PERCEPTION OF TRANSLATIONAL MOTION IN THE ABSENCE OF NON-OTOLITH CUES

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INTRODUCTION

The otolith organs transduce linear accelerations of the head, thus serving the dual purpose of conveying head tilt with respect to gravity and linear accelerations arising during translational motion. These two types of acceleration are transduced ambiguously by the otoliths; **a constant tilt of the head is indistinguishable from a constant translational acceleration**. This inherent ambiguity must be resolved in order to support normal spatial behavior and postural stability, because responses necessary to maintain orientation and equilibrium are different for tilt and translation. The observation that we successfully maintain balance, clear vision, and accurate orientation throughout our normal activities, which include both translation and tilt of the head, indicates that this ambiguity is resolved sufficiently for natural behavior.

This tilt/translation ambiguity is thought to be partially resolved through a central frequency-parsing mechanism in which high frequency otolith activity is interpreted as translation, and low frequency as tilt. There is experimental evidence from a variety of otolith-mediated behaviors in support of the existence of a frequency-parsing mechanism. The ocular motor response to head translation **(the Translational Linear VOR)** is high-pass in nature, attenuating as stimulus frequency declines. The otolith-mediated ocular motor response to tilt of the head **(the tilt LVOR)** is most robust at low frequency. **Tilt perception** also undergoes frequency parsing, with low-frequency translational or centripetal accelerations resulting in a compelling perception of tilt.

The perception of translation has not been found to be consistent with a frequency-parsing mechanism. Subjects have typically been able to report fairly accurate descriptions of their translational motion even during long periods of constant-velocity (i.e., zero acceleration) translation, in direct conflict to a frequency-parsing mechanism. However, because of the great difficulty in eliminating non-vestibular cues, such as vibration and noise, during translational motion, it is possible that otolith-mediated perception still undergoes frequency parsing, **but higher order perceptual systems use any available extra-vestibular information to supplement the response at low frequency.** In this study, we attempt to investigate the otolith-mediated perception of translational motion in the **near absence of extra-vestibular cues.**

METHODS

Subjects: Normal human subjects (N=11, with 6 naïve), age range 24-61

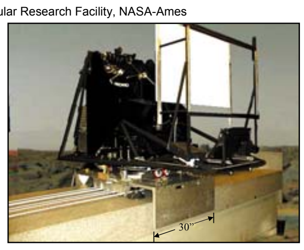
Stimuli: All experiments were performed at the Vestibular Research Facility (NASA-Ames) on a sled with an overall excursion of approximately 8.2m. The sled carriage rode on air-bearings, enabling translational motion in the near absence of noise and vibration typically encountered during translation experiments. Velocity profiles were approximately trapezoidal. Subjects were secured in a chair on the sled carriage, oriented with the interaural (IA) axis aligned with the motion of the sled. Subjects' heads were comfortably restrained with a custom-fit bitebar molded from dental impression compound.

A bungee mechanism was used to provide transient periods of linear acceleration up to ~0.5g, resulting in speeds exceeding 100cm/sec. Following initial launch, subjects traveled the available length of the sled in darkness (~8.3m) at speeds exceeding 100cm/s, until decelerated and reversed by the bungee mechanism. Motion continued for ~70s, with accelerations and velocities gradually decreasing (deceleration during "constant velocity" of <1cm/s2 due to natural decay). The bungee mechanism was not in contact with the sled carriage during periods of near-constant velocity.

Report of Perception: Subjects were instructed to manipulate a spring-centered joystick left-right proportionally with their **perception of interaural translational velocity**. None of the subjects reported undue difficulty with the task.

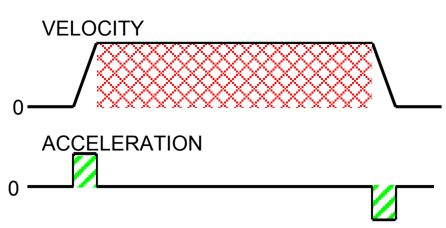
Air-Bearing 30-ft Sled

Vestibular Research Facility, NASA-Ames



Background retouched for clarity

VESTIBULAR AND NON-VESTIBLAR CUES PRESENT DURING TRANSLATION



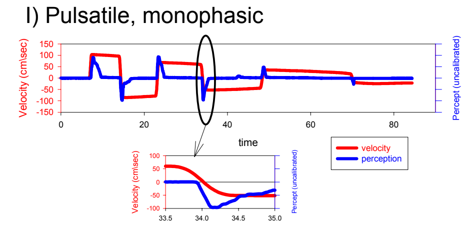
"TYPICAL" EXERIMENT	AIR-BEARING SLED
Acceleration Phase	**Acceleration Phase**
Otolith Stimulation Noise Vibration Wind Somatosensation	**Otolith Stimulation** Noise Vibration Wind Somatosensation
Constant-Velocity Phase	**Constant-Velocity Phase**
Noise Vibration Wind Somatosensation	Wind

The air-bearing sled largely eliminates non-vestibular cues during constant-velocity motion.

RESULTS

The perception of translational velocity during approximately trapezoidal linear motion was highly variable, ranging between highly pulsatile (i.e., very high-pass) to approximately veridical reflections of actual velocity (i.e., all-pass). Subjects' responses generally fell into one or more of the following four categories.

I) Pulsatile, monophasic

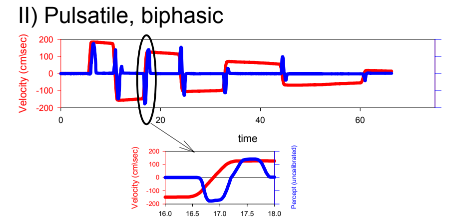


•Velocity percept closely resembled the acceleration signal, and therefore the otolith afferent activity.

•This response form was largely limited to knowledgeable subjects. The preceptual reports of two knowledgeable and one naïve subject included responses in this category.

•Subjects often reported a premature reversal in perceived velocity (see graph detail).

II) Pulsatile, biphasic

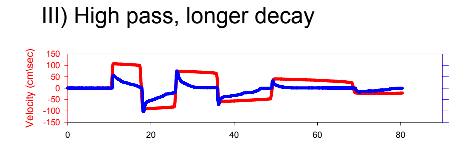


•This perceptual response most closely resembles jerk.

•This response was largely limited to knowledgeable subjects, but was also reported by one naïve subject. In total, three subjects showed this type of response

•The response might possibly reflect the influence of somatosensory cues available during periods of acceleration

III) High pass, longer decay



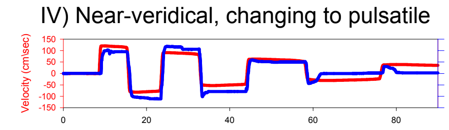
•These perceptual responses resemble an acceleration signal that has undergone leaky integration.

•Responses in this category often exhibit a premature reversal in perceived velocity.

•Time constants range between near pulsatile and approximately 3.5s.

•Perceptual responses in this category might include a partial influence of non-vestibular cues.

IV) Near-veridical, changing to pulsatile



•Responses in this category begin with an accurate report of the actual velocity profile, but gradually change to pulsatile in nature.

•This response profile was fairly typical in naïve subjects, with three out of five naïve subjects included in this category. Knowledgeable subjects did not report perceptions in this category.

•These responses likely reflect a heavy reliance on non-vestibular cues or a preconception of the motion experienced, which diminishes as velocity decreases and as subjects become disoriented.

SUMMARY AND CONCLUSIONS

•Ten out of eleven subjects (including five of six naïve) showed high-pass characteristics in their perception of translational velocity.

•When present, subjects (particularly the naïve) are likely to use non-vestibular cues to generate their perception of self motion, thus it is important to eliminate non-vestibular cues from investigations of vestibularly-mediated perception.

•Data are consistent with the use of a frequency-parsing mechanism to distinguish translation from tilt.

•The integration of otolith signals to yield linear velocity estimates is leaky at best, suggesting that "path integration" of otolith input during natural navigation is weak.

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