How to Simulate Realistic Forward Accelerations on a 6-DOF Motion Platform

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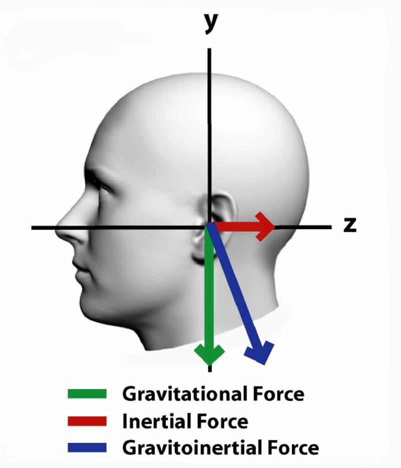
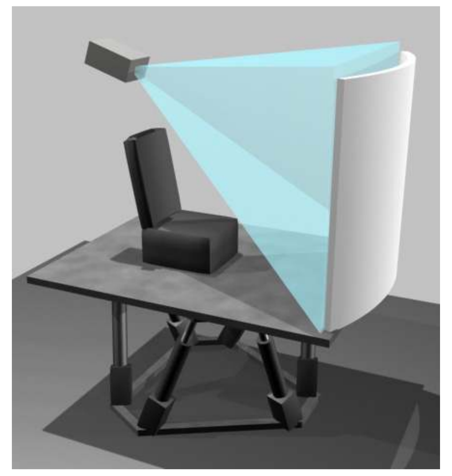
• Introduction

- Many motion simulators try to create the impression of movements which are much larger than the possible working range of the simulator device, using visual and body motion cues.
- Using our motion platform and an appropriate combination of pitch and short forward translations, we can simulate the vector sum shown in the figure to the right, creating an illusion of extended forward acceleration. We sought to optimize the combination of this motion with a visual scene for greatest plausibility.



- We were also interested in the amount of inter-individual variability, effect of prolonged exposure, and whether a visually presented forward acceleration could suppress otherwise noticeable pitch rotation from vestibular canal stimulation.

• Experimental Setup



Participants were seated on a six-degrees-of-freedom motion platform equipped with a flat projection screen.

The visual scene consisted of a ground plane and sky with random texture. A fence and people standing on the ground plane provided absolute size cues (Figure 1). The simulated height of the observer's eye was set at two meters above the ground.

Participants were seated at a distance of 1.16 m from the projection screen and viewed the scene with the right eye only, to disable stereopsis cues.

A square aperture was mounted directly in front of the participant's face so that they could not see the edges of the projection screen. Their field of view was approximately 50° horizontally and vertically. We adjusted the seat so that their eye height was exactly level with the horizon and they had the impression of moving exactly horizontally.

Participants wore headphones presenting random noise so that they could not hear the platform motors. Additionally, shakers mounted under the foot plate and the seat were used to cover vibrations caused by the platform legs.

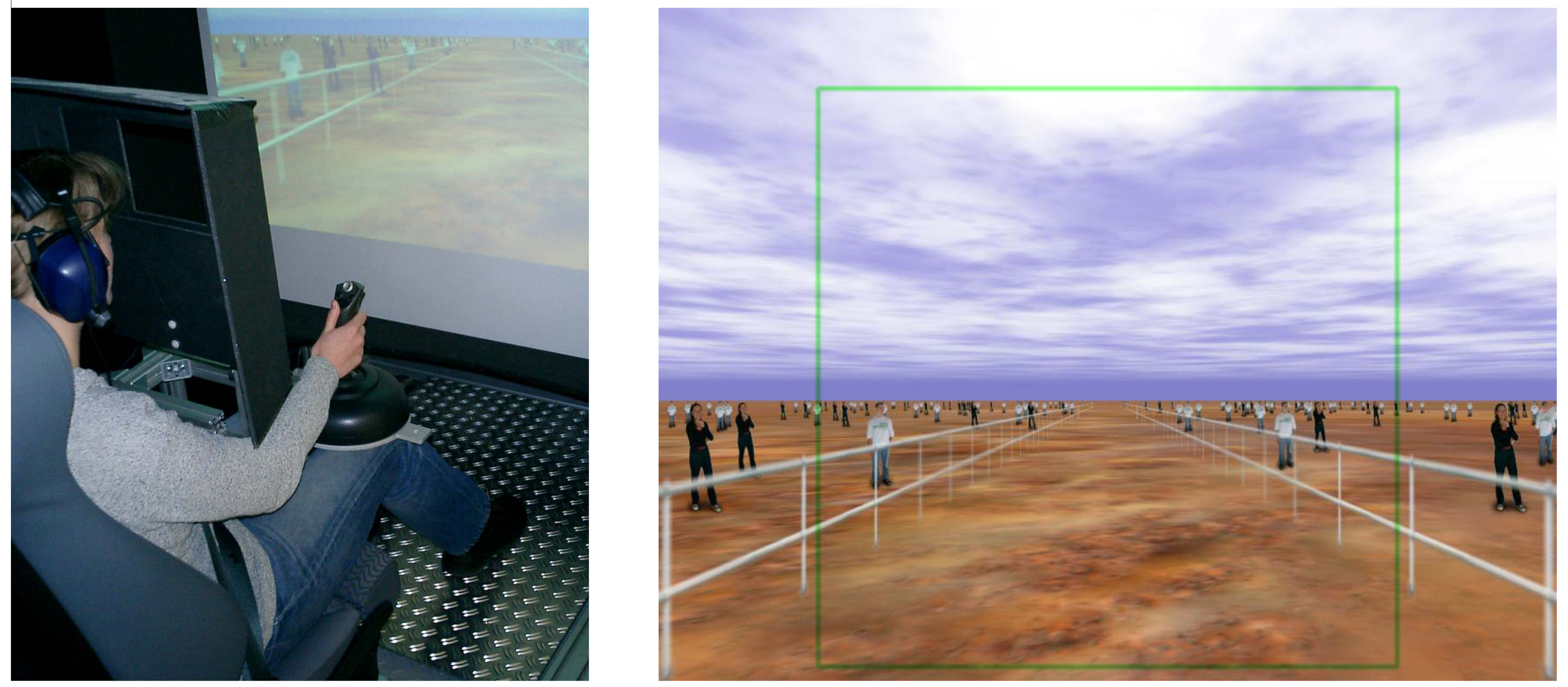


Figure 1: Left: participant on motion platform, looking through the aperture at the projection screen. Right: screen shot of the visual scene. The green frame shows the approximate field of view through the aperture.

• Methods

12 students participated in this experiment (9 female, 3 male).

Each participant judged the realism of 180 forward accelerations (two blocks of 90 trials each) using a joystick to set a visually displayed bar on a continuous scale. Participants were explicitly told to give high ratings for trials in which they felt convincing forward motion in accordance with the visual stimulus, and low ratings in trials in which they noticed conflicts.

In each trial, the participant experienced a brief simulated forward acceleration (4s ramp, followed by 2s of constant acceleration) presented as both platform movement and movement of the visual scene. After the acceleration, the screen went dark and the platform returned to zero in 6 seconds.

In each trial, stimuli were chosen randomly within fixed intervals for all six varied parameters independently:

- final visual forward acceleration (0 - 1.5 m/s^2) (fig 2a)
- final platform backwards pitch (0° - 15°) (fig 2b)
- forward translations of the platform (0 - 0.5m in 4s) (fig 2c, differently colored curves)
- ratio of acceleration/deceleration durations for the translations (0.11 - 1.5) (fig 2c, different curves of the same color)
- amplitude of up-down noise in both visual and platform movements simulating ground roughness (0 - 7 cm) using low-pass filtered noise (cosine window, 0.3s - 1s)

We used MATLAB for correlation analysis and plots, and SPSS for multiple hierarchical regression analyses.

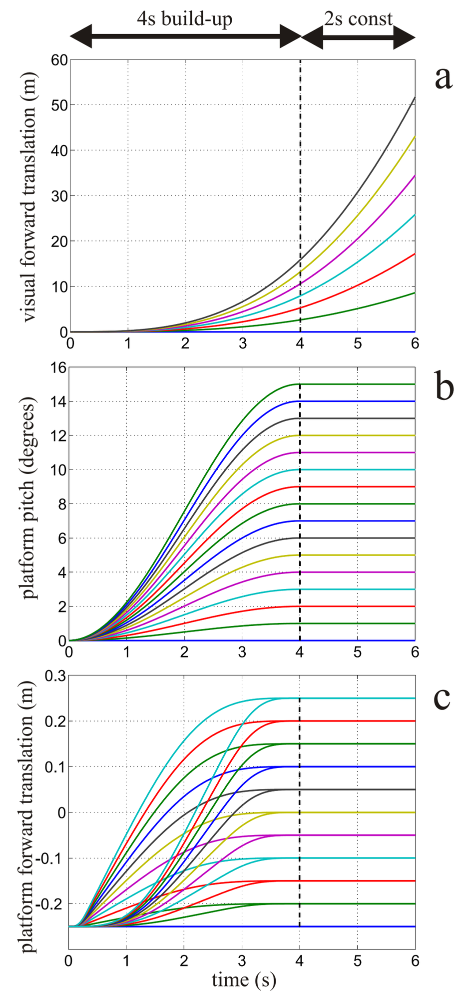


Figure 2: ranges of movement profiles. Explanation left in text

• Results and Discussion

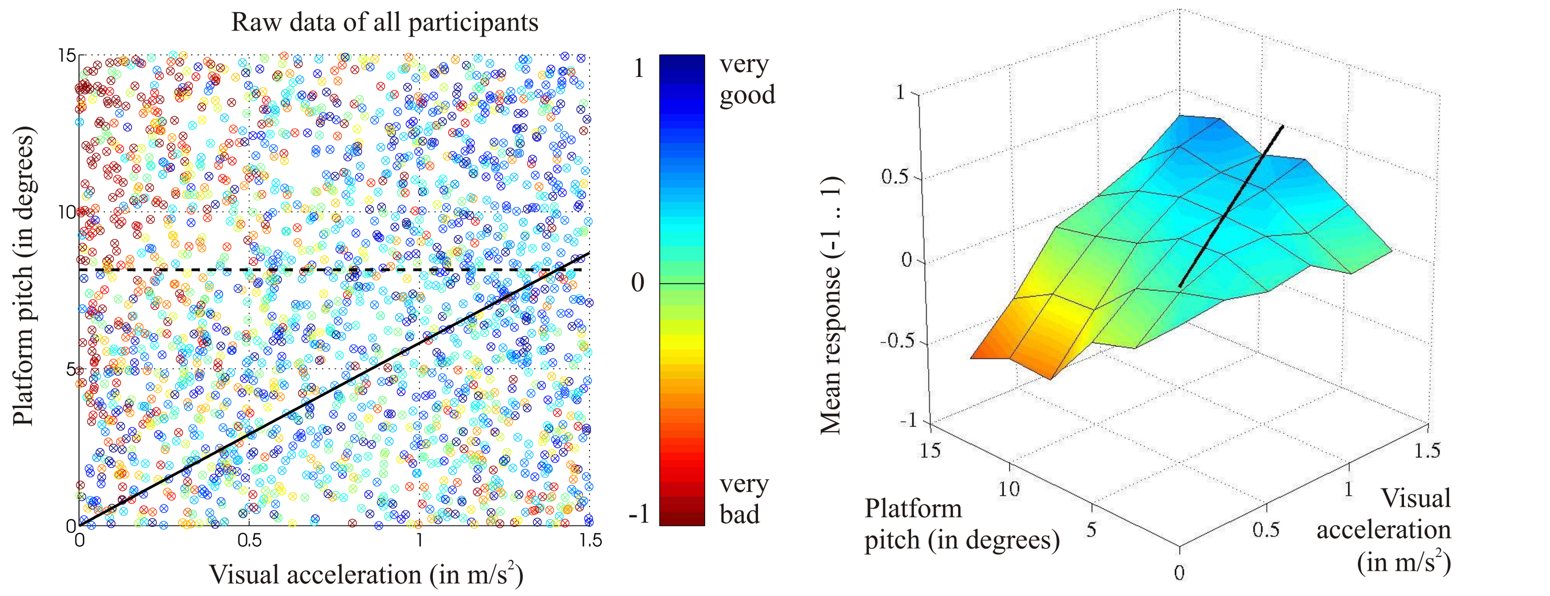


Figure 3: Left: All single ratings of all participants, shown along visual acceleration and platform pitch. The ratings of each trial are color-coded. The oblique black line shows correct pitch/acceleration pairs. The dashed line shows the approximate human threshold for pitch rotation perception (Benson et al., 1989). The right figure shows the same data as the left figure, with data points averaged in a grid of 6x6 areas.

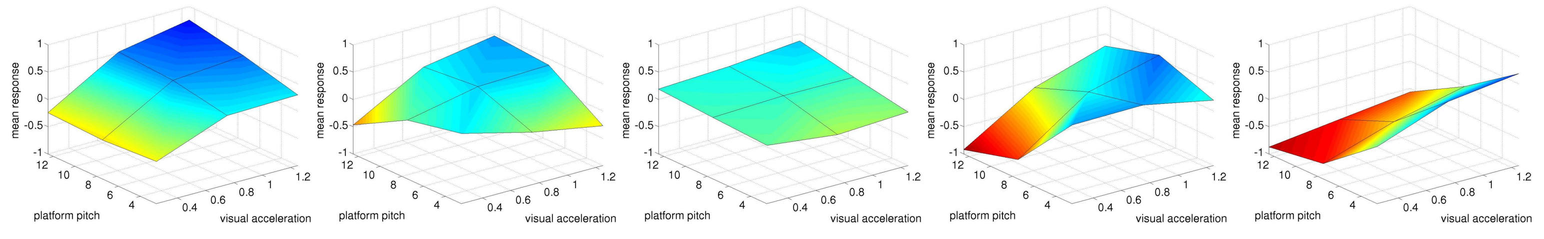


Figure 4: Variability of participant response patterns. From left to right: participants 2, 3, 6, 10, 12.

Subj. no.	Visual accel.	Platform pitch	Ac./dec. coef.	UD-noise amplitude	UD-noise cutoff	Translation size	Time in Experiment
1	0.359***	-0.396***	0.038	0.022	-0.117	0.048	-0.026
2	0.611***	0.171*	0.002	-0.065	0.012	0.109	0.034
3	0.246***	0.109	-0.043	0.088	-0.097	-0.025	0.030
4	0.076	-0.057	-0.053	0.040	0.002	0.047	0.096
5	0.694***	0.073	-0.116	-0.011	0.140	0.020	-0.001
6	0.065	0.393***	0.019	0.053	-0.189*	-0.036	0.000
7	0.344***	0.128	0.127	-0.071	-0.084	-0.211**	0.087
8	0.188*	0.253***	-0.055	-0.032	0.040	-0.056	-0.109
9	0.368***	-0.278***	0.056	-0.039	-0.095	-0.060	-0.015
10	0.476***	-0.413***	-0.037	0.038	-0.025	0.060	0.142
11	0.408***	-0.211**	0.030	0.063	0.019	-0.104	0.084
12	0.426***	-0.704***	0.145	-0.109	0.087	0.065	0.052

Table 1: Correlation coefficients between each factor and ratings for all participants. Significant values are marked in purple.

Subj. no.	Visual accel.	Platform pitch	Ac./dec. coef.	UD-noise cutoff	Translation size	Adjusted R Square
1	.332	-.372				**.258**
2	.628	.218				**.415**
3	.265	.144				**.070**
4						
5	.691		-.129	.118		**.502**
6		.375		-.140		**.164**
7	.352	.140	.154		-.208	**.184**
8	.169	.239				**.082**
9	.40	-.318				**.227**
10	.455	-.388				**.370**
11	.394	-.179				**.190**
12	.370	-.673				**.627**

Table 2: Standardized beta coefficients of the multiple regression analyses and adjusted R Squares for all participants. Only significant factors are listed.

- When asked after the experiment, all participants reported that some of the forward accelerations were really convincing.
- Only two parameters had a clear influence on the ratings: platform pitch and visual accelerations (tables 1 and 2). Simulated accelerations were judged best if the visual acceleration was accompanied with a matching platform pitch (figure 3).
  Brief forward translations and up-down movements had almost no effect on the responses.
- There was a high inter-subject variability (figure 4).
- A platform pitch without visual acceleration resulted in a more salient conflict than a visual acceleration without platform pitch.
  When a strong visual acceleration was present, participants often did not perceive the platform pitch as a rotation, even though it was super-threshold for the vestibular canal system.
- For none of the participants was there a significant influence of exposure time on the responses (r=0.021, p=0.328).

• Conclusions

From these findings we can conclude that in human perception, a platform pitch which is consistent with a presented visual acceleration is sufficient for a believable simulation of a forward acceleration, even if the angular pitch rotation velocity is above threshold.

This is consistent with a Bayesian model that holds vision as more reliable. For strong visual acceleration and large platform pitch, where simulated forward accelerations were perceived as most realistic by the participants, the visual signal and the vestibular otolith signal approximately match. Together, these two signals can apparently suppress the perception of the conflicting signal from the vestibular canals.

These results have important implications for ego-motion simulation and simulator design.

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