Head iitter enhances 3D motion perception

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Supplemental Information

Movie S1. Movie illustrating the visual stimulus and experimental design. Binocular stimuli were presented in an Oculus DK2 head-mounted display. The movie depicts the left- and right-eye views side-by-side. When the observer views the display, the two eyes' views are fused into the percept of a 3D scene. The scene depicts a circular aperture within a 1/f noise-textured surround at the focal distance of the display. At the start of each trial, the observer fixates the center of the aperture, aided by the small textures and nonius lines near fixation ("Inter-trial Interval (until keypress)") and when ready pressed the Up Arrow key to initiate the target motion. In two example trials, a high contrast target (Weber contrast level = .75) moves along its random trajectory ("Trial X Target (1s)"). Target motion was always within the x-z plane (there was no y motion) and lasted 1s. After the target disappears, a 3D paddle (textured block) appears ("Trial X Paddle Response (unlimited)". The observer adjusts the location of the paddle along an invisible orbit about the fixation point, providing an estimate of the perceived motion trajectory. The stimulus elements were always rendered under perspective projection, so that both monocular (size, looming (target)) and binocular cues (disparity, inter-ocular velocity differences) were present. Note that in our primary experimental condition ('head-tracking on') the display could update according to the observer's head movement, providing slightly different viewpoints of the 3D scene over time. The small jitter in the display depicts the head-motion

contingent updating in response to the observer's head movement while carrying out the task in this condition. The textured surround was rendered within a virtual room with textured walls, ceiling, and floor (see Methods for details). Larger head movements brought those features into view. Once the observer is satisfied with their paddle setting, they press the spacebar to initiate the visual and auditory feedback ("Trial X Feedback (to paddle orbit)"). Note that the trial component labels are included in the movie for descriptive purposes and were not present during the actual experimental trials.

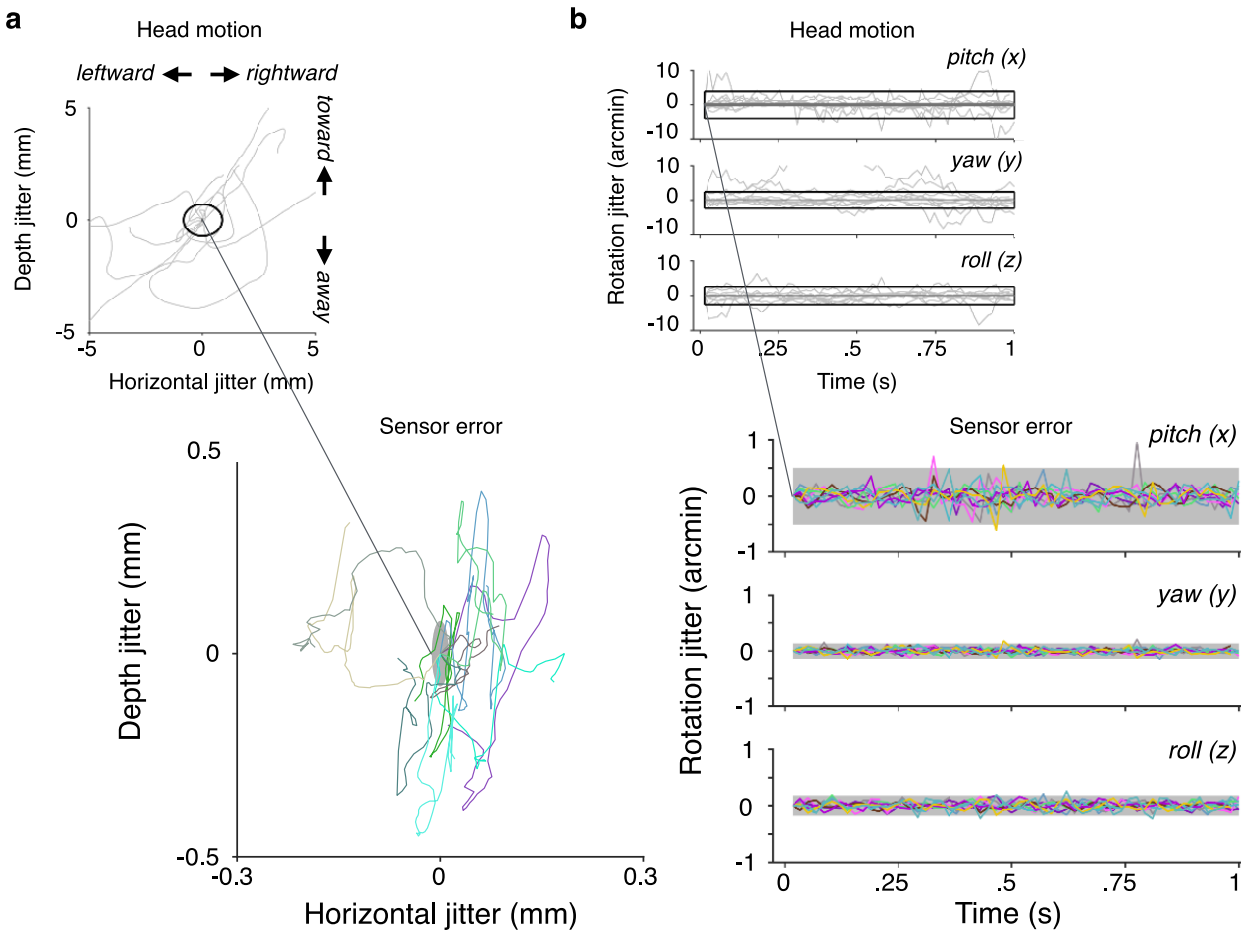

Figure S1. Characterization of the head-tracking sensitivity of the VR headset. Sensor error in jitter measurements for the stabilized DK2 used during the experiment is substantially smaller than the head jitter measured from observers while performing the experimental task. a. Translation sensor error jitter (mm) in the X (horizontal) and Z (depth) directions during the target's 1 s presentation for 10 randomly-selected trials. For presentation purposes, translation jitter in the Y (vertical) direction is not depicted. The solid gray ellipse corresponds to the between-subjects 95th percentiles for the horizontal and vertical translations between any two of the 13.33 ms sampled time points. We reproduced **Fig. 3a** in gray-scale with shortened axes in the upper left corner for reference, showing head jitter for representative observer S22 when head tracking was on. b. Rotation sensor error jitter about the three axes during the target 1 s

presentation for the same 10 randomly-selected trials. The solid gray bars correspond to the between-subjects 95th percentiles for the rotations between any two of the 13.33 ms sampled time points. For comparison, **Fig. 3b** is reproduced in gray-scale with shortened axes in the upper left corner.

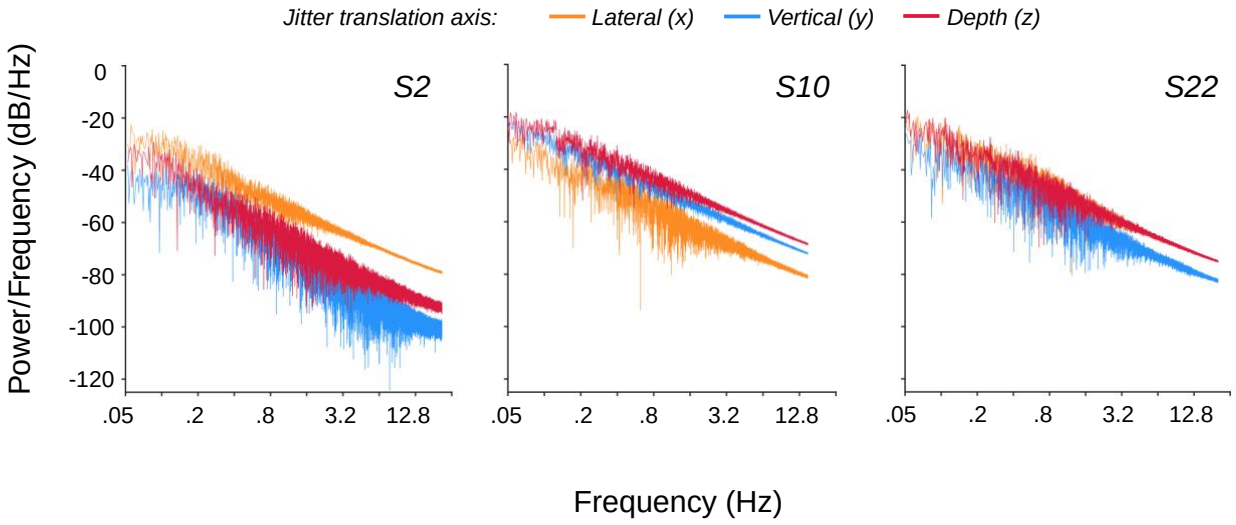

Figure S2. Head jitter follows a 1/f noise spectrum. Periodograms based on the discrete Fourier transform of the full trace for three observers including the same representative observer (S22) whose data are depicted in **Fig. 3.** Each plot depicts the periodograms of the three jitter translation axes - lateral (orange), vertical (blue), and depth (red) - when head-tracking was on. Results exhibit a 1/f (pink) power spectrum suggesting that head jitter is driven by physiological noise. Similar patterns were observed when head-tracking was off or lagged (although with overall smaller power, not shown here), supporting the interpretation that head jitter is suppressed when it might introduce cue conflicts.