Gravitoinertial Force Magnitude and Direction Influence Head-Centric Auditory Localization

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DiZio, Paul, Richard Held, James R. Lackner, Barbara Shinn-Cunningham, and Nathaniel Durlach. Gravitoinertial force magnitude and direction influence head-centric auditory localization. *J Neurophysiol* 85: 2455–2460, 2001. We measured the influence of gravitoinertial force (GIF) magnitude and direction on head-centric auditory localization to determine whether a true audiogravic illusion exists. In *experiment 1,* supine subjects adjusted computer-generated dichotic stimuli until they heard a fused sound straight ahead in the midsagittal plane of the head under a variety of GIF conditions generated in a slow-rotation room. The dichotic stimuli were constructed by convolving broadband noise with head-related transfer function pairs that model the acoustic filtering at the listener's ears. These stimuli give rise to the perception of externally localized sounds. When the GIF was increased from 1 to 2 *g* and rotated 60° rightward relative to the head and body, subjects on average set an

observers correctly indicated a sound from the speaker located in that plane. When the room was spinning, the GIF was rotated inboard, and observers felt their whole body was tilted backward or outboard. They now identified as being in the horizontal plane sounds emitted by a speaker physically below the median plane of their head. Howard and Templeton (1966) and Howard (1982) have argued that this effect is not an audiogravic illusion but represents accurate auditory localization with respect to a changed reference frame. In other words, the subject feels tilted in relation to the horizontal and thus chooses a speaker that is displaced in relation to his or her body by the extent of means of a joystick connected to the PC through an A/D converter. Applying isometric torque to a sleeve (15 cm long 3 2.5 cm diameter) around the joystick handle increased or decreased the azimuthal angle of the HRTF pair used by the Convolvotron. The rate of change in stimulus azimuth varied randomly between trials (12–18°/s). The subject depressed a button switch at the free end of the joystick handle to indicate when he or she was satisfied the sound was in the median plane of the head.

PROCEDURE. The subjects were blindfolded throughout the experiment. They were always kept earth-horizontal while the magnitude and orientation of GIF were manipulated by rotating the SRR. In the prerotation baseline phase, the SRR was stationary while auditory settings to the midsagittal plane of the head were made over a 100-s period. In phase two, the SRR was accelerated at $1°/s^2$ for 152 s, held at 152°/s for 100 s, and decelerated to a stop at $1°/s^2$. At constant

Ten subjects participated. Nine had been in *experiment 1*, including two of the authors. All gave informed consent to the Human Subject Committee approved protocol. The apparatus and procedure were the same as in *experiment 1* with one exception. The restrained subject was tilted 60° right ear down from the supine position toward the center of the rotating room (see Fig. 3*B*). In the no-rotation periods, the GIF equaled 1.0 *g* and was oriented 60° left of the subject's median plane; when the room was rotating at 152°/s constant velocity, the GIF equaled 2.0 *g* and was aligned with the subject's median plane. The average of the five prerotation midline settings for each subject was taken as his or her zero baseline.

Experiment 3: tilt of the median plane in a normal 1.0 g environment

Six subjects who had participated in the prior experiments took part. The rotating room was always stationary so that the GIF was always 1.0 *g*. The subject's orientation to gravity was set to 1 of 11 bed angles around the *z*-axis between 75° right and left at 15° increments (see Fig. 3*C*). Subjects made auditory settings to center a sound in the head's median plane as in the earlier experiments. The bed angles were presented in random order and each angle was repeated six times within a session. A position was held long enough for the subject to make one setting and then the bed was manually moved to a new position.

RESULTS

Experiment 1

Figure 4*A* shows the averaged sequential auditory midline settings for subjects exposed to rightward rotation of the GIF relative to the midsagittal plane. During acceleration, auditory settings shifted to the right relative to the 1.0 *g* baseline and then plateaued at constant velocity (GIF equal 2.0 *g*, tilted 60° right re the head). In the six trials done at constant velocity, subjects indicated as being straight ahead auditory stimuli 7.3 6 4.17° (mean 6 representing rightward displacement of the GIF in relation to the median plane. The midline settings at zero tilt angle were used as the baseline reference value. Each subject's six repeated settings at the same tilt angle were averaged and linear regression lines were fit to the auditory settings versus GIF tilt. Statistical comparisons were made of the average slopes. Figure 6 summarizes the results.

In tilted conditions, the settings shifted slightly but systematically in the direction that the GIF rotated. The average slope was only 0.05, but this was significantly different from 0 ($t = -6.497$, $P < 0.001$) because the results were very consistent from subject to subject.

DISCUSSION

Experiment 1

The observations in *experiment 1* unequivocally confirm the existence of an audiogravic illusion when the GIF vector is increased in magnitude and rotated away from the median plane of the head. Sounds must be shifted in the same direction as the rotation of the GIF relative to head azimuth to be perceived in the head's median plane.

Experiment 2

The results in *experiment 2* indicate that an audiogravic illusion does not occur when the GIF doubles and rotates into the median plane of the head and body. The absence of an auditory shift in this condition and the significant shifts seen in *experiment 1* indicate that an increase in GIF magnitude in the sagittal plane is not sufficient to cause an audiogravic illusion but that a rotation of the GIF vector is necessary for the shift in localization to be induced. The final experiment determined how auditory localization would be affected by the direction of the GIF vector when its magnitude was always 1 *g*.

The findings in *experiment 3* point to small but systematic changes in perceived azimuth of an acoustic stimulus when a subject is reoriented in a normal terrestrial force background. A system. Psychophysical mappings of HRTF information to perceived azimuth have been established empirically (Wightman and Kistler 1989). However, the relationship between physical acoustic information (HRTFs) and perceived spatial location is remapped by alterations in GIF. This means the neural computations underlying sound localization interrelate binaural auditory HRTF information about the acoustic target with vestibular, proprioceptive, and somatosensory representations of GIF direction and magnitude.

The GIF influence on auditory localization may act at a level that affects sensory localization in multiple modalities. For