The role of visual cues and whole-body rotations in helicopter hovering control

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I. Introduction

Helicopters in flight are unstable, much like an inverse pendulum, and hovering at one spot requires the pilot to do a considerable amount of active control. To date, it is still under discussion which sensory cues helicopter pilots use for this stabilization task, and how these cues are combined.

Experiments which specifically addressed sensorimotor control in helicopter stabilization are rare. A study by Ricard and Parrish (1984) found significantly better stabilization performance (in terms of mean-distance-to-target) when inertial motion cueing was available. An earlier study (Ringland et al. (1971), cited in Ricard and Parrish (1984)) found best control performance when rotations, but not translations, were simulated inertially. Hall (1978) also reported that inertial motion cueing can improve roll stabilization in a *Harrier GR Mk 3* flight simulation.
Schroeder et al. (1999) investigated the effect of inertial motion cueing and two different visual scenes on controlling a helicopter that performs a vertical step motion (change of altitude). They found a significant influence of the visual scene, and of the natural frequency of the wash-out filter.

There are several sensory cues a pilot might use for stabilizing a helicopter (hovering at a target spot). The horizon provides visual information for the orientation of the helicopter in pitch and roll. Optic flow provided by movement of visual features in the observer's view during self-motion can tell the observer about translations and rotations. Apart from vision, pilots can also use force cues of self-motion. Rotations and accelerations of the head can be detected by the vestibular system in the inner ear, and body accelerations are measured by pressure sensors in the skin and by proprioceptive sensors.

Here we investigated how cues from different sensory modalities (visual cues and body cues) are used when humans stabilize a simulated helicopter at a target location in a closed perception-action loop.

II. Methods

Participants were seated inside a closed cabin on a Stewart platform (*CueSim MaxCue*), equipped with a projection screen (see von der Heyde (2001) and Figure 1, left). A real-time simulation of the dynamics of a small helicopter (similar to a *Robinson R-22*) was used (Terzibas, 2004). The task was to stabilize the helicopter on a target spot. This was visualized using two spheres, one representing the target and the other marking the position of the helicopter (Figure 1, right panel). Participants used a realistic helicopter cyclic stick to control forwards-backwards and sideways drift. Height above ground and heading were automatically stabilized.

We measured stabilization performance in four different visual conditions, black background (B), horizon (H), optical flow (OF), and both horizon and optical flow (H+OF) (see Figure 1, right), both with and without platform rotation cueing. The visual backgrounds provided ambiguous information without creating conflicts.

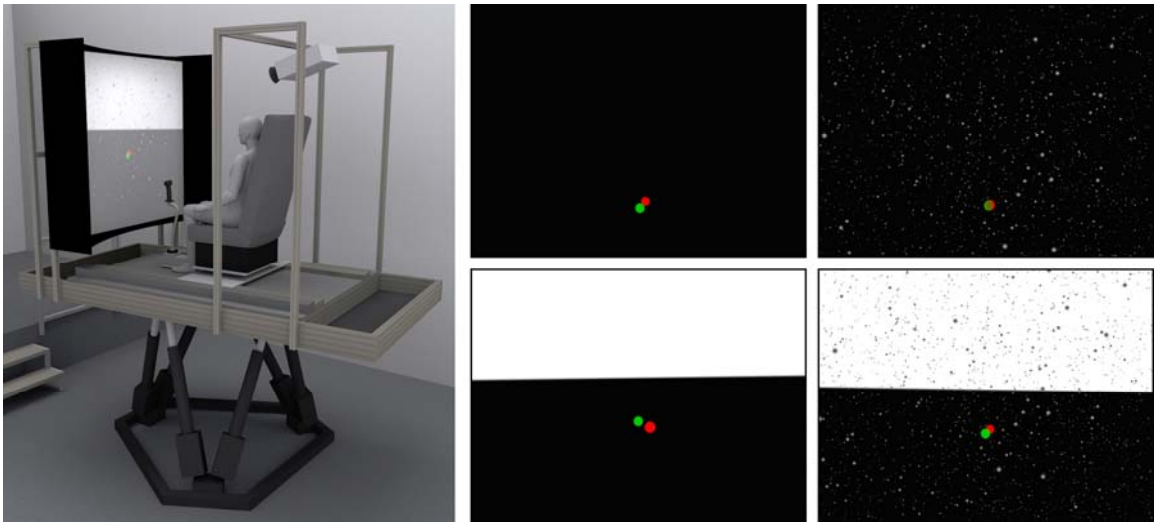

Figure 1: *Left:* Motion simulator set-up. *Right:* Four visual conditions: black background (B), random dot pattern to provide optical flow (OF), horizon (H), and both horizon and optical flow (H+OF). The red sphere is the target, and the green sphere represents the position of the helicopter.

The random dot pattern used in the OF and H+OF conditions were static in world coordinates and provided visual cues for translations and rotations of the helicopter, but not for absolute position or orientation in space. The horizon in the H and the H+OF conditions provided visual information on helicopter pitch and roll orientation, but not on helicopter translations, because ground plane and sky were uniformly colored. The black background served as a control condition to see how much information can be gained from the relative position or motion of the two spheres. Physical pitch and roll body rotations were presented by tilting the platform exactly as the simulated helicopter tilted. The duration of each trial was 120 seconds. Each participant ran a total of 10 minutes of stabilization per experimental condition.

III. Results

Six participants (five male and one female), who had already been trained on the task in a previous experiment, took part in this study.
Figure 2 shows the resulting stabilization performance measures (mean distance from target) for all participants and all conditions. This data was analyzed with a four-way ANOVA with direction (left / right vs. forward / backward), platform (rotation cueing on/off), horizon (on/off) and optical flow (on/off) as within-subject variables. In this analysis, all factors had significant main effects on distance-to-target. Also, many interactions were significant.

Overall, participants stabilized significantly better in the left/right direction than in the forward/backward direction. The B condition without platform cueing (where visual feedback for control only came from the two spheres) caused much larger deviations than all other conditions (blue error bars above 'B' in Figure 2), because participants quickly lost control of the helicopter. If, in contrast, platform rotations were provided in the B condition, stabilization performance was almost as good as in the other visual conditions with the platform turned on. Also a horizon (H) and optic flow (OF) improved stabilization significantly, compared to the B condition. In all visual conditions, platform rotation improved stabilization performance compared to visual-only stimulation. The best performance was reached when all three cues were presented together.

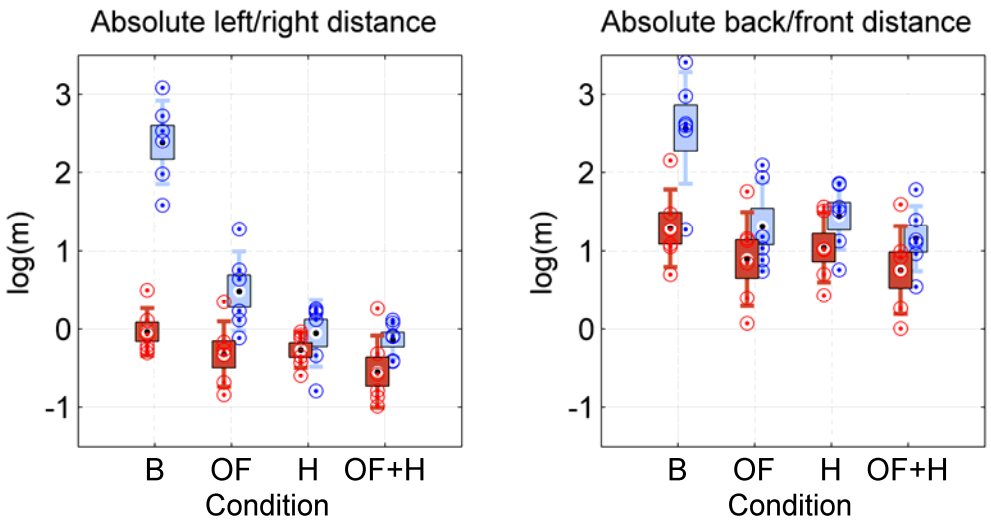

Figure 2: Results of all six participants. B: black background, OF: optic flow, H: horizon; blue: platform off, red: platform on. Measures are shown on logarithmic scale of helicopter-to-target distance in meters. Error bars show standard deviations and standard error.

These results show that all three cues, horizon, optic flow, and platform rotations, can help the participants to stabilize a simulated helicopter. Platform rotations tended to help most. Adding physical rotation cues to visual stimulation in a simulator can thus significantly improve the ability of trained participants to stabilize the simulated helicopter at a target location.

Which cues are used in helicopter stabilization is also an issue for pilot training in a simulator. If trainees adopt a different control strategy in the simulator, pilot training will not transfer well to real flight (Hall, 1978). To make the trainee adopt a 'natural' control strategy, inertial motion cueing might be essential. Our results support this assumption.

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