Human Orientation Perception of Roll Tilt in Hyper-Gravity

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Introduction

Astronauts experience a series of novel gravitational environments during space missions. They must maintain accurate perceptions of self- or vehicle orientation for tasks such as planetary landing, rendezvous and docking, and postural control. Misperceptions of orientation, particularly during vehicle control tasks, could lead to incorrect control inputs, resulting in an incident, accident, or abort.

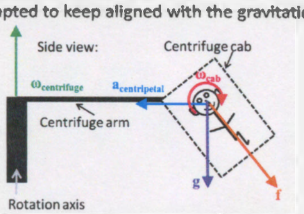
Objective

Study human perception, of both dynamic and static roll tilts, in a hyper-gravity environment. Hyper-gravity is a test-bed to study the effect of the altered gravity environments experienced by astronauts during space exploration missions. **We hypothesize that hyper-gravity will cause overestimation in roll tilt perception during both dynamic and static tilts.**

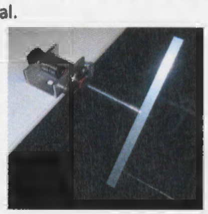
Methods

A long-radius (7.6 m) centrifuge (NASTAR Center's ATFS-400) was utilized to produce hyper-gravity environments. During each trial, subjects (N=8) experienced passive whole-body roll tilts in the dark in different gravity conditions (1, 1.5, or 2 Earth G's). A range of roll angles (10, 20, 40, and -20 degrees) and roll rates (4, 8, 16 seconds per rotation or 0.25, 0.125, and 0.0625 Hz) were studied. Perception of roll tilt was assayed using a "somatosensory indicator" which consisted of a bar that subjects attempted to keep aligned with the gravitational horizontal.

NASTAR Center's ATFS-400



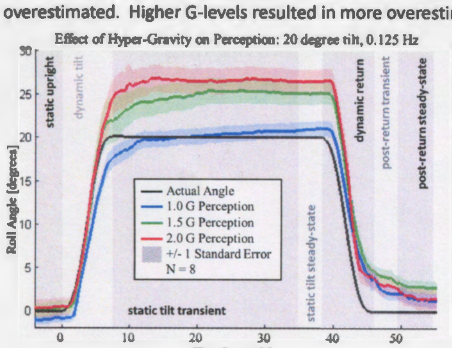
Hyper-gravic Environment Motion Paradigm



Somatosensory Indicator

Results

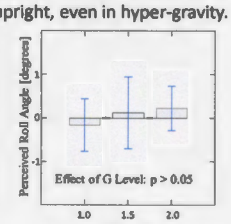
In 1-G, subjects fairly accurately perceived their roll angle, but in hyper-gravity roll tilt was overestimated. Higher G-levels resulted in more overestimation.



Overestimation of Roll Tilt in Hyper-Gravity

Static Upright Results

Subjects accurately perceived their orientation when statically upright, even in hyper-gravity.



Upright Perception

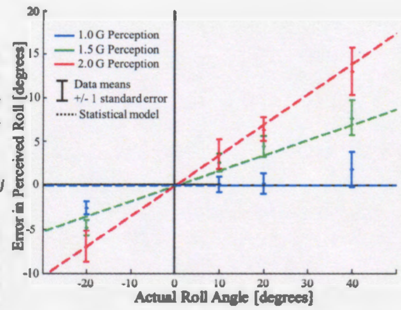
Static Tilt Steady-State Results

Static tilts were overestimated in hyper-gravity. Overestimation errors were proportionally greater for higher G-levels and larger angles.

$$(\theta_{per} - \theta)_{ij} = \rho_i + \beta[(G-1)\theta] + \epsilon_{ij}$$

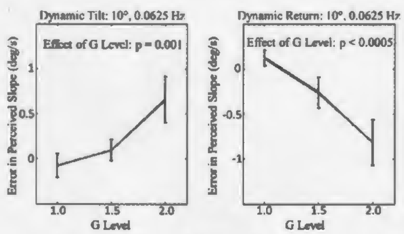
$i = 1 - 8$ *subjects*

	Coeff	SE	t	p-value
$\bar{\rho}_i$	-0.065	0.819	-0.079	0.937
β	0.346	0.026	13.39	<0.0005



Static Tilt Error in Hyper-Gravity

Dynamic Tilt and Dynamic Return Results



Dynamic Tilt and Return Error Examples

Perception during dynamic tilt and return was quantified by calculating the slope of the perception during the middle 50% of the phase. The perceived slope was compared to the actual slope; overestimation was found at nearly all combinations of angles and frequencies tested.

$$(m_{per} - m)_{ij} = \rho_i + \beta(G-1) + \epsilon_{ij}$$

Angle [degrees]; rows: Frequency (Hz)

[illegible]	10	20	40
0.0625	p=0.001	p=0.001	p<0.0005
0.125	p=0.009	p<0.0005	p=0.021
0.25	p=0.034	p=0.008	p=0.015

Angle [degrees]; rows: Frequency (Hz)

Return	10	20	40
0.0625	p<0.0005	p<0.0005	p=0.001
0.125	p=0.111	p=0.011	p=0.001
0.25	p=0.038	p=0.034	p=0.018

Dynamic perceptions were compared to the equivalent static slope. The outcome depends upon the maximum angular velocity of the dynamic tilt. Dynamic tilts at low angular velocity have similar overestimation as static tilts. At higher angular velocities, dynamic tilts are less overestimated than static tilts (sensory integration).

$$\left(\frac{m_{dyn} - m_{static}}{m}\right)_{ij} = \rho_i + \alpha[G-1] + \beta[(G-1)\omega_{max}] + \epsilon_{ij}$$

Tilt	Coeff	SE	t	p-value
$\bar{\rho}_i$	-0.183	0.064	-2.847	0.004
α	0.100	0.052	1.929	0.054
β	-0.011	0.005	-2.230	0.026

Return	Coeff	SE	t	p-value
$\bar{\rho}_i$	-0.34	0.030	-1.145	0.252
α	0.084	0.048	1.749	0.080
β	-0.011	0.005	-2.262	0.024

Conclusion

Astronaut orientation perception of dynamic vehicle tilt in novel gravity environments is critical for the success and safety of human space missions. We quantified perceptions of dynamic and static roll tilts in hyper-gravity as produced by a centrifuge. A greater understanding of how human orientation perception is influenced by novel gravitational environments may lead to the development of more effective training and countermeasures.

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HUMAN PERCEPTION OF ROLL TILT IN HYPER-GRAVITY

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INTRODUCTION

Astronauts experience a series of novel gravitational environments during space missions. These include hyper-gravity during launch and re-entry, microgravity while on orbit, and partial gravity if landing on the Moon or Mars. Astronauts must maintain accurate perceptions of orientation in these novel gravitational environments for tasks such as planetary landing, vehicle docking, and postural control. Misperceptions of orientation, particularly during vehicle control tasks could lead to incorrect control inputs, resulting in an abort or accident. We aim to study human orientation perception, for both dynamic and static roll tilts, in a hyper-gravity environment.

METHODS

A long-radius (7.6 m) centrifuge (NASTAR Center's ATFS-400) was utilized to produce hyper-gravity environments. A pre-experimental adaptation protocol helped reduce the intensity of the Coriolis cross-coupled illusion normally associated with dynamic, out-of-plane tilts in a rotation environment. During each experimental session a subject (N=8) experienced passive whole-body roll tilts in the dark in different gravity conditions (1, 1.5, or 2 Earth G's) as produced by the long-radius centrifuge. Each dynamic tilt rotates the subject from "upright", or aligned with the net gravito-inertial direction, to a roll tilt angle. This is followed by a static tilt period and then a reverse roll returning back to upright. A range of roll angles (10, 20, 40, and -20 degrees) and roll rates (4, 8, 16 second per rotation or 0.25, 0.125, and 0.0625 Hz) were studied. Perception of roll tilt was assayed using a "somatosensory indicator" which consisted of a bar that subjects attempted to keep aligned with the gravitational horizontal. We hypothesize that hyper-gravity will cause overestimation in roll tilt perception during both dynamic and static tilts.

RESULTS

When statically upright (zero roll tilt), subjects accurately perceived their orientation, even in hyper-gravity. However, when statically tilted, roll angle was significantly overestimated in hyper-gravity with more overestimation at higher G-levels and larger angles. The overestimation was approximately 17% of the actual angle in 1.5 G's and 34% in 2 G's, with no evidence of a left/right tilt asymmetry. The overestimations observed were substantially less than those predicted by prior models, such as the utricular shear (sine model) or tangent model; however were consistent with several previous experiments. We propose a modified version of the utricular shear model which fits the current and previous data well. Significant overestimation was also seen during dynamic roll rotations for all combinations of angles and frequencies tested. However the dynamic overestimation was not greater than that seen during static tilts, implying that the roll dynamics did not exacerbate the perceptual errors. Following the dynamic roll tilt, subjects' perception of roll angle transiently increased with time during the initial static period. The amount of increase following the dynamic roll tilt was independent of gravity level and roll tilt frequency, but was proportionally greater for larger angles.

CONCLUSIONS

Astronaut orientation perception of dynamic vehicle tilt in novel gravity environments is critical for the success and safety of human space missions. We have quantified human perception of both dynamic and static roll tilts in hyper-gravity. Subjects significantly overestimated roll tilt in hyper-gravity, even during dynamic rotations. In a vehicle control task in an altered gravity environment these misperceptions may reduce piloting performance. A greater understanding of how human orientation perception is influenced by novel gravitational environments may lead to the development of more effective training and countermeasures.

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