

The background of the slide is a light gray gradient, decorated with numerous realistic water droplets of various sizes. The droplets are rendered with soft shadows and highlights, giving them a three-dimensional appearance. They are scattered across the slide, with a higher concentration in the top-left and bottom-right corners.

TEMPORARY THRESHOLD SHIFT (TTS): CAUSES, EFFECTS AND ITS ROLE IN ACOUSTIC IMPACT ASSESSMENTS

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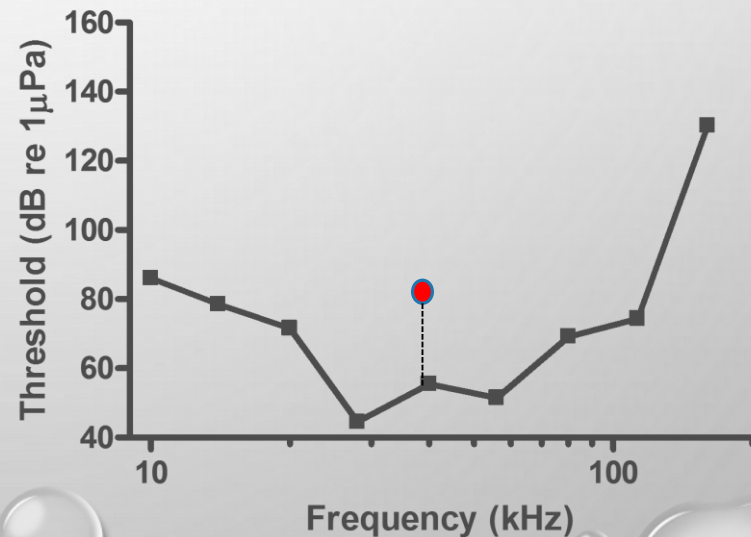
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WHAT IS TTS?

- TTS STANDS FOR “TEMPORARY THRESHOLD SHIFT”
 - A HEARING THRESHOLD IS THE LOWEST LEVEL OF SOUND THAT CAN BE DETECTED AT A GIVEN FREQUENCY
 - A THRESHOLD SHIFT IS AN ELEVATION IN HEARING THRESHOLD
 - A TTS IS RECOVERABLE OVER TIME (I.E. TEMPORARY)

- IF A THRESHOLD SHIFT NEVER RECOVERS, IT IS A “PERMANENT THRESHOLD SHIFT,” OR PTS

- WE ARE INTERESTED IN TTS AS A FUNCTION OF SOUND EXPOSURE



TTS IS AFFECTED BY THE DURATION OF A SOUND

- FOR A GIVEN LEVEL OF SOUND (SOUND PRESSURE LEVEL=SPL), LONGER DURATIONS CAUSE GREATER TTS
 - AS DURATION INCREASES, THE ENERGY OF THE SOUND INCREASES
 - SOUND EXPOSURE LEVEL (SEL)

TTS IS AFFECTED BY THE DURATION OF A SOUND

From Hirsh et al. (1955)

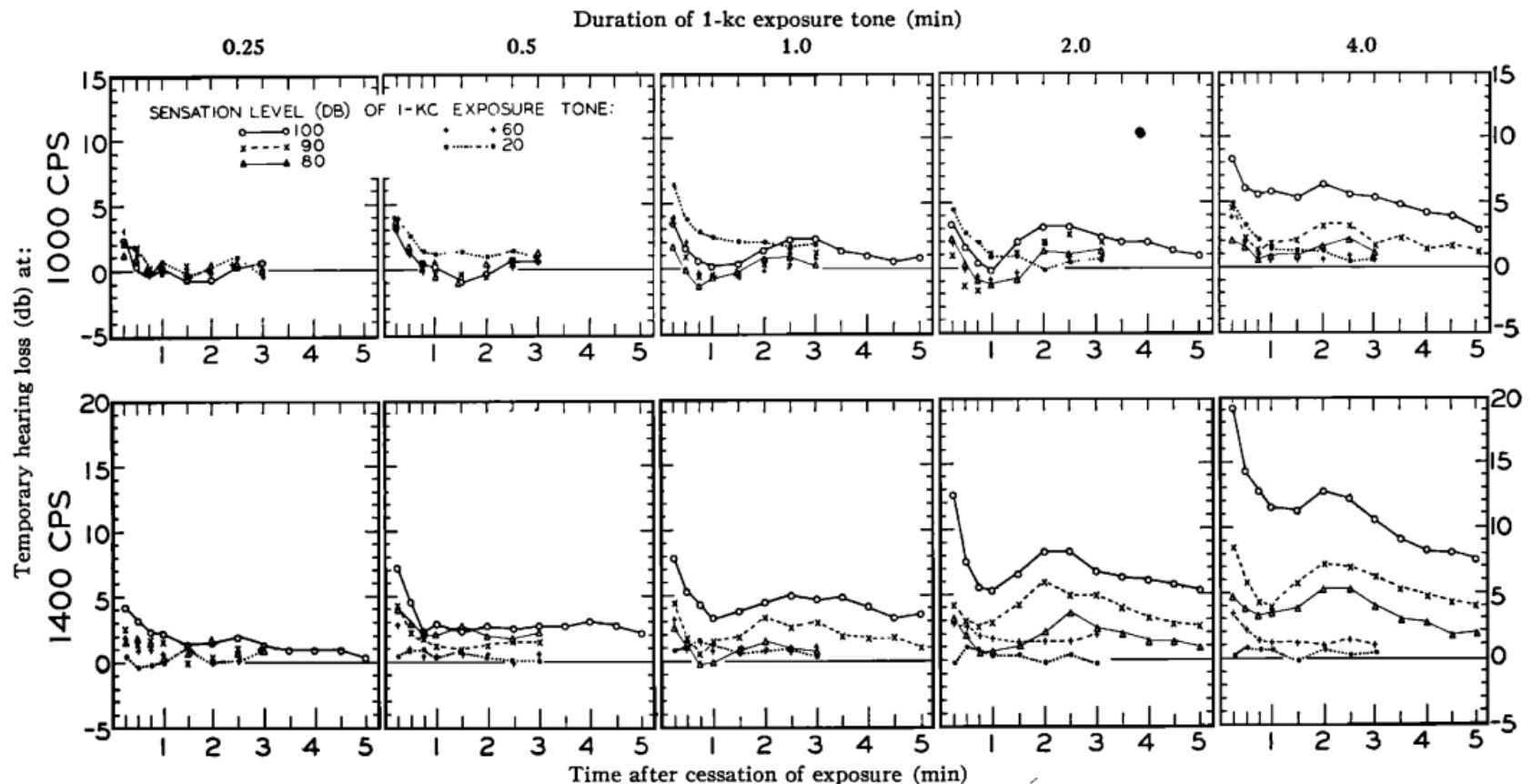


FIG. 3. Recovery curves (THL as a function of time after exposure) for 1000 (top) and 1400 (bottom) cps following exposures at 1000 cps. The five columns of curves represent five exposure durations. Within each family of curves, the parameter is the SL of the exposure.

TTS IS AFFECTED BY THE DURATION OF A SOUND

- FOR A GIVEN LEVEL OF SOUND (SOUND PRESSURE LEVEL=SPL), LONGER DURATIONS CAUSE GREATER TTS
 - AS DURATION INCREASES, THE ENERGY OF THE SOUND INCREASES
 - SOUND EXPOSURE LEVEL (SEL)
- BREAKS IN THE TRANSMISSION OF SOUND CAUSE LESS TTS
 - THE EAR RECOVERS FROM FATIGUE DURING QUIET PERIODS

TTS AFFECTED BY SOUND AMPLITUDE

- FOR A CONSTANT DURATION SOUND, THE HIGHER THE SOUND PRESSURE LEVEL, THE GREATER THE POTENTIAL FOR TTS
- BOTH AMPLITUDE AND DURATION CONTRIBUTE TO THE SEL

TTS AFFECTED BY SOUND AMPLITUDE

From Hirsh et al. (1955)

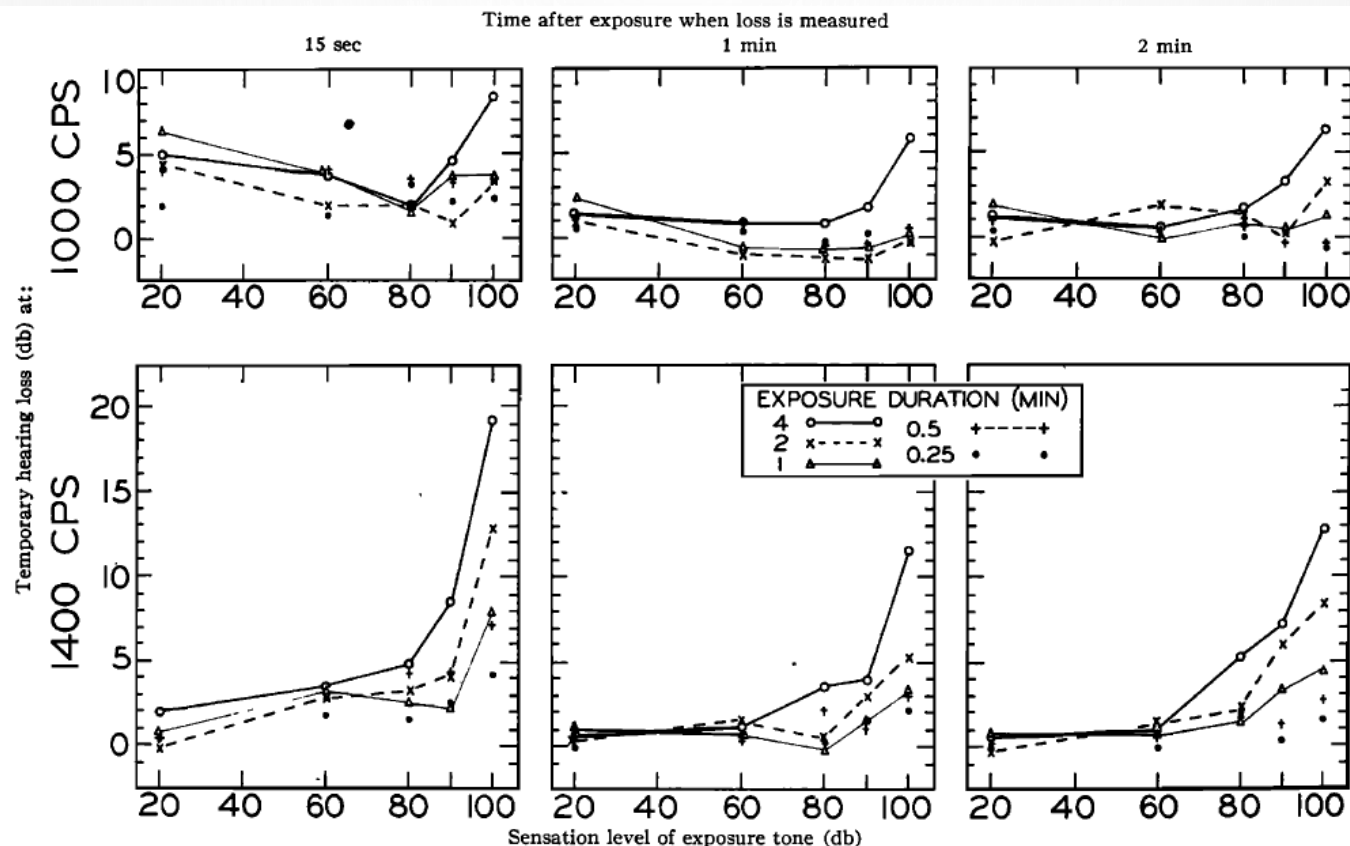
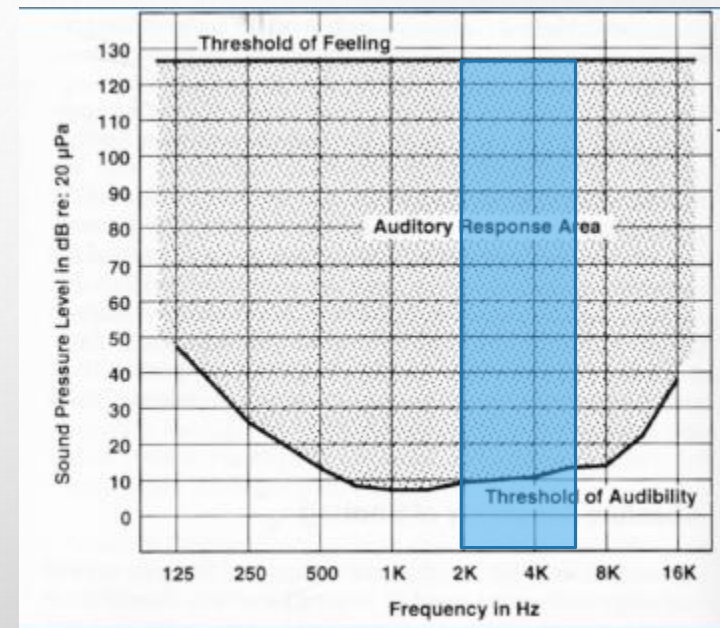


FIG. 4. Dependence of temporary hearing loss (measured 15 sec, 1 min, and 2 min after a 1-kc exposure) on the SL of exposure. The more regular dependence is seen for 1400 (bottom) than for 1000 (top) cps. In all cases the relation between THL and exposure level becomes greater as the duration (parameter) is increased. Only the THL measured 15 sec after exposure shows the greater value after 20 than after 60, 80, or 90 db exposures, and even then only clearly for durations greater than 30 sec.

TTS IS AFFECTED BY SOUND FREQUENCY

- NOT ALL FREQUENCIES AT WHICH WE HEAR HAVE THE SAME POTENTIAL FOR TTS
- IN HUMANS, THE GREATEST POTENTIAL FOR TTS APPEARS TO BE BETWEEN 2–6 KHZ
- THIS IS CLOSE TO THE REGION OF BEST SENSITIVITY OF HEARING IN HUMANS

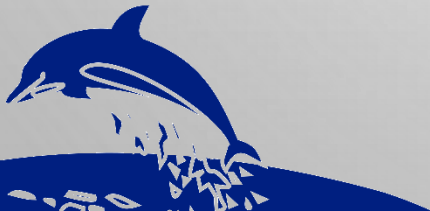


THE ROLE OF TTS IN ASSESSING ACOUSTIC IMPACTS TO MARINE MAMMALS

- NMFS REGULATES MARINE MAMMALS UNDER THE MMPA
- MMPA HARASSMENT CATEGORIES
 - LEVEL A – HAS THE POTENTIAL TO INJURE A MARINE MAMMAL OR MARINE MAMMAL STOCK IN THE WILD
 - LEVEL B – HAS THE POTENTIAL TO DISTURB A MARINE MAMMAL OR MARINE MAMMAL STOCK IN THE WILD BY CAUSING DISRUPTION OF BEHAVIORAL PATTERNS, INCLUDING, BUT NOT LIMITED TO, MIGRATION, BREATHING, NURSING, BREEDING, FEEDING, OR SHELTERING.
 - (NOTE – NOT FOR MILITARY READINESS ACTIVITIES)

TTS IS CURRENTLY CONSIDERED LEVEL B HARASSMENT

- SINCE TTS IS A REDUCTION IN HEARING SENSITIVITY, IT “POTENTIALLY” AFFECTS AN ANIMAL’S ABILITY TO HEAR BIOLOGICALLY RELEVANT SIGNALS; I.E. IT HAS THE POTENTIAL TO DISRUPT NORMAL BEHAVIOR
- WHETHER TTS OCCURS WITHOUT INJURY HAS RECENTLY COME INTO DEBATE

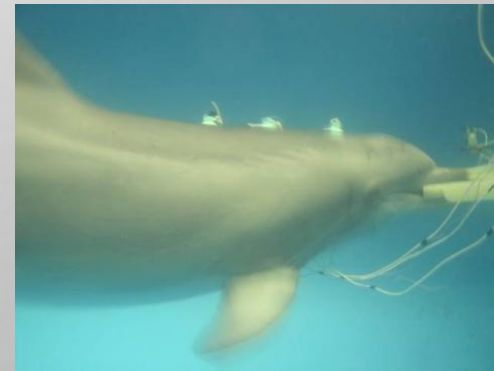


REGULATORY CONCERNS

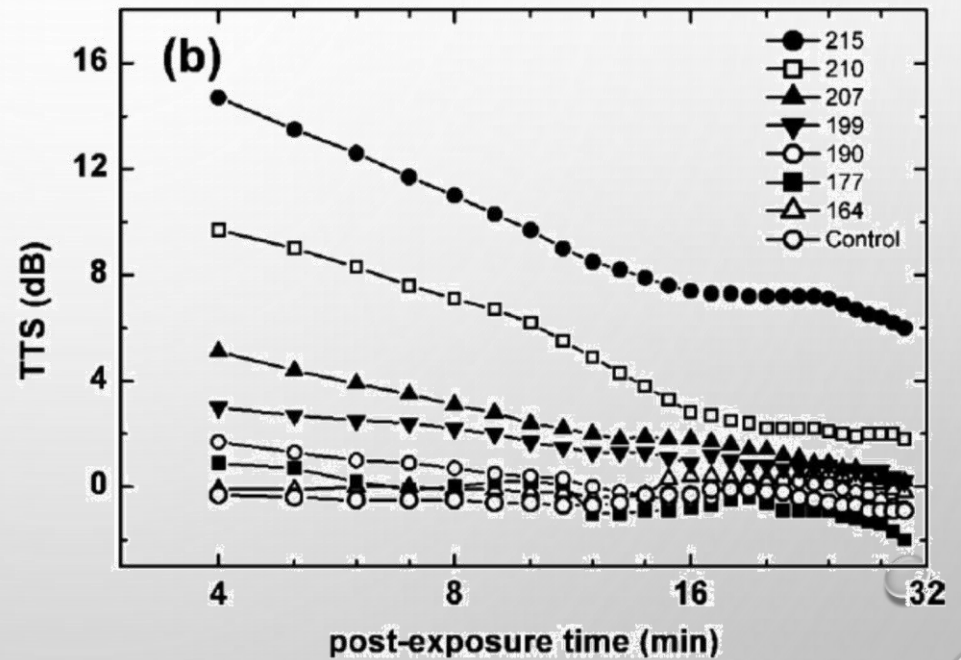
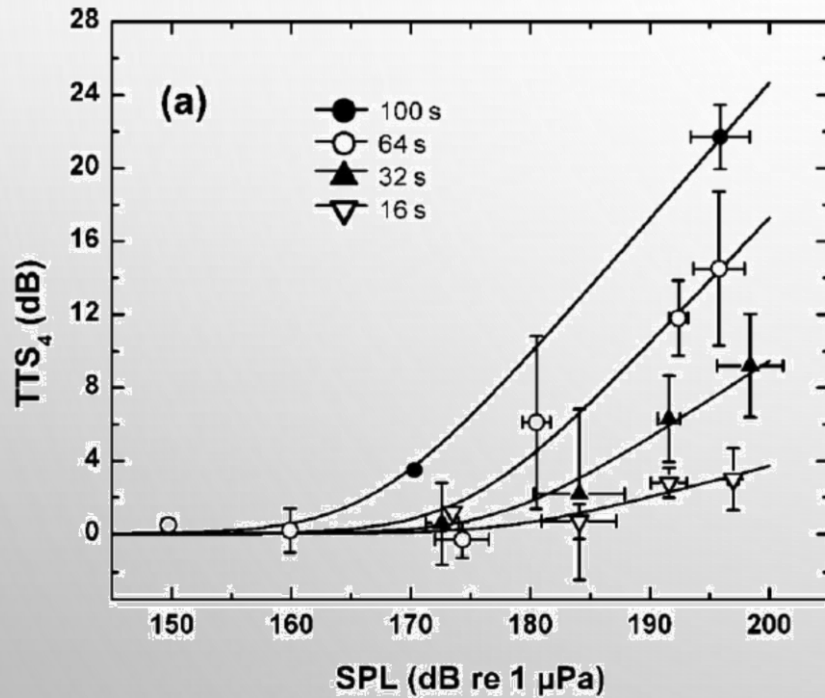
- THE EAR DOES NOT RESPOND THE SAME TO ALL TYPES OF SOUND
- IMPULSIVE SOUND
 - FOR EXAMPLE, EXPLOSIONS, ECHOLOCATION CLICKS, SNAPPING SHRIMP
- NON-IMPULSIVE SOUND
 - FOR EXAMPLE, SONAR SIGNALS, WHALE CALLS, BOAT ENGINE NOISE
- REGULATORS HAVE TO ADDRESS HOW ANTHROPOGENIC TYPES OF THESE SOUNDS MIGHT IMPACT MARINE MAMMALS

TTS STUDIES IN MARINE MAMMALS

- SPECIES INVESTIGATED INCLUDE BOTTLENOSE DOLPHIN, BELUGAS, YANGTZE FINLESS PORPOISE, HARBOR PORPOISE, HARBOR SEAL, SEA LION, AND ELEPHANT SEAL
- EXPOSURE SOUNDS INCLUDE INTENSE TONES, BAND-LIMITED NOISE, AND UNDERWATER IMPULSES
- VARIOUS SOUND PRESSURE LEVELS, FREQUENCIES, DURATIONS, AND TEMPORAL PATTERNS
- CONDUCTED BY SIX LABORATORIES ACROSS EUROPE, RUSSIA AND THE U.S.
- REVIEW BY FINNERAN (2015) – “NOISE-INDUCED HEARING LOSS IN MARINE MAMMALS: A REVIEW OF TEMPORARY THRESHOLD SHIFT STUDIES FROM 1996 TO 2015,” JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA



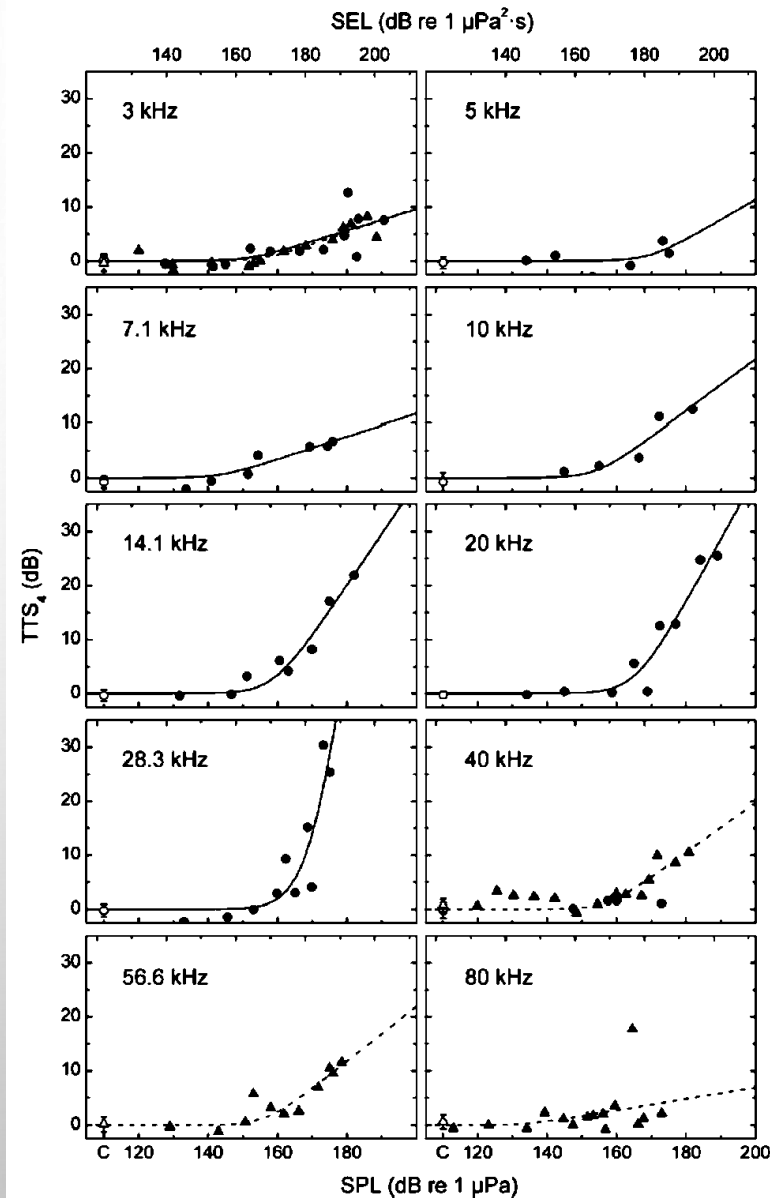
TTS AFFECTED BY SOUND AMPLITUDE AND DURATION



From Finneran 2015

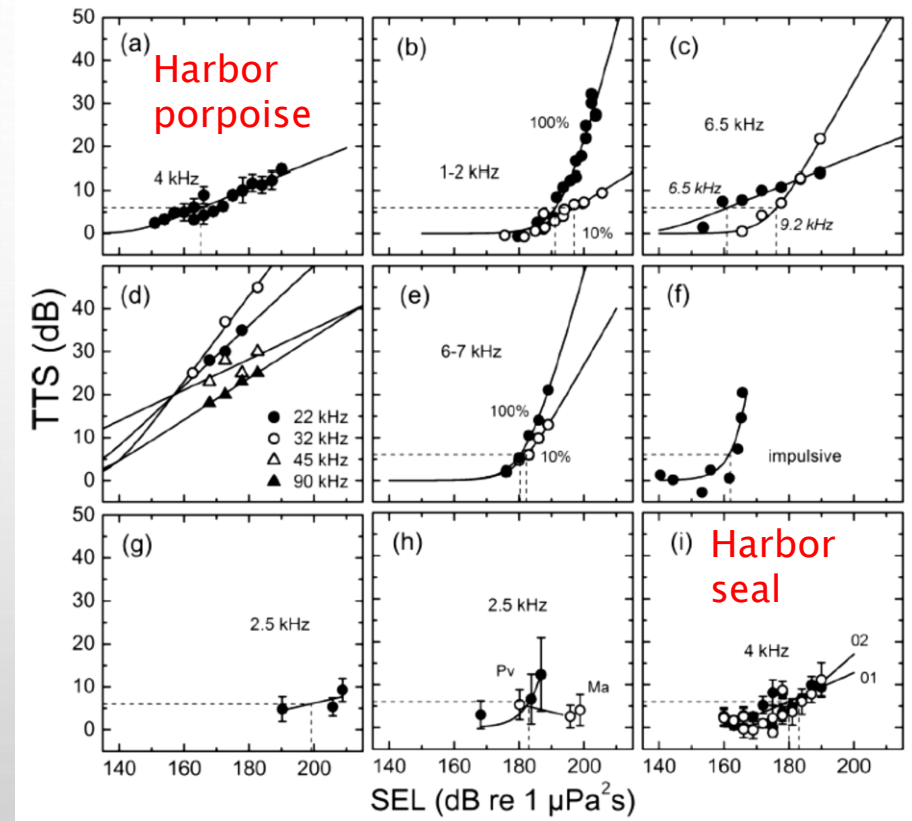
TTS IS AFFECTED BY SOUND FREQUENCY

- LIKE HUMANS, NOT ALL FREQUENCIES AT WHICH MARINE MAMMALS HEAR HAVE THE SAME POTENTIAL FOR TTS
- UNLIKE HUMANS, THE GREATEST POTENTIAL DOES NOT NECESSARILY CORRESPOND TO THE REGION OF BEST HEARING SENSITIVITY
- RELATIVELY RECENT FINDINGS NOT REPLICATED IN MOST SPECIES



SPECIES' DIFFERENCES IN SUSCEPTIBILITY

- TESTING MULTIPLE SPECIES IS IMPORTANT
- NOT ALL SPECIES OF MARINE MAMMAL SHARE THE SAME SUSCEPTIBILITY



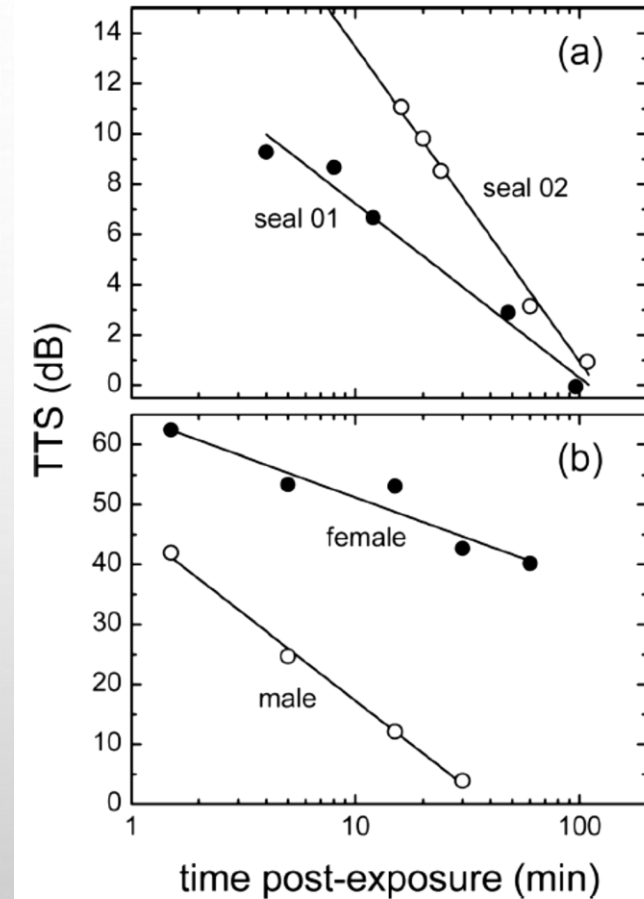
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SPECIES' DIFFERENCES IN SUSCEPTIBILITY

Functional Hearing Group or Species	PTS Threshold (all weighted SEL)	TTS Threshold (all weighted SEL)
LF Cetaceans	(Type II) SEL: 198 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$	(Type II) SEL: 178 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$
MF Cetaceans (<i>except beaked whales</i>)	(Type II) SEL: 198 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$	(Type II) SEL: 178 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$
Beaked whales	(Type II) SEL: 198 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$	(Type II) SEL: 178 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$
HF Cetaceans (<i>except harbor porpoises</i>)	(Type II) SEL: 172 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$	(Type II) SEL: 152 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$
Harbor porpoises	(Type II) SEL: 172 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$	(Type II) SEL: 152 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$
Phocids Sirenians (in water)	(Type I) SEL: 197 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$	(Type I) SEL: 183 dB re 1 $\mu\text{Pa}^2\cdot\text{s}$

WARNINGS

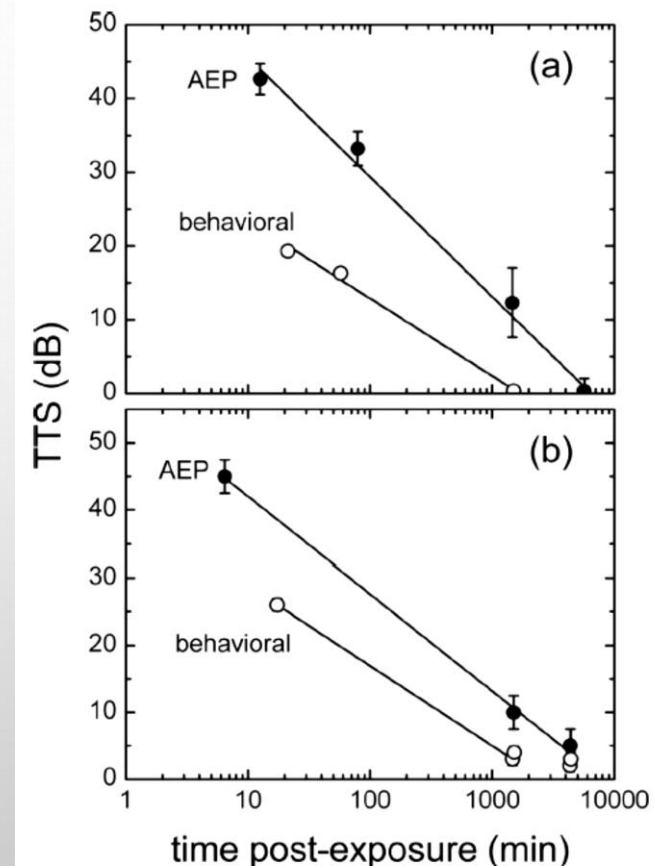
- INDIVIDUAL VARIABILITY CAN BE HIGH
- IN HUMANS (AND LAB ANIMALS), THIS IS ALSO A PROBLEM
- DAMAGE RISK CRITERIA FOR HUMANS ARE BASED ON THOUSANDS OF MEASUREMENTS



From Finneran 2015

A WARNING – NOT ALL TTS IS THE SAME

- HEARING IS NOW COMMONLY MEASURED WITH AEP METHODS
 - ELECTROPHYSIOLOGICAL MEASURE OF BRAIN ACTIVITY
- BEHAVIORAL AND AEP THRESHOLD MEASUREMENTS ARE NOT EQUIVALENT
- THEY DIFFER IN
 - CALIBRATION
 - TEST STIMULUS
 - WHAT THEY ARE MEASURING



“IS TTS INJURY?”

- THE IMPACT OF TTS WORK IN LABORATORY ANIMALS (KUJAWA AND LIBERMAN 2009)
 - 40 DECIBELS OF TTS 24 HOURS AFTER NOISE EXPOSURE CEASED
 - AUDITORY NERVE DEGENERATION / WITHOUT HAIR CELL LOSS
- HAIR CELL LOSS DOES NOT NECESSARILY REFLECT “NO DAMAGE”
- GANGLION CELL DEGENERATION CAN OCCUR IN THE ABSENCE OF HAIR CELL LOSS
 - THIS MAY OCCUR WEEKS TO MONTHS AFTER A PRONOUNCED TTS
- IS THIS A CONCERN FOR MARINE MAMMALS
 - DOES THIS HAPPEN AT MODEST TTS
 - DO MARINE MAMMALS RECEIVE TTS OF THIS MAGNITUDE IN THE REAL WORLD