Assessment and mitigation of the effects of noise on habitability in deep space environments: report on non-auditory effects of noise

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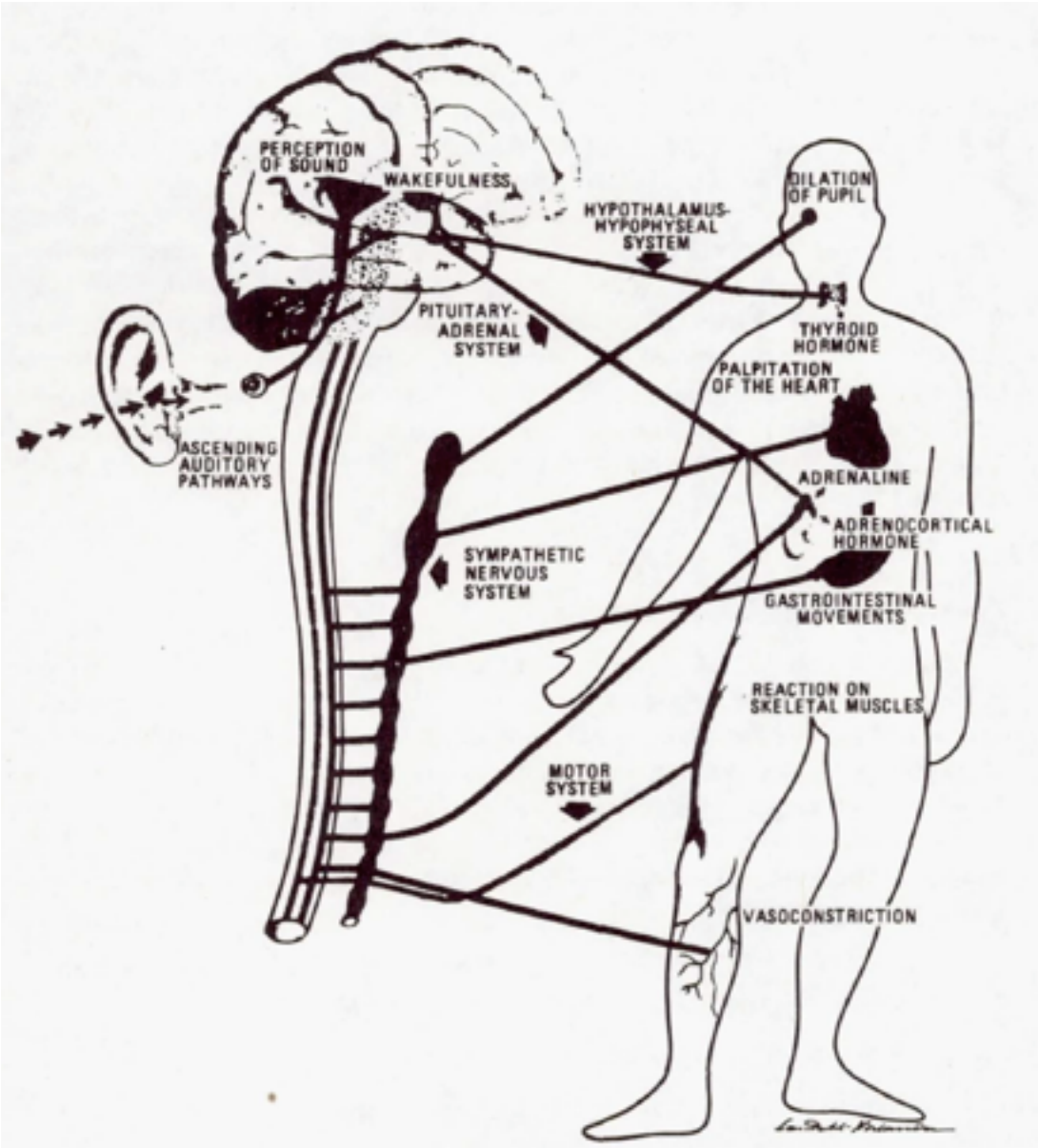
GAPS ADDRESSED

Gap HAB-01*, Risk of Incompatible Vehicle/Habitat Design*:
"We need to understand how new aspects of the natural and induced environment (vehicle/habitat architecture, acoustics, vibration, lighting) may impact performance, and need to be accommodated in internal vehicle/habitat design."

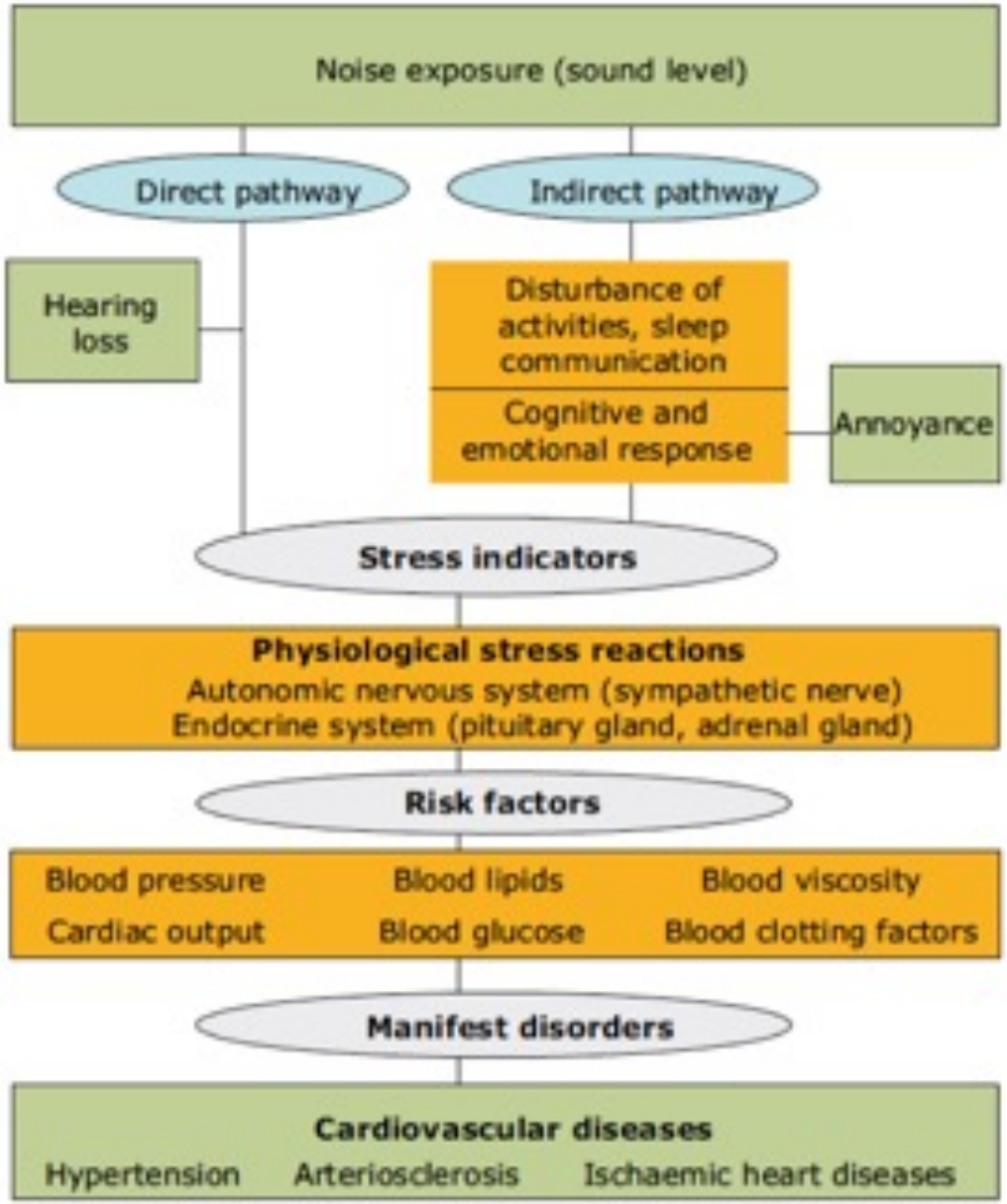
Gap BMed7, *Risk of Adverse Cognitive or Behavioral Conditions and Psychiatric Disorders*:
"We need to identify and validate effective methods for modifying the habitat/ vehicle environment to mitigate the negative psychological and behavioral effects of environmental stressors (e.g., isolation, confinement, reduced sensory stimulation) likely to be experienced in the long duration spaceflight environment."

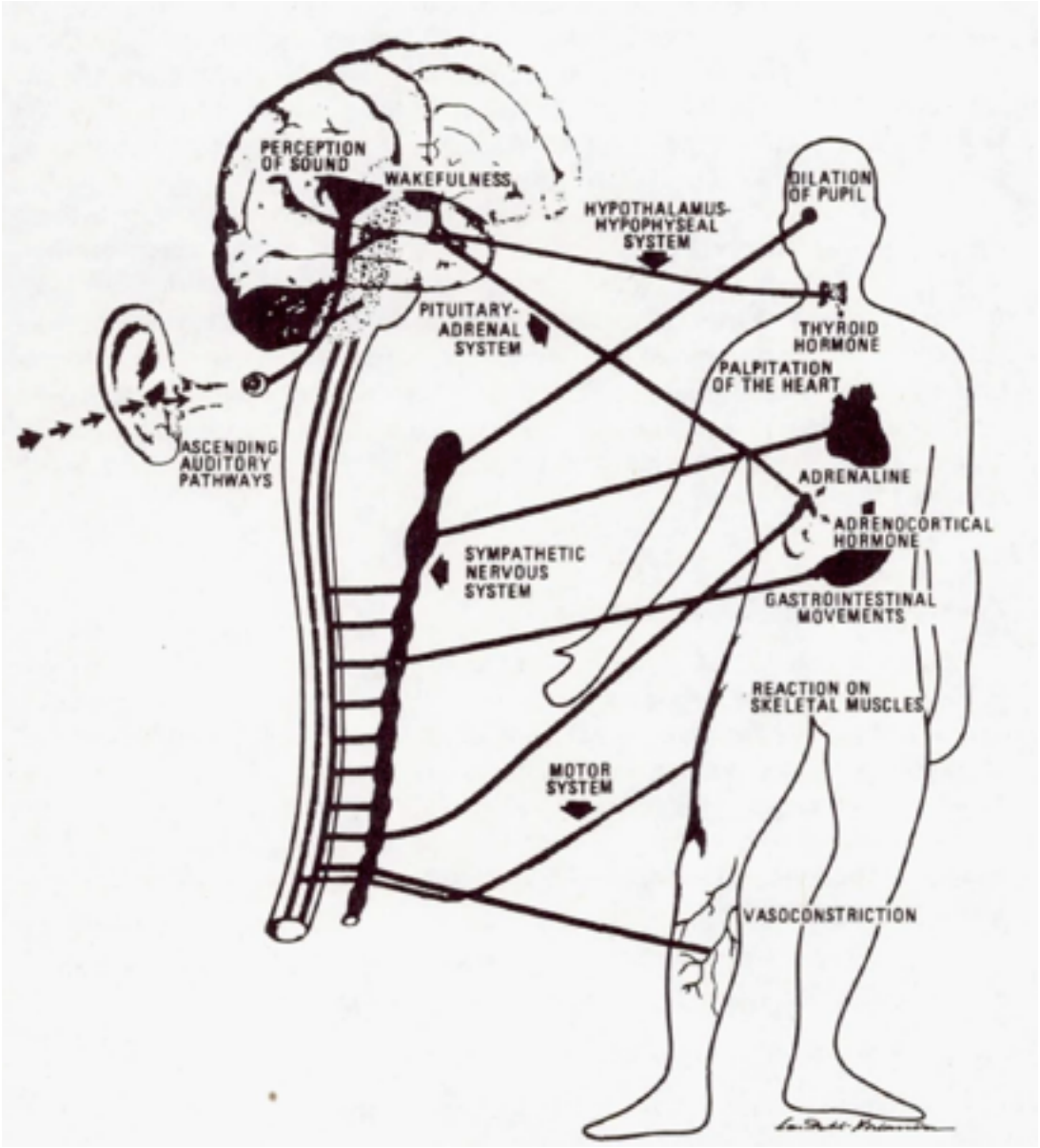
OUTLINE OF RESEARCH ON NON-AUDITORY EFFECTS OF NOISE

- ACOUSTIC MEASUREMENT TECHNIQUES
- TEAM & INDIVIDUAL PERFORMANCE
- SLEEP QUALITY
- PSYCHOLOGICAL WELL-BEING



NON-AUDITORY EFFECTS OF NOISE: PATHWAYS





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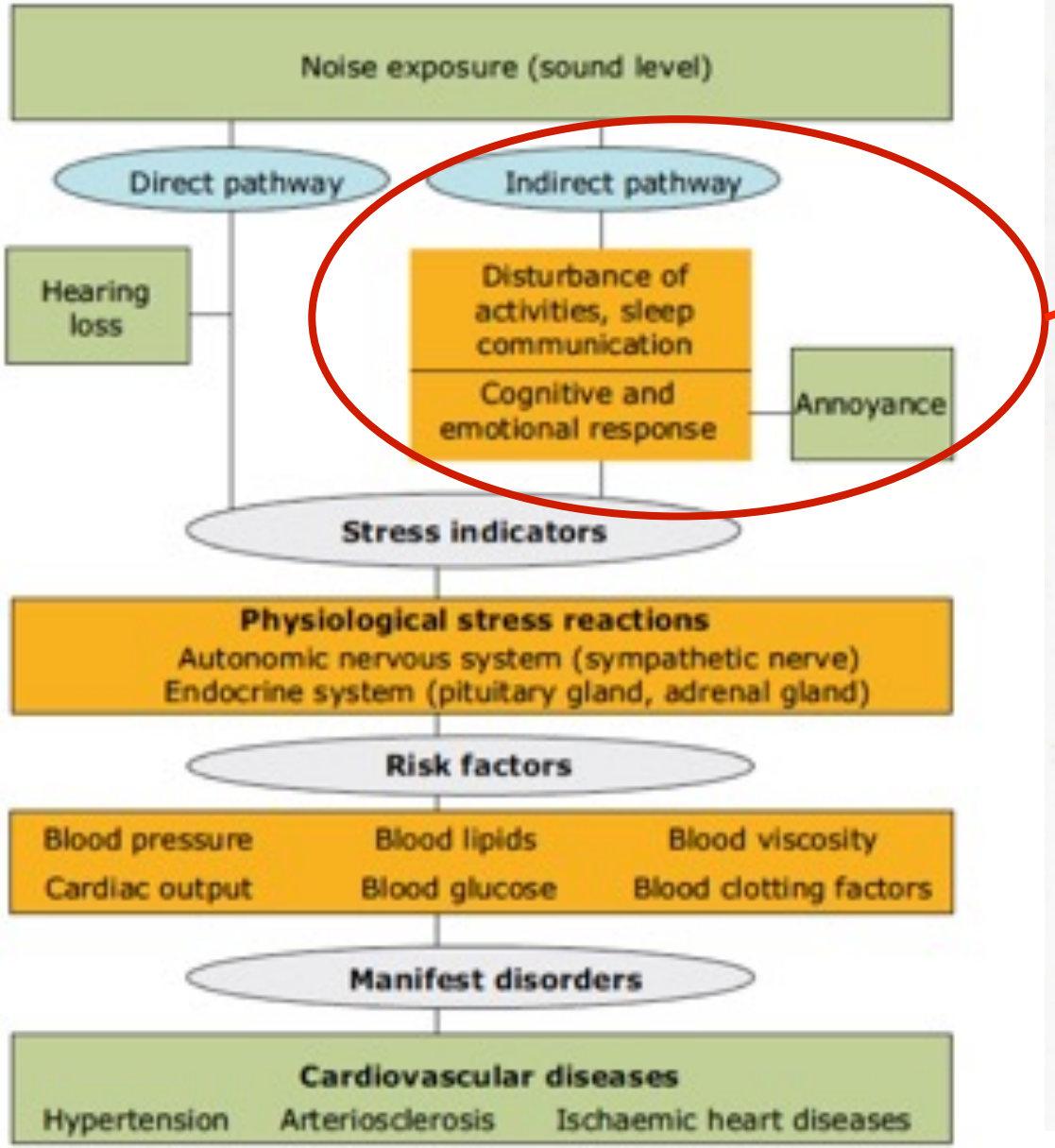

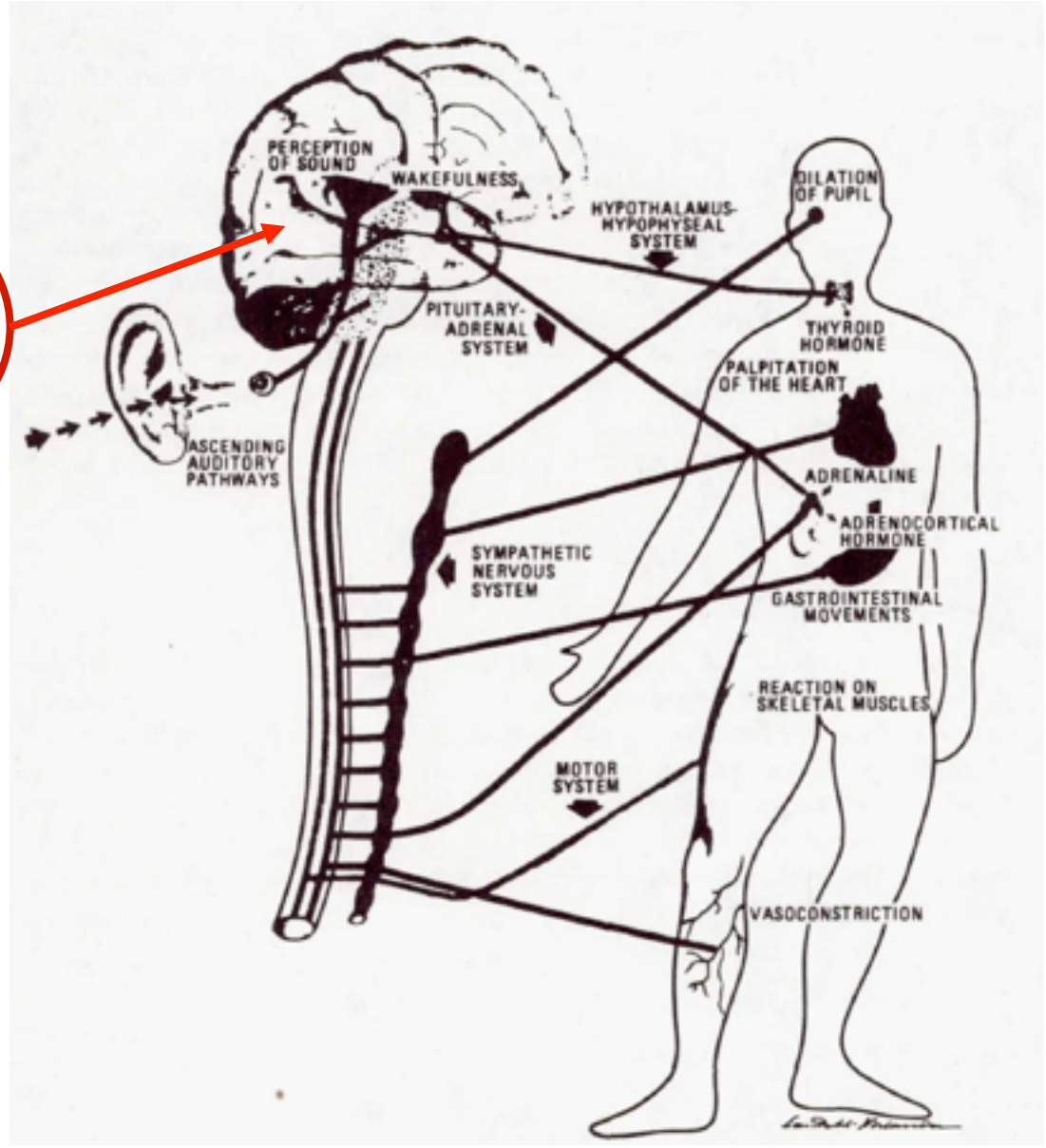

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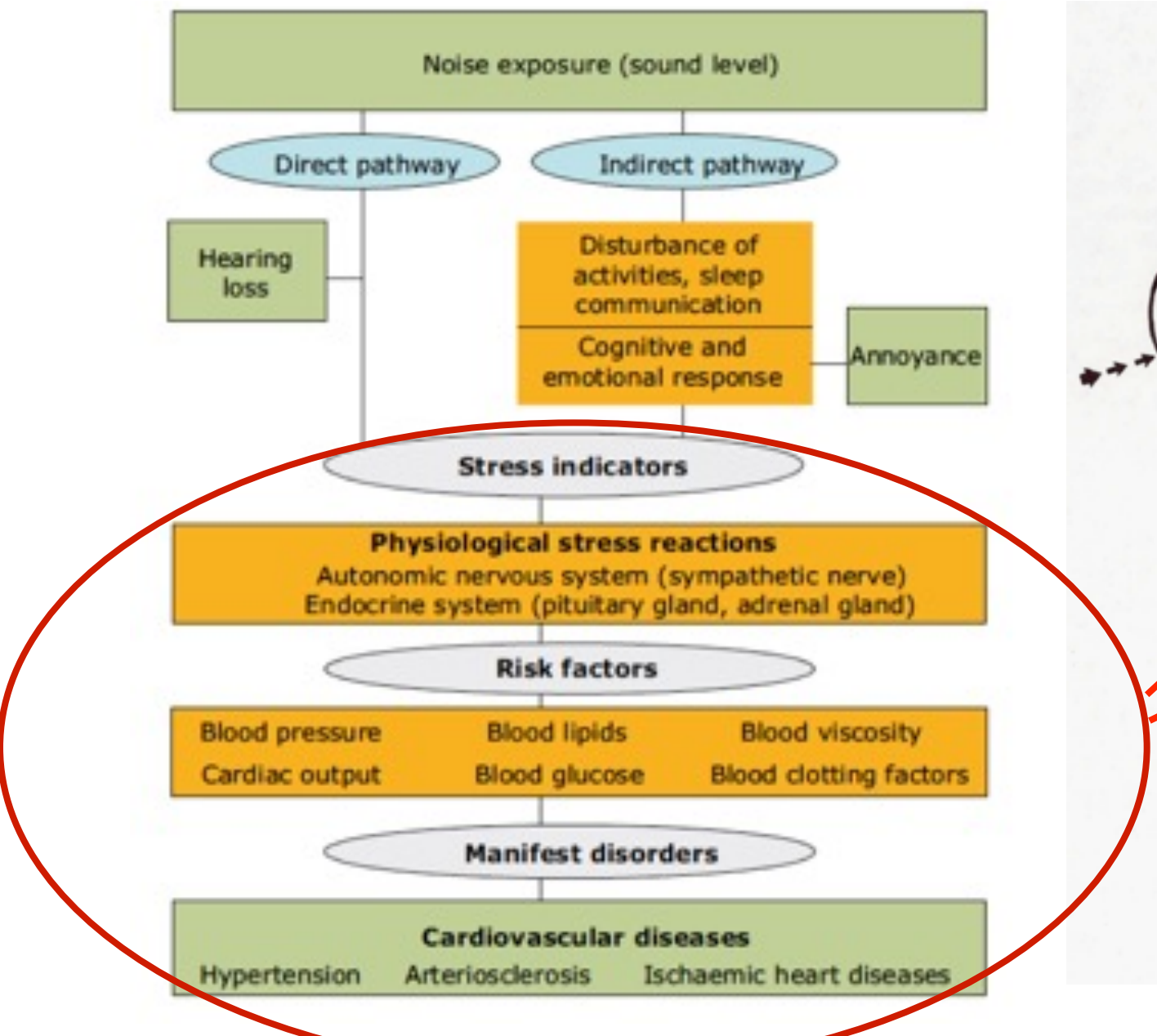
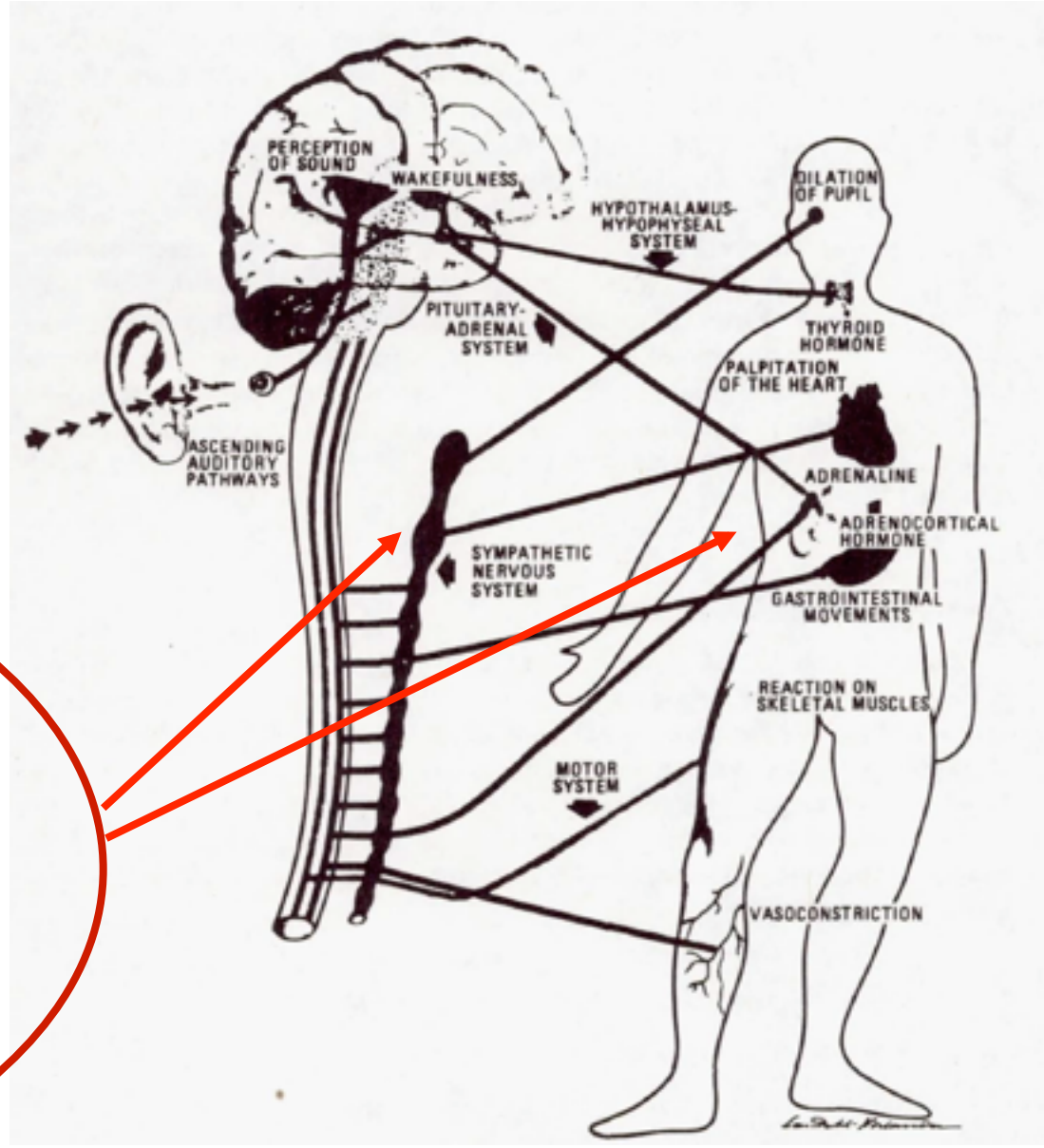




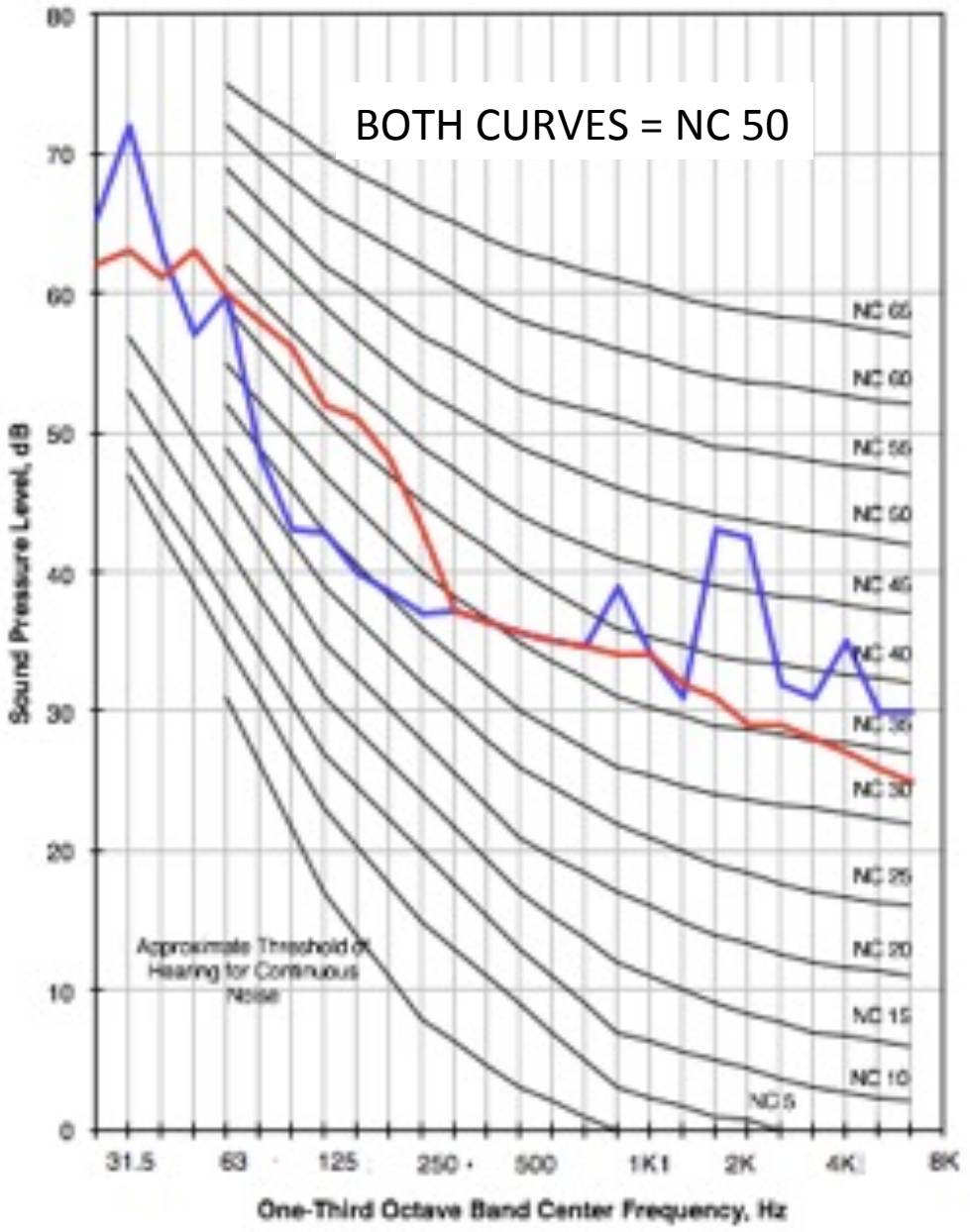
ACOUSTIC MEASURMENTS

RECOMMENDATION	ACTIONS
To best assess subjective response, noise should be measured and specified using best available psychoacoustic-based measures.	Implement noise measurement methods that take into account loudness and masking level differences. Adapt future NASA standards to use Room Criteria (RC) metric in place of Noise Criteria metrics. Conduct research to define what aspects of intermittent noise are impactful.

”IF YOU CAN’T MEASURE IT, YOU CAN’T MITIGATE IT”

RECOMMENDED IMPROVEMENTS IN ACOUSTIC MEASUREMENTS USED BY NASA TO ADDRESS NON-AUDITORY EFFECTS OF NOISE

- **Implement standards that better address loudness**
- **Implement standards that better address tonal noise**
- **Implement standards that better address low frequencies**
- **Implement standards that better address intermittent noise**

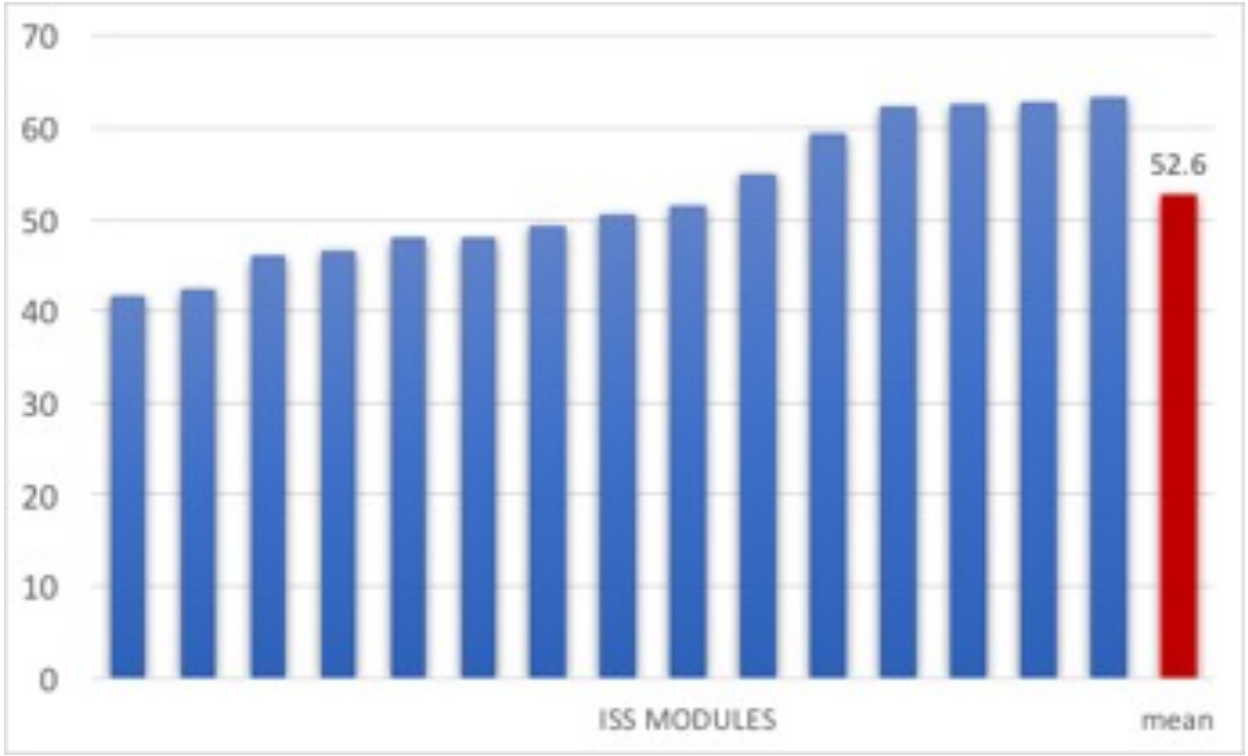


INDIVIDUAL AND TEAM PERFORMANCE

RECOMMENDATION	ACTIONS
To facilitate individual and team performance, background noise levels in habitat workspaces should reflect a balance between maintaining speech privacy (reduction of irrelevant speech and noise to minimize distraction) and enhancement of team communications.	To the degree practicable, implement design criteria in future NASA standards to meet NC-40 (~45 dB L_{eq}), in line with recommendations for open plan offices.

NASA STD-3001 standard for background noise is NC-50

- Equivalent to threshold for normal speech levels for face-face communication.
- Only marginally acceptable for the acoustical design of a factory.
- Exceeds recommended NC 40-45 level for restaurants or a open office and NC 30-35 for a private office

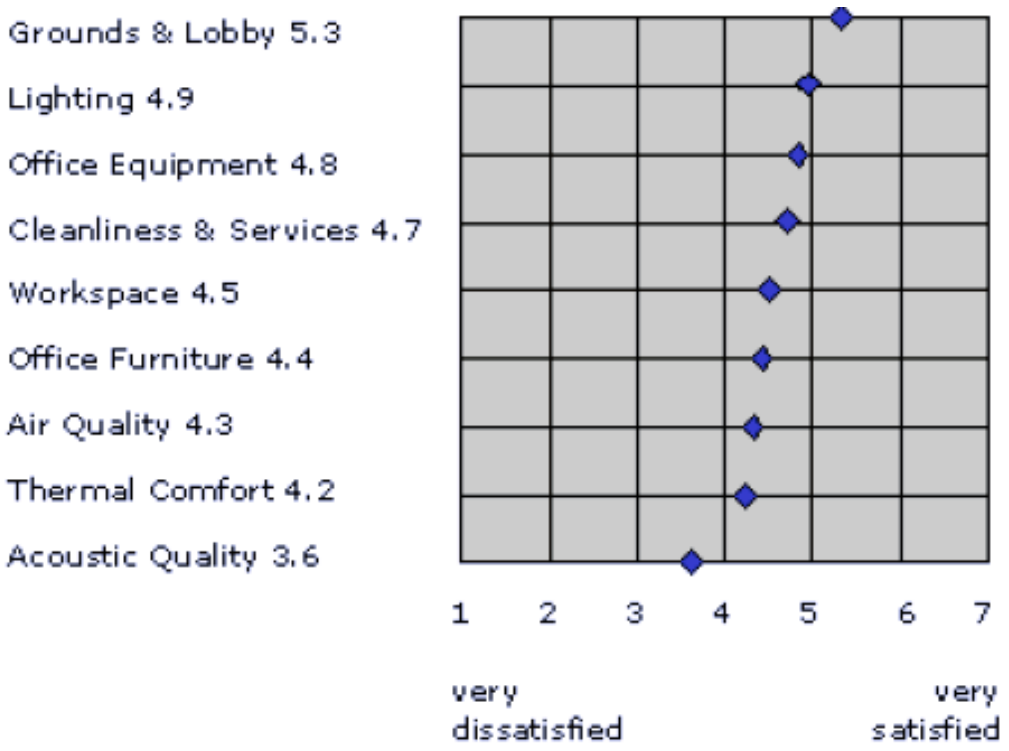


NC measurements in various ISS modules.
Mean = NC 53; range ~NC 42-63

Noise affects individual and team work communications in workplaces

- GSA open plan office research; Speech privacy rated as most important factor for perceived efficiency

- Optimal goal: balance between maintaining speech privacy (reduction of irrelevant speech and noise to minimize distraction) and enhancement of team communications.



Research findings for individual performance re Noise: detrimental effects

- Habituation is possible, but unexpected or intermittent noise can degrade performance
- Speech noise degrades processing capability for reading and for the performance of work, particularly for complex tasks
- The masking of “internal dialogue” can hamper performance where short-term memory is required.
- Noise that causes a startle reflex can delay action-response by as much as 30 s in aeronautical context
- Noise masking of speech communications or acoustic cues from effectors such as switches or controls can have significant effects on performance. Timely reaction to alarms or communication signals can be impacted by the masking effect of noise.
- Tasks requiring vigilance, such as detection of a sequence of numbers, can be detrimentally affected. Focused attention tasks are affected more than search tasks
- Noise increases workload due to the increased need for focused attention and can alter task completion strategies.

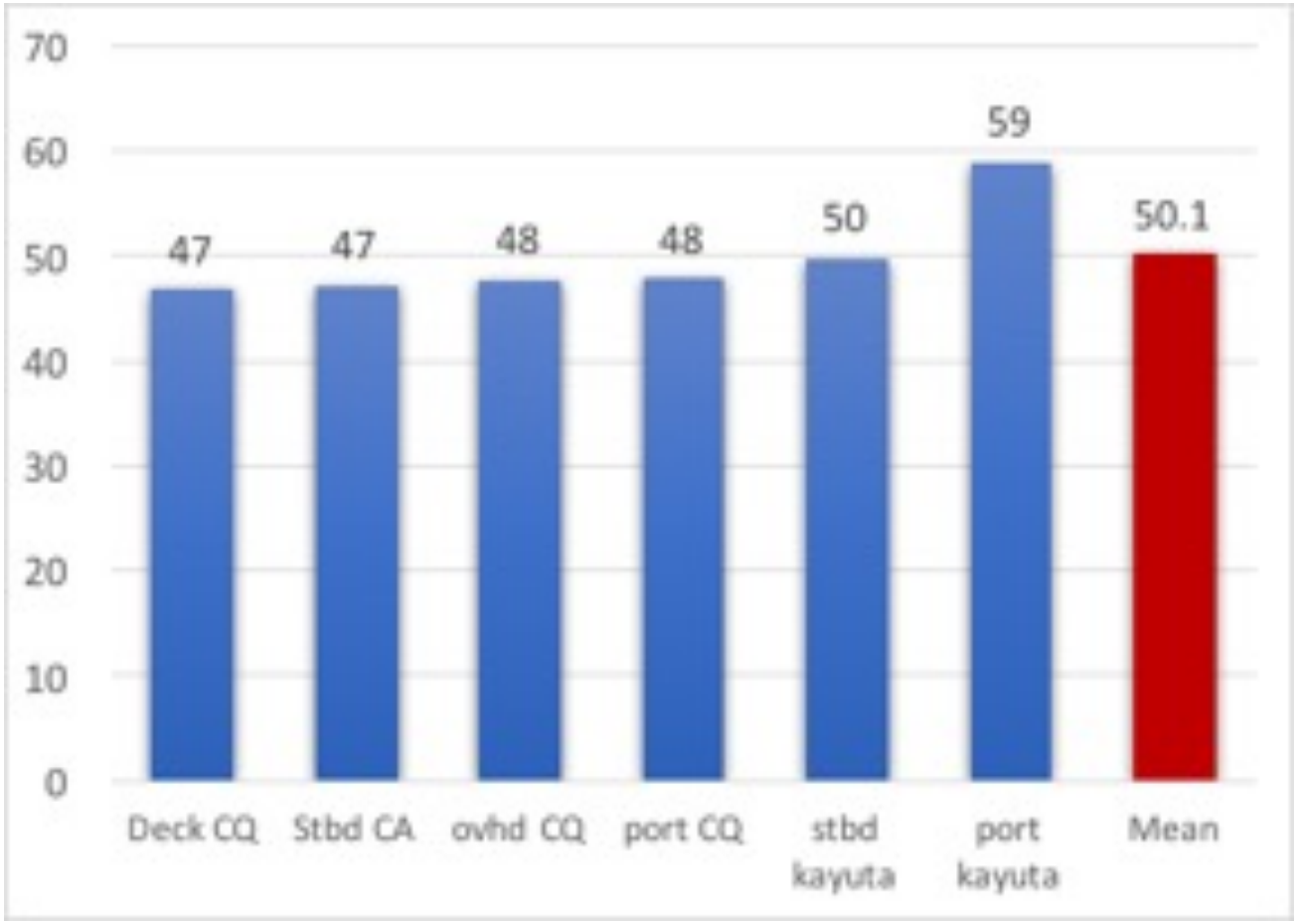
Research findings for individual performance re Noise: benign effects

- Undemanding tasks under conditions of expected and familiar noise are unaffected.
- Reaction times and accuracy for easily visible stimuli are unaffected.
- Visual tasks depending on acuity, distance judgments, eye movement and focus are unaffected.
- Haptic performance is unaffected (Harris, 1973).
- An arousal effect of intermittent or continuous noise can improve performance or vigilance.

SLEEP QUALITY

RECOMMENDATION	ACTIONS
To facilitate sleep quality, background noise levels should be minimized to levels in line with existing research recommendations. Familiar sounds from common areas such as speech or equipment and intermittent sounds should be minimized. Background noise levels should correspond to earth-based research recommendations. Entrainment can be effected through sensory augmentation.	To the degree practicable, implement design criteria in future NASA standards to meet NC-30 (~35 dB L_{eq}), in line with research recommendations for sleep quality. To the degree practicable, separate sleep quarters to be non-adjacent to common areas and from intermittent sounds. Provide means for sound isolation (HPDs, headphones). Utilize acoustic cues for their potential in sleep cycle entrainment.

Sleep areas of ISS average NC-50;
Recommended level NC-30



Research findings for sleep quality re Noise:

- Noise levels should be ~ NC 30 or less in sleeping quarters
- Humans evaluate and react to sound during sleep: as a result,
    - Speech noise or noise with meaning to the listener can disrupt sleep at levels lower than random noise
    - Isolation of sleep quarters from common area noise is recommended
- Intermittent noise affects sleep more than continuous noise. Masking sound (or loud constant HVAC noise) can aid in reducing arousals from intermittent noise
- Evidence has been found for a non-photic effect of meaningful noise that can affect circadian rhythm.

SLEEP QUALITY: additional factor

RECOMMENDATION	ACTIONS
Arousal from sleep using only acoustic alarms is unreliable due to individual differences and depth of sleep, and the use of HPDs.	For sleep quarters, future NASA standards should include multi-sensory alerting methods.

PSYCHOLOGICAL WELL-BEING

Psychological well-being is impacted by confined space, lack of privacy, and monotonous acoustic conditions, for which the crew member has no control.	Provide virtual acoustic methods to allow crew members to control their acoustic environment. Acoustic sensory augmentation of instruments, tools and machinery allows “useful” sounds to mask the noise environment. Research should be conducted to determine useful approaches and designs, including adaptive noise cancellation. Headphone signal playback quality and comfort should be specified in future NASA standards.

Research findings for cognitive well-being re Noise:

- Classifying noise as ”unwanted” versus “acceptable” sound is subjective. Noise annoyance is a subjective quantity that correlates well with acoustic measures for most persons but not certain sensitive groups

- Some types of noise are preferable to silence (or an unchanging ambient sound); e.g., *sonification* or *social situational awareness*

- The ability (or even the *perceived* ability) to control aversive noise improves acceptance. After-effects of uncontrollable, intermittent noise can lead to “learned helplessness” which in some cases causes degraded performance

- Habituation (using voluntary coping mechanisms) may mitigate averse effects.

- The use of *restorative environments* (that offer control over noise) can facilitate coping with an adverse situation.

Technologies for augmenting personal control of habitat acoustics

- Headphones/personal entertainment systems
- Adaptive sound masking (based on masked thresholds)
- Reverberation modification
- Virtual acoustic cueing from instruments and machinery

  Examples:
  - *audio augmentation to Advanced Resistive Exercise Device (ARED)*
  - *Robotic arm feedback for proximity (parallel audio-haptic cues from tools)*