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SPATIAL ORIENTATION AND MANUAL CONTROL IN REDUCED GRAVITY

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INTRODUCTION

We are creatures of Earth's gravity – yet we increasingly are asked to work, locomote, explore, and even fly aircraft and spacecraft in altered gravity environments. Our ability to adapt to gravity levels (or G levels) as different as microgravity, lunar gravity, or Martian gravity is impressive, but poorly understood. Our research is aimed at human adaptation to "hypo-gravity" or "fractional gravity," such as encountered on the moon or Mars. To control possible motion sickness during centrifugation we explored the use of promethazine – and investigated its influence on basic vestibular sensitivity.

METHODS

Since we can only produce brief periods of hypo-gravity in parabolic flight, and do not yet have a human centrifuge on the ISS, we used a ground-based centrifuge paradigm to manipulate only the Gz component (i.e. that along the body longitudinal axis) of centripetal acceleration and explored the transitions between different G levels. Human spatial orientation was measured by a Subjective Visual Vertical (SVV) task. In a second experiment, manual control capability was measured in a roll attitude stabilization task. Both activities informed the process of adaptation and could be used to design pre-flight training and to assess an individual's ability to "learn to learn."

RESULTS

Each transition of centrifuge speed and therefore the resulting G-level, produces an immediate disruption of both roll tilt perception and roll tilt control capability. With only a reduced gravitational force acting on the otolith organs when the head is tilted, the perceived tilt angle in the dark is significantly reduced (perceptual gain reduced by 27%, $p<0.01$). After extended exposure to hypo-gravity, with intermittent veridical visual feedback, the perceptual underestimate decayed back towards accurate tilt perception with an average effective adaptation time constant of 16 tilts, which took 38 minutes. Roll tilt manual control performance is similarly reduced when attempted to maintain an upright position in reduced gravity, with a 36% ($p<0.05$) decrement in steady-state performance in 0.5 Gz vs. 1 Gz. We also found a 10% ($p<0.05$) improvement in performance in 1.33 Gz vs. 1 Gz. A positive, linear correlation across subjects was found between manual control variability and vestibular thresholds as a function of gravity level ($p<0.01$), suggesting that sensory precision is a limiting factor in manual control performance. Some reduction in sensitivity to roll tilt was observed with administration of promethazine, with thresholds increasing 31% ($p<0.01$). Yaw rotation and lateral translation thresholds were both unaffected by a standard oral dose of promethazine.

DISCUSSION

The decrement in manual control performance observed in 0.5 Gz is particularly relevant for future human exploration missions to the moon and Mars where gravity is reduced. These results suggest that in low gravity environments, there is an increased risk of errors in orientation perception and vehicle control. Habituation or perceptual learning in response to repeated roll stimuli also occurs, but differs among subjects.

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