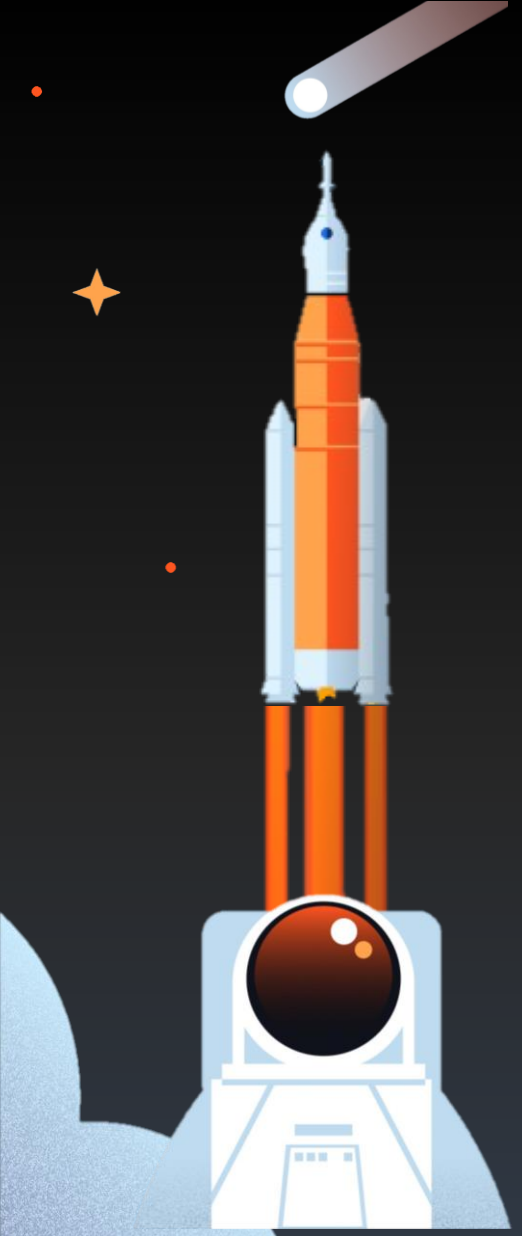

Long-Term Health Metric Development Effort

B. E. Lewandowski[1], C. A. Gallo[1], M. T. Prelich[1], M. E. Sickinger[1,2], H. Rehm[3], M. Matar[1], S. A. Gokoglu[1], A. A. Nelson[1], L. McIntyre[1], J. G. Myers[1], J. M. Charvat[4], J. A. Keune[5], M. VanBaalen[5]

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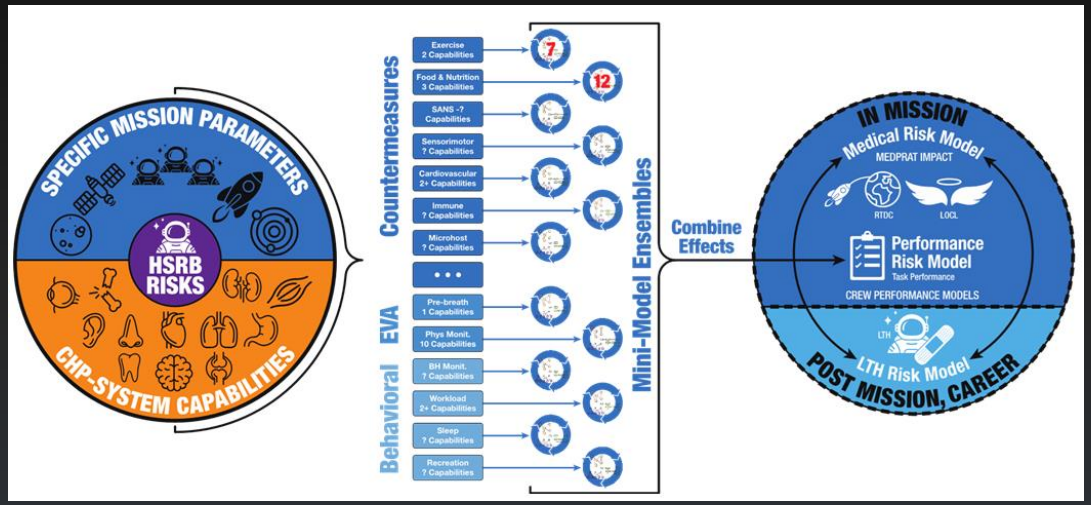
2024 Human Research Program
Investigators' Workshop

Agenda

- Motivation for the development of a Long-Term Health (LTH) risk metric
- LTH risk overview
  - Human System Risk Board (HSRB) risks with an LTH component
  - LTH risk outcomes
- LTH metric development efforts
  - LTH metric criteria
  - Metric for quantifying end of mission health status (cumulative task impairment estimates)
  - Metric for quantifying the time to return to preflight physiological baseline status
- Next steps

Motivation for LTH Metric Development

- The NASA Human Research Program (HRP) has initiated the development of Crew Health and Performance Probabilistic Risk Assessment (CHP-PRA) capabilities*
- CHP-PRA efforts will build upon medical system PRA experience, to enable trade study assessments across all Crew Health and Performance (CHP) system components
- LTH risk will be a model component so that LTH risk can be considered in addition to in-mission risk
- Trade studies will aid determination of in-mission resources that should be included to minimize LTH risk



J.G. Myers et al., CHP-PRA Proof-of-Concept Sensitivity Assessment, NASA HRP IWS, Galveston, TX, 2024.

LTH Risk Overview – Risks with an LTH Component

NASA's Human System Risk Board (HSRB) maintains LTH risks in addition to in-mission risks

Partial view of the HSRB risk chart from the HSRB Risk Tool Homepage: https://hhp.sp.jsc.nasa.gov/sadocs/hsrb/risktool/Pages/Home.aspx

18 HSRB risks contain an LTH component

HSRB Risks with an LTH Component	
Behavioral Medicine	Immune
Bone Fracture	Medical
Crew Egress	Microhost
Decompression Sickness	Non-ionizing Radiation
Dust	Radiation Carcinogenesis
Dynamic Loads	Renal Stone
Electric Shock	SANS
Food	Toxic Exposure
Hearing Loss	Urinary Retention

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LTH Risk Overview – Risk Outcomes

- Astronaut LTH risk covers a continuum, including:
  - Immediately post-flight
  - Through the rest of the astronaut's career
  - Through retirement
  - Until death
- LTH risk includes several types of outcomes:
  - Post-flight recovery
  - Complications affecting morbidity
  - Post-flight health conditions

Birth	Before selection/ Astronaut training	Mission(s)	Post-flight recovery	Post mission/ Retirement	Death
	Astronaut selection **Preflight training**	**Mission characteristics:** • Vehicle shielding • Mission length • Mission location • Number of EVAs performed **CHP System capabilities:** • In-flight monitoring • In-flight medical system • Physiological countermeasures	**Recovery from in-mission medical events** • Clinical phase 3 effects persisting into post-flight **Recovery from spaceflight induced physiological changes** • Amount of time required to return to baseline	**Changes in morbidity: Medical conditions that occur with a higher incidence rate or with more severity because of spaceflight experiences**	**Changes in life expectancy**

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LTH Risk Overview – Quantifying Risk Outcomes

- HSRB LTH risk consequences:
  - Impact on quality of life: An impact on day-to-day physical and mental functional capacity and/or lifetime loss of years
  - Amount of support needed for activities of daily living
  - Number, severity, and level of care required for career related medical conditions
  - Timeline for a return to baseline and the level of intervention needed to return to baseline

Consequence

Long Term Health (post mission) (LTH)

High	• Unknown and improbable return to baseline (requires drastic intervention surgery & therapy) • Major impact on quality of life (permanent reduced function, premature death)
Medium	• Return to near baseline requires extended medical intervention w/ known clinical methods/technologies (pharmaceuticals, etc.) • Moderate impact on quality of life
Low	• Return to baseline values within 1 year with nominal intervention (time, exercise, nutrition, lenses) • Negligible effect on quality of life
Very Low	• Return to baseline values within 3 months with limited intervention • No effect on the quality of life

Quality of Life is defined as impact on day to day physical and mental functional capability and/or lifetime loss of years

LIKELIHOOD RATING	In-Mission	Flight Recertification	Long Term Health
5 Very High	More likely to happen than not during the mission or probability (P) >10%	Very likely to happen. Controls are insufficient or P> 10%	Likelihood is very high OR >10% excess risk
4 High	Likelihood is during the mission or 1%<P≤10%	Likely to happen. Controls have significant limitations or uncertainties or 1%<P≤ 10%	Likelihood is high OR 6-10% excess risk
3 Moderate	May happen during the mission or 0.1%<P≤1%	Not likely to happen. Controls exist with some limitations or uncertainties or 0.1%<P≤1%	Likelihood is moderate OR 3-6% excess risk
2 Low	Unlikely to happen during the mission or .01%<P≤0.1%	Not expected to happen. Controls have minor limitations or uncertainties or 0.01%<P≤0.1%	Likelihood is low OR 1-3% excess risk
1 Very Low	Nearly certain to not occur in-mission or P≤0.01%	Extremely remote possibility that it will happen. Strong controls in place or P≤0.01%	Likelihood is very low OR < 1% excess risk

L x C Matrix

LIKELIHOOD \ CONSEQUENCE	1	2	3	4	5
5	5	10	16	20	23	25
4	4	7	13	18	22	24
3	3	4	9	15	19	21
2	2	2	6	11	14	17
1	1	1	3	5	8	12

Risk Score Card values are constant across all risks and prioritize consequence over likelihood.

Time frame

Expected Need for Mitigation

Near	0 < 2 Years
Mid	2-7 Years
Far	> 7 Years

CONSEQUENCES		1	2	3	4	5
IN MISSION	Crew Health Impact OR Mission Objectives Impact	Temporary discomfort / Insignificant impact to crew performance and operations – no additional resources required	Minor injury/illness that can be dealt with by crew without ground support, minor crew discomfort / Minor impact to crew performance and operations – requires additional resources (time, consumables)	Significant injury/illness or incapacitation that requires diagnosis and/or treatment support from ground, may affect personal safety / Significant reduction in crew performance, threatens loss of a mission objective	Critical injury/illness of one crew member requiring extended medical intervention and support, may result in temporary disability / Severe reduction of crew performance that results in loss of multiple mission objectives	Death or permanently disabling injury/illness affecting one or more crewmember (LOCI/LOC) / Loss of mission due to crew performance reductions or loss of crew
FLIGHT RECERT	Crew Flight Recertification Status	Immediate flight recertification status	Flight recertification status within 3 months with limited intervention	Flight recertification status within 1 year with nominal intervention or restricted flight status	Flight recertification status requires extended medical intervention and takes > 1 year	Unable to be Recertified for Flight Status, premature career end
LONG TERM HEALTH	Health Outcomes OR Quality of Life	Career related short term self-resolving medical conditions / No impact on quality of life OR independence in activities of daily living	Career related medical conditions manageable with outpatient medical treatments / Minor, short-term impact on quality of life OR rare support required for activities of daily living	Treatable career related medical condition that requires hospitalization for management / Moderate long-term impact on quality of life OR may require some time-limited support for activities of daily living	Chronic career related medical condition requiring intermittent hospitalization or nursing care / Major long-term impact on quality of life OR requires intermittent support for activities of daily living	Career related premature death or permanent disability requiring institutionalization / Chronic debilitating impact on quality of life OR requires continuous support for activities of daily living

LTH Metric Development Efforts - Morbidity and Mortality Risk

- Literature studies have found no appreciable increase in astronaut morbidity or mortality vs. the general population or appropriately matched comparison cohorts

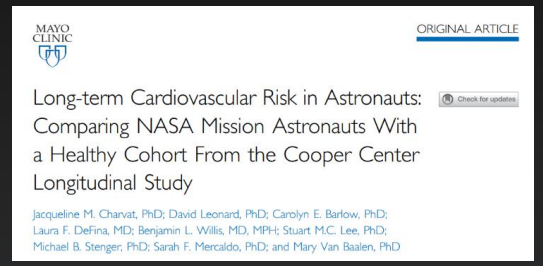
- Analyses of publicly available astronaut data did not reveal spaceflight induced increase to astronaut mortality*


Workplace
Original research

Cancer incidence and mortality in the USA Astronaut Corps, 1959–2017

Robert Reynolds [1, 2], Mark P Little [3], Steven Day [1], Jacqueline Charvat [2, 4], Steven Blattnig [5], Janice Huff [5], S Patel [2, 4]

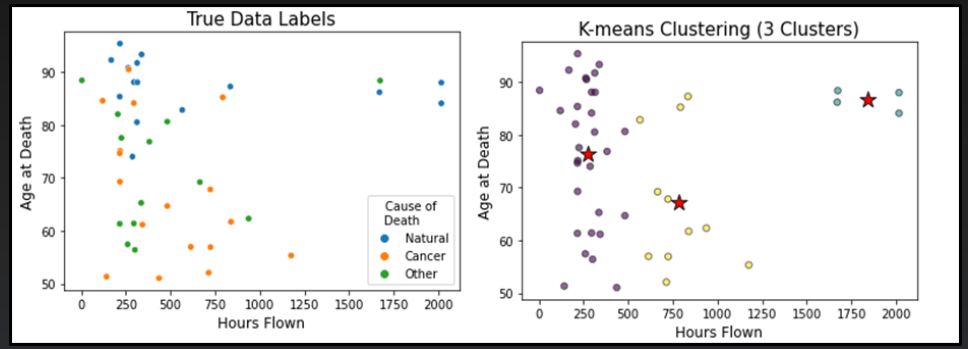
Correspondence to Dr Robert Reynolds, Mortality Research & Consulting Inc, City of Industry, CA 91748, USA; rreynolds@mortalityresearch.com

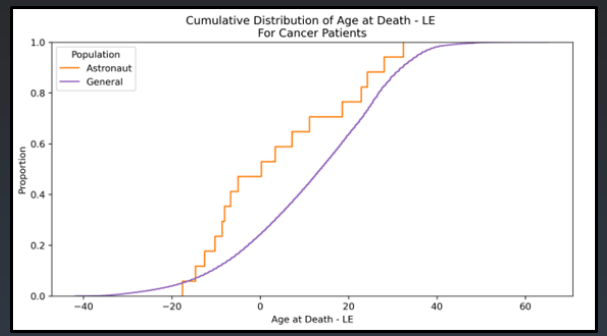

MAYO CLINIC

ORIGINAL ARTICLE

Long-term Cardiovascular Risk in Astronauts: Comparing NASA Mission Astronauts With a Healthy Cohort From the Cooper Center Longitudinal Study

Jacqueline M. Charvat, PhD; David Leonard, PhD; Carolyn E. Barlow, PhD; Laura F. DeFina, MD; Benjamin L. Willis, MD, MPH; Stuart M.C. Lee, PhD; Michael B. Stenger, PhD; Sarah F. Mercaldo, PhD; and Mary Van Baalen, PhD





Using SEER*Stat cancer data for all types of cancer, male and female Age at Death – LE for astronauts who died of cancer vs. the general population (male and female)

**M.T. Prelich et al., Assessing Long-Term Health Outcomes in Astronauts, NASA HRP IWS, Galveston, TX, 2024.*

LTH Metric Development Efforts – Metric Criteria

- An LTH Metric Development Technical Interchange Meeting (TIM) was held on June 1, 2023
- LTH Stakeholders participating in the TIM included representatives from:
  - HSRB
  - Lifetime Surveillance of Astronaut Health (LSAH)
  - CHP-PRA
  - HRP Space Radiation Element
- TIM outcomes included development of LTH metric criteria, where targeted LTH outcomes:
  - Have causes tied to spaceflight experience
  - Are significantly different from normal aging
  - Can be affected by changes in in-mission resources
- After establishing the LTH metric criteria, metric development efforts shifted towards metrics quantifying *End of Mission Health Status* and *Time to Return to Preflight Baseline*

Metric for Quantifying End of Mission Health Status

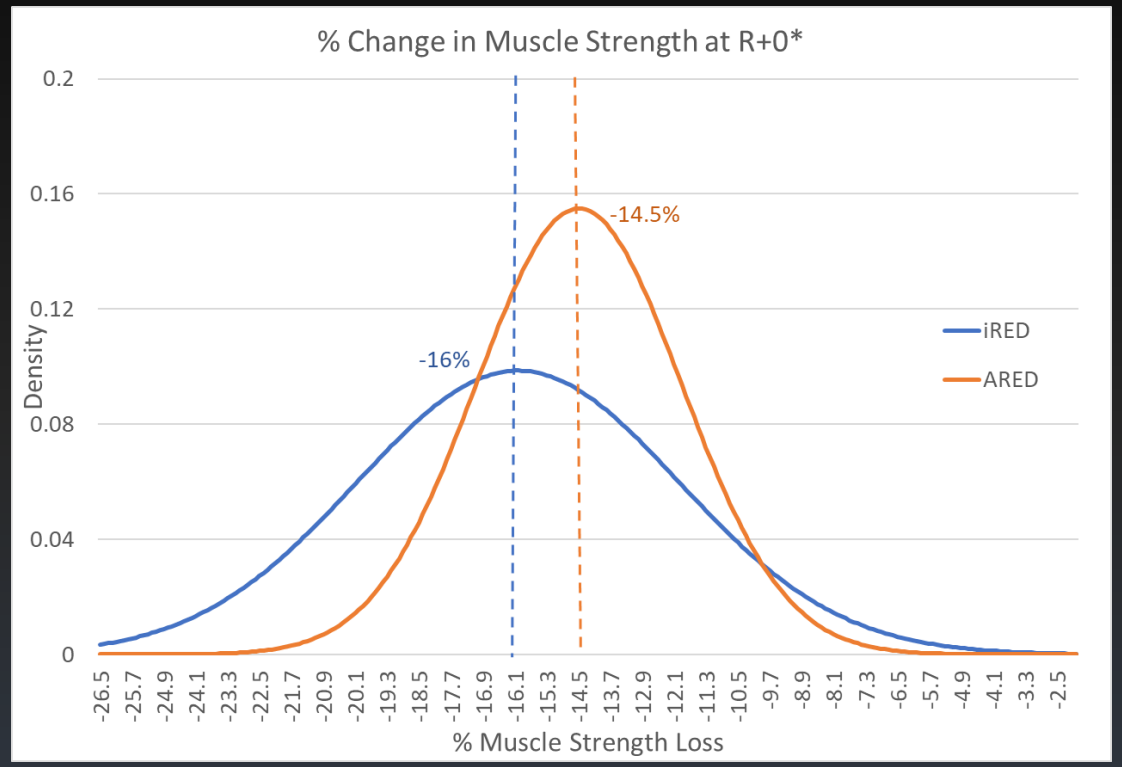
- Tools used to assess in-mission medical risk include:
  - Integrated Medical Model (IMM)
  - Informing Mission Planning via Analysis of Complex Tradespaces (IMPACT)
  - Medical Extensible Dynamic Probabilistic Risk Assessment Tool (MEDPRAT)
- The outcomes these tools include:
  - The Task Impairment (TI) and duration of impairment due to in-mission medical events
  - The probability for the need for removal to definitive care after medical event occurrence
  - The probability of loss of crew life due to medical events
- The TI present at the end of the mission captures the lingering effects of medical events persisting throughout the remainder of the mission
- *The cumulative TI present at the end of the mission is a candidate metric for quantifying the astronaut's health status at the end of the mission*

Metric for Quantifying End of Mission Health Status - Example

- The end of mission health status will change with the amount and type of medical system resources available during the mission
- The cumulative TI increases when the amount of medical system resources decreases

Time to Return to Preflight Baseline Metric

- Spaceflight exposures cause physiological degradation, such as:
  - Muscle atrophy
  - Loss of bone mineral density
  - Sensorimotor disturbance
  - Loss of cardiac capacity
- The amount of degradation present at the end of the mission is dependent on the:
  - Length of the mission
  - Type and amount of exercise performed
  - Exercise device capabilities, such as the interim Resistive Exercise Device (iRED) or the Advanced Resistive Exercise Device (ARED)
  - Individual factors
- Post-flight rehabilitation is performed to restore the astronaut to their preflight physiological status

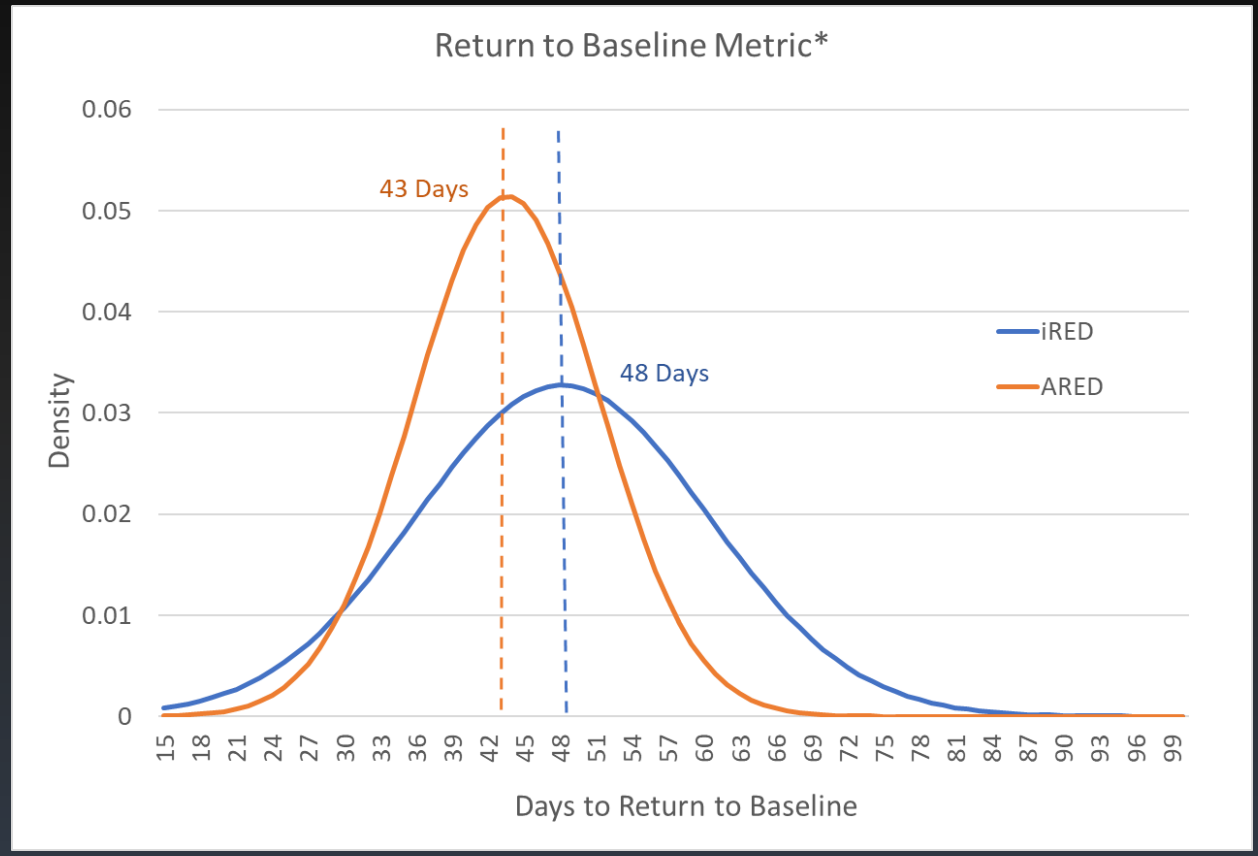


- *The time it takes for the astronaut to return to baseline values is a candidate LTH metric*

**K.L. English et al., Isokinetic Strength Changes Following Long-Duration Spaceflight on the ISS, Aerosp Med Hum Perform, 86(12), 2015.*

Time to Return to Preflight Baseline Metric - Example

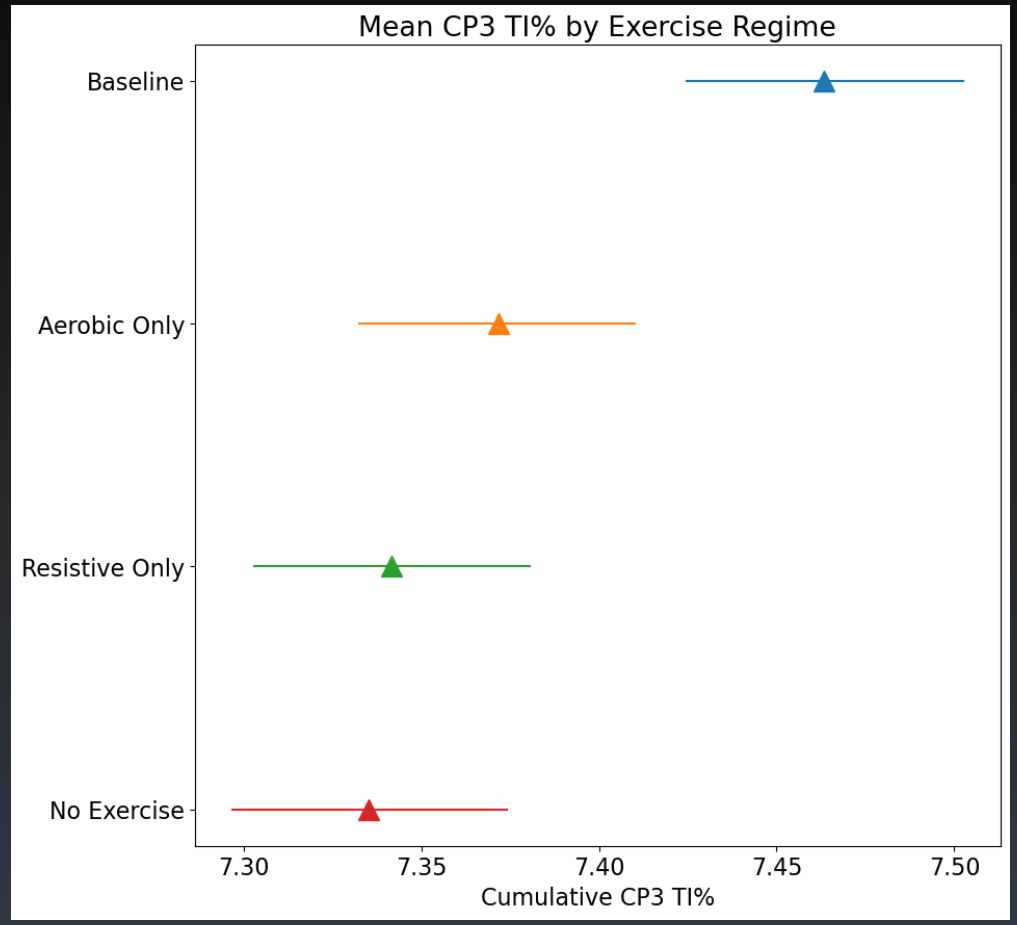
- Larger muscle strength decreases were observed at the end of 180-day missions when the interim Resistive Exercise Device (iRED) was used on ISS vs. the Advanced Resistive Exercise Device (ARED)
- This allows for a relationship between muscle atrophy and effectiveness of exercise (ARED = effective exercise, iRED = less effective) and can be used to determine muscle strength decrements upon landing
- The decrement at landing becomes the starting point for calculating the time to return muscle strength to preflight levels
- The time to return to preflight baseline levels is dependent on rehabilitation protocols and individual factors



**K.L. English et al., Isokinetic Strength Changes Following Long-Duration Spaceflight on the ISS, Aerosp Med Hum Perform, 86(12), 2015.*

Incorporation of Example LTH Metrics into CHP-PRA

- The CHP-PRA proof-of-concept model explored how exercise capability reduction, to save mass and volume, affects medical risk
- Only small changes in risk result, but significant changes in consumable resource utilization was realized
- Incorporation of the LTH End of Mission Health Status Metric provides similarly small changes in the results, but provides an illustration of how an LTH risk metric could be incorporated into CHP-PRA



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Next Steps

- Present these proof-of-concept LTH metric models to stakeholders for feedback
- Perform additional development on the End of Mission Health Status and Time to Return to Baseline LTH Metrics, for example determine:
  - How long do the in-mission task impairment effects last into the post-flight period?
  - What interventions are needed for full recovery?
  - Do any effects become permanent impairments?
  - What is the time to return to baseline for other muscle groups?
  - What is the time to return to baseline for other physiological decrements?
  - What other factors should be incorporated into the relationship between physiological decline, in-mission capabilities, and recovery time
- Continue to explore metrics appropriate for quantifying longer-term astronaut morbidity and mortality risk

Thank you!

Questions?

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