Background

The vestibular system is the sensory mechanism of the inner ear (labyrinth) that helps the body maintain its postural equilibrium. There are two distinct sets of end organs in the labyrinth: the utricle and saccule within the vestibule, which respond to linear accelerations and changes in the position of the head with respect to gravity; and the semicircular canals, which respond to rotational movements (angular acceleration). The information that these organs deliver is proprioceptive in nature. The left and right utricular sensory epithelia (maculae) are in the same, approximately horizontal plane and because of this position they appear to be the dominant partner and are more useful than the saccular maculae in providing information about the position of the head and its side-to-side tilts when a person is in an upright position. The maculae are stimulated by shearing forces between the otolithic membrane and the cilia of the hair cells beneath it. However, the measurement or quantification of this 'otolith function' in patients is very difficult.

Many methods have been proposed to try and evaluate otolith function: ocular counter-rolling (OCR) induced by lateroflexion, whole body roll, eccentric rotation and translational acceleration have all been explored and promoted as indicators of vestibular otolith function [1]. However, these methods showed poor sensitivity and specificity, thereby preventing a sound clinical application [1].

Lateroflexion or body roll is a simple physiological test that changes the orientation of the head and the otolith system in space and measures the responses, such as eye movements in response to a counter roll. The subject tilts their head to one side and, as a consequence the eyes counter roll to a certain extent. Unfortunately, this simple test is associated with very low sensitivity and specificity and there is a large overlap between patients and healthy subjects. For example, an extensive study in healthy subjects can reveal a wide range of ocular counter rolling, from 3 to 11 degrees, induced by this simple lateroflexion test [2]

It is also possible to measure responses to a linear acceleration (translation), which is also one of the specific stimuli for the otolith system. A linear sled device can change a subject's position in space, is motor driven and can move very fast (up to 1.2 G). However, if the sled is moving very fast and thus causing substantial motion, it is important to reduce the movements of the head using a mask specifically designed for each subject. In addition, the sled involves complex and advanced technology, and so is very expensive, and again there is limited sensitivity and a large overlap between patients and healthy subjects. Responses can also be elicited by eccentric rotation in a 'human centrifuge' that can rotate up to 7 cycles/second and induce up to 6G [3]. Ocular counter rolling can be measured in this way, at constant rotation velocities with the amplitude of the response depending on the centrifugal force acting upon both labyrinths. When combining a centrifuge with a motor driven linear sled, it is also possible to test each of the labyrinths separately by rotation around one labyrinth in order to centrifuge the other labyrinth alone. Although this centrifuge technology has been used for many years, it is also associated with many problems and low sensitivities. The equipment is expensive, the eye movement responses are very small and correct position of the labyrinths difficult and responsible for false positive outcomes.

The aim of this study was therefore to investigate whether the thresholds for the perception of linear acceleration might allow for a better measure for the clinical evaluation of the otolith function than measurement of eye movements. When auditory and visual cues are excluded and body movement is minimised, the detection of dynamic motion stimuli of small intensity appears to be primarily dependent on the otolith and the somatosensory systems response to pressure changes on the body surface [4]. Previous studies have shown that when oscillatory stimuli of 0.3 – 0.4 Hz are employed, the thresholds for detection of linear movements in the horizontal plane range from 1.8 – 6.3 cm/s^2 for anterior-posterior (AP) accelerations and 1.9 – 5.7 cm/s^2 for lateral accelerations [5].

However, the literature shows that the acceleration thresholds vary with the stimulus profile used to determine the thresholds (sinus, parabolic, linear, steps), but that thresholds expressed in terms of velocity are more constant and less variable with the stimulus profile [6-9]. For example, Gianna et al observed mean normal thresholds of 4.84 cm/s2 using acceleration steps, 12.1 cm/s2 for linear ramps and 16.7 cm/s2 for parabolic stimuli [8,9]. Expressed in terms of velocity all thresholds were close to 20 cm/s. A practical problem of these stimulus profiles is that they require a long sled and that after each stimulus a deceleration period and adaptation period is required, which makes the test procedure long lasting. We therefore investigated the threshold for perception of the direction of linear horizontal motion using a raised cosine bell profile.

Methods

Whole body motion stimulus was generated by a motor driven linear sled running on a horizontal track of 4.2 metres (maximum velocity 3.7 m/s; maximum acceleration 1.2 m/s^2 adjustable in steps of 1 cm/s^2). The seat could be changed into one of two positions in which the