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USING SURVIVAL ANALYSIS AND ACCLIMATION TRAINING TO DEVELOP A TOLERABILITY METRIC FOR CENTRIFUGE DESIGN AND SPACEFLIGHT ARTIFICIAL GRAVITY IMPLEMENTATION

Abstract

The current suite of countermeasures to mitigate astronaut deconditioning is incomplete and inefficient. Artificial gravity (AG) has the potential to provide a novel, comprehensive countermeasure, mitigating deconditioning in multiple physiological systems concurrently; however, there exists a lack of optimized AG conceptual architecture. This work develops a human tolerability trade parameter to accompany existing engineering trades (mass, volume, power), assisting in short-radius centrifuge design.

The allowable radius of previous AG designs has been limited by the cross-coupled (CC) illusion, which causes disorientation and motion sickness due to head movements performed during sustained rotation. We aimed to improve tolerability of the CC illusion in 21 human subjects via a personalized, incremental acclimation protocol in a ground-based study. Subjects were exposed to the CC illusion over up to 50 sessions, each 25 minutes in duration. We quantified improvement in illusion threshold (i.e., the highest spin rate at which no illusion was experienced). The acclimation progression of each individual subject provided the input for a statistical survival analysis to predict population acclimation to the CC illusion. For each spin rate of interest, we used the product limit method of Kaplan-Meier analysis to calculate a cumulative probability of reaching a given threshold over a number of days of training.

Our 21 subjects acclimated to an average threshold of 18.6 RPM (range: 3-38 RPM) at which no illusion was experienced, after training for an average of 22 sessions (range: 10-50 sessions). In employing the survival analysis, we found there to be a 76% probability (95% CI: 49-89%) that subjects would acclimate to a threshold of 10 RPM after 8 days of training, or a 100% probability (95% CI: 53-100%) of acclimating after 28 days of training. Similar probabilities can be calculated for any spin rate over any duration of training days.

Previously, the tolerable spin rate limit was thought to be 4-6 RPM for AG implementation via centrifugation. With training, human subjects can acclimate to higher spin rates. We analyzed acclimation data to develop a tolerability metric based on the probability of acclimating to an operationally relevant spin rate over a number of training days (both quantities within the trade space).

This analytical approach allows us to integrate human tolerability data into the conceptual design to increase our confidence in the feasibility of using AG as a countermeasure, enabling better protection of astronauts in flight.