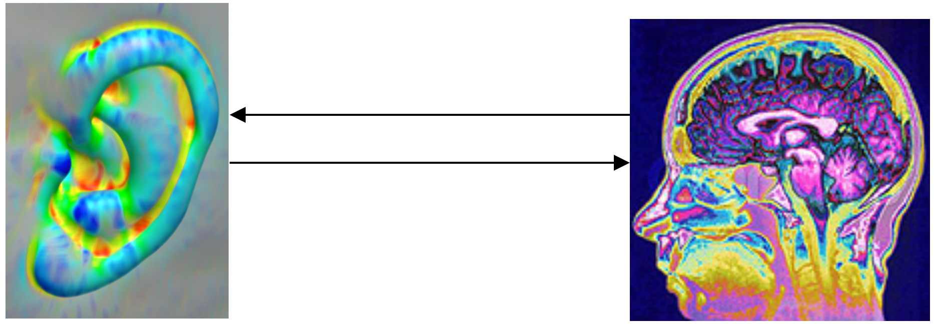
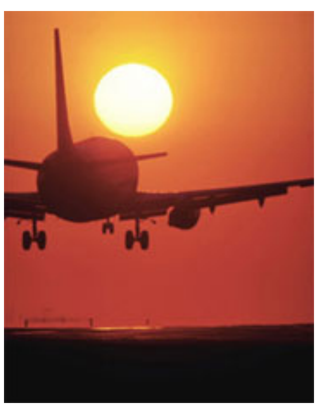


Sensory-Cognitive Interactions: How Sensory Impairments Can be Mistaken for Cognitive Deficits

Carryl L. Baldwin, Ph.D.



Is speech processed automatically? Or, is it harder (literally) to hear and remember when the input is degraded? What are the ramifications?

Overview

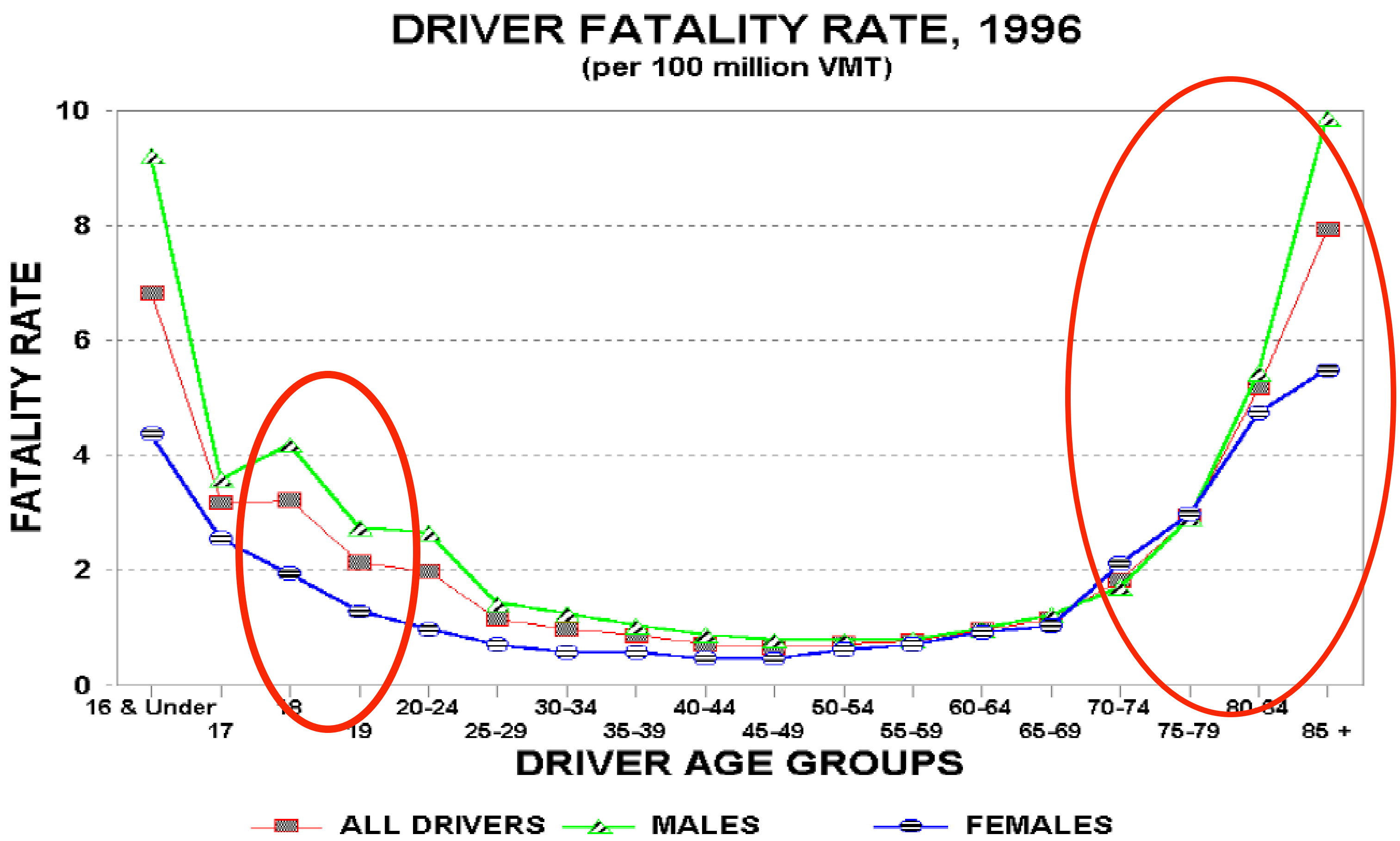
- How I got interested in Sensory-Cognitive Interaction and Aging
  - Simulated Driving Experiment
    - Sensory deficits or cognitive deficits? (Exp.1)
  - Simulating hearing impairment (Exp. 2)
  - Speech Augmentation (Exp. 3)
- Mechanisms
  - Echoic memory persistence (Exp. 4)
  - Decreased working memory storage (Exp. 5)
  - Delayed processing (Exp. 6)
- Applications
  - Auditory In-vehicle Displays
    - Voice Navigation Systems (Exp. 7)
    - Auditory requirements of Voice Systems (Exp.8)
    - Lead Time for Older Drivers (Exp. 9)
    - Collision Avoidance Systems (Exp. 10)

Sensory-Cognitive Interaction

- Sensory factors impact attentional resource requirements more than previously thought.
    - Acoustic variation within a clearly audible and comfortable range
- Degraded sensory stimuli (or hearing impairment)
    - – Can degrade task performance
    - – Can exacerbate or be mistaken for cognitive impairments

How I became interested in sensory-cognitive interactions

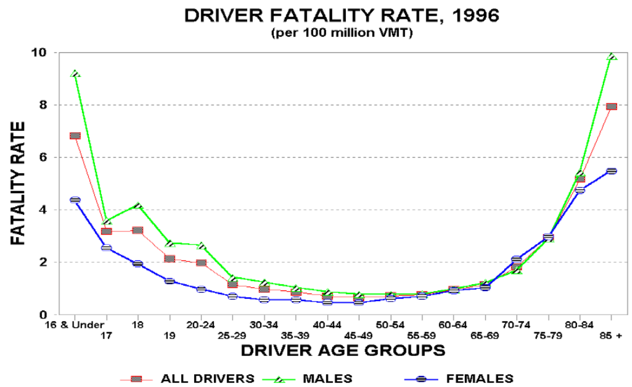
Crashes and Age in Perspective



Source: Cerrelli (1998)

Older driver crashes..

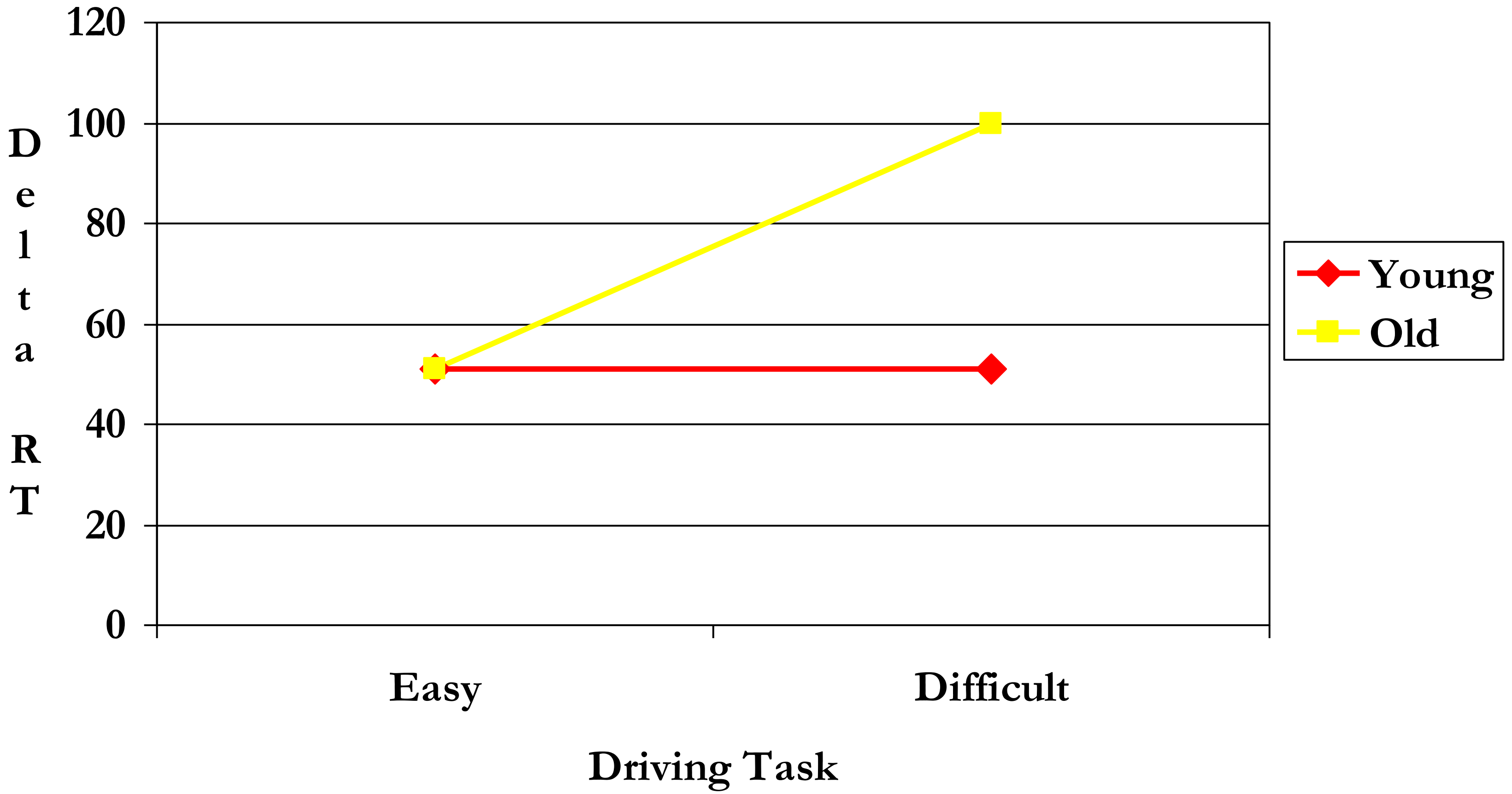
- Due to perceptual-cognitive issues
    - Looked but didn't see
    - Misjudge speed/distance
  - Drive fine under normal conditions
  - Identify reduced attentional resource capacity



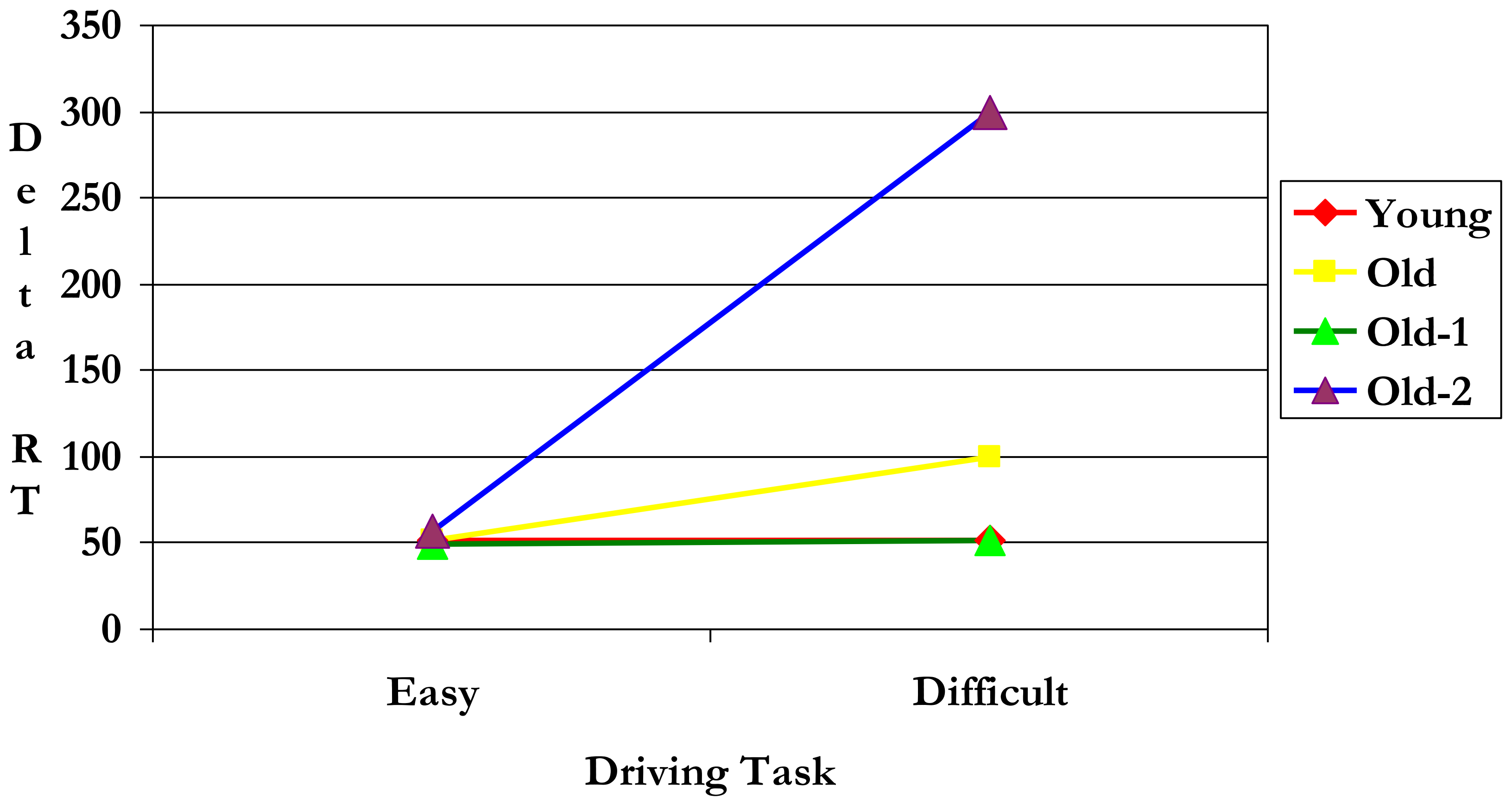
Experiment 1: Methods

- Dual Task Study
  - Simulated Driving task
    - Easy and Difficult
  - Auditory Mental Arithmetic
    - verbal response

Older drivers took longer to perform the auditory math task in the more difficult driving condition



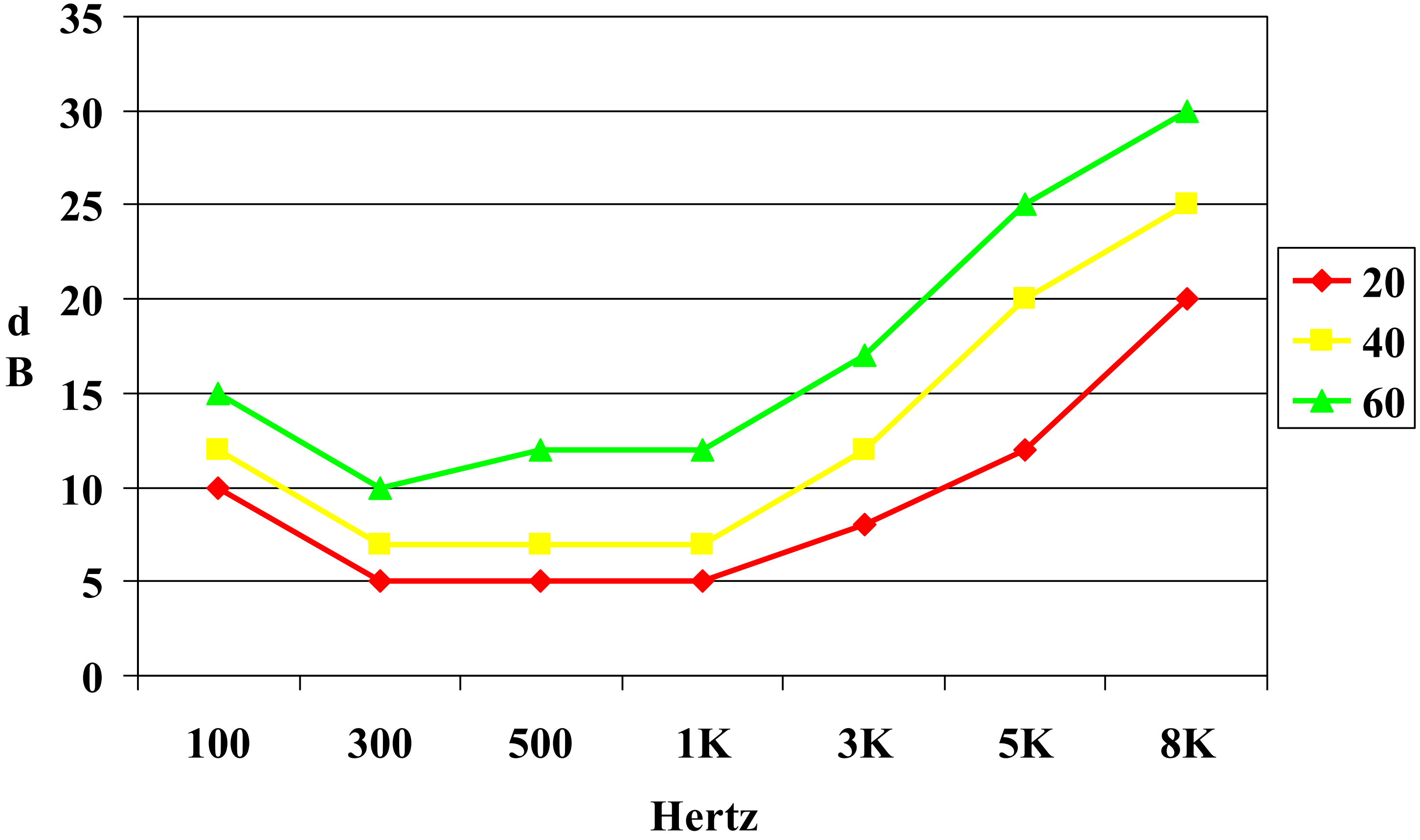
Four of 15 responsible



Sensory deficits masquerading as cognitive deficits?

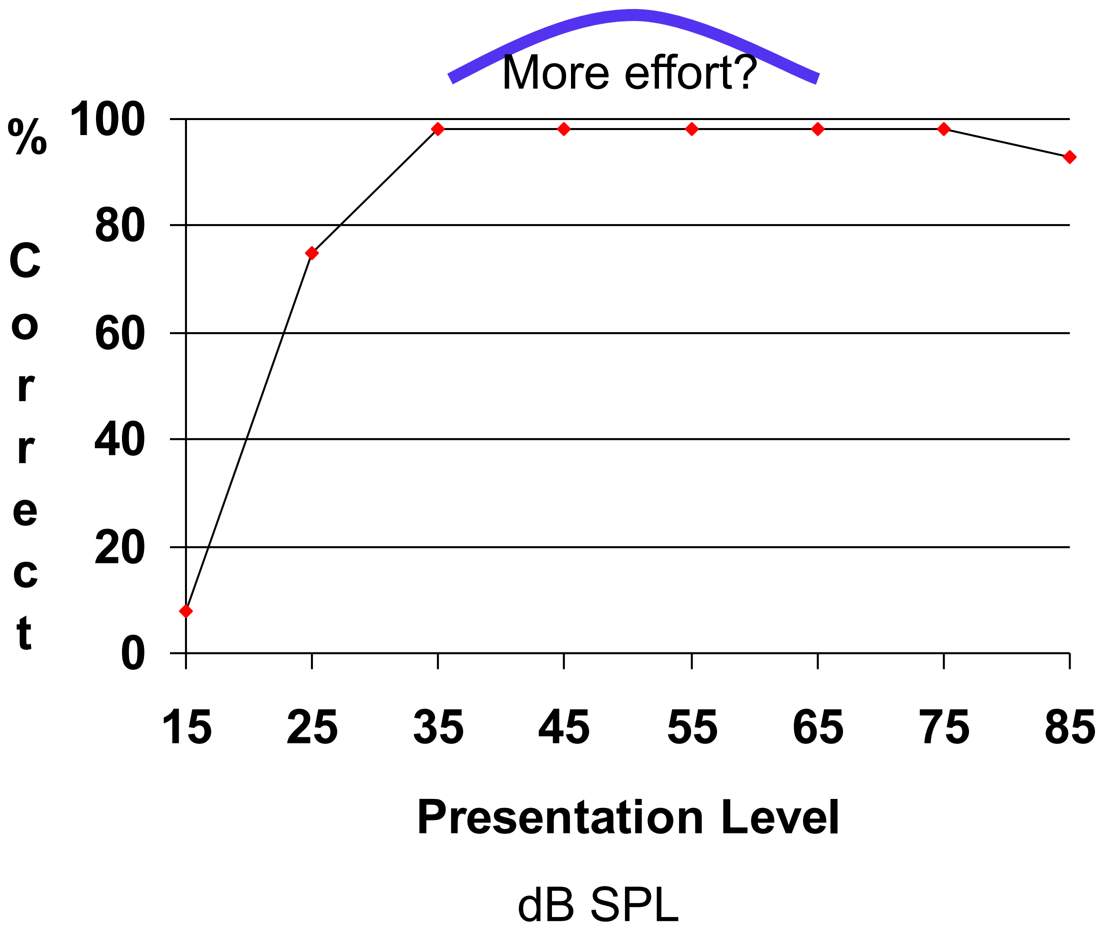
- Stimuli were audible
  - Single and low task load near 100% accuracy
- However, sensory impairment may increase attentional demands
  - Work harder just to hear
  - Less attentional energy (spare resource capacity) to perform the task
  - Most impact when demands are high

Age-related changes in pure-tone thresholds ubiquitous



Adaptation of Corso (1963)

Audibility levels of simple sentences under ideal listening conditions (Fletcher, 1953)



If degraded sensory input is harder to process…

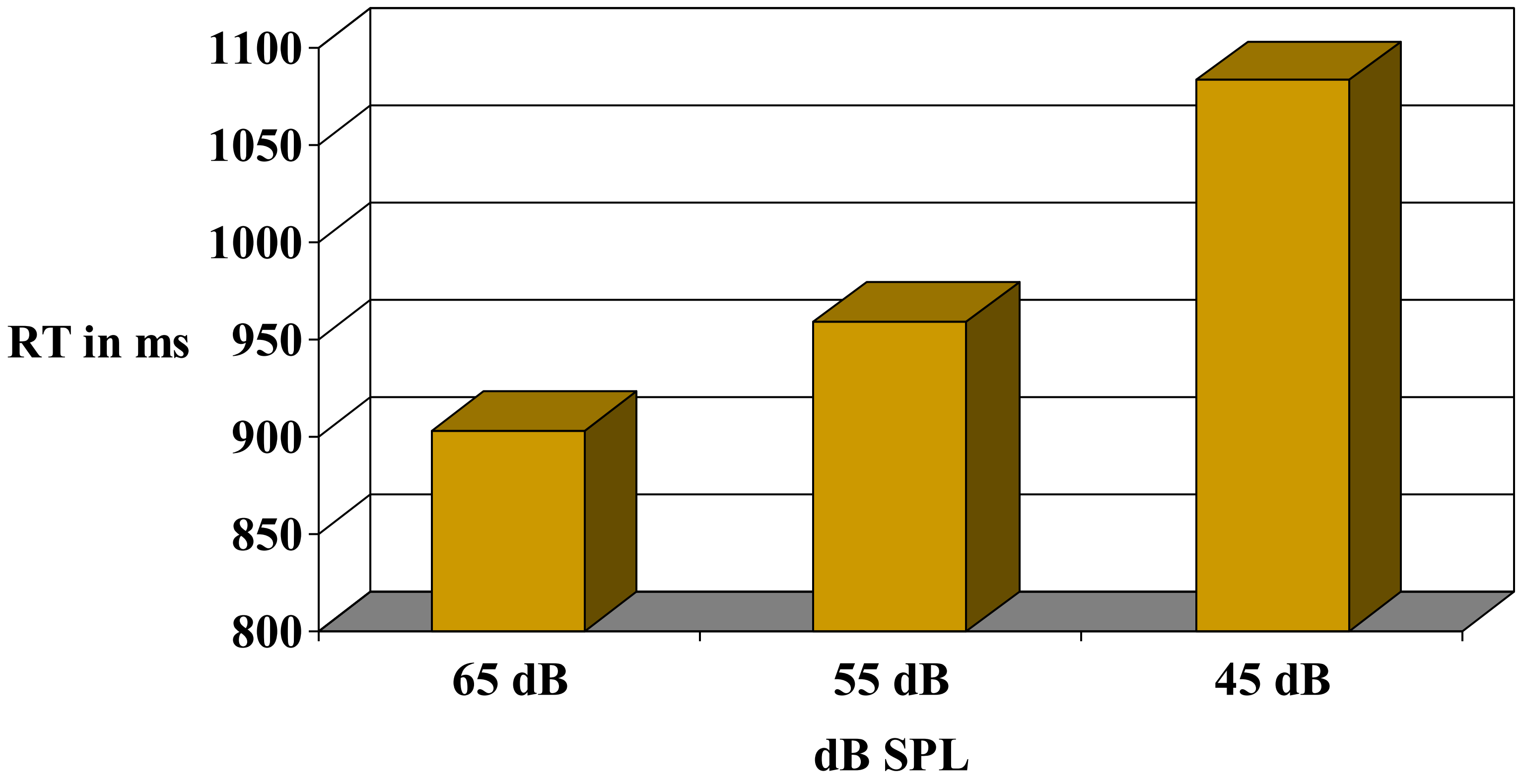
…then it should show up in young people also

Simulated Hearing Impairment- Experiment 2:

- Young normal hearing
  - Simulated driving task
    - loading task
  - Sentence processing task
    - “Birds can fly.” Vocally respond, “Yes”
    - “Dogs can fly.” Vocally respond, “No”
      - Presented at 45, 55, & 65 dB SPL

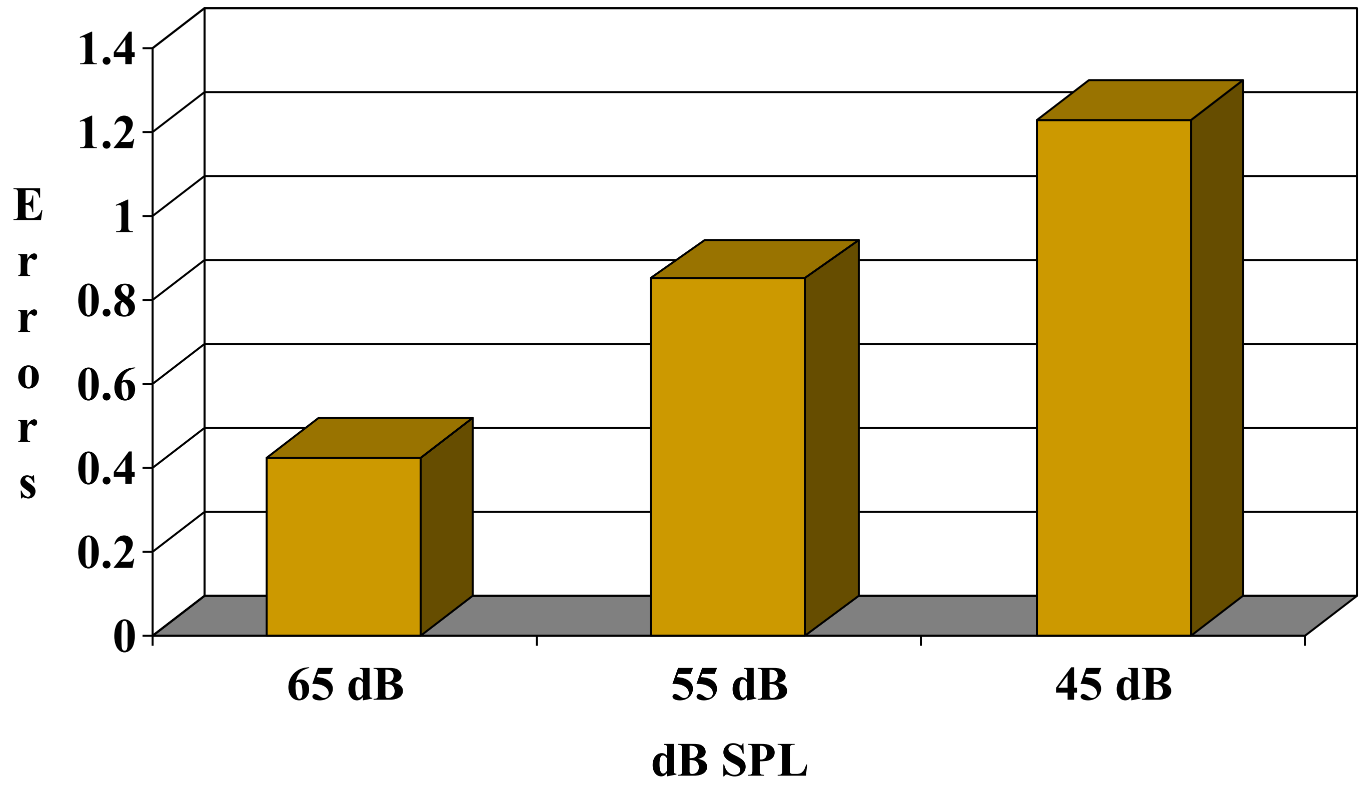
Baldwin & Struckman-Johnson (2002), *Ergonomics*

As presentation level decreased, young people took longer to respond…



Baldwin & Struckman-Johnson (2002), *Ergonomics*

And made more errors…



Implications

- Young performed like older (Exp. 1) when presentation level was low and demand high
- Degraded stimuli –increases resource demands
  - Compromise performance in demanding tasks
- Expect degraded performance in real world tasks:
  - Listeners - hearing impaired
  - Stimuli - poor signal quality
  - Environments – noisy classrooms & industrial settings

- Attenuation degrades performance in young listeners.
- Does augmentation enhance performance in older listeners?

Sensory Augmentation- Experiment 3:

- Participants: 21 older adults (60-84 y) and 27 young adults (18-29 y)
  - Cognitive and audiometric screening
- **Goal** - Assess Functional Hearing Level (FHL)
  - Idea - determine intensity level at which listener can achieve 90% accuracy on an auditory task in single task trials.

Baldwin, Lewis & Morris (2006)

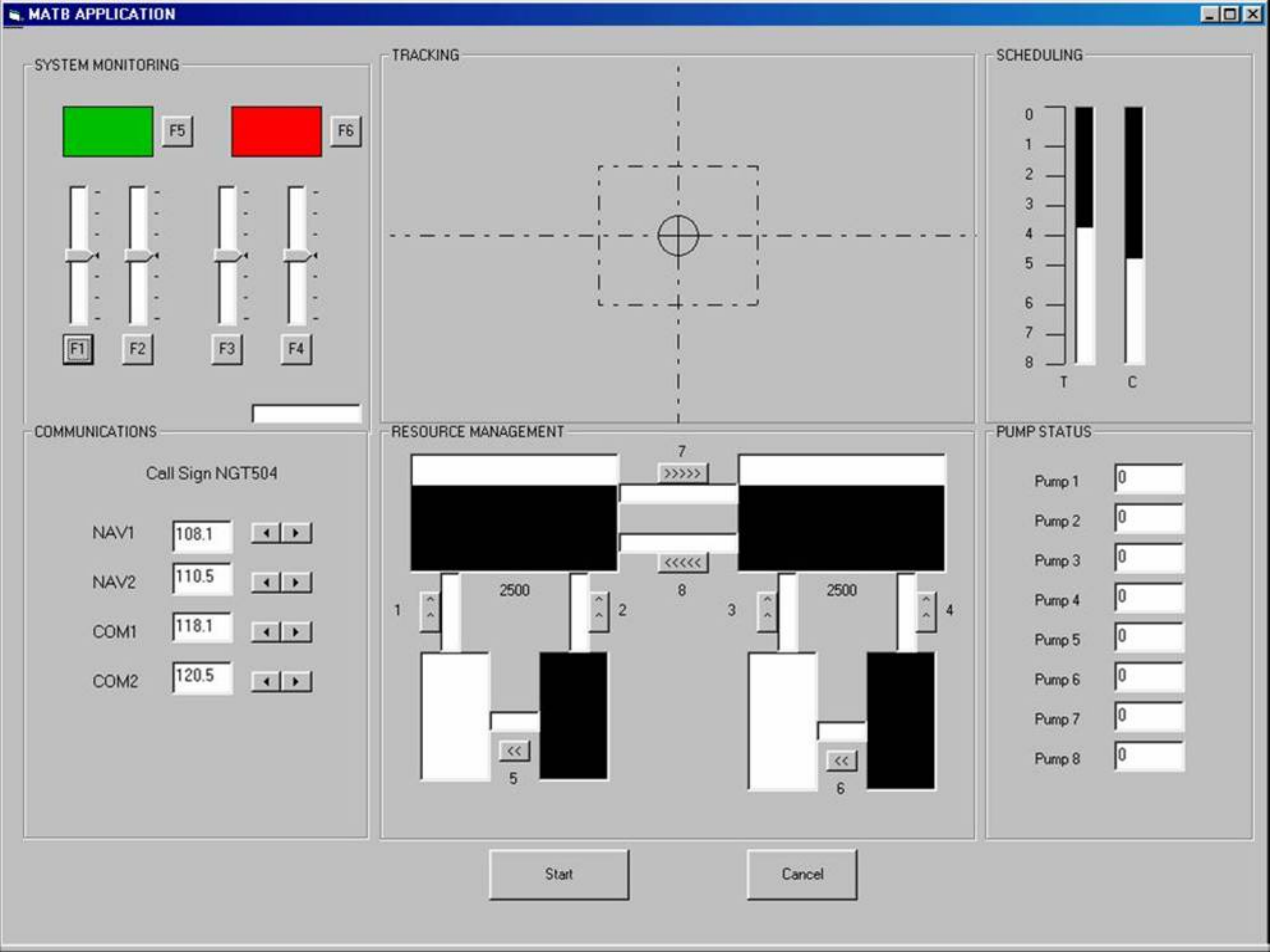
Does presenting stimuli at a FHL equate performance of Young and Old?

- Determined "Functional Hearing Ability"
  - Present stimuli well above pure-tone threshold

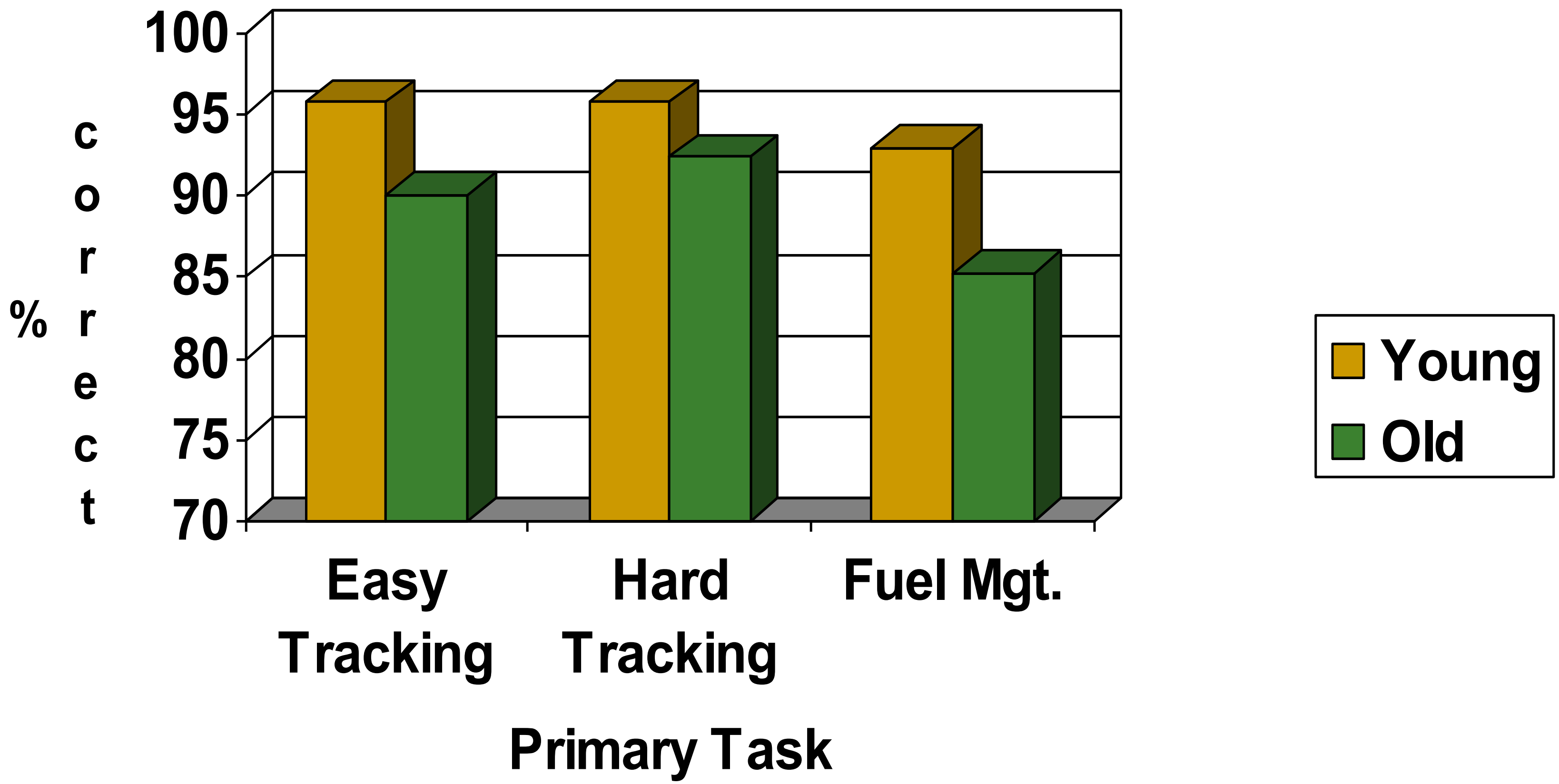
- Sentence verification task
  - Manual response via key press "Yes" or 'No"
    - i.e., "Birds can fly" or "Dogs can fly"

- Multi-attribute Task Battery tasks (Comstock & Arnegaard, 1992):

1. Easy tracking
2. Difficult tracking
3. Visual monitoring and decision-making task.


MATB APPLICATION
SYSTEM MONITORING
F5
F6
F1
F2
F3
F4
TRACKING
SCHEDULING
0
1
2
3
4
5
6
7
8
T
C
COMMUNICATIONS
Call Sign NGT504
NAV1
108.1
NAV2
110.5
COM1
118.1
COM2
120.5
RESOURCE MANAGEMENT
7
>>>>>
<<<<<
8
2500
2500
1
2
3
4
<<
5
<<
6
PUMP STATUS
Pump 1
0
Pump 2
0
Pump 3
0
Pump 4
0
Pump 5
0
Pump 6
0
Pump 7
0
Pump 8
0
Start
Cancel

Sentence Accuracy Decreased as Overall Task Difficulty Increased – but particularly for Older

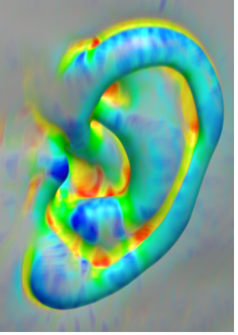


However, after controlling for differences in pure-tone threshold, only the effects of task difficulty remained.

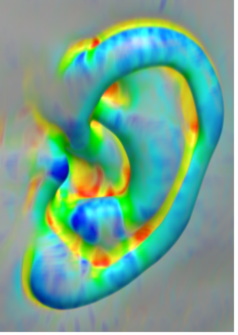
Baldwin, Lewis & Morris (2006)

Implications of 1-3

- Sensory-cognitive interaction
- Hearing impairment results in more effortful processing
- Largely a sensory issue….
  - Since young normal hearing show same performance detriments
  - Accounting for hearing impairment removes much of the “age-related” performance difference
- WHY?



Mechanisms



Hearing impairment may..

- Degrade quality of the stimulus (~presentation level) resulting in:

1. Greater attentional resource demands
   - Cat, cab, cap???
   - More reliance on context
2. Duration of echoic memory trace
3. Slow early sensory stages
4. **All of the Above** –take longer to do more in less time ?

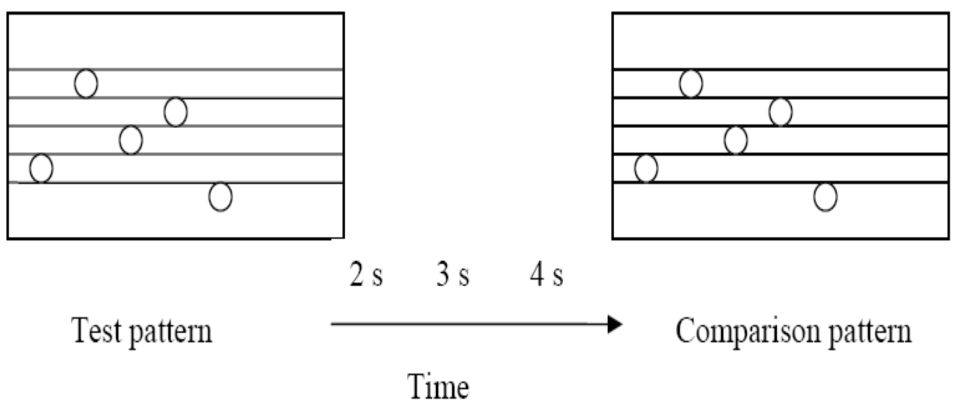
.

Echoic Memory (Exp. 4)

- Essential for processing speech, music, etc…
- Retain auditory image long enough to use context to decode
  - Familiar songs
  - Words, sentences
  - “The bank was a favorite spot for the towns people to ________.
    - ______ sit and watch the ships go by.
    - ______ cash their checks on Fridays.

Experiment 4: Methods

- Participants:
  - Young normal hearing; no formal musical training
- Tone Pattern Comparison Task
  - Presentation Level – (60, 65, & 70 dB SPL)
  - Delays of 2, 3, & 4 s

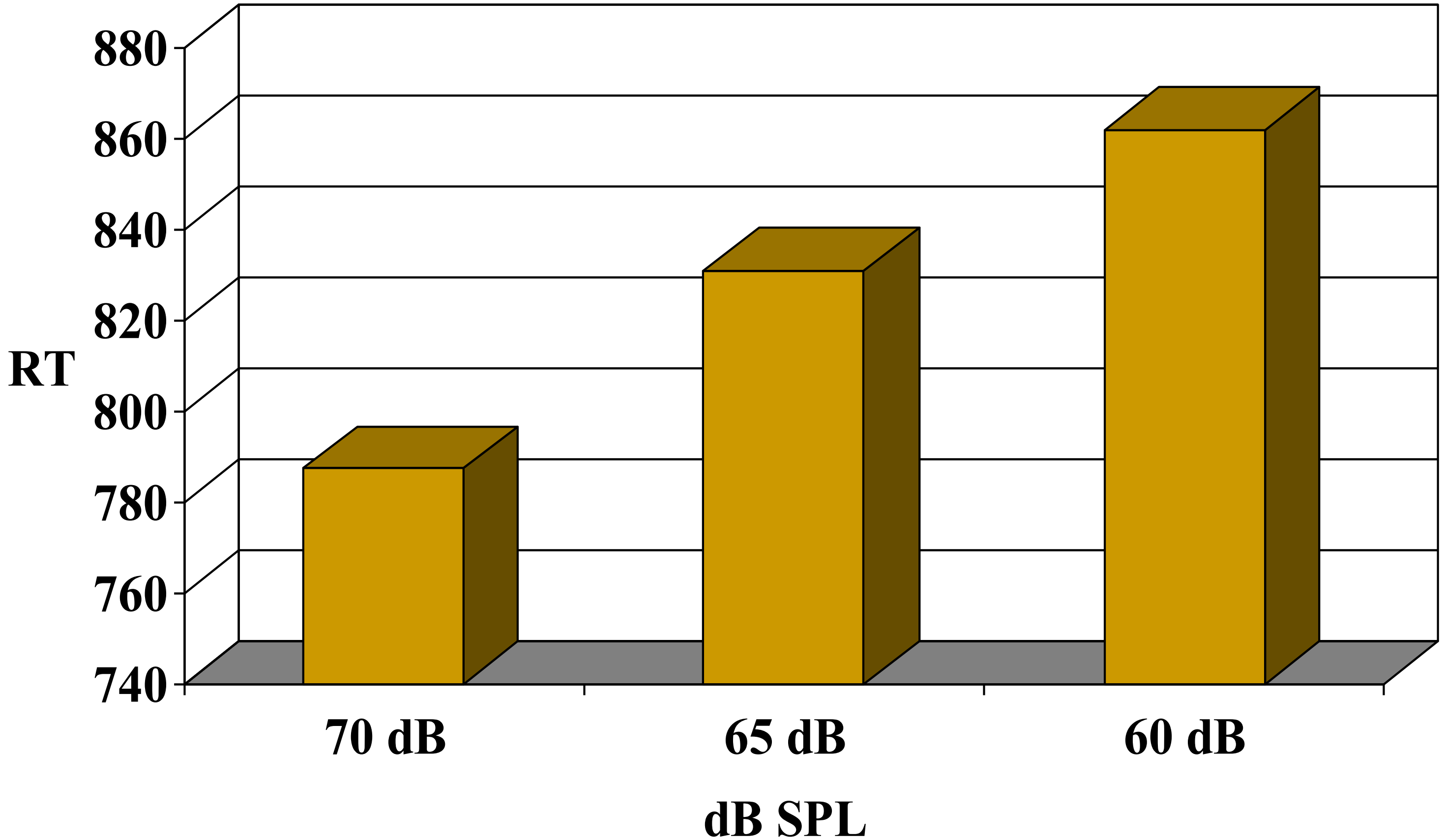


"Same" or "Different"

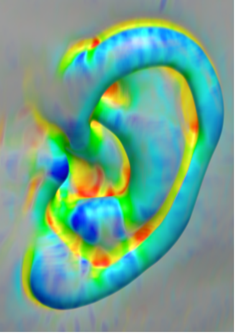
- Simulated driving task used as loading task

Baldwin (2007), *Memory & Cognition*

In the hardest (4 s) condition, performance degraded (people took longer) to make the comparison as intensity decreased.



Baldwin (2007), *Memory & Cognition*



Experiment 4 - Implications

- Stimulus intensity affects echoic persistence
  - In dual task situations, persistent traces more likely to be processed during transient reductions in resource demand
  - Older adults particularly disadvantaged in high workload situations
- So, if hearing impairment results in a lower quality, less persistent echoic trace….

Would this also effect working memory storage?

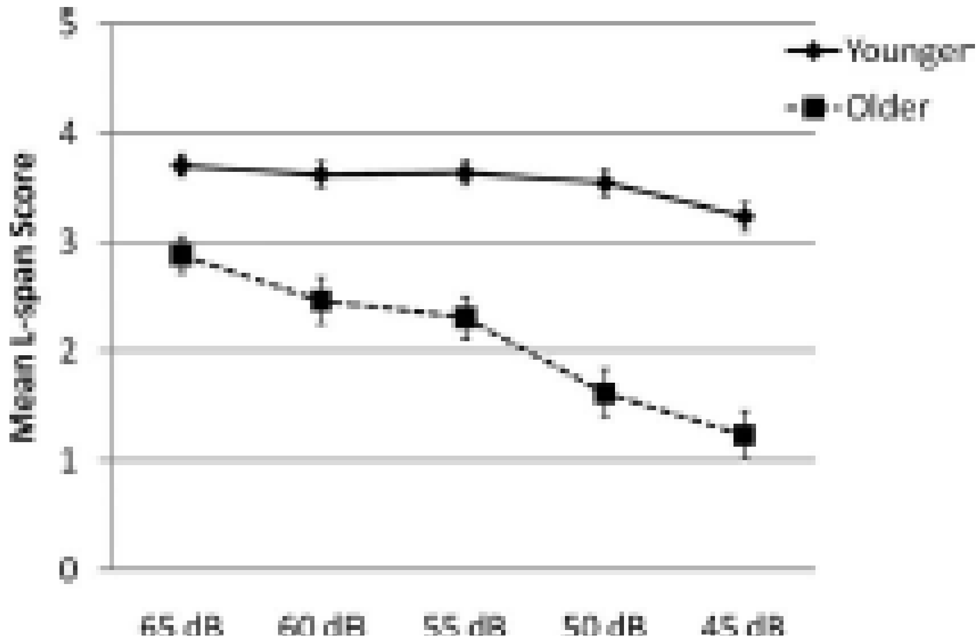
…the lower quality, less persistent echoic trace

Sensory Acuity & Complex Working Memory Span – Experiment 5

- Complex Span (Daneman & Carpenter, 1980, Conway & Engle, 1996.)
  - Visually - Reading span task
  - Auditorially - Listening span task
    - – Dogs can **fly** _N_.
    - – Tables have **legs** _Y_.
      - » Recall the words “fly & legs”
  - – Older adults frequently shown to have reduced complex span (Parks, et al. 2002)
  - – Does reduced acuity contribute?

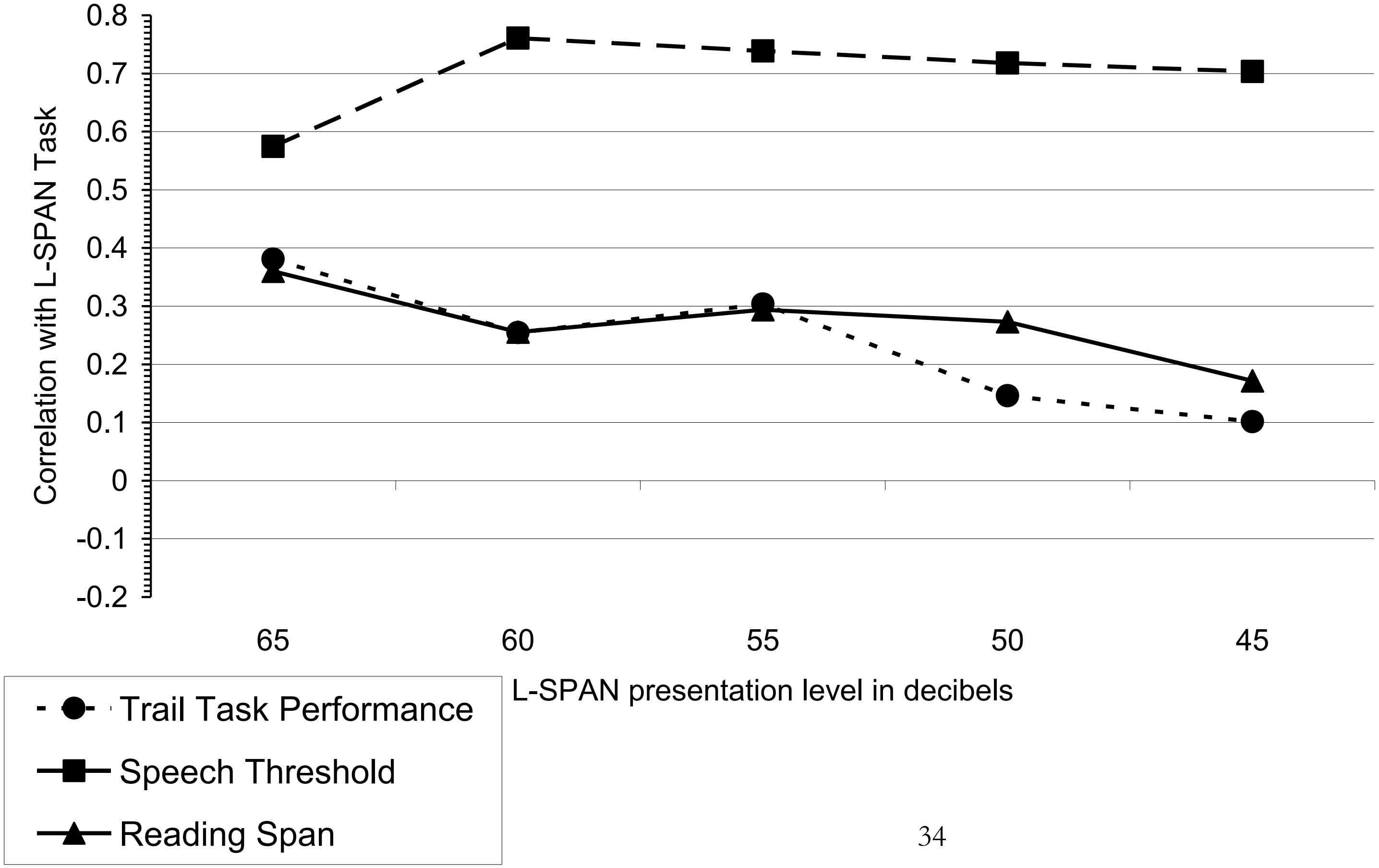
Baldwin & Ash (2010) Psychology & Aging

Complex span score decreased for young and old as presentation level decreased

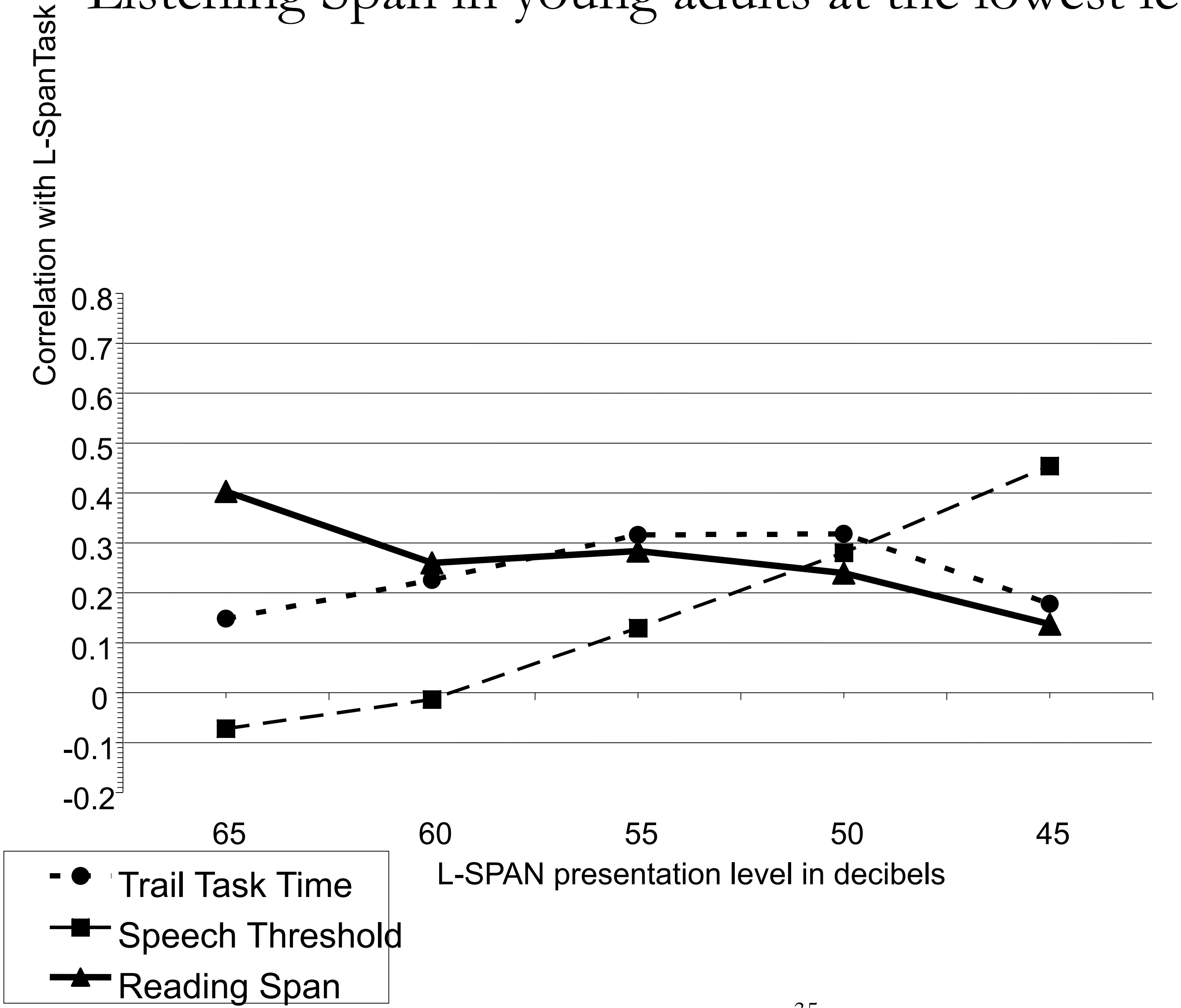


- But it started earlier and was more dramatic for older listeners

Sensory Acuity was the best predictor of Listening Span in older adults at all presentation levels



And Sensory Acuity became the best predictor of Listening Span in young adults at the lowest level



Implications – Experiment 5

- Both hearing impairment and degraded listening conditions can masquerade as reduced working memory capacity.

Time course of sensory – semantic processing – Exp. 6

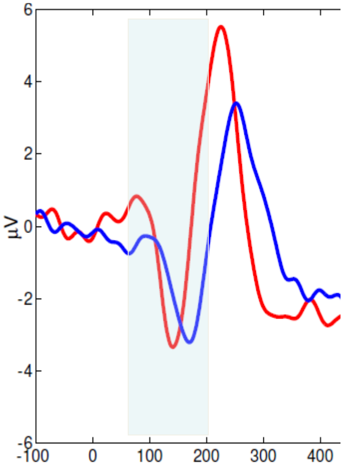
Event related potential (ERP) components:

N100 – sensory

N400 - semantic

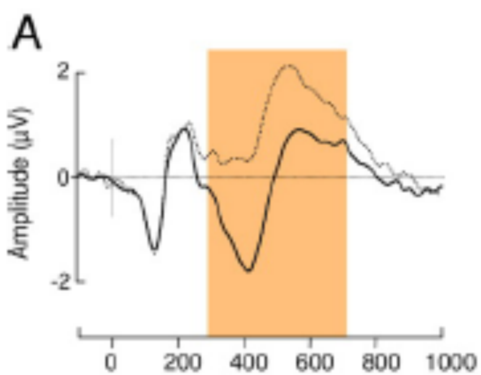
ERP Components of Interest

- N100 – exogenous (obligatory responses)
  - Negative deflection ~100 ms after a stimulus
  - Amplitude & Latency affected by:
    - Intensity/salience of the stimuli
    - Inversely related to age



ERP Components of Interest

- N400 – endogenous (higher-order processing)
  - Negative deflection ~400 ms after
  - Amplitude based on:
    - –Integration of semantic information in memory
      - »Predictability of words in sentential context



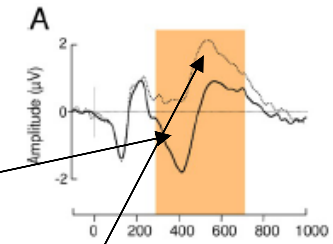
Thierry, et al. (2007)

Kutas and Hillyard (1980)

Semantic Content & the N400

- **Predictable**: She could tell he was mad by the tone of his **voice.**

  After hitting the iceberg the ship began to - **sink.**



Thierry, et al. (2007)

- **Anomalous**: The dentist recommends - brushing your teeth twice a **voice.**

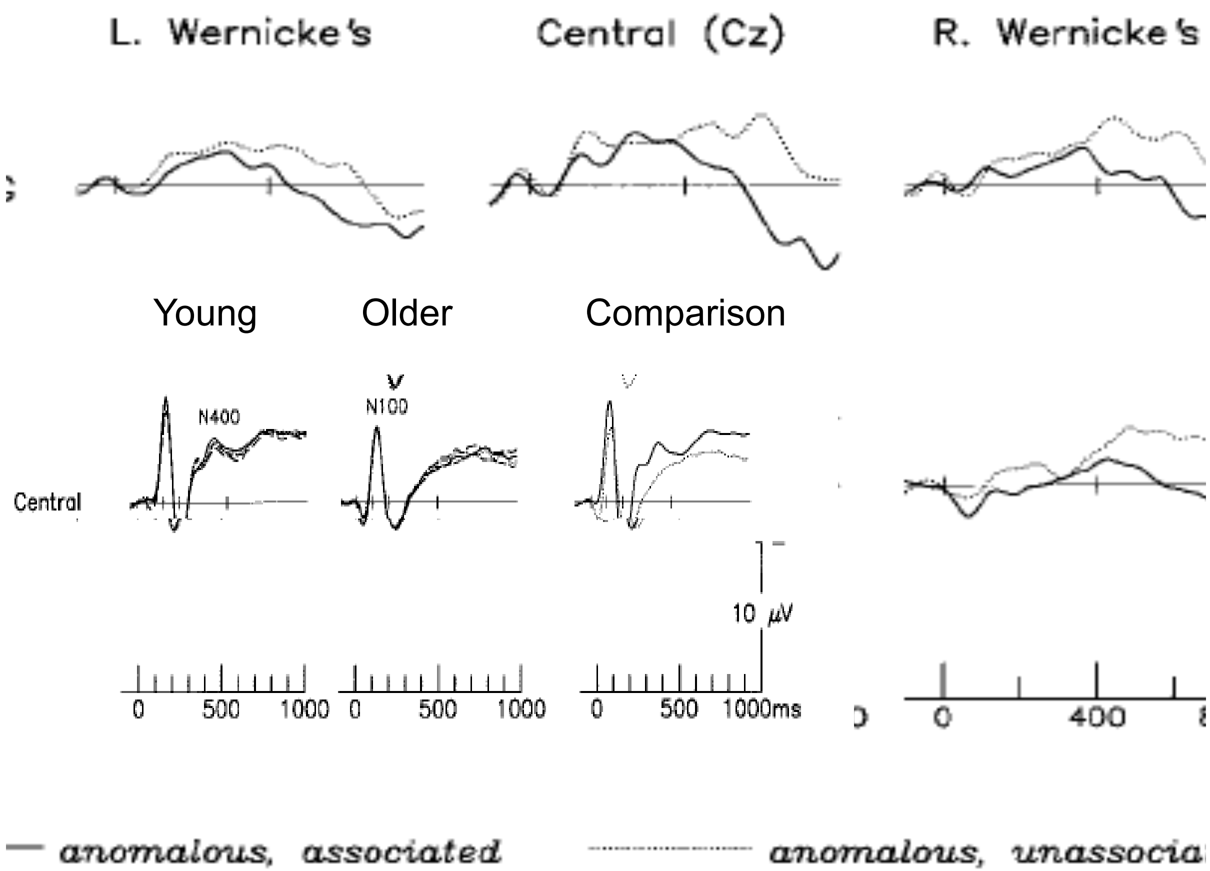
  He mailed the letter without a **sink.**

Block & Baldwin (2010) *Behavior Research Methods*

N400, cont…

- N400 –
  - Latency influenced by:
    - Time taken to incorporate contextual information
  - Age
    - Decreases amplitude
    - Sometimes increases latency

Sensory & semantic stages of processing in young and older listeners



No delay in later component

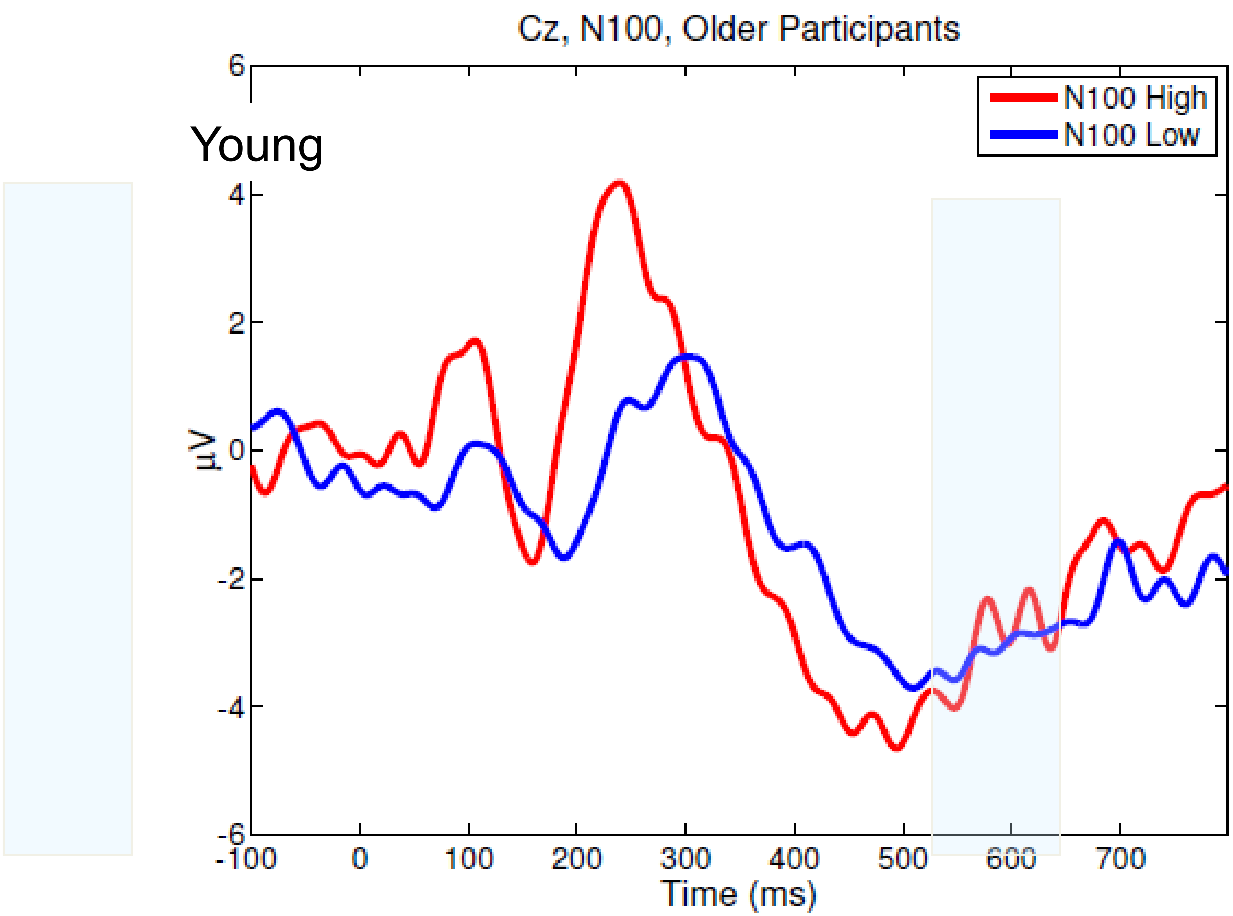
~25 ms delay for older listeners

N100 = Sensory Component

N400 = Semantic Component

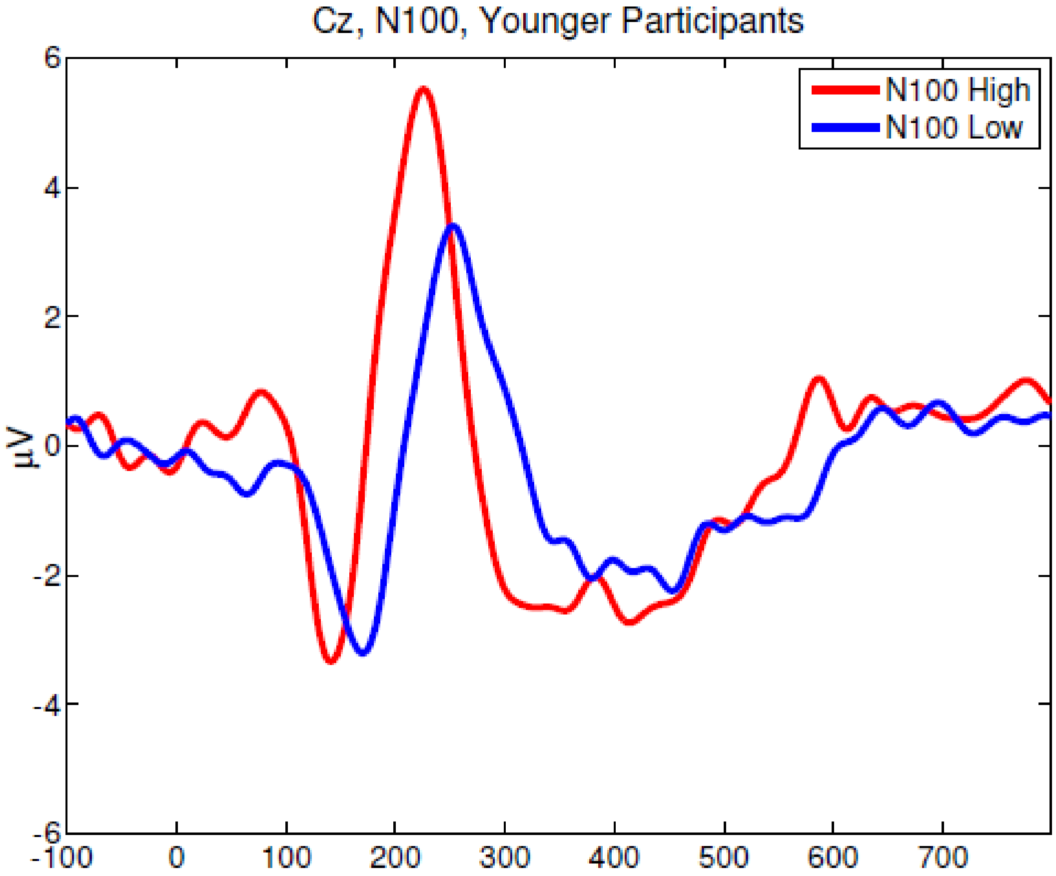
Federmeier et al. (2003)

N100 delayed and attenuated by both reduced intensity and advanced age.



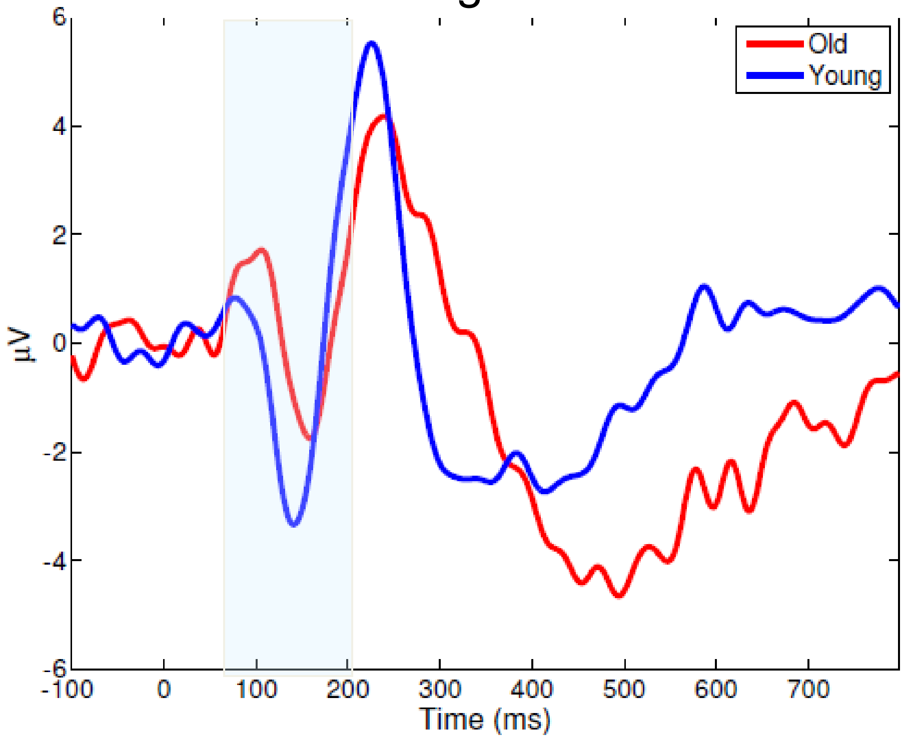
At Cz

Delay by Presentation Level in Younger

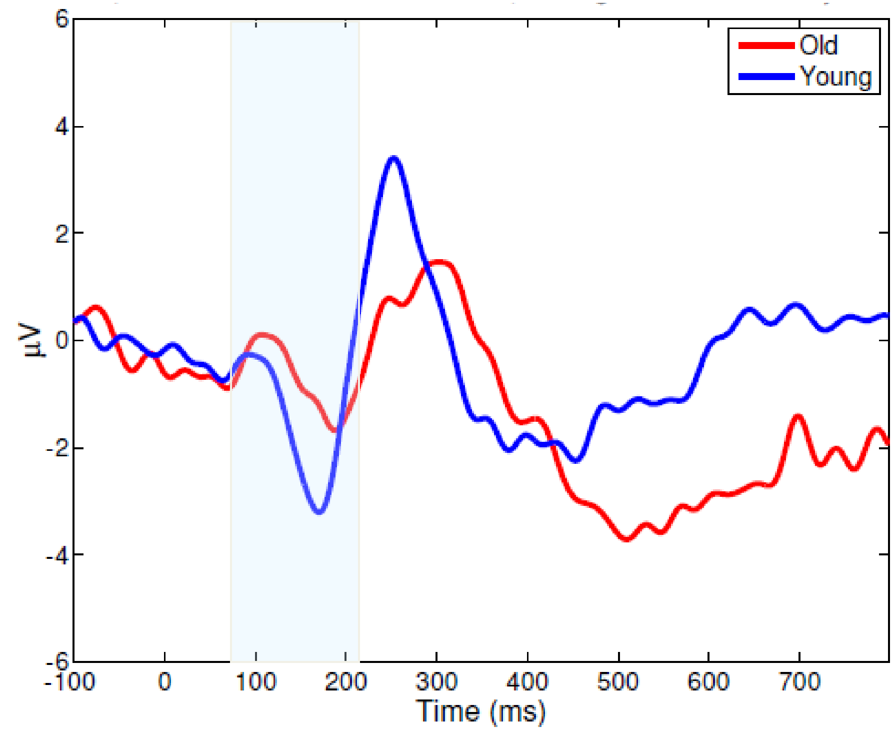


N100 delay and attentuation

High PL



Low PL



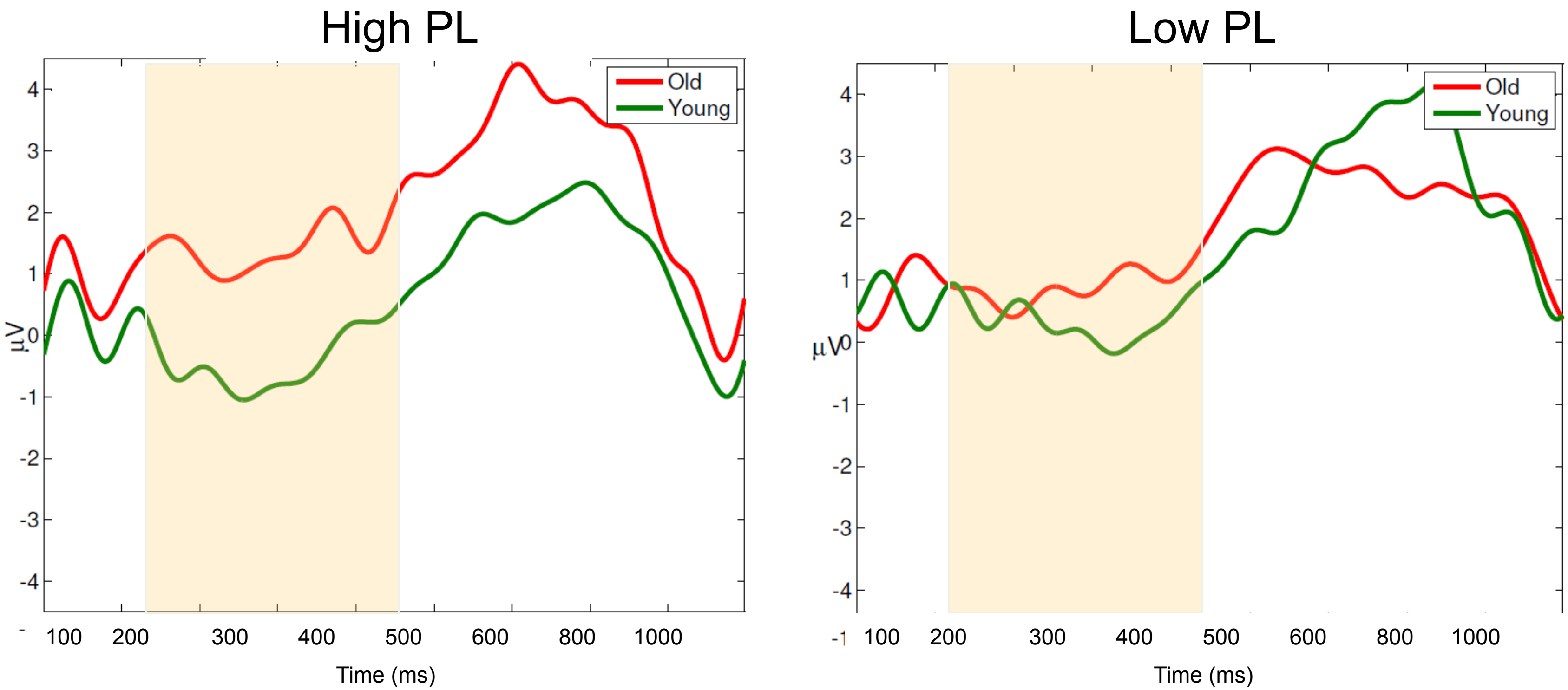
At Cz

Paradigm Check -N400 & Congruency

- N400 peak was significantly larger (more negative) for incongruent relative to congruent sentences.

- Incongruent sentences only now examined for N400 latency & amplitude.

N400 attenuated by age & Low PL

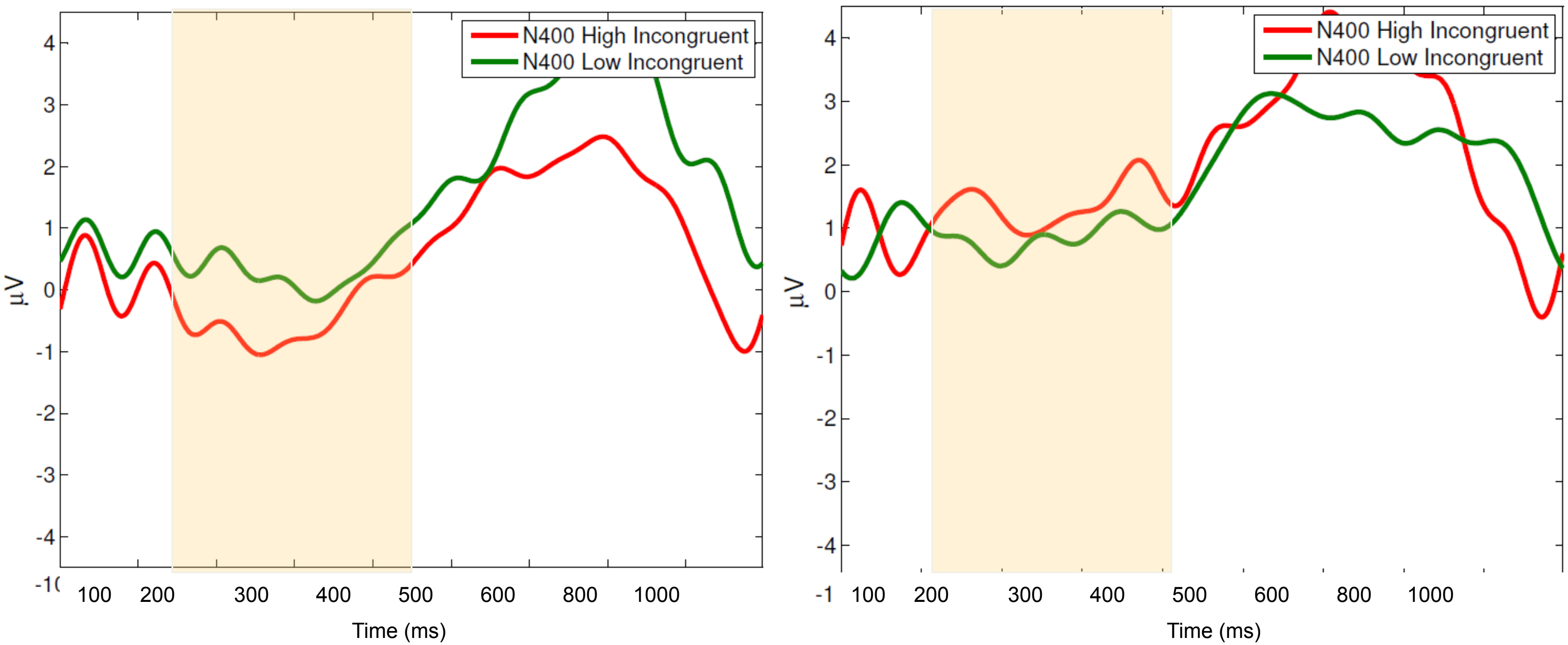


At Pz

N400 is delayed at Low PL in young, but not older adults

Young

Old



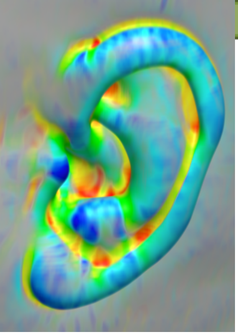
At Pz

Implications of Experiment 6

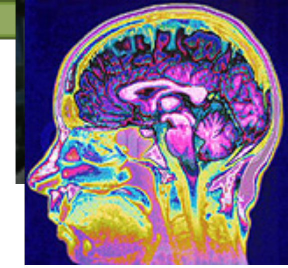
- Both reduced intensity (Low PL) and advanced age delay & attenuate N100.
- Both reduced intensity and advanced age attenuate N400.
- Reduced intensity also delays N400 in young but not older participants.

Suggests

- Older adults are making up for time lost in early sensory stages by greater reliance on context.
  - May actually be faster at the later cognitive stages

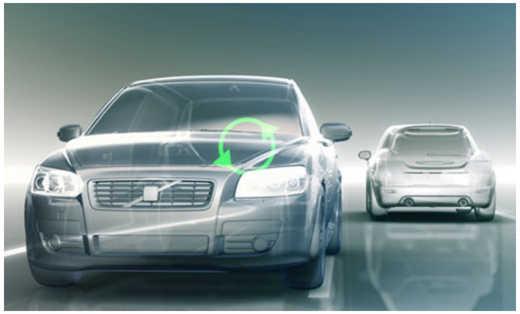


Implications of Experiments 4-6



- Hearing impairment seems to ...
  - Degrade quality of the stimulus
    - Greater attentional resource demands
      - More reliance on context
    - Decrease duration of echoic trace
    - Reduce working memory capacity <u>(Indirectly)</u>
    - Slow early sensory stages requiring “catch-up” time in later stages
    - **<u>All of the Above</u>**
  - **<u>Take longer to do more in less time !?!</u>**

.



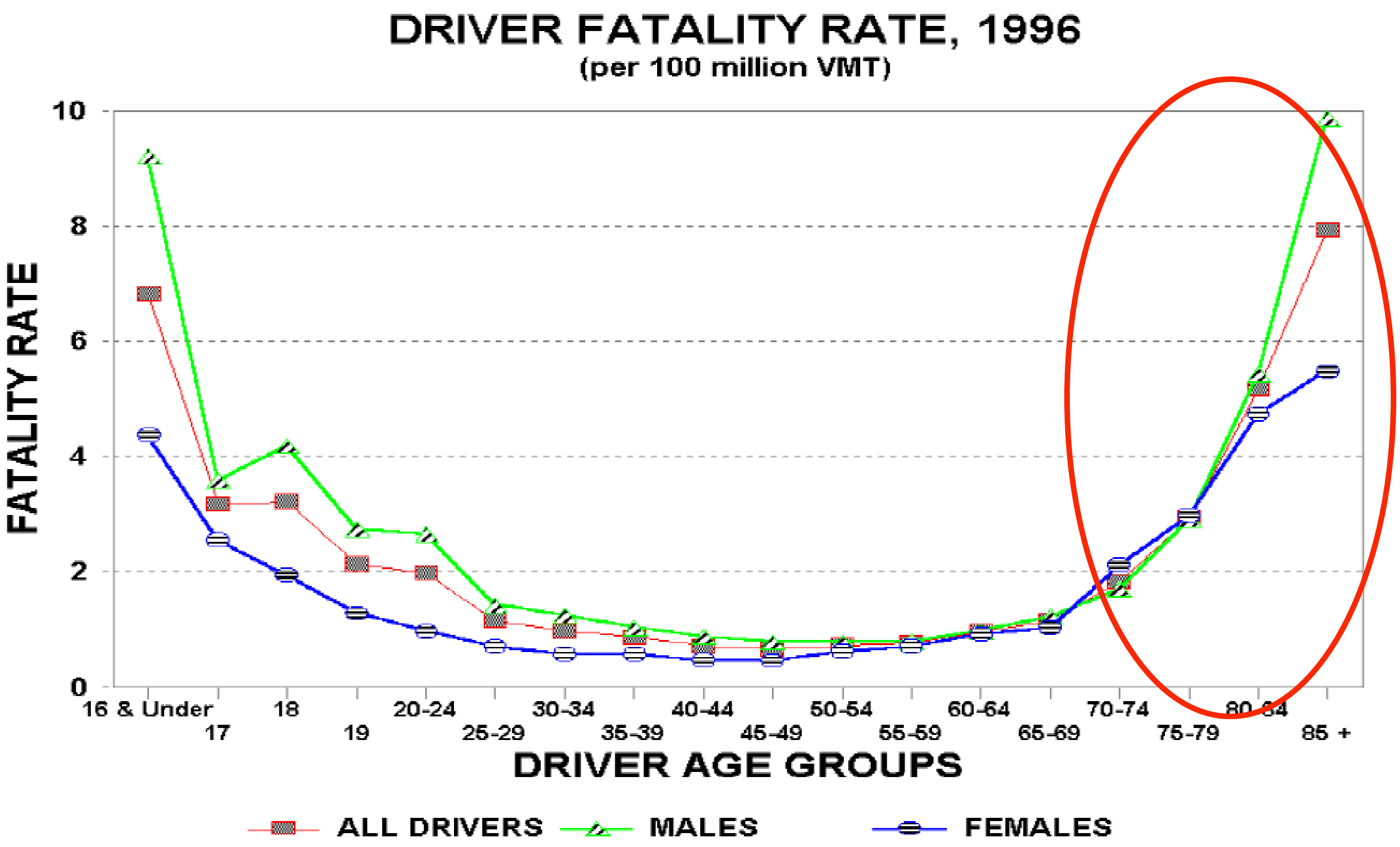
Applications


GMU's custom simulator developed by RTI and IMX-IDEAS (hardware developer)

Auditory In-vehicle Displays

Impact of Sensory/Cognitive Factors?

Crashes and Age in Perspective



Source: Cerrelli (1998)

Accident Causation

- Older drivers
  - Perceptual/cognitive errors
    - (i.e., looked but didn't see)
  - Attention issues
    - Distraction from relevant driving tasks
    - Difficulty switching attention appropriately

Older Driver Issues

- Difficulty maintaining safe control of vehicle while simultaneously:
  - Performing Navigational Tasks,
  - Maneuvering complex intersections (particularly unprotected left turns)
  - Avoiding Roadway Obstacles

- Decreased UFOV (particularly when workload is high
  - Hard to detect collision situations and visual alerts

See Ball et al., 1988, 1990, 1993 – for UFOV; and Burns, 1999; Dingus et al., 1997; Rothe et al., 1990; Warnes et al., 1993 for general driving

Design In-vehicle Driver Aids that take into account sensory-cognitive interaction

Baldwin (2002) Theoretical Issues in Ergonomic Science (TIES)

In-vehicle Technologies & Driver Age

- Relatively few investigations specifically addressing the benefits and costs for older drivers
  - – Exceptions: (Baldwin, 2002, Dingus et al., 1997; Llaneras et al., 2000; Fleischman & Dingus, 1998)
- Results indicate:
  - <u>Auditory modality</u> to reduce visual processing demands (Dingus et al., 1997)

In-vehicle Navigation Systems

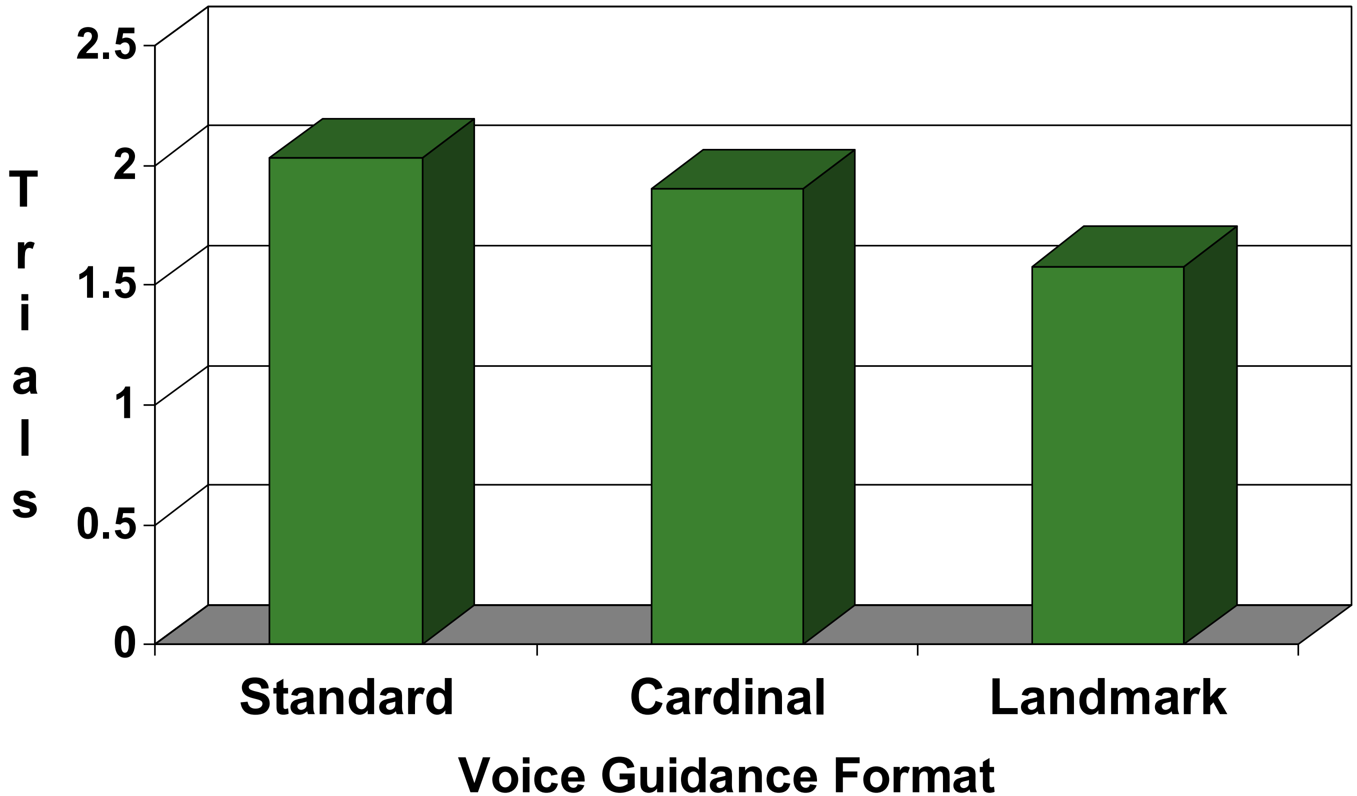
- Navigation
  - challenging task for drivers (particularly older)
- Supporting technologies
  - Wayfinding & Cognitive Map formation
- Format – egocentric vs geocentric
  - Egocentric – supports wayfinding
  - Geocentric – supports cognitive map formation
- Modality/format
  - Auditory –
  - Visual –

Voice Navigational Guidance Experiment 7

- Can auditory support both wayfinding & cognitive map formation?
- **Three Formats:**
  - **Standard**: "Turn left in 2 blocks on 5th avenue."
  - **Landmark**: "Turn left in 2 blocks on 5th avenue at the fire station."
  - **Cardinal**: "Turn left in 2 blocks on 5th avenue heading north."
- **Task**: Drive route with voice guidance and then without.
  - Navigational errors & # trials to learn routes

Driving Simulator

Referencing Landmarks reduced navigational errors and facilitated route learning



Reagan & Baldwin (2006), Journal of Environmental Psychology

Implications of Exp. 7

- Pointing out salient landmarks decreased navigational errors and improved route learning
- May particularly benefit older drivers
  - However, care must be taken to ensure auditory commands are highly intelligible.

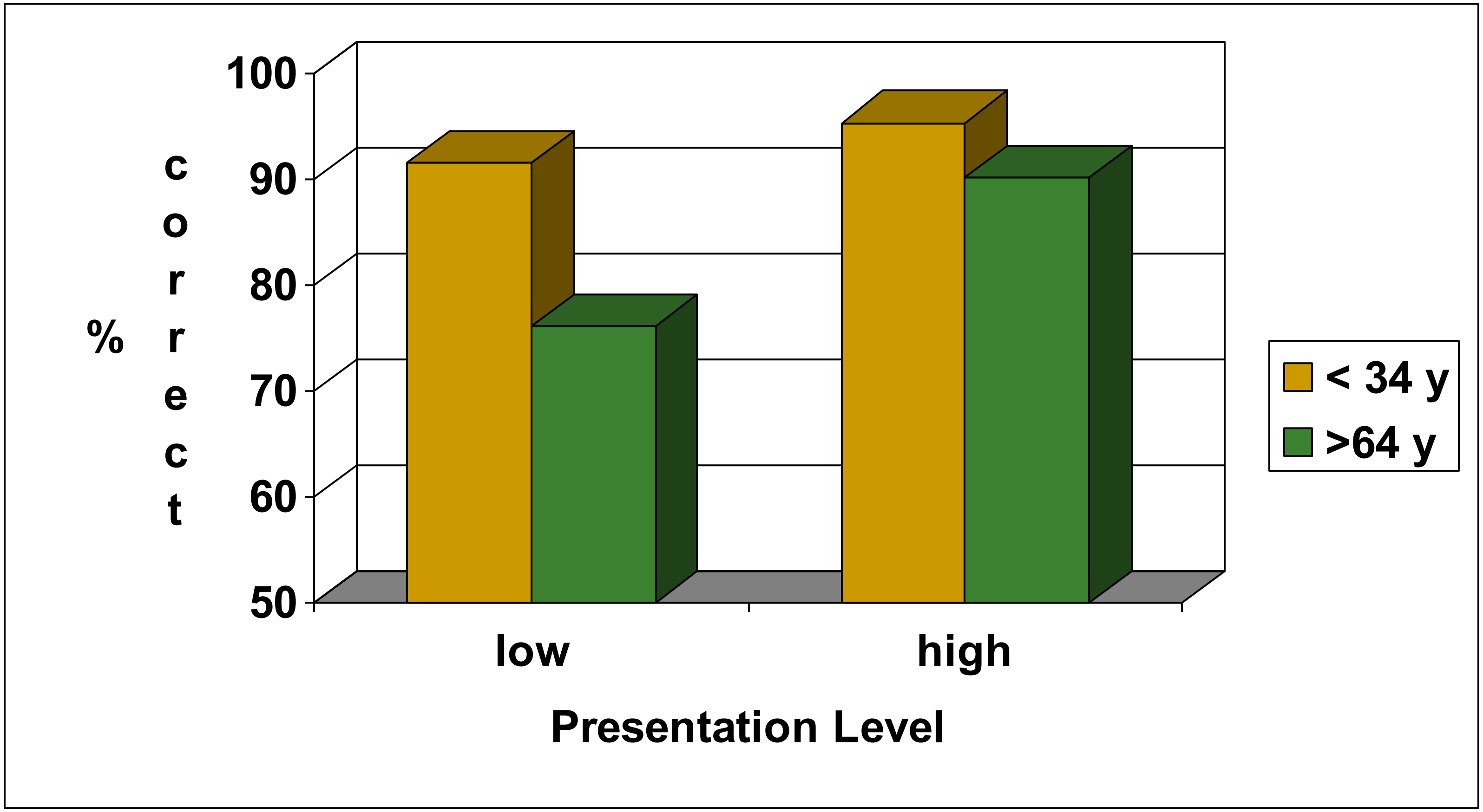
Acoustic Requirements of Voice Guidance Displays for Older drivers

Experiment 8

Experiment 8: Methods

- Participants: 20 young, 19 older >64 (M = 70.32)
- **Simulated Car Following Task**
  - – lead car – 55 mph on straight 2-lane freeway
  - – Criterion <= 5 mph from speed limit with no lane deviations
- **Sentence Processing task**
  - Low ~50-58 dB and High ~ 75 dB presentation levels
    - – All audible to baseline criterion = 90% accuracy on sentence task during baseline
- Realism coupled with repeated instructions emphasized that the driving task was the primary task.

Number of sentences answered correctly by older adults engaged in driving task*

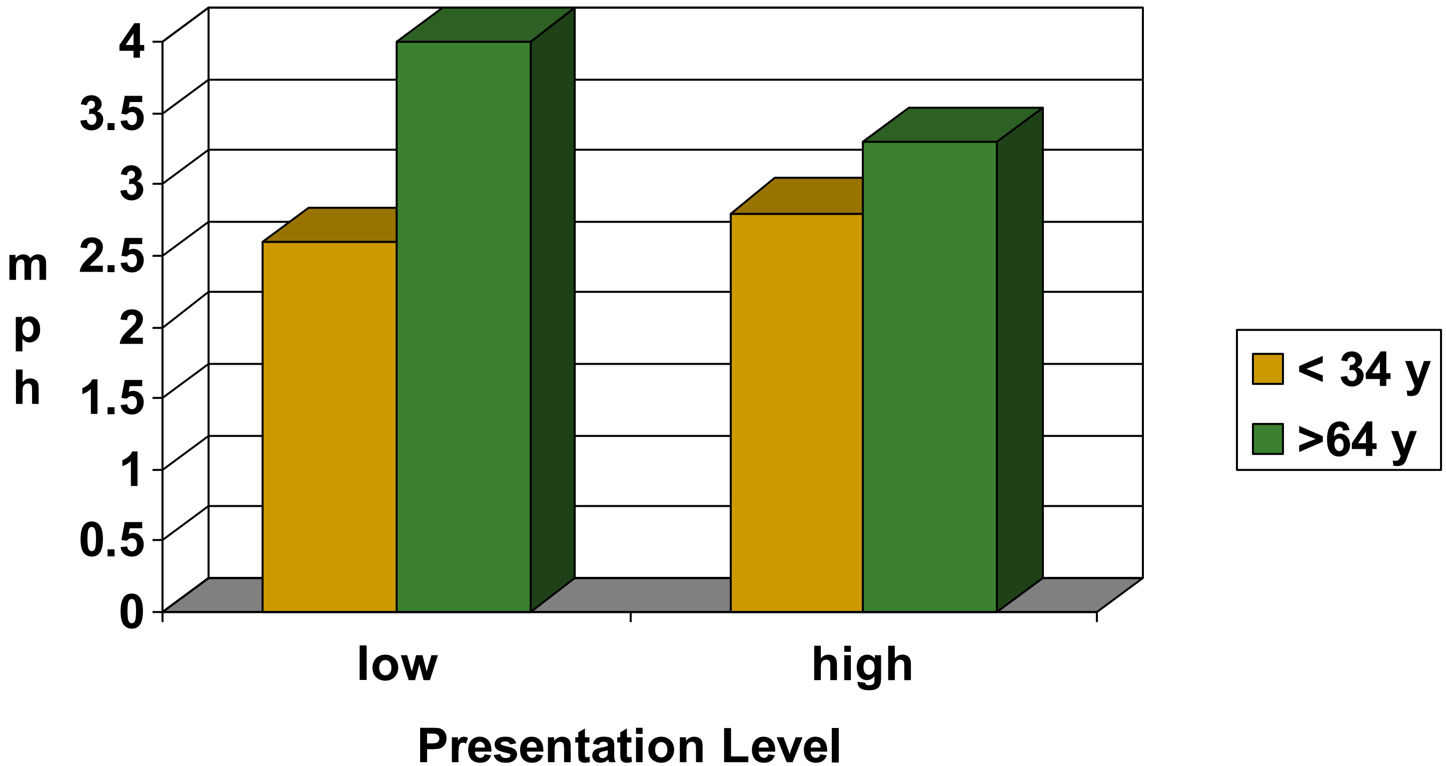


Low ~50-58 dB

High ~ 75 dB

*even after correcting for pure-tone threshold shifts (Baldwin, May & Reagan, 2006)

Older drivers - trend toward greater speed variability when messages were harder to hear



Implications of Exp. 8

- Navigational commands MUST be well above auditory threshold levels to be effective
- Difficult to hear messages may compromise driving performance.

- Timing?

Timing -

- In-vehicle commands
- Collision warnings

- Do older driver’s need them presented sooner?

Older Drivers & Lead time for Auditory Directions – Experiment 9

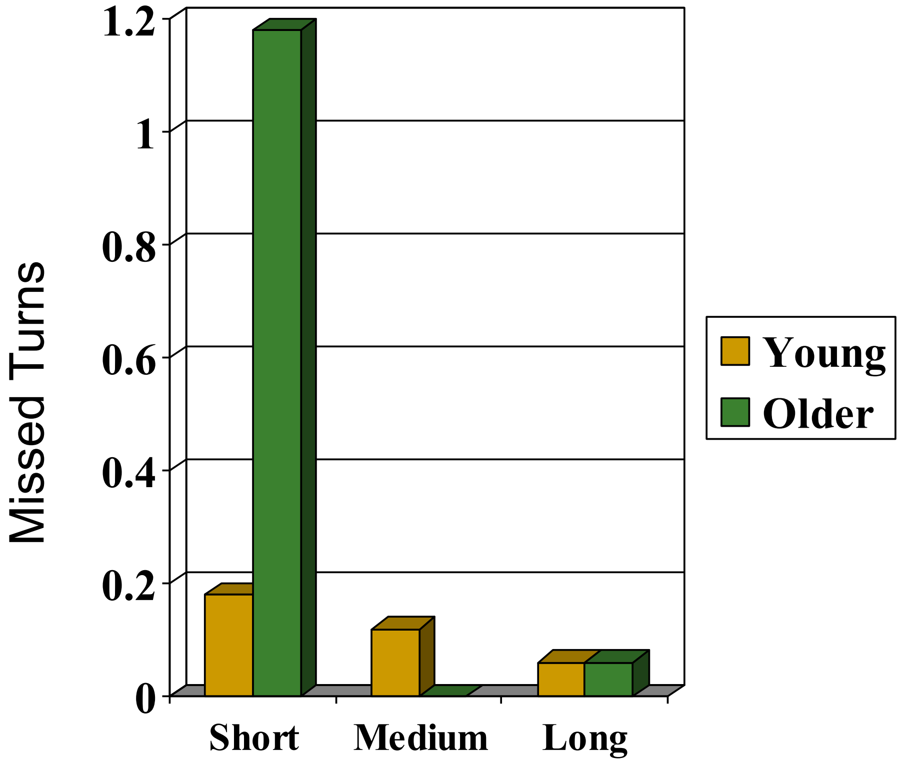
- Young drivers (20-35) & Older drivers (65-80)
- Simulated city & rural driving
- Verbal navigational Command Distances
  - i.e., "Turn Left at the next intersection."

	Short	Medium	Long
City (25 mph)	100 ft	250 ft	400 ft
Rural (45 mph)	250 ft	500 ft	750 ft

Baldwin & Ferris (2002)

Older drivers required more time to negotiate turns after a navigational instruction

- 81% (13/16) older drivers missed at least one turn in the "short" lead time condition



Ferris & Baldwin (2002)

Implications – Exp. 7-9

- Auditory Navigational Systems can support both wayfinding & cognitive map formation
  - Salient landmark might particularly benefit for older adults
- Older adults need higher intensity levels & information presented earlier
- Older drivers need more time to process and prepare for navigational maneuvers.
- Auditory Collision Avoidance System (CAS) warning likely to follow same trend

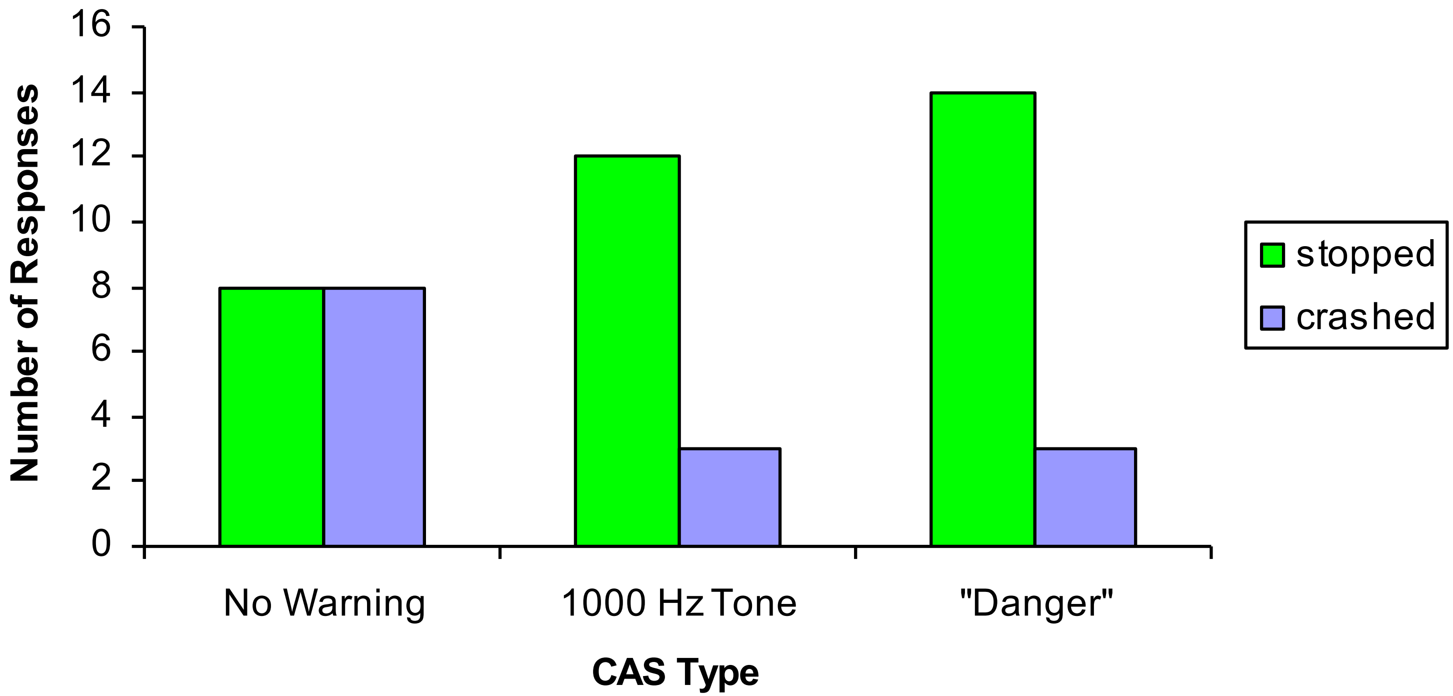
Auditory Collision Avoidance System (CAS) Warnings – Experiment 10

- Younger & older drivers
  - Car-following task in driving simulator ~ 1.5 hours
  - Secondary task also
- Time-on-task fatigue triggered critical event
  - based on excessive lane position variability

Collision scenario

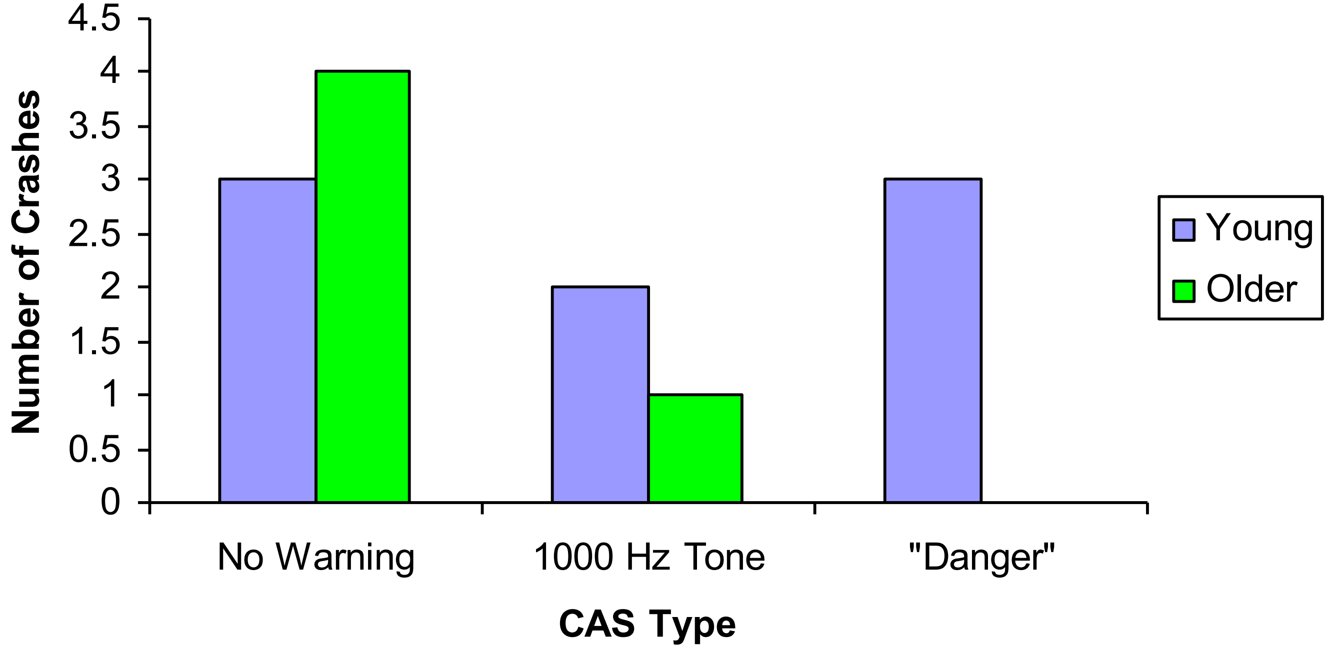
- The lead car suddenly and forcefully applied its breaks, coming to a complete stop.
  - When the lead car slowed to 50 mph (from 55 mph), three possible CAS conditions occurred.
    - 16 received **no warning** (control condition)
    - 15 heard the **1000 Hz tone**
    - 14 participants heard **“Danger”**
      - no prior information regarding this potential crash

CAS Warnings reduced crash probability



- 27% or (13 of 48) crashed.
- Of these, 61.5% (8 of 13) crashed in the no warning condition, 23% (3 of 13) crashed in nonverbal warning condition and 15% (2 of 13) crashed in the verbal warning condition.

CAS Warnings Particularly benefited older drivers



- Only 1 older driver crashed when provided a warning
- Older drivers headway nearly 2 xs that of young

Implications -

- Sensory-Cognitive Interactions
  - Sensory factors impact attentional resource requirements
  - Degraded sensory stimuli (or hearing impairment)
    - Can degrade task performance
    - Can be mistaken for cognitive impairments
    - Will impact the effectiveness of in-vehicle assistive devices.
- Guide design for older adults
  - Auditory in-vehicle driver aids

Thanks for your time and attention!

Questions?

Wish to acknowledge:

NIH: National Institute on Aging, (Grant # 1R03 AG023881-01), & NASA Langley, ONR, AFOSR

And

the many students whose assistance in these investigations was essential

Auditory Research Group