Supplementary Material for 'Determining the direction of vestibular-evoked balance responses using stochastic vestibular stimulation' by Mian OS and Day BL

Prior to all analyses, any dc offset was removed from raw time series on a segment by segment basis.

Cumulant Density

For in-depth detail, refer to Halliday et al (1995). In this analysis we used the Neurospec 1.0 MATLAB toolkit (www.neurospec.org). The SVS and F time series are broken down into non-overlapping segments of equal duration. Estimates of power spectra are obtained using the discrete Fourier transform on individual segments and then averaged across segments. The cumulant density function, $q_{AB}(u)$, defined as the inverse Fourier transform of the cross-spectrum, f_{AB}, is then calculated:

$$q_{AB}(u) = \int_{-\pi}^{\pi} f_{AB}(\lambda) e^{i\lambda u} d\lambda$$

where λ is frequency and *u* is lag. For analyses in the paper, we used 42 segments of 4096 data points each. At our sampling frequency of 1000 Hz this resulted in spectra with a frequency resolution of 0.244 Hz (see next section for discussion). Segments were not permitted to overlap trials. Thus, we discarded the first 1328 data points (1.328 s) from each trial, leaving 7 complete segments per trial. This approach utilised 172.032 s of the 180 s of data collected per condition. Positive and negative 95% confidence intervals were determined for the cumulant density as detailed in Halliday et al (1995 p.248).

Cumulant Density using different segment lengths

Segment length influences the frequency resolution of the spectra used in the construction of the cumulant density. With our sampling frequency of 1000 Hz, segment sizes of 4096, 8192, and 16384 data points lead to frequency resolutions (and therefore minimum included frequency) of 0.244 Hz, 0.122 Hz, and 0.061 Hz respectively.

To establish if the smaller segment sizes provide sufficient frequency resolution we determined power spectra for each 30 s stimulus period (trial) using 32768 point Fast Fourier transforms (*fft* function in MATLAB) (frequency resolution 0.03 Hz; zero padding used at end of each 30000 data point stimulus period) averaged across trials to obtain average spectra per subject, per condition. On average (across subjects and across conditions) the power contained up to 0.061 Hz, 0.122 Hz, and 0.244 Hz were 0.2 %, 0.5 %, and 4.1 % of the total F_{LabX} signal power and 0.4 %, 1.0 %, and 4.2 % of the total F_{LabY} signal power. In each case, we considered this negligible. The power contained in the SVS signal up to 0.244 Hz was just 1 % of total signal power.

Figure S1A shows the average (across subjects) SVS-F_{LabX} cumulant density in the head forward condition constructed using segment sizes of 4096, 8192, and 16384 from a fixed duration of data (98.304 s; resulting in 24, 12, and 6 disjoint segments respectively). This comparison was limited to 98.304 s because when preventing segments from overlapping trials, as was done here, our 30 s trials only enable a single 16384 point segment per trial. We used the initial 16384 data points per trial. The results reveal little difference in the cumulant density, particularly for the ML_F peak that is of interest in the current study.

Finally, the relationship between head angle and response direction was determined using different segment lengths for constructing the cumulant density. As above, this comparison was restricted to 98.304 s (utilizing first 16384 data points per trial). As shown in Table S1 there were no significant differences in the relationship when different segment lengths were used.

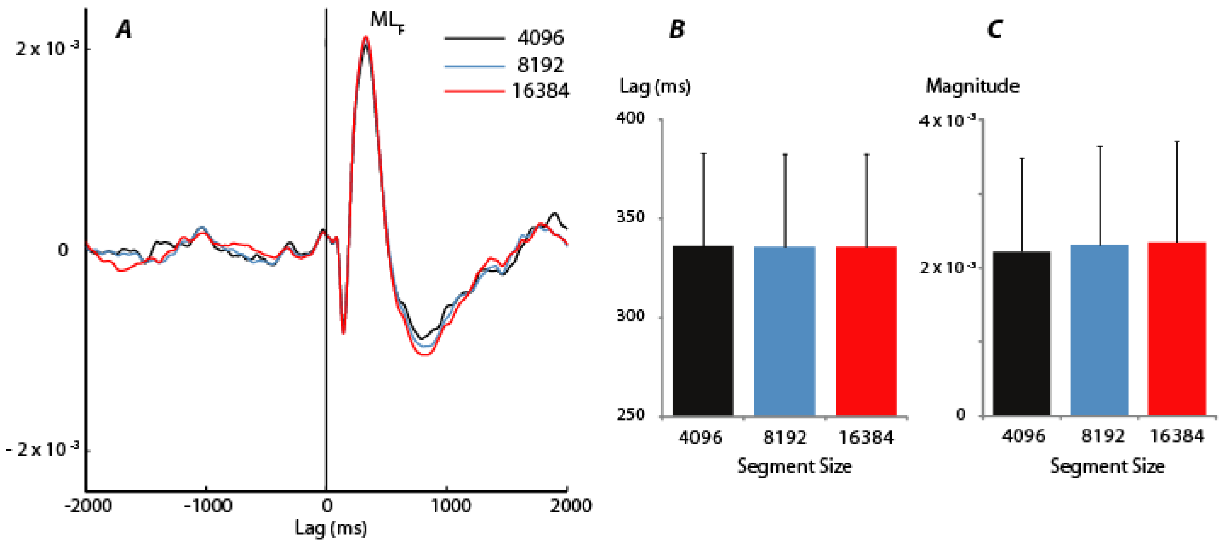

Figure S1. A) Average (across subjects) SVS-F_{LabX} cumulant density in the head forward condition using different segment lengths (4096, 8192, and 16384 data points). B) Lag and C) Magnitude of ML_F using the different segment lengths. Error bars show across-subjects standard deviation.

	Cumulant Density			Cross Correlation
Segment size	4096	8192	16384	16384
Number of segments	24	12	6	6
Intercept	-0.03 ± 6.2	-0.36 ± 6.1	-0.13 ± 6.3	-0.12 ± 6.5
Slope	1.03 ± 0.12	1.03 ± 0.11	1.03 ± 0.11	1.04 ± 0.11

Table S1. Mean +/- SD (across subjects) regression coefficients for the head angle – response direction relationship constructed using cumulant density with different segment lengths and using cross correlation as measures of the SVS-$F_{Rot\theta}$ relationship.

Cumulant Density versus Cross Correlation

We determined cross correlation using the *xcorr* function in MATLAB with the 'unbiased' normalization option. This normaliser divides the raw cross correlation at each lag by [L – l], where L is the number of data points in the segment and l is the lag data points. Figure S2 compares the average (across subject) cross correlation and cumulant density. Both are constructed (per subject) by averaging 6 x 16384 data point segments. Per subject we divided the average cumulant density or cross correlation by its root mean square value in the interval -2000 to -500 ms. This ad hoc scaling was employed to present the curves on an equivalent scale. As can be seen, both approaches produce virtually identical averaged curves.

Furthermore, Table S1 demonstrates that the use of cross-correlation to determine the head angle – response direction relationships does not produce a different result to the use of cumulant density.

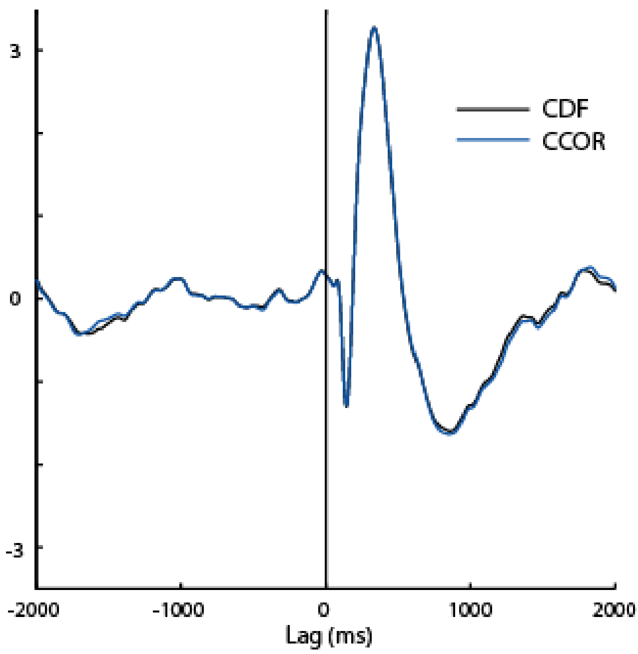

Figure S2. Average (across subjects) SVS-F_{LabX} cumulant density and cross correlation in the head forward condition. Both cumulant density and cross correlation have undergone ad-hoc scaling for comparison (see body text for details).

Repeatability Assessment

A comprehensive assessment of repeatability and reproducibility is yet to be conducted. Nine separate measurements, across an eight month period, made on one of the authors (OSM) (standing in the head forward condition and using the current stimulus properties) allows for an initial single subject, single condition assessment of variability. Analysis parameters were as used for the analysis in the paper. Measured response directions were in the range -3 to -12 deg (mean direction ± circular standard deviation of -7 ± 3 deg). Mean direction was calculated as the direction of the mean vector of the response direction unit vectors and circular standard deviation (SD) was calculated as

$$SD = \frac{180}{\pi} \sqrt{-2 \ln r}$$

where *r* is the length of the mean vector of the response direction unit vectors (Zar, 1999, p.599-604). Furthermore, we assessed the influence of data duration on variability by making measurements using 28.7, 57.3, 86.0, 114.7, 143.4, and 172.0 s of data (i.e., 1, 2...6 trials worth). As can be seen in Figure S3, using less than 172 s of data may produce less reliable results. Analysis using 57.3 s or less of data sometimes produced SVS-F CDFs which barely exceeded the 95 % confidence intervals (not shown) and resulted in particularly high response direction variability (Figure S3).

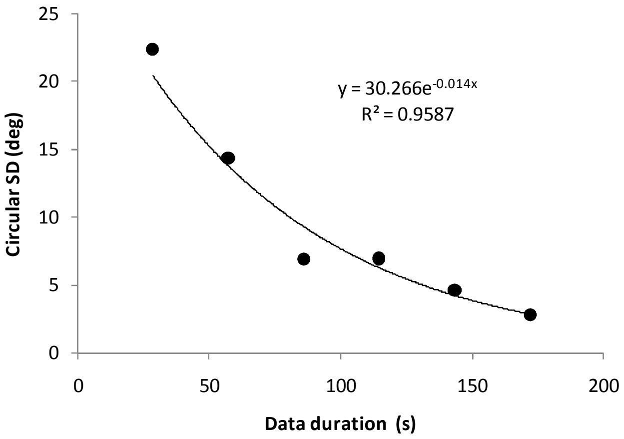

Figure S3. Inter-experiment variability (circular standard deviation) in measured response direction as a function of data duration. An exponential function is fitted to the data.