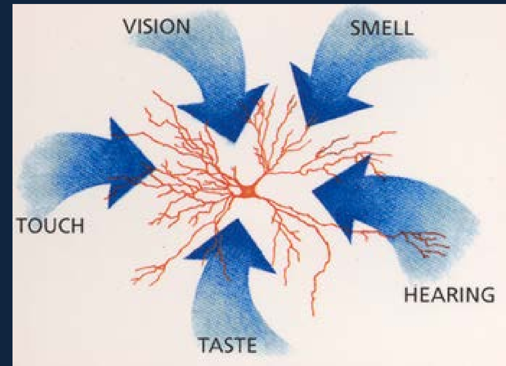


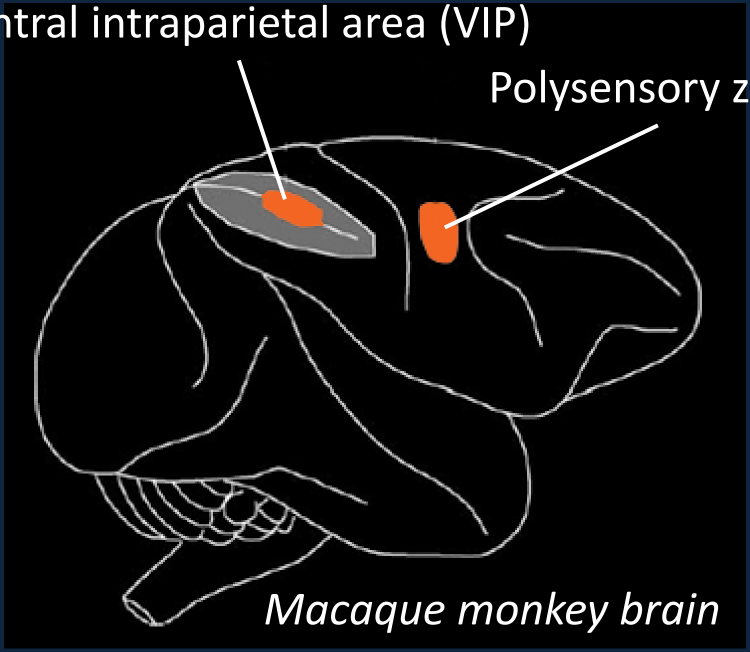
Looming Auditory & Vibrotactile Collision Warnings for Safe Driving

Cristy Ho[†], Charles Spence[†], & Rob Gray[‡]

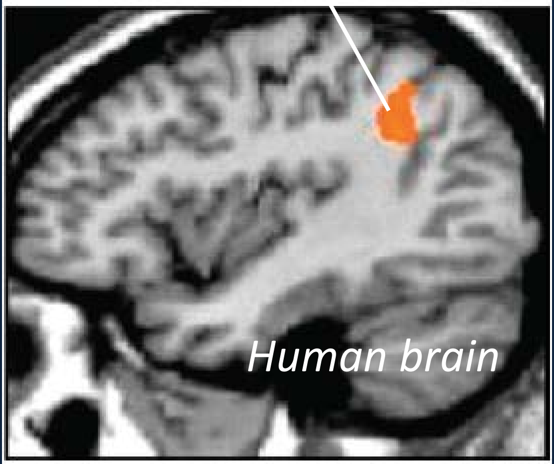
[†]Crossmodal Research Lab, University of Oxford, UK

[‡]School of Sport and Exercise Sciences, University of Birmingham, UK

Neuroergonomics-inspired warning signal design



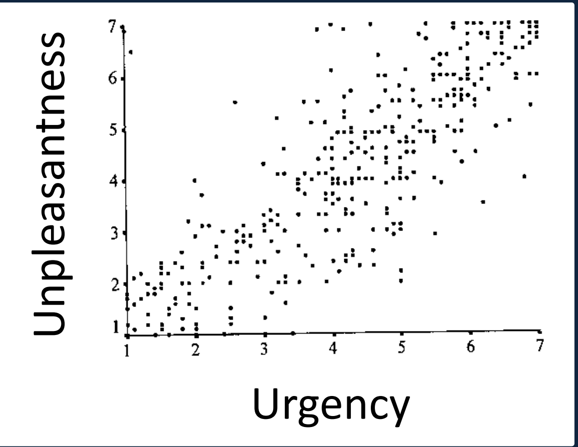
- Control defensive movement triggered by stimuli on or near the head (Graziano & Cooke, 2006)



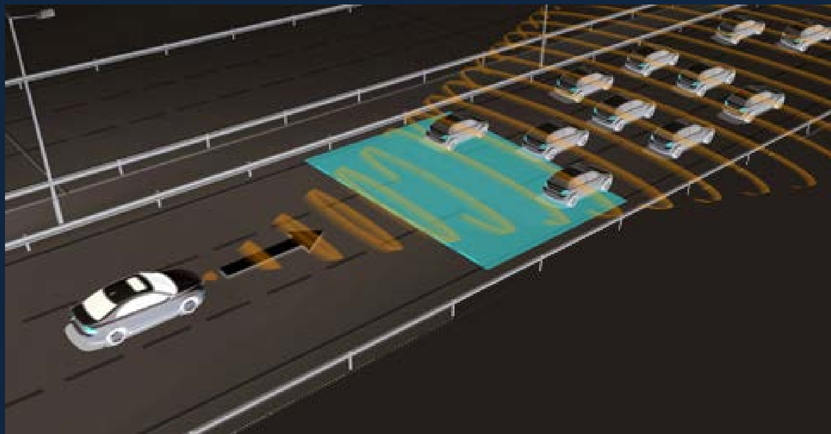
- Respond to rising as compared to falling sound intensity (Bach et al., 2008)
- Respond to moving stimuli from different modalities, especially simultaneous input from multiple modalities

Goal of the present study

- Beyond alerting…
- To examine warning signals that contain intrinsic, unconditioned properties that convey approach (urgency) information for effective collision avoidance responses
- Sudden onset of sounds may shock drivers if presented very infrequently



Isherwood et al. (2004)



Auditory looming

- Time-to-collision (TTC) of object can theoretically be detected based on rising sound intensity (Shaw, McGowan, & Turvey, 1991)

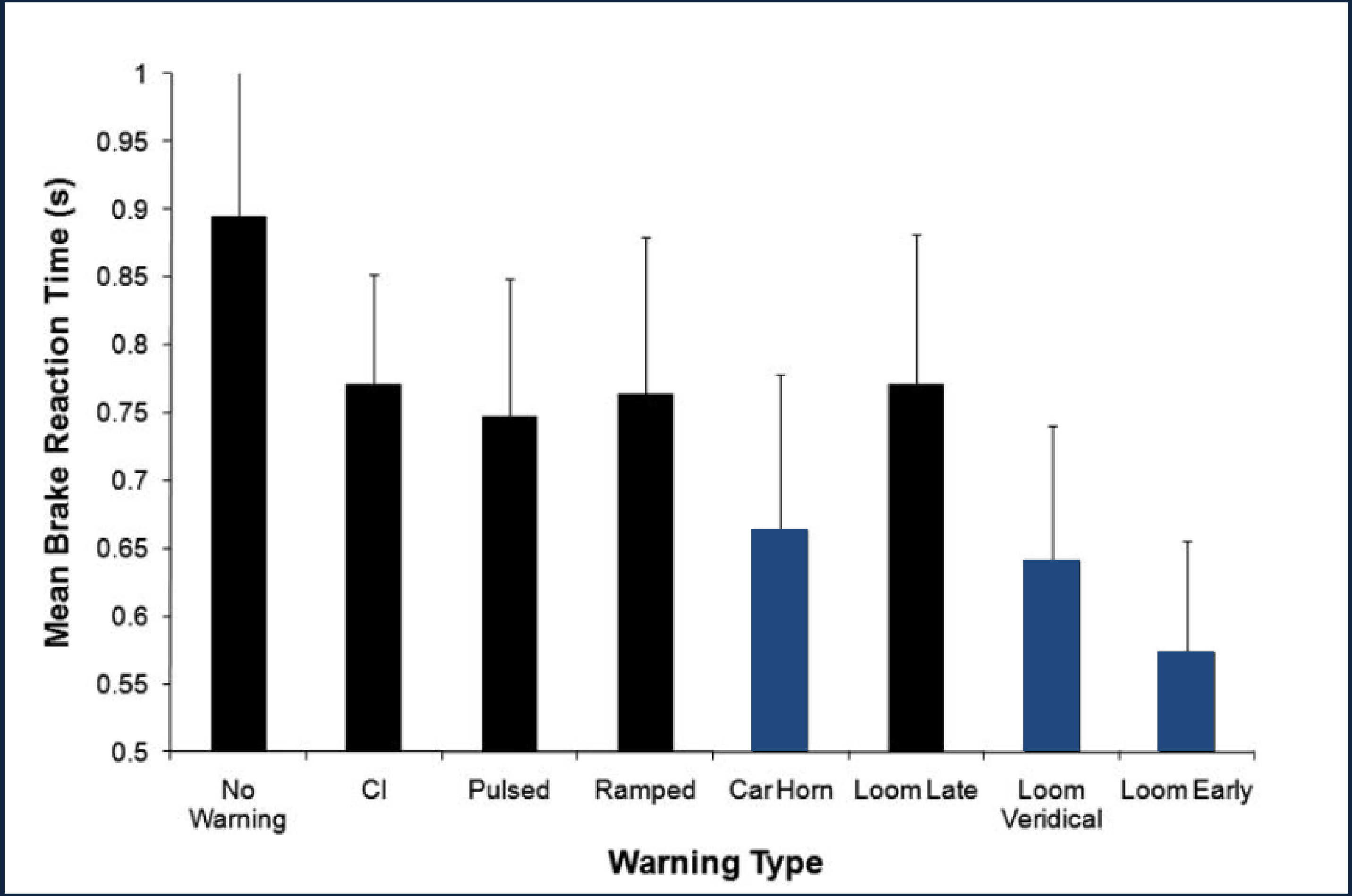
$$TTC \approx \tau = 2\frac{I}{dI/dt}$$

- Analog of visual τ (rate of change of size of retinal image of an approaching object; Lee, 1976)
- Underestimate TTC by 40-77% of the actual TTC (Schiff & Oldak, 1990)

Auditory looming intensity

- Gray (2011)

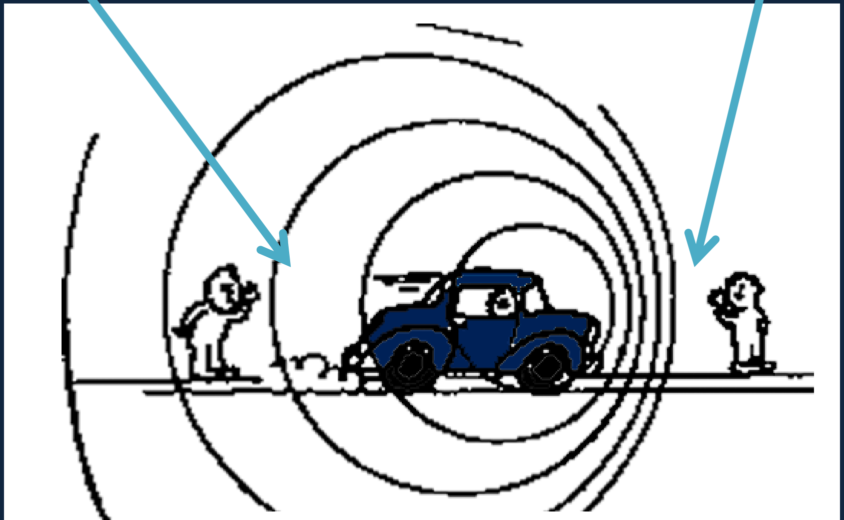
* Lower false alarm rate for looming warning over car horn warning



Design rationale: Frequency/pitch

Low frequency wave,
Low-pitched sound

High frequency wave,
High-pitched sound



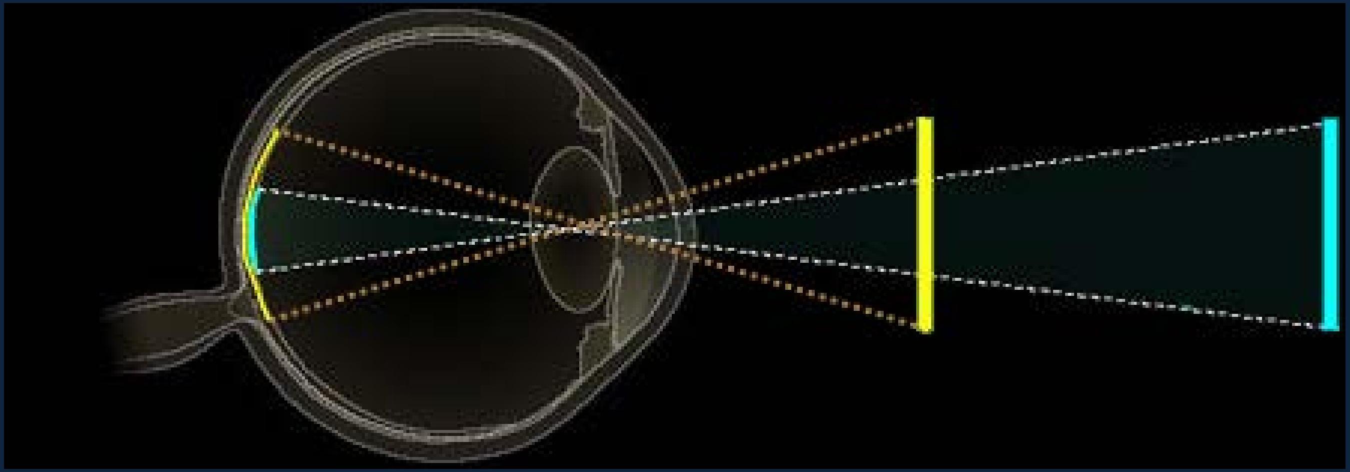
Doppler shift

Experiment 1:

Looming frequency auditory warnings

Design rationale: Spatial expansion

Looming visual signal,
Increasing visual size on retina



Experiment 2:
Looming spatial auditory warnings

Driving simulator setup

- DS-600c Advanced Research Simulator (DriveSafety™)
- 300° wraparound display
- Full-width Ford Focus cab
- Motion platform
- All of the auditory warnings were 1000 ms in duration
- Presented from a 6.5-cm diameter speaker located inside vehicle dashboard aligned to center of the steering wheel

Warning signal conditions

Experiment	Warning signal conditions				
1	No warning	Constant intensity tone	Looming intensity tone	Looming frequency tone	Looming intensity tone + Looming frequency tone
2	No warning	Constant intensity white noise	Looming intensity white noise	Looming spatial white noise	Looming intensity white noise + Looming spatial white noise

Warning sigr

Constant intensity tone

- 2000 Hz tone
- Within range of frequencies that produce the lowest detectable thresholds
- 75 dB

Experiment	Warn				
1	No warning	Constant intensity tone	g intensity tone	Looming frequency tone	ning nsity tone + Looming frequency tone
2	No warning	Constant intensity white noise	Looming intensity white noise	Looming spatial white noise	Looming intensity white noise + Looming spatial white noise

l conditions

signal conditions		
Looming intensity tone	Looming frequency tone	Looming intensity tone + Looming frequency tone
Looming intensity white noise	Looming spatial white noise	Looming intensity white noise + Looming spatial white noise

Looming intensity tone

- 2000 Hz tone
- Intensity was determined according to

$$I_w = a + kD^{-2}$$

  where D at each instance was determined by the driver’s speed at the onset of the warning
- a = 50 and k = 30000 such that intensity rising from 60 dB up to a maximum of 85 dB at simulated distance of 100 m
- Sound level of ~10 dB to 15 dB above ambient noise of approximately 50 dB is typically recommended for auditory warning signals (Sorkin, 1987)

Warning signal conditions

Looming frequency tone

- Initial frequency of 2000 Hz
- Frequency was modified according to

$$F_w = a + kD^{-2}$$

where D at each instance was determined by the driver's speed at the onset of the warning

- a = 1000 and k = 10^7 such that frequency ranged between roughly 2000-5000 Hz

Expe	nditions	
	Looming frequency tone	Looming intensity tone + Looming frequency tone
	Looming spatial white noise	Looming intensity white noise + Looming spatial white noise

Warning signal conditions

Experiment	Warning signal conditions				
1				Looming frequency tone	Looming intensity tone + Looming frequency tone
2	No warning	Constant intensity white noise	Looming intensity white noise	Looming spatial white noise	Looming intensity white noise + Looming spatial white noise

Constant intensity white noise

- White noise presented at 75 dB

Warning signal conditions

Experiment	Warning signal conditions				
1	No warning	Constant intensity tone	Looming intensity tone	Looming frequency tone	Looming intensity tone + Looming frequency tone
			Looming intensity white noise	Looming spatial white noise	Looming intensity white noise + Looming spatial white noise

Looming intensity white noise

- Same as looming intensity tone but used white noise instead

$$I_w = a + kD^{-2}$$

Looming spatial white noise

- Nine-speaker array
- Output levels balanced for each configuration at 75 dB from the driver's position
- Angular size of looming spatial warning signal was modified according to

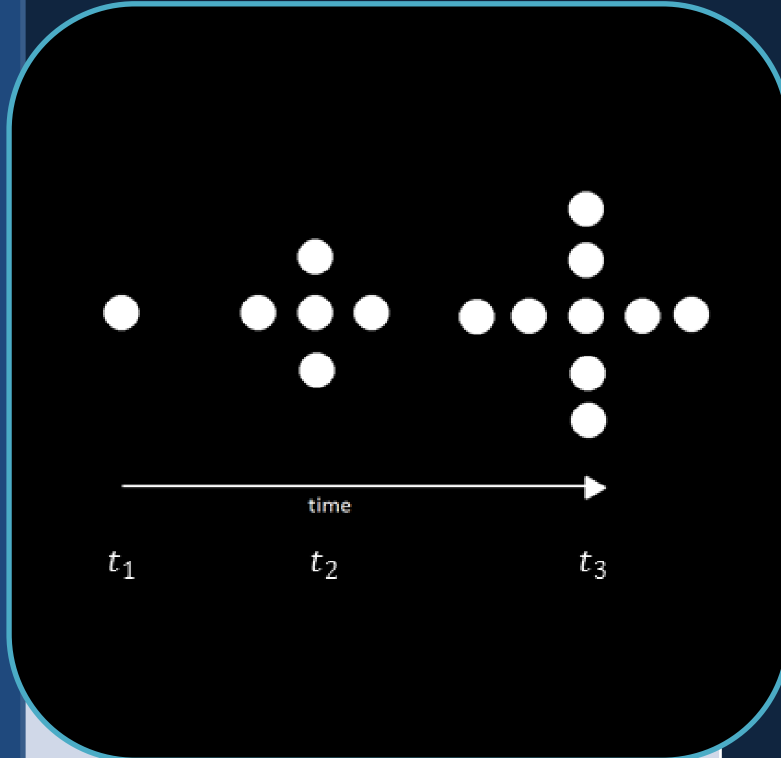
$$\theta = \text{atan}(W/D)$$

where W = width of lead vehicle (1.8 m), and D = distance of lead vehicle

- Distance of lead vehicle at warning onset was determined by

$$D_w = TTC_{thres} \times \frac{dD}{dt} + SP \times V_F$$

where TTC = time-to-collision threshold, $\frac{dD}{dt}$ = closure rate , SP = speed penalty, V_F = driven vehicle's speed



se

Looming spatial white noise

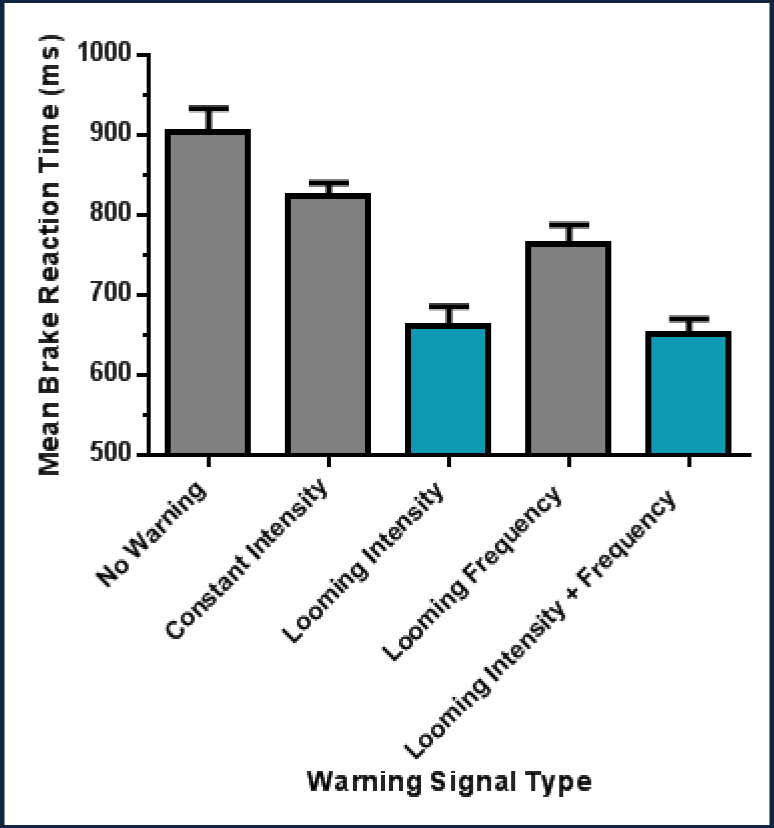
Looming intensity white noise + Looming spatial white noise

Design and Procedure

- Car-following scenario
- Driver instructed to maintain a 2.0 s time headway with the lead car
- Lead car traveled between 55-65 mph
- 10 driving tracks (2 repeats per warning signal condition)
- 10 unpredictable full stops at $-6\ m/s^2$ per track at random locations on track

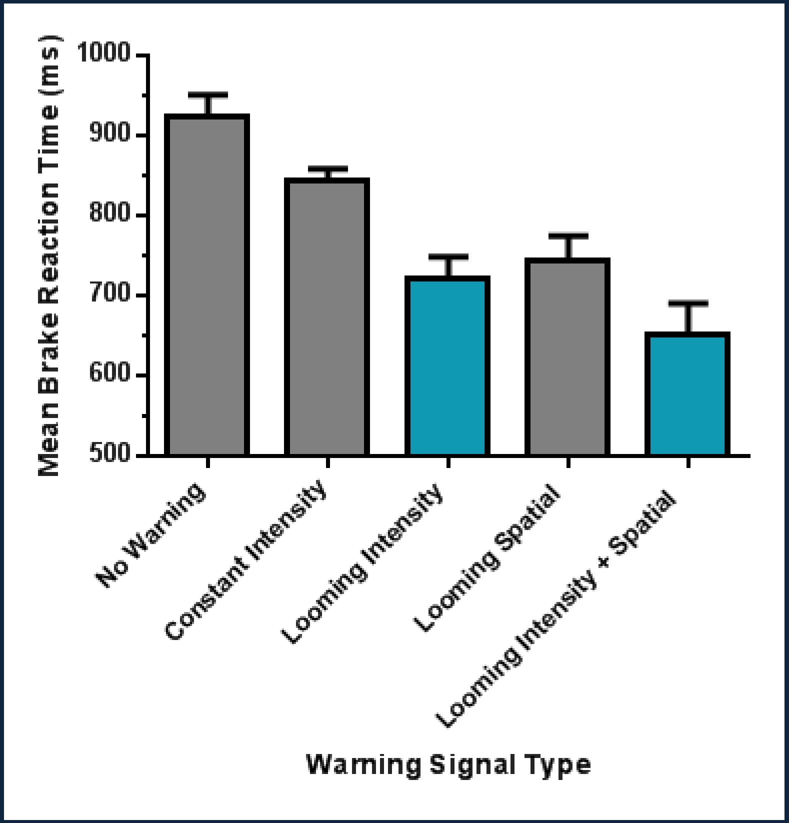
Results: Experiment 1

- One-way RM ANOVA and post hoc Tukey's Test to determine relative effectiveness of different warnings
- A significant main effect of warning signal type, $p < .001$
- L.I. and L.I.+F. significantly shorter BRT than C.I., *ps* < .001, and L.F., *ps* < .05



Results: Experiment 2

- A significant main effect of warning signal type, $p < .001$
- L.I. and L.I.+S. significantly faster braking responses than C.I., $p < .05$ and $p < .001$

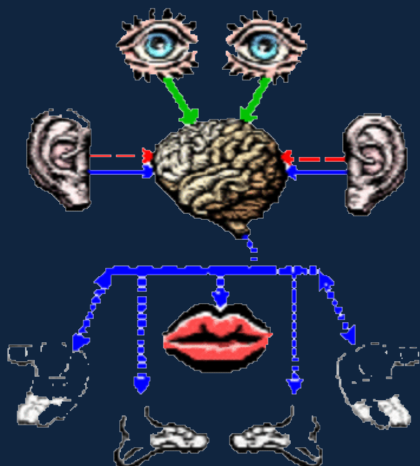


Interim summary

- Auditory looming intensity warnings outperform other forms of auditory looming signals in facilitating a driver's speeded collision avoidance responses
- Looming intensity may convey some sort of perceptual and behavioral salience?
- Effectiveness of looming intensity remained even when combined with different looming warnings

Experiment 3: Vibrotactile looming

- An alternative to auditory looming given the growing trend to install vibrotactile warning systems in next generation cars
- Theoretical implication relating to the transfer of distal information to peripersonal space



Distal senses of vision and audition

Proximal sense of touch

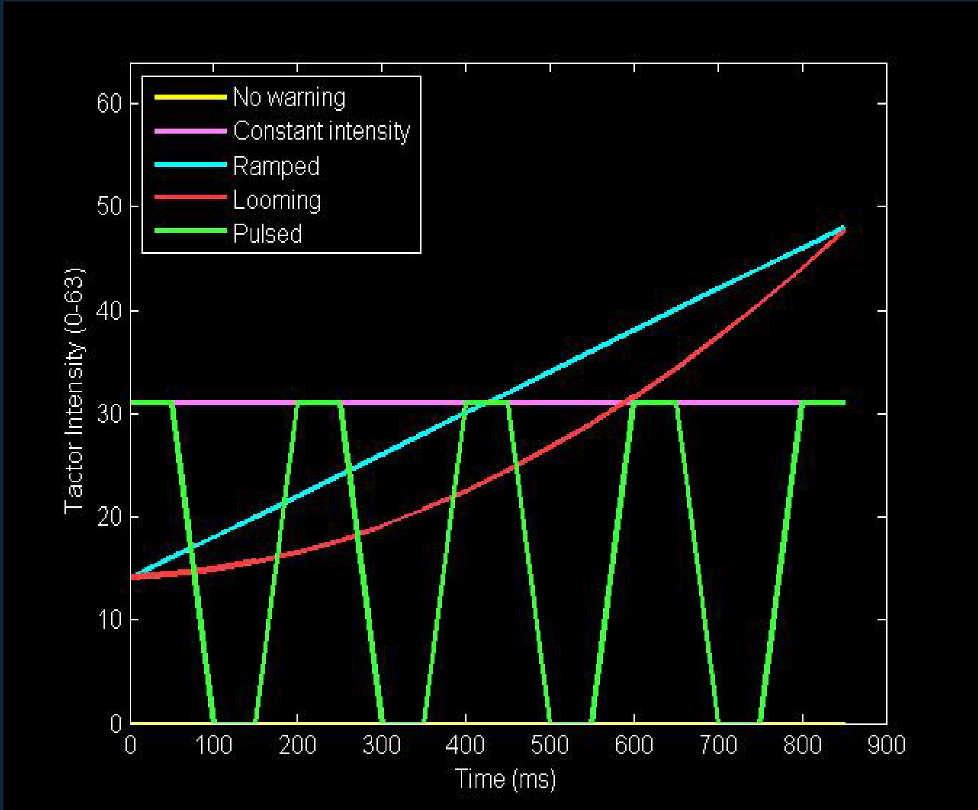
Experiment 3: Warning signal conditions

Experiment	Warning signal conditions				
3	No warning	Constant intensity vibrations	Ramped vibrations	Looming vibrations	Pulsed vibrations

- Vibrotactile stimuli of 250 Hz for 900 ms
- Looming updated according to

$$I \approx a + k(T/250)^2$$

where a = initial intensity, k = 2.6, and T = time from onset of warning

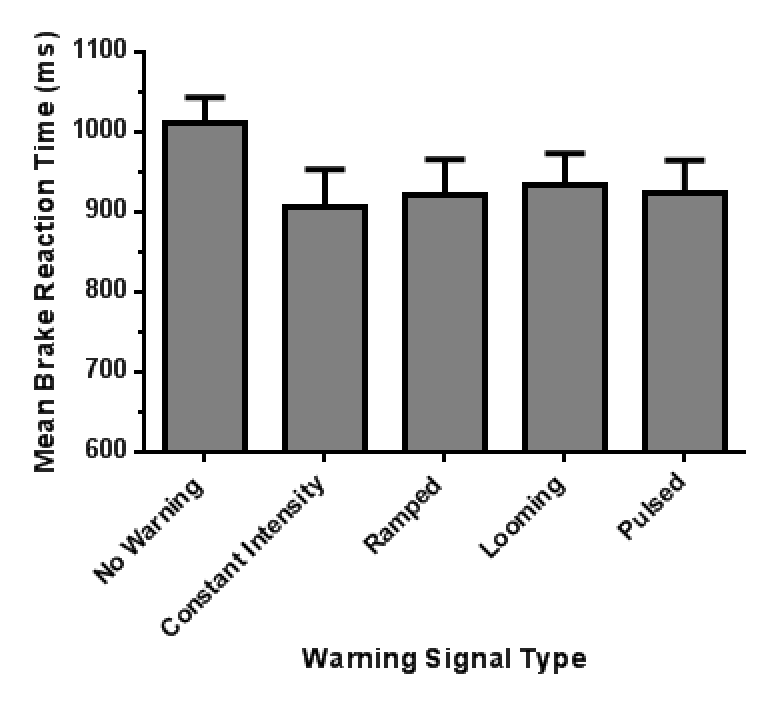


Experiment 3: Design

- Simulated driving task in lab
- Depress brake pedal upon detection of sudden closing-in on the lead car in video clips
- Interval between onset of sudden closing-in and collision was 1900 ms
- 4 blocks of 72 trials (warning signal types randomized within block)

Experiment 3: Results

- A significant main effect of warning signal type, *p* < .001
- Post hoc Tukey's Test revealed performance advantage of all four warning signal types over no warning baseline, *ps* < .001
- Pairwise comparisons among the four warning signals failed to reach statistical significance



Experiment 3: Summary

- Vibrotactile looming intensity warnings did not stand out from other non-looming vibrotactile signals
- Rate of closing-in of lead car was kept constant in Experiment 3 so perhaps TTC information was not critical for the initiation of response

Conclusions

- Increasing auditory intensity as a function of TTC clearly represents a promising means of alerting and redirecting a driver's attention for immediate safety-critical reactions
- Progressively presented at an initially less intrusive manner (less unpleasant)
- Maintain a relatively low false alarm response
- Looming vibrations starting at steering wheel then reaching body…

Thank you!

Funded by EPSRC Engineering and Physical Sciences Research Council

EP/J008001/1

http://www.psy.ox.ac.uk/xmodal