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Interaction of Semicircular Canals and Otoliths in the Processing Structure of the Subjective Zenith

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In order to discriminate between translatory and gravitational linear acceleration as well as to locate the direction of "up" (the subjective zenith, SZ) during and after movements an interaction of otoliths (linear acceleration sensors) and canals (angular velocity sensors) for human spatial orientation is necessary. Three basic assumptions underlying the present model of interaction are confirmed by experiments in which subjects were asked to adjust dynamically a display to their subjective vertical (SV) during and after motion stimuli.

1. Since translatory and gravitational acceleration cannot be measured separately, the processing structure proposed here is based on the assumption first made by Mayne[1], that in a low frequency range linear acceleration is interpreted as a change of gravitational acceleration. The slow increase of the subjective vertical (SV) in the "oculogravic illusion" experiment (see FIGURE 1 or, e.g., Reference 2) validates the assumption that estimation of gravitational acceleration uses the low pass filtered otolith afferents.
2. The function of the semicircular canals is to rotate the SZ contrary to the rotation of the head and accomplish a constant orientation. Thus high frequency changes of the direction of gravity are distinguished from translational acceleration. As found experimentally, after a brisk tilt around the X-axis of the head the SV reaches its static value very quickly.
3. Problems which arise from the dynamics of the semicircular canals (which indicate angular velocity fairly accurate only in a frequency range of app. 0.01 to 10.0 Hz) are solved in the proposed model by testing the canal output for plausibility and by blocking inappropriate information. This hypothesis is corroborated by a) the time course of the "oculogravic illusion" (see FIGURE 1; without blocking an oscillation of the SV would be expected) and b) own centrifuge experiments with "free" cabin (stimulation of the canals equivalent to a tilt of 60° without tilting the resulting acceleration vector has almost no effect on the SV). It is supposed that canal information is only used to rotate the actual estimate of gravity if this rotation would decrease the angle between the estimated gravity vector and the measured linear acceleration vector (otolith afferents).

The model (see FIGURE 2 for block diagram), which also incorporates the static model proposed by Mittelstaedt[4], is able to reproduce all of the mentioned experimental results and to explain some other phenomena like "orbiting" during barbecue spit rotation (see Reference 5).

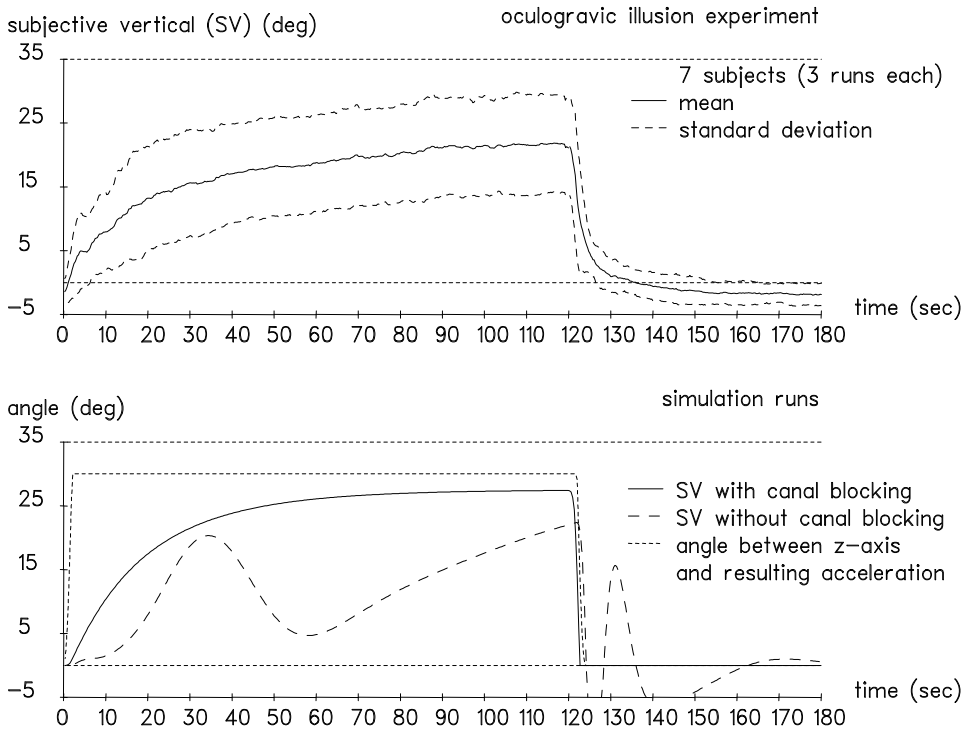

Figure 1 "Oculogravic illusion" experiment (upper part) and model simulations (lower part) with and without blocking of inappropriate canal information. The simulation with blocking is fitting the results, whereas an oscillating time course like that of the simulation without blocking has not been found experimentally (centrifuge data: radius 10m; angle between acting acceleration and z-axis of the head during run 30°, time from start to constant velocity app. 2 sec).

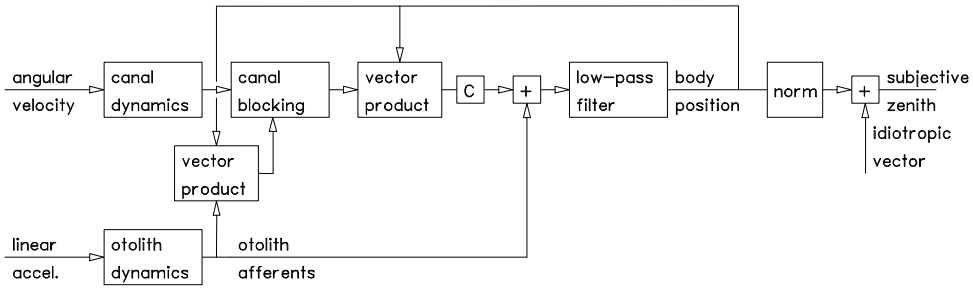

Figure 2 Block diagram of the three-dimensional processing structure of the subjective zenith. All model states are vectors. Sensor dynamics are modelled after Ormsby[3]. Short description of the diagram : "C" denotes a constant factor. "norm" means normalization of the input vector (for details on the last two parts of the model see Mittelstaedt[4]). "canal blocking" symbolizes a switch depending on both inputs, the output is either zero or equal to the output of the "canal dynamics". In the latter case the structure performs the rotation of the vector called "body position", in the former case "body position" becomes equal to the low-pass filtered otolith afferents.

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