# VISUAL VESTIBULAR INTERACTIONS FOR SELF MOTION ESTIMATION

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## Abstract

Accurate perception of self-motion through cluttered environments involves a coordinated set of sensorimotor processes that encode and compare information from visual, vestibular, proprioceptive, motor-corollary, and cognitive inputs. Our goal was to investigate the visual and vestibular cues to the direction of linear self-motion (heading direction). In the vestibular experiment, blindfolded participants were given two distinct forward linear translations, using a Stewart Platform, with identical acceleration profiles. One motion was a standard heading direction, while the test heading was randomly varied using the method of constant stimuli. The participants judged in which interval they moved further towards the right. In the visual-alone condition, participants were presented with two intervals of radial optic flow stimuli and judged which of the two intervals represented a pattern of optic flow consistent with more rightward self-motion. From participants' responses, we compute psychometric functions for both experiments, from which we can calculate the participant's uncertainty in heading direction estimates.


## Résumé

# Visual Vestibular interactions for self motion estimation

## Introduction

Accurate perception of self-motion through cluttered environments, such as often occurs in driving, involves a coordinated set of sensorimotor processes that encode and compare information from visual, vestibular, proprioceptive, motor-corollary, and cognitive inputs. The extent to which visual information dominates these processes is no better demonstrated than by the compelling illusion of self-motion generated in a stationary observer by a large-field visual motion stimulus, e.g., the moving train illusion, Berthoz et al., (1975).

The vestibular input to self-motion perception originates in the inner ear. There are two sets of organs in each inner ear to detect motion of the head in space. The otolith organs, the saccule and utricle, respond to linear acceleration and changes in orientation with respect to gravity. Three semicircular canals, approximately mutually orthogonal, respond to rotations of the head, specifically angular acceleration.

Self-motion is also experienced by the visual flow fields produced on the retina. The nature of the flow fields depends on both the direction of gaze and direction of travel. Such flow fields, known as "optic flow", have long been known to play an important role in spatial orientation and visual navigation. For example, subjects can evaluate the direction of self-motion quite precisely from optic flow, even when they are stationary and the visual scene simulates self-motion.

When constructing an optimal driving simulator it becomes very important to consider the interaction of both visual and vestibular inputs. The smoother the combination of the visual and vestibular, the more believable the virtual environment will be.

## Goals

The aim of the research reported here was to investigate the interaction between visual and vestibular cues to the direction of linear self-motion (heading direction) Smith et al., (2006). With this goal in mind, we designed two experiments to examine the contributions of vestibular and visual information for self-motion estimation.

## Materials and Methods

*Subjects*

Seven subjects, aged between 18 and 37 years, participated in the experiment. Three subjects participated in both visual and vestibular experiments, two subjects participated in only the visual experiment and two subjects participated in only the vestibular experiment.

*Apparatus*

Experiments were carried out on a six-legged Stewart Platform, providing all six degrees of freedom. Participants wore noise-cancellation headphones. Subwoofers installed under the subject's seat and foot plate were used to mask the vibrations causes by the platform motors. The visuals were displayed on a projection screen, with a field of view of 86°×65° and a resolution of $1400 \times 1050$ (von der Heyde, 2001), see Figure 1. To keep head motion to a minimum, we used a foam head rest. Subjects responded using a two alternative forced choice button box. All experiments were coded using a graphical real-time interactivity programming language (Virtools$^{TM}$, France).

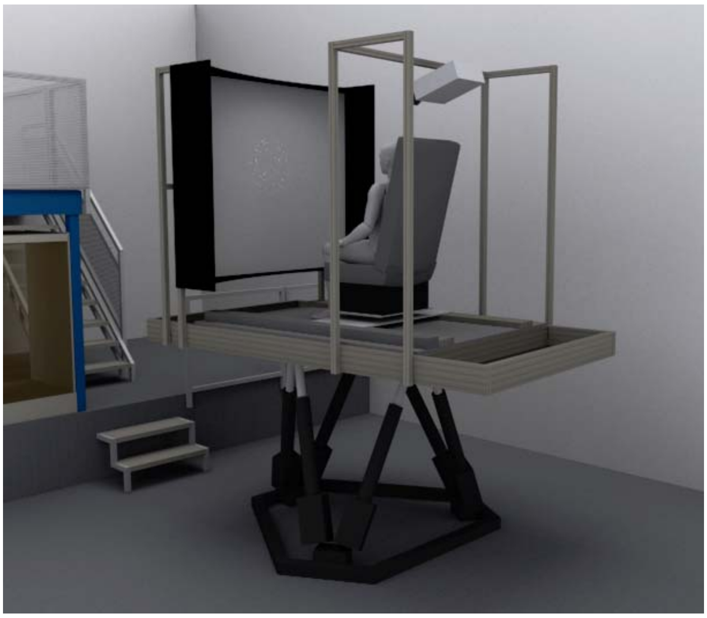

**Figure 1: Motion simulator set-up**

*Stimulus values*

Using classical stimulus profiles, Benson et al., (1986), we have a displacement profile of
$s(t) = \dfrac{A(\omega t - \sin(\omega t))}{\omega^2}, 0 < \omega t < 2\pi$ ,
where A is the maximum acceleration and $\omega$ is the angular frequency in radians per second. Thus the velocity profile is a raised cosine
$s'(t) = \dfrac{A(1 + \cos(\omega t))}{\omega}, 0 < \omega t < 2\pi$ ,
gives a sinusoidal acceleration profile
$s''(t) = A \sin(\omega t), 0 < \omega t < 2\pi$ .
For our experiments we choose a maximum acceleration of 0.48 m/s$^2$, such that body cues are kept to a minimum. Each stimulus is one second in length, therefore the angular frequency, $\omega$, is $2\pi$ .
We vary the standard heading angles for both visual and vestibular experiments to be ±5º and ±40º, with 0° defined as straight ahead.

*Experimental Procedure*

Presenting each subject with method of constant stimuli was used (Treutwein, 1995). Subjects are presented with only one standard heading angle for each experiment block. On average each experimental block lasted 80 minutes, which was divided into three 25 minute sub-blocks to avoid fatigue.

*Data Analysis*

The "psignifit" MATLAB toolbox was used to analyze and plot the data Wichmann et al, (2001a) and (2001b). The psychometric curves general form is

$$\psi(x;\alpha,\beta,\gamma,\lambda) = \gamma + (1-\gamma-\lambda)F(x;\alpha,\beta),$$

where α and β determine the shape of the curve and γ and λ correspond to the miss rate of the observer, it is a reflection of the rate at which the observers lapse. $F(x;\alpha,\beta)$ is a cumulative Gaussian. Each psychometric curve had a minimum of 210 points. We use the slope of the psychometric function as a representation of uncertainty, Kontsevich et al., (1999).

## Experiments

*Vestibular Experiment*

In the vestibular experiment, blindfolded participants were given two distinct forward linear translations with identical sinusoidal acceleration profiles, Benson et al., (1986). Either the first or second interval of motion was presented to participants with a standard heading direction; while in the other interval, the test heading was randomly varied using the method of constant stimuli. The participants judged in which of the two intervals they moved further towards the right.

The subject was presented the first stimulus, with a one second delay until the onset of the second stimulus. The subject then responded with a two-alternative forced choice. When the subject had responded, the platform would return to the neutral position at a constant velocity.

*Visual Experiment*

The objective of the visual experiment was to create a visual stimulus that will increase the uncertainty of a purely visual translation. We used Banks et al., (1993) stimuli as a template for this experiment, as the subject's uncertainty increases with respect to the eccentricity of the standard reference angle.

The visual stimulus consisted of 40 Gaussian blobs mapped onto a sphere of 10 degree radius in a pseudo random fashion. The sphere was centered 2m at the beginning of the trial, as shown in Figure 2.

The participants were given two purely visual translations, and judged which of the two visual translations would have moved them more to their right.

From participants' responses, we compute a psychometric function for the visual experiments from which we can calculate the participant's uncertainty.

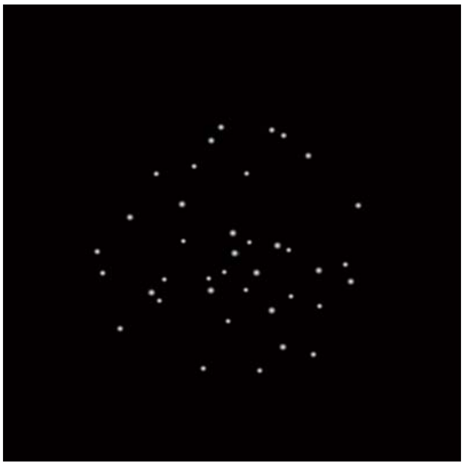

**Figure 2 Enlarged screen shot of the visual stimulus, 40 Gaussian blobs mapped on to a sphere of 10 degrees radius.**

## Results

Figure 3 shows the results of one experimental block for a standard heading of -5 degrees for the vestibular condition. In Figure 3, the subject's heading angle is plotted along the x-axis with the probability of a rightward response along the y-axis. The solid line is the best-fitting cumulative Gaussian of the subject's recorded data represented by the dots. As we can see to the left and right of the standard heading, -5 degrees, the subject's responses are close to chance level. From the best fitting cumulative Gaussian, we compute an uncertainty value of 13.04 and lapse parameters γ=0.001 and λ=0.059 for this specific case.

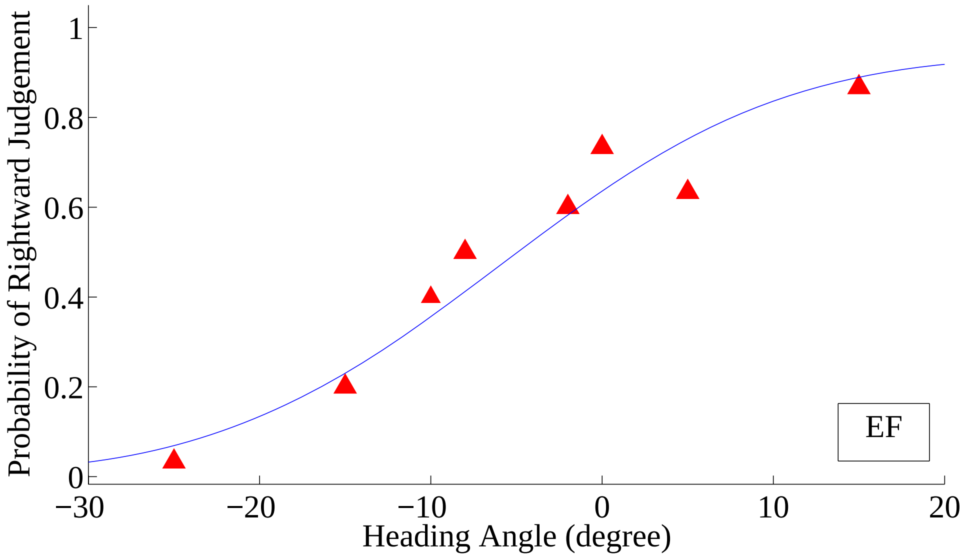


**Figure 3 Raw psychometric data for one subject at a standard heading of -5 degrees from the vestibular experiment. Data of probability of rightward from standard judgments plotted as a function of the heading direction relative to standard. Best fitting cumulative Gaussian shown as solid line.**

Figure 4 shows a psychometric function for a subject from the visual experiment with a standard heading of -5 degrees. From the best fitting cumulative Gaussian, we compute an uncertainty value of 2.8 and lapse parameters γ=0.003 and λ=0.059 for this specific case.

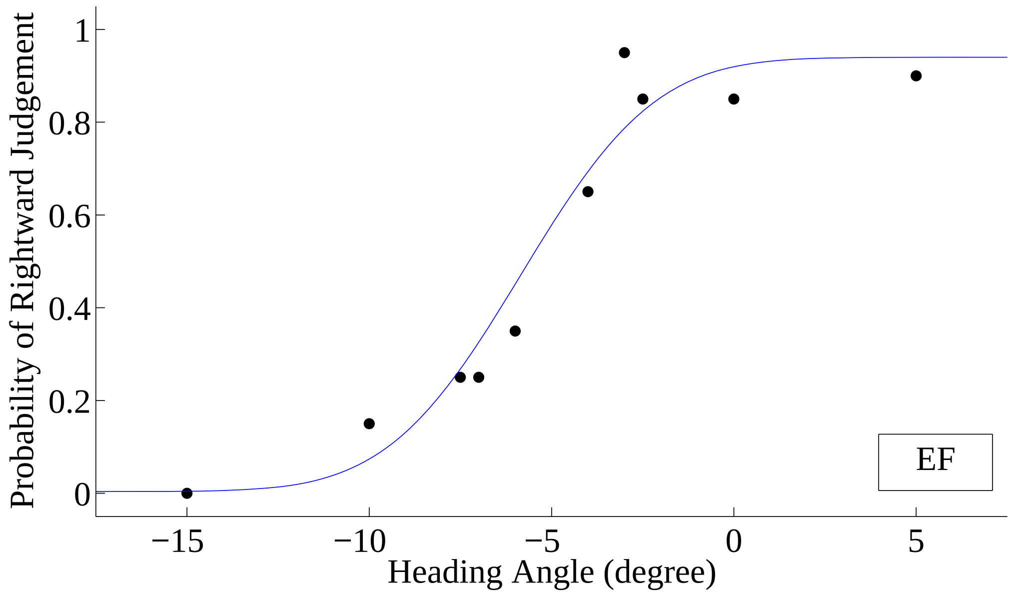


**Figure 4 Raw psychometric data for one subject at a standard heading of -5 from the visual experiment. Data of probability of rightward from standard judgments plotted as a function of the heading direction relative to standard. Best fitting cumulative Gaussian shown as solid line.**

Figure 5 shows the average and standard error of the mean of the uncertainty values for the five participants that completed the vestibular condition and the five participants that completed the visual condition. In the visual condition, there is an obvious correlation between the increase in heading eccentricity and an increase in uncertainty. We see that at the heading eccentricities of ±40 degrees, the average uncertainty value is at least three times more than the uncertainty values of the heading eccentricities of ±5 degrees. In the vestibular condition the uncertainty level is high but is more or less constant for all heading eccentricities.

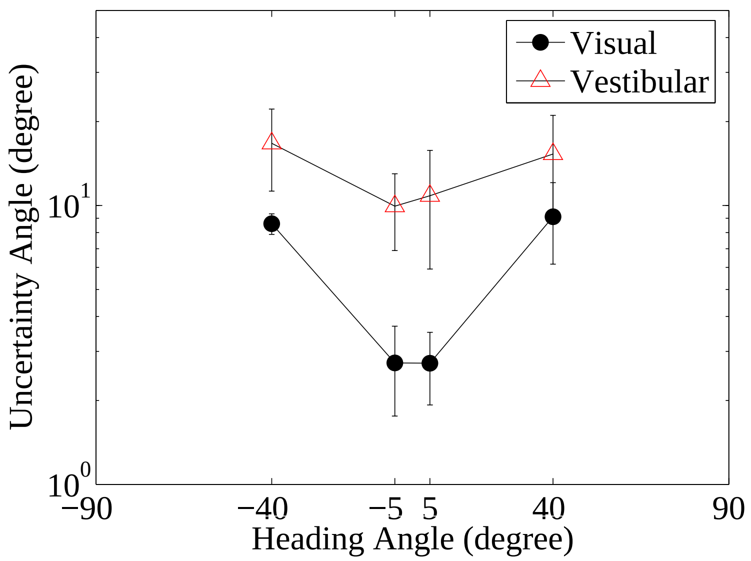


**Figure 5 Uncertainty as a function of standard heading angle for both visual and vestibular conditions. The error bars denote standard error of the mean.**

## Conclusion

These experiments show the dominant nature of the visual condition for the discrimination of forward linear translations. The large increase in visual uncertainty with respect to the heading eccentricity is still more reliable than the vestibular uncertainty at all reported eccentricities.

Benson et al., (1986) and Kingma (2005), have shown that the threshold of detection of motion for the anterior-posterior and lateral direction are similar. While this was not a detection experiment this finding could sheds some light on the uniform nature of the vestibular uncertainty across heading eccentricities. We also noted that with sustained training a subject can decrease their vestibular uncertainty, which was also reported by Benson et al., (1989) and Kingma (2005).

## Future work

We have begun experiments with a new visual stimulus, which has yielded larger uncertainty, with the added bonus of a larger field of view Celebrini et al., (1995). With the new visual condition, we will combine the visual and vestibular experiments; thus participants will be presented with a translation stimulus that had both vestibular and visual information. Using the uncertainty values from the vestibular-alone and visual-alone experiments, we will predict the outcome of this experiment using a maximum-likelihood method Ernst et al., (2004).

Bertin & Berthoz (2004) have shown a small initial vestibular motion can be used to distinguish ambiguous visual stimulus. With this in mind the continuation of these experiments can give insight into the processing of low level inputs which could be beneficial when considering visual and vestibular cues on a limited scale, as experienced in driving simulation.

We intend to reproduce these experiments on the recently acquired new setup, a simulator robot arm (KUKA RoboCoaster), see Figure 6, which will give us a much larger range of motion, See Table 1.

**Figure 6 KUKA RoboCoaster**

| Position | Stewart Platform | KUKA Robocoaster |
|---|---|---|
| x | 0.93 m | 1.6 m |
| y | 0.86 m | 4.0 m |
| z | 0.5 m | 2.0 m |
| Yaw | ±44 deg | ±45 deg |
| Pitch | +34/-32 | ±45 deg |
| Roll | ±28 | Unlimited |

**Table 1: Comparison of the range of motion of the Stewart Platform and the KUKA Robocoaster**

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