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(71) **Applicant**: **UNIVERSITÄT ZÜRICH** [CH/CH]; Prorektorat MNW, Rämistraße 71, CH-8006 Zürich (CH).

(72) **Inventor**: **HEGEMANN, Stefan**; Schneckenmannstr. 27, CH-8044 Zürich (CH).

(74) **Agent**: **SCHULZ JUNGHANS PATENTANWÄLTE**; Chausseestr. 5, 10115 Berlin (DE).

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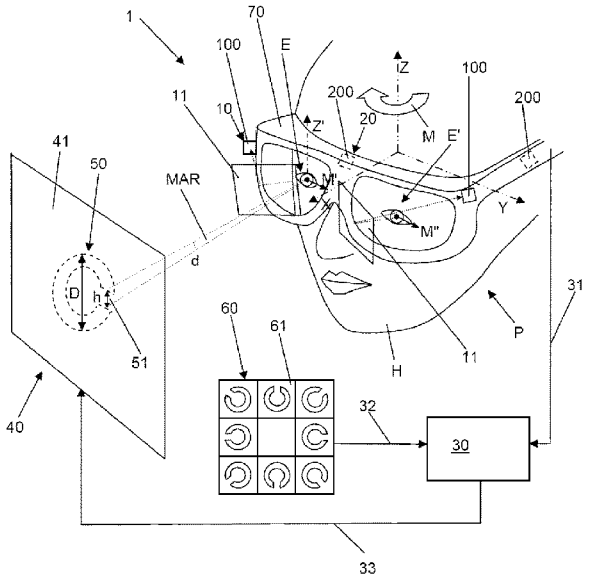
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(54) **Title**: SYSTEM FOR EXAMINING EYE MOVEMENTS, PARTICULARLY THE VESTIBULO-OCULAR REFLEX AND DYNAMIC VISUAL ACUITY

Figure 1



(57) **Abstract**: The invention relates to system (1) for examining simultaneously the vestibulo-ocular reflex and dynamic visual acuity, comprising: a sensor means (10, 20) being designed to detect a movement (M', M") of at least one eye (E, E') of a person (P) relative to the head (H) of the person (P) and a movement (M) of the head (H) with respect to a space-fixed coordinate system, and a processing means (30) interacting with said sensor means (10, 20), which processing means (30) is configured to process said detected movements (M, M', M"). According to the invention, the system (1) further comprises a display means (40) that is designed to display an optotype (50) on a screen (41) of the display means (40) for a pre-defined period of time, wherein the processing means (30) is configured to trigger the display means (40) for displaying the optotype (50) on the screen (41) depending on said movement (M) of the head (H) detected by the sensor means (20). Further, the invention relates to a method for determining the VOR and DVA.

System for examining eye movements, particularly the vestibulo-ocular reflex and dynamic visual acuity

Specification

The invention relates to a system for examining eye and head movements. Such a system comprises a sensor means being designed to detect a movement of at least one eye of a person (e.g. relative to the head of the person), particularly when said at least one eye fixates an optotype displayed on a screen in front of the person during a movement of the head generated by another person for instance (e.g. physician), wherein said sensor means is also designed to detect a movement of the head with respect to a space-fixed coordinate system, wherein said movement may be generated by another person that rotates the head an amount of 10 to 20°, particularly 15° randomly to the left or to the right about the vertical (head) axis (or an axis perpendicular to the plane of two vertical semicircular canals (LARP and RALP plane), i.e., in the axis of maximal vertical SCC sensitivity), while the person fixates the optotype by means of the at least one eye, and a processing means (processing unit) connected to said sensor means, which processing means is configured to process said detected movements, particularly to compare said movements and/or to determine said movement of the at least one eye with respect to said space fixed coordinate system in order to determine/estimate the vestibulo-ocular reflex (response) of the at least one eye associated to the respective movement of the head upon fixating the optotype.

Such a test is also known as a head-impulse-test (HIT) and serves for measuring the vestibulo-ocular reflex (VOR). The vestibular labyrinths of a human allow for measuring head position, head velocity and head acceleration in space. These parameters are used to stabilize the eyes in space during head movements. This reflex being the most essential reflex to optimize vision during head movements is called the vestibulo-ocular reflex (VOR). It is the fastest reflex in humans having a very short latency (typically about 7-10 ms) as well as a very high accuracy permitting eye stabilization and thus retinal image stabilization at head movements of high velocities (up to about 600deg/s) and high frequencies (up to about 20 Hz). No other visual system can completely surrogate or supplant it and some can only partly compensate it. To measure the VOR is a challenge for health care providers and several tests are often needed as a basis allowing for a clear diagnosis. Current

methods to measure vestibular function are often suboptimal with regard to some of the following aspects: accuracy, reproducibility, validity, sensitivity, specificity, patient acceptance or patient comfort, time and need for highly skilled operators. In HIT the variability is often generated by changing head accelerations or peak velocities. E.g. to reduce such variability, a limited range of head accelerations or velocities is helpful. Some of these tests cannot be performed simultaneously for technical or ethical reasons. An example would be the combination of bilateral bithermal vestibular stimulation - in the following called calorics - and rotary chair testing or HIT. Some tests can only measure special sensors in the vestibular organs, e.g. calorics, for instance merely the horizontal semicircular canals. Performing all available tests in patients would require high costs, extremely high skilled technical operators and intensive analysis of all available data to deal with partly contradicting results from the tests performed. Conducting all tests also causes discomfort for most patients.

Based on the above, the problem underlying the present invention is to improve the afore-mentioned system for examining eye movement concerning reliability, particularly to reduce discomfort for the person whose ocular motor system is to be examined.

This problem is solved by a system having the features of claim 1.

According thereto, the system according to the invention further comprises a display means that is designed to display an optotype on a screen (e.g. a beamer and a screen or a display such as an LCD) for a short period of time (e.g. 100 ms), such that the optotype can be seen by the person by means of the at least one eye of the person when the screen is positioned in front of the person and faces the at least one eye, wherein the processing means is configured to trigger the display means for displaying the optotype on the screen depending on said movement detected by the sensor means.

Thus, the system according to the invention allows for a combination of HIT with the dynamic visual acuity (DVA) test that measures (dynamic) visual acuity during fast head movements. It compares vision in stable head position and during head movements. Particularly, the type and number of head movements to be performed in DVA is almost identical to HIT. The visual target (optotype) is projected/generated on a screen and occurs only for a specified (short) period of time after the head velocity reaches a certain velocity for instance (other criteria are also conceivable, see below) triggering the target (optotype) appearance over said period of time.

Since visual stability during fast head movements can only be reached by a good VOR this test (DVA) is a (although subjective) measurement of the VOR, too, and reaches a sensitivity of up to 100% compared to the gold standard of HIT-testing, the magneto-oculographic search coil technique (Vital et al 2008). This is shown for the horizontal canals but vertical canals can also be tested with DVA. It is comparable to a pure tone audiogram which is also a subjective but easy to perform and well accepted method. Since it is subjective, reduced concentration and also simulation can reduce the expected results compared to HIT. On the other hand, if DVA is normal than the HIT must also be normal. If HIT-testing shows a pathologic VOR gain, than vision cannot be stabilized or the HIT result must be wrong. If both tests show similar results, than the reliability of these test results is markedly increased. In other words the combination of both tests, i.e., a corresponding system particularly allowing for performing these tests simultaneously supports the physician in making a more significant and reliable diagnosis. DVA may also work in the head heave and head surge test to measure otolith function, i.e. the function of the sensors for linear acceleration and gravity, or the linear VOR.

In one embodiment of the present invention, the processing means is configured to trigger the display means for displaying the optotype on the screen when the head reaches (or exceeds) a pre-defined velocity, acceleration and/or position, wherein particularly these quantities are angular quantities (i.e. angular velocity, acceleration and/or position) with respect to a specified rotation axis, for instance the vertical (head) axis. Other axes/coordinate systems may also be employed. However, said quantities may also correspond to linear velocity, linear acceleration and/or position.

Particularly, the processing means is configured to trigger the display means for displaying an optotype having an orientation that is randomly chosen out of a finite number of possible orientations. Usually such an optotype comprises a structure (feature), wherein particularly said orientations correspond to different positions of the structure obtained by rotating the optotype in its extension plane. In one variant of the invention, the optotype is a Landolt ring having a break (recess) as said structure, wherein the break comprises a length along the periphery of the ring that is one-fifth of the overall (outer) diameter of the ring, and wherein particularly said orientations correspond to the break being positioned at 0° (upwards), 45°, 90° (showing to the right), 135°, 180° (downwards), 225°, 270° (showing to the left), and 315° with respect to the vertical (when the system and person take their respective proper position).

According to an aspect of the invention, the processing means may control the display means to display a point or any other suitable structure on the screen, which disappears when the movement of the head starts, wherein the respective optotype appears at the position of said point. In case the optotype is a Landolt ring, the Landolt ring may appear around said point.

This allows the person to be tested to exactly fixate the respective optotype more easily. Preferably, the size of the point is constant and does not change when the size of the optotype changes.

The processing means (unit) may be formed by a computer, on which a suitable software is executed. The computer may have suitable interfaces for connecting to the sensor means, the display means and to an input means (see below).

According to an aspect of the invention, an input means being connected to the processing means is provided, wherein said input means preferably comprises a number of actuating elements (e.g. keys), wherein each of these actuating elements uniquely corresponds to one of the different orientations of the optotype (in case of a Landolt ring eight such actuating elements corresponding to the eight different orientation stated above may be present).

The person is advised to press the actuating element corresponding to the currently shown optotype. The pressed actuating element and the associated orientation (whether perceived correctly or not) may be stored for further processing by means of the processing means (e.g. computer).

Further, the processing means is particularly configured to reduce the outer diameter of the optotype during a test conducted with the system according to the invention in order to estimate a measure for the dynamic visual acuity, which particularly corresponds to the reciprocal value of the length of the break of the smallest Landolt ring in angular minutes that can be perceived by the person (with a pre-defined certainty).

A particularly interesting value is the visual loss, which can be determined by comparing the SAV (stable visual acuity) with the DVA, i.e., by subtracting from the stable visual acuity the DVA.

In case a structure of an optotype (break of a Landolt ring) is barely seen by the person during stable head position (i.e. the head is at rest and not pivoted randomly) under an angle of 2' (MAR for Minimum Angle of Resolution) for instance, the stable visual acuity is 0.3 logMAR. Hence, the outer diameter of the optotype (Landolt ring)

is varied (decreased) until the break of the Landolt ring is barely recognized. By means of the distance d between the at least one eye of the person and the length h of the break of the Landolt ring (along the peripheriy of the ring) said MAR [angular minutes] can be automatically determined by the processing means using

$$\text{MAR [angular minutes]} = 120 * \arctan(h/(2*d)),$$

where d is the distance between the at least one eye (person) and the screen (optotype). The decadic logarithm of this quantity (logMAR) is usually used as a unit when for stating the stable visual acuity (SVA).

In the same manner, the DVA can be determined, wherein this time the head of the person is moved as described above.

In one embodiment, the sensor means may be formed by a stationary camera that is not moving with the head and is designed to be arranged in front of the person in order to record (upon a movement of the head as described above) a sequence of images (movie or live stream) of the pupil of the at least one eye as well as of at least a region of the head (face) containing the at least one eye, wherein particularly the processing means is designed to determine from said sequence of images the movement of the at least one eye, particularly with respect to the head or a space-fixed coordinate system, as well as said movement of the head, particularly with respect to a space-fixed coordinate system.

Preferably, the processing means is designed to determine from said sequence of images the angular acceleration, angular velocity and/or angular position of the at least one eye (in three dimensions) with respect to a head-fixed and/or space-fixed-coordinate system.

Preferably, the processing means is also designed to determine from said sequence of images the angular acceleration, angular velocity and/or angular position of the head of the person (in three dimensions) with respect to a space-fixed-coordinate system.

In this regard, it is to be noted that – in case of a perfect VOR – the three dimensional rotation axes of the eye and head movement essentially coincide, wherein the directions of the rotations are opposite, i.e., there is almost no rotation of the respective eye with respect to a space-fixed coordinate system.

Further, as a head-fixed coordinate system for describing eye movements (rotations), one may also employ a three-dimensional coordinate system, in which each axis is perpendicular to an associated plane of a semicircular canal (see above).

In addition, the processing means may also be designed to determine from said sequence of images a linear acceleration, linear velocity, and/or linear position of the head (in three dimensions) with respect to a space-fixed-coordinate system.

In an alternative variant of the invention, the sensor means comprises (at least) a first sensor being designed to detect the movement of the at least one eye, particularly relative to the head of the person, as well as a second sensor being designed to detect the movement of the head of the person, particularly with respect to a space-fixed coordinate system. The first and second sensor may each consist of several sensor elements (components), which may be designed to detect movements concerning at least one direction (axis), respectively.

In this respect, the first sensor is designed to detect the angular acceleration, angular velocity and/or angular position (i.e. angle) of the at least one eye about a first rotation axis of the at least one eye, wherein particularly the first rotation axis of the at least one eye is a vertical rotation axis (yaw) with respect to an upright position of the head of the person (i.e. with respect to a head-fixed coordinate system). Furthermore, the first sensor may be designed to also detect the angular acceleration, angular velocity and/or angular position (angle) of the at least one eye of the person about a second rotation axis of the at least one eye (also denoted as pitch) extending orthogonal to the first rotation axis, wherein particularly the second rotation axis is a (further) horizontal rotation axis extending particularly along the frontal plane of the person. Furthermore, the first sensor may be also designed to detect the angular acceleration, angular velocity and/or angular position (angle) of the at least one eye about a third rotation axis of the at least one eye (also denoted as roll) running orthogonal to the first and/or second rotation axis. Particularly, the third rotation axis is also a horizontal rotation axis running along the sagittal plane of the person. From the movements (components) along the three orthogonal axes, the three-dimensional axes of head and eye rotation in space can be calculated (e.g. by the processing means).

Likewise, in a variant of the invention, the second sensor is designed to detect the angular acceleration, angular velocity and/or angular position (i.e. angle) of the head about a first rotation axis, wherein particularly the first rotation axis is a vertical rotation axis with respect to an upright position of the head of the person (this is also denoted as yaw). Further, the second sensor may be designed to also detect the angular acceleration, angular velocity and/or angular position (angle) of the head of the person about a second rotation axis (also denoted as pitch) running orthogonal to

the first rotation axis, wherein particularly the second rotation axis is a (further) horizontal rotation axis extending particularly along the frontal plane of the person. Furthermore, the second sensor may be also designed to detect the angular acceleration, angular velocity and/or angular position (angle) about a third rotation axis (also denoted as roll) running orthogonal to the first and/or second rotation axis. Particularly, the third rotation axis is also a horizontal rotation axis running along the sagittal plane of the person.

Alternatively (or in addition), in another variant of the invention, the second sensor is preferably designed to (also) detect a linear acceleration, linear velocity, and/or (linear) position of the head at least along a first translation axis, particularly also along a second translation axis orthogonal to the first translation axis, particularly also along a third translation axis orthogonal to the other translation axes. Therefrom, of course, the three-dimensional movement (particularly axis in case of a linear movement) in space may be calculated by means of the processing means.

In a preferred embodiment of the invention, the processing means is adapted to trigger the display means for displaying the optotypes when the head (due to its respective movement) reaches (or exceeds) a pre-defined angular acceleration, angular velocity, and/or angular position with respect to the first rotation axis (vertical). Other criteria related to other axes and movements of the head (see above) are also conceivable.

In order to be able to also track the eye movement of the person being a response to the respective head movements, the first sensor comprises at least one camera in an embodiment of the invention, particularly a CCD-camera, that is designed to capture (i.e. record) the pupil of the at least one eye. Particularly, the second sensor comprises a mirror that is designed to be arranged in front of the at least one eye so as to reflect light coming from the pupil into the camera (i.e. on an objective of the camera so that said light can be detected by the CCD of said camera). Preferably, the first sensor comprises an infrared light source (such as an IR diode) that is designed to illuminate the pupil with infrared light that can be detected by the camera. Particularly, said mirror is a beam-splitter (e.g. a half silvered mirror), which is transparent so that the person can recognize the displayed optotypes through the mirror.

Of course, the first sensor may also comprise a camera for the other eye of the person in an analogous fashion, so that the system may measure the VOR/DVA of both eyes (or either the left eye or the right eye). The camera does not necessarily

need a beam splitter. One may also employ a camera, which may directly detect the eye movement without being displaced by the head movement (e.g. a space-fixed camera), which may be designed to simultaneously detect head movement and eye movement in a space-fixed coordinate system (see above).

Particularly, the at least one camera generates (records) a movie or live stream of the at least one eye, wherein the processing means is preferably configured to analyze said stream, particularly a contour (shape) of the pupil or reflections in the region of the pupil, in order to determine the direction along which the eye moves (e.g. the three-dimensional eye rotation) as a response to the respective head movement.

In an alternative embodiment, the first sensor may instead comprise at least one search coil being designed to be attached to the at least one eye (or two such search coils for each eye so that measurements can be performed with respect to both eyes of the person), wherein the first sensor particularly comprises at least one magnetic field generation means. Particularly, the magnetic field generation means may be designed to generate three magnetic fields each being associated to a different spatial axis of a (space-fixed) coordinate system, which fields oscillate with different pre-defined frequencies such that currents of corresponding frequencies are induced in the search coils, which allow for determining the movement of the at least one eye with respect to said axes. In case a search coil is fixed to the head of the person to be tested also the head movement in space can be measured (gold standard).

Particularly, the search (induction) coil may be embedded in a flexible carrier (e.g. a ring or a kind of contact "lens"), which may be produced out of a silicone rubber, and which can be attached to the limbus of the at least one eye so that it is arranged concentric with respect to the cornea. Particularly, for detecting different directions, an alternating horizontal and vertical magnetic field (spatially and temporally in quadrature) may be generated by the magnetic field generation means such that two analog voltages may be obtained from the search coil(s), which are proportional to the sine of the horizontal and vertical eye position, i.e., the angular movement about the vertical axis (yaw) and about the horizontal axis (pitch). In addition to this, a further search coil may be provided (for each eye) being wound in the sagittal plane, so that the horizontal, vertical and torsional eye position (roll) can be measured (with respect to a space-fixed coordinate system since the magnetic field generation means is preferably static, i.e., not moving with the head).

According to a further aspect of the invention, the processing means is configured to store a time series of the angular velocity of the head, particularly about the first rotation axis (e.g. vertical axis), and the angular velocity of the at least one eye (or of both eyes), particularly about the first rotation axis of the respective eye, particularly when the head of the person is rotated, particularly about the first rotation axis (vertical axis or yaw), while fixating by means of the at least one eye (or both eyes) an optotype displayed on the screen. In this regard, it is to be noted that in all embodiments described herein, the first rotation axis of the head and the first rotation axis of the at least one eye (or further eye) may be the actual three-dimensional rotation axis of the respective rotational movement or any other (suitable) three-dimensional rotation axis (in a space-fixed coordinate system for head movements or in a head- or space-fixed coordinate system for eye movements) that can be used to describe the respective rotational movement or components thereof.

Preferably, the processing means is configured to determine from said recorded movements (angular velocity over time) the vestibulo-ocular reflex (VOR) gain, namely for instance by determining the ratio between said angular velocity of the head and said angular velocity of the at least one eye (for instance at the respective peak angular velocity of the head).

In this regard, the processing means may be configured to display the angular velocity of the head, particularly about the first rotation axis (vertical axis), and the angular velocity of the at least one eye (or both eyes), particularly about the first rotation axis of the eye, particularly in real time, in order to visualize deviations between the two angular velocities in particular, wherein the processing means is particularly designed to display the two angular velocities (e.g. on a screen of the processing means or a print-out generated by the processing means) on top of each other or in a mirror-symmetrical manner with respect to the time axis, wherein in case the two angular velocities are displayed on top of each other, one of the two velocities is particularly inverted by the processing means, so that in case of a VOR gain of essentially 1.0, the two velocities (as a function of time) are essentially congruent. This allows one to determine eye movements that do not originate from the vestibulo-occular reflex (VOR) such as fast saccades that occur during the respective head movement or after the end of it. Alternatively, the processing means may be designed to display the two velocities such that they oppose each other, i.e., such that they are (essentially) mirror-symmetrical with respect to the time-axis in case of a VOR gain being equal to 1.0.

In order to be able to fix the sensors (especially the cameras being designed to move with the head) to the head of the person whose VOR/DVA is to be measured, the system preferably comprises a retainer that is designed to circulate the head along a periphery of the head (such as a goggle) in order to secure the retainer on the head of the person. The retainer has a tight fit so that it does not move with respect to the head, when the latter is moved (rotated). The retainer may be adjustable in order to guarantee said tight fit.

Instead of moving the person's head manually (e.g. physician or another skilled operator), the system according to the invention may comprise a movement generating device that is designed to be controlled by the processing means, wherein the movement generating device comprises a first element that is mounted on a second element, wherein the first element can be moved with respect to the stationary second element by means of at least one actuator (such as a motor), and wherein the first element is designed to be coupled to the head of the person, such that the head can be moved by the at least one actuator along a pre-defined track, which may be variable. Preferably, the movement generating device is designed to move the first element such that the head (coupled to the first element) is rotated, particularly about a vertical axis. The generated movement of the head may also correspond to a translation or superposition of a translation and a rotation when necessary.

Particularly, the processing means may be designed to trigger movements of the first element randomly in opposite directions, particularly rotations about the vertical head axis. The movement generating device can also be formed by a device as described in detail in WO2009/129222 A2 for instance.

A further aspect of the present invention is to control the display means by means of the eye position (movement). For this, the eye-movement signal as generated by the sensor means or alternatively by the first sensor (see above) has to be send to a processing means controlling the displayed image (e.g. optotype) according to said eye position. The system thus enables retinal image stabilization even during eye movement or the control of retinal shift. This may also be combined with stabilization of gaze in space, i.e. on a target, even during simultaneous head and eye movements.

In detail, such a system may comprise a sensor means, particularly as described above, being designed to detect a movement of at least one eye of the person relative to the head, and a processing means connected to the sensor means, which

processing means is configured to process the detected movement, wherein the device further comprises a display means (e.g. a beamer and an associated screen or a display such as an LCD) that is designed to display an image, particularly an optotype, on a screen, such that the image/optotype can be seen by the person by means of the at least one eye of the person when the screen is positioned in front of the person and faces the at least one eye, wherein the processing means is configured to control the display means in order to adjust a position of the image/optotype on the screen depending on said movement (position) of the at least one eye, particularly so as to stabilize the image on the retina of the at least one eye or to control retinal shift.

In order to also stabilize gaze in space, the sensor means may further be designed to detect a movement of a head of the person (with respect to a space-fixed coordinate system for instance), wherein the sensor means (e.g. the second sensor) interacts with the processing means, and wherein the processing means is configured to control the display means in order to adjust a position of the image on the screen depending also on said movement (position) of the head.

Again, as already described above, the sensor means may be formed by a single stationary camera or may consist of further units/devices, e.g., a first and a second sensor (see above).

The afore-described systems may all comprise a stimulating device interacting with the processing means, which stimulating device is designed to stimulate the vestibular sensors of the person, particularly by means of caloric vestibular, galvanic vestibular, air-conducted or bone-conducted stimulation.

Further, the problem according to the invention is solved by a method for examining eye movements, particularly the vestibulo-ocular reflex (VOR) and dynamic visual acuity, according to claim 20, wherein the method is particularly conducted using a system according to the invention, wherein the method comprises the steps of:

- generating a pre-defined number of movements of a persons head, wherein upon each head movement an optotype is automatically displayed for a pre-defined period of time on a screen in front of that person who's head exceeds a certain acceleration, velocity and/or reaches a certain position (due to the respective movement),
- wherein during each of these movements the respective head movement as well as movements of the at least one eye of the person trying to fixate the optotype

are automatically detected, particularly by a sensor means (for instance as described above),

- determining the dynamic visual acuity with help of the displayed optotypes which the tested person is trying to recognize, wherein particularly the respective answers of the person are fed into the processing means (for evaluation of the DVA) via an input means (see above) or some comparable method, and wherein
- the vestibulo-ocular reflex gain is determined (simultaneously) by means of the detected movements of said head and the associated detected movements of the at least one eye trying to fixate the respectively displayed optotype when said head undergoes the respective movement.

Preferably, for determining DVA, upon each movement, an optotype having an orientation that is randomly chosen out of a finite number of possible orientations is displayed when said head of said person exceeds a certain acceleration, velocity and/or reaches a certain position due to the respective movement, wherein particularly said optotype comprises a structure or detail as already described above so that said orientations correspond to different positions of said structure/detail obtained by rotating the optotype in the plane of the screen.

Particularly, the person to be tested is asked to actuate one of a plurality of actuating elements of an input means connected to said processing means, wherein the actuating element has to be actuated that corresponds to the currently displayed optotype, wherein particularly the processing means stores whether the actuated actuating means corresponds to the displayed optotype or not. Thus, by analyzing which of the optotypes were recognized correctly by the person, a determination of DVA is possible. The visual loss can be determined by comparing the DVA with the SVA (see above).

Now, the dynamic visual acuity is particularly determined from the smallest optotype that can be resolved by the person (with a pre-defined certainty). Therefore, during the test, an outer diameter of the displayed optotypes is stepwise reduced between successive movements of the head of the person in order to find the smallest optotype whose orientation can be correctly recognized by the person. Alternatively, the DVA may be calculated by the head velocity or acceleration for which an optotype of a fixed size is still barely visible.

Particularly, in case of an optotype in the form of a Landolt ring the dynamic vision acuity corresponds to the reciprocal value of the length of the break of the smallest Landolt ring in angular minutes that can be perceived by the person.

Preferably, said movements of the head of the person are generated by another person (e.g. by a physician) or are automatically generated.

Further features and advantages of the invention shall be described by means of detailed descriptions of embodiments with reference to the Figures, wherein

Fig. 1 shows a schematic overview of the setup of a system according to the invention, and

Fig. 2 shows the head and corresponding eye velocity in case of a proper VOR and in a case where eye adaptation needs additional saccades.

Figure 1 shows a system 1 according to the invention for measuring the VOR as well as DVA.

The system 1 comprises a first sensor 10 comprising two CCD cameras 100 for generating a live stream of the eyes E, E' of a person P whose eye movements M', M'' shall be examined. Light coming from the eyes E, E' (an illumination of the eyes by means of an infrared source is possible) is coupled into the optical path of the respectively associated camera 100 by means of a half-silvered (transparent) mirror 11, which is arranged in front of the respective eye E, E'. The cameras 100, mirrors 11 and eventually an infrared source are fastened to a goggle-like retainer 70 that can be fixed on the head H of the person (P).

The system 1 further comprises a second sensor 20 fastened to the retainer 70 for detecting a movement M of the head H about the rotation axes Z, Y and X, wherein presently a rotation M of the head H by an angle of approximately 15° about the vertical axis Z is considered that is randomly generated by another person (either to the left or to the right). The second sensor 20 may comprise a sensor component 200 arranged on the retainer 71 at the fore head of the person P for measuring rotation about the Z axis (first rotation axis or yaw) and about the Y axis (second rotation axis or pitch) and another sensor component 200 positioned on a side of the head (H) for measuring rotation about the X axis (third rotation axis or roll).

The sensors 10, 20 are connected via a data connection 31 to a processing means 30 that is designed to determine from the live stream of the cameras 100 the current position and thus movement M', M'' of the eyes E, E' relative to the head H being a

reaction to the head's H movement M. Instead of the sensors 10, 20 also the single stationary camera described above may be employed.

In order to determine VOR and DVA simultaneously, the head M is moved a number of times, wherein for each such random head rotation M (either to the left or to the right, see above) the angular velocity V of the respective head movement M and the corresponding angular velocities V of the eyes E, E' are stored by means of the processing means 30, wherein the person P is told to fixate a Landolt ring 50 that is displayed on a screen 41 of a display means 40 upon each movement M of the head H, once the respective movement M of said head H fulfils a certain criterion, e.g., shows a threshold angular velocity, acceleration and/or position. Thus, the eye movements M', M'' are movements compensating for the respective random head movement M and thus allow for accessing VOR and DVA. In order to be able to trigger the display means 40 properly, the latter is connected via a data connection 33 to the processing means 30 that is designed to trigger the display means 40 according to said pre-defined criterion.

In order to determine DVA the person P is asked to identify the orientation of the break 51 of the Landolt ring 50 that is shown during a head movement M by pressing a uniquely associated actuating element 61 of an input means 60 being connected via a data connection 32 to the processing means 30. The orientations are chosen randomly by the processing means 30 and the outer diameter D of the Landolt ring is reduced from time to time by the processing means 30 (for instance the Landolt ring 50 shown in Figure 1 has an orientation corresponding to a position of 270° of the break 51 with respect to the vertical; thus the key 61 showing a ring opening to the left has to be pressed).

Then, the DVA of the person P can be computed from the smallest Landolt ring 50 whose orientation can be correctly identified. The corresponding MAR is given by

$$\text{MAR [angular minutes]} = 120 * \arctan(h/(2*d)),$$

wherein d is the distance between the person's eyes E, E' and the optotype 50 (i.e. screen 41). The DVA is usually stated using logMAR, i.e., the decadic logarithm of the MAR (see also above). (Comparing the DVA with the SVA that may determined in beforehand using the system according to the invention (static head), the visual loss can be determined, see above).

At the same time, the VOR can be for instance determined by comparing the respective head movement M with the corresponding eye movements M', M''. Therefore, the processing means 30 is designed to record said movements M, M', M''

and to compare the head movements M to the associated eye movements M', M'' as illustrated in Figure 2, which shows the head movement's angular velocity V (solid line) over the time t when the head H is abruptly pivoted about the yaw axis Z for an angle between 10° to 20°, for instance, and more slowly back to its initial position. Also shown is the angular velocity V about the vertical eye rotation axis Z' of eye E for instance in case of a proper VOR where the eye movement M' essentially corresponds to the head movement M and the VOR gain (ratio between head and eye angular velocity V) is essentially 1.0 (dashed dotted line).

Also shown is a case where the VOR does not function properly (dashed line). As can be inferred from the angular velocity V of the eye E additional saccades S are needed to compensate for the head movement M and the VOR gain is significantly below 1.0. In Figure 2 the velocities of the eye E are inverted for comparing them to the head movement M.

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Claims

1. System, for examining eye movements, particularly for examining synchronously the vestibulo-ocular reflex and dynamic visual acuity, comprising:

   - a sensor means (10, 20) being designed to detect a movement (M', M'') of at least one eye (E, E') of a person (P), particularly relative to the head (H) of the person (P), as well as a movement (M) of the head (H) of the person (P), particularly with respect to a space-fixed coordinate system, and

   - a processing means (30) interacting with said sensor means (10, 20), which processing means (30) is configured to process said detected movements (M, M', M''),

   characterized in that,

   the system (1) further comprises a display means (40) that is designed to display an optotype (50) on a screen (41) of the display means (40) for a pre-defined period of time, wherein the processing means (30) is configured to trigger the display means (40) for displaying said optotype (50) on the screen (41) depending on said movement (M) of the head (H) detected by the sensor means (20).

2. System as claimed in claim 1, **characterized in that** the processing means (30) is configured to trigger the display means (40) for displaying the optotype (50) on the screen (41) when the head (H) reaches a pre-defined velocity (V), acceleration and/or position.

3. System as claimed in claim 1 or 2, **characterized in that** the processing means (30) is configured to trigger the display means (40) to display an optotype (50) having an orientation that is randomly chosen out of a finite number of possible orientations, wherein particularly the optotype (50) comprises a structure (51), wherein particularly said orientations correspond to different position of the structure (51) obtained by rotating the optotype (50) in a plane along which the screen (41) extends, wherein particularly the optotype (50) is a Landolt ring having a break (51) as said structure, wherein the break (51) comprises a length (h) that is one-fifth of the outer diameter (D) of the ring (50), and wherein particularly said orientations correspond to the break (51) being positioned at 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315° with respect to the vertical (Z).

4. System as claimed in claim 3, **characterized in that** the system (1) comprises an input means (60) being connected to the processing means (30), wherein the input means (60) comprises a number of actuating elements (61), wherein each of these actuating elements (61) corresponds to one of the different orientations of the optotype (50).

5. System as claimed in one of the preceding claims, **characterized in that** the processing means (30) is configured to reduce the outer diameter (D) of the optotype (50) in order to determine the dynamic visual acuity of the person (P), which particularly corresponds to the reciprocal value of the length (h) of the break (51) of the smallest Landolt ring (50) in angular minutes that can be perceived by the person (P).

6. System as claimed in one of the claims 1 to 5, **characterized in that** the sensor means is formed by a camera, particularly a CCD camera, being designed to be arranged in front of the person (P) so as to record a sequence of images of the pupil of the at least one eye (E, E') as well as of at least a region of the head (H) of the person (P), wherein particularly the processing means (30) is designed to determine from said sequence of images the movement (M', M'') of the at least one eye (E, E'), particularly with respect to the head (H) or a space-fixed coordinate system, as well as said movement (M) of the head (H), particularly with respect to a space-fixed coordinate system.

7. System as claimed in one of the claims 1 to 5, **characterized in that** the sensor means (10, 20) comprises a first sensor (10) being designed to detect the movement (M', M'') of at least one eye (E, E'), particularly relative to the head (H) of the person (P), as well as a second sensor (20) being designed to detect the movement (M) of the head (H) of the person (P), particularly with respect to a space-fixed coordinate system.

8. System as claimed in claim 7, **characterized in that**, the first sensor (10) is designed to detect the angular acceleration, angular velocity (V) and/or angular position of the at least one eye (E, E') with respect to a first rotation axis (Z') of the at least one eye (E, E'), wherein particularly the first rotation axis (Z') of the at least one eye (E, E') is a vertical rotation axis, wherein particularly the first sensor (10) is designed to detect the angular acceleration, angular velocity (V) and/or angular position of the at least one eye (E, E') with respect to a second rotation axis of the at least one eye (E, E') running orthogonal to said first rotation axis (Z') of the at least one eye (E, E'), wherein particularly the second

rotation axis of the at least one eye is a horizontal rotation axis extending particularly along the frontal plane of the person (P), wherein particularly the first sensor (10) is designed to detect the angular acceleration, angular velocity (V) and/or angular position of the at least one eye (E, E') with respect to a third rotation axis of the at least one eye (E, E') running orthogonal to the first and/or second rotation axis of the at least one eye (E, E'), wherein particularly the third rotation axis of the at least one eye (E, E') is a horizontal rotation axis running along the sagittal plane of the person (P).

9. System as claimed in claim 7 or 8, **characterized in that** the second sensor (20) is designed to detect the angular acceleration, angular velocity (V) and/or angular position of the head (H) with respect to a first rotation axis (Z), wherein particularly the first rotation axis is a vertical rotation axis (Z), wherein particularly the second sensor (20) is designed to detect the angular acceleration, angular velocity (V) and/or angular position of the head (H) with respect to a second rotation axis (Y) running orthogonal to said first rotation axis (Z), wherein particularly the second rotation axis is a horizontal rotation axis (Y) extending particularly along the frontal plane of the person (P), wherein particularly the second sensor (20) is designed to detect the angular acceleration, angular velocity (V) and/or angular position of the head (H) with respect to a third rotation axis (X) running orthogonal to the first and/or second rotation axis (Z, Y), wherein particularly the third rotation axis (X) is a horizontal rotation axis running along the sagittal plane of the person (P).

10. System as claimed in claim 7 or 9, **characterized in that** the second sensor (20) is designed to detect a linear acceleration, linear velocity, and/or linear position of the head (H) at least along a first translation axis, particularly also along a second translation axis orthogonal to the first translation axis, particularly also along a third translation axis orthogonal to the other translation axes.

11. System as claimed in one of the claims 6 to 10, **characterized in that** the processing means (30) is configured to trigger the display means (40) for displaying an optotype (50) when the head (H) reaches a pre-defined angular acceleration, angular velocity (V), and/or angular position, particularly with respect to the first rotation axis (Z), or in that the processing means (30) is configured to trigger the display means (40) for displaying an optotype (50) when the head (H) reaches a pre-defined linear acceleration, velocity (V), and/or position, particularly with respect to at least one of the linear axes.

12. System as claimed in claim 7 or one of the claims 8 to 11 when referred back to claim 7, **characterized in that** the first sensor (10) comprises at least one camera (100), particularly a CCD-camera, that is designed to capture the pupil of the at least one eye (E, E') in order to detect said movement (M', M") of the at least one eye (E, E'), wherein the first sensor (10) particularly comprises a mirror (11) that is designed to be arranged in front of the at least one eye (E, E') so as to reflect light coming from the pupil into the camera (100), and wherein particularly the first sensor (10) comprises an infrared light source that is designed to illuminate the pupil with infrared light, wherein particularly the first sensor (10) comprises a further camera (10), particularly a CCD-camera, that is designed to capture the pupil of a further eye (E') of the person (P) in order to detect a movement of the further eye (E'), wherein the first sensor (10) particularly comprises a further mirror (11) that is designed to be arranged in front of the further eye (E') so as to reflect light coming from the pupil of the further eye (E') into the further camera (100), and wherein particularly the first sensor (10) comprises a further infrared light source that is designed to illuminate the pupil of the further eye (E') with infrared light.

13. System as claimed in claims 7 or one of the claims 8 to 11 when referred back to claim 7, **characterized in that** the first sensor (10) comprises at least one search coil being designed to be attached to the at least one eye (E, E"), wherein the first sensor (10) particularly comprises at least one magnetic field generation means, which magnetic field generation means is particularly designed to generate at least one magnetic field such that said movement (M', M") of the at least one eye (E, E') corresponding to a rotation of the at least one eye (E, E') about a first rotation axis (Z') of the at least one eye (E, E'), particularly a vertical rotation axis, induces a voltage in the search coil representing said rotation, wherein particularly the first sensor (10) comprises a further search coil being designed to be attached to a further eye (E') of the person (P), such that a movement (M") of the further eye (E') corresponding to a rotation of the further eye (E') about a first rotation axis (Z') of the further eye (E'), particularly a vertical rotation axis, induces a voltage in the further search coil representing said rotation of the further eye (E').

14. System as claimed in claim 6 or in claims 8 and 9, **characterized in that** the processing means (30) is designed to record the angular velocity (V) of the head (H) about the first rotation axis (Z) and the angular velocity (V) of the at least one

eye (E, E') about the first rotation axis (Z') of the at least one eye (E, E'), particularly when the head (H) of the person (P) is rotated about the first rotation axis (Z) while fixating by means of the at least one eye (E, E') an optotype (50) displayed on the screen (41), wherein particularly the processing means (30) is designed to determine the vestibulo-ocular reflex gain by determining the ratio between said angular velocity (V) of the head (H) and said angular velocity (V) of the at least one eye (E, E'), wherein particularly the processing means (30) is designed to display the angular velocity (V) of the head (H) about the first rotation axis (Z) and the angular velocity (V) of the at least one eye (E, E') about the first rotation axis (Z') of the at least one eye (E, E'), particularly in real time, in order to visualize deviations between said two angular velocities (V) in particular, wherein the processing means (30) is particularly designed to display the two angular velocities (V) on top of each other, wherein one of the two velocities (V) is particularly inverted by the processing means (30), so that in case of a VOR gain of essentially 1.0, the two velocities (V) are essentially congruent.

15. System as claimed in claim 7 or one of the claims 8 to 14 when referred back to claim 7, **characterized in that** the system (1) comprises a retainer (70) for retaining the first and second sensor (10, 20), which retainer (70) is designed to fix the first and second sensor (10, 20) on the head (H) of the person (P), wherein the retainer (70) is designed to circulate the head (H) along a periphery of the head (H).

16. System as claimed in one of the preceding claims, **characterized in that** the system (1) comprises a movement generating device interacting with the processing means (30), wherein the movement generating device comprises a first element that is mounted on a second element, wherein the movement generating device is designed to move the first element with respect to the second element by means of at least one actuator, and wherein the first element is designed to be coupled to the head (H) of the person (P), such that the head (H) is taken along when the first element is moved with respect to the second element, wherein the movement generating device is particularly designed to move the first element such that the head (H) is rotated, particularly about a vertical axis (Z), and/or translated.

17. System, particularly according to one of the preceding claims, wherein particularly the system is adapted for retinal image stabilization, comprising:

- a sensor means (10) being designed to detect a movement (M', M") of at least one eye (E, E') of the person (P), particularly relative to the head (H) of the person (P),

- a processing means (30) interacting with the sensor means (10), which processing means (30) is configured to process said detected movement (M', M"),

characterized in that,

the system further comprises a display means (40) that is designed to display an image, particularly an optotype (50), on a screen (41), wherein the processing means (30) is configured to control the display means (40) in order to adjust a position of the image on the screen (41) depending on said movement (M', M") of the at least one eye (E, E'), particularly so as to stabilize the image on the retina of the at least one eye (E, E').

18. System as claimed in claim 17, **characterized in that** the sensor means (20) is designed to detect a movement (M) of a head (H) of a person (P), particularly with respect to a space-fixed coordinate system, wherein the sensor means (20) interacts with the processing means (30), and wherein the processing means (30) is configured to control the display means (40) in order to adjust a position of the image on the screen (41) depending also on said movement (M) of the head (H), particularly so as to stabilize the gaze on the image.

19. System as claimed in one of the preceding claims, **characterized in that** the system (1) comprises a stimulating device connected to the processing means (30), which stimulating device is designed to stimulate the vestibular sensors of the person (P), wherein particularly said stimulating device is designed to provide for caloric vestibular, galvanic vestibular, air-conducted or bone-conducted stimulation.

20. Method for examining eye movements, particularly the vestibulo-ocular reflex and dynamic visual acuity, wherein the method is particularly conducted using a system as claimed in one of the claims 1 to 16, the method comprising the steps of:

- moving a head (H) of a person (P) several times,

- wherein upon each of said movements (M) of the head (H) an optotype (50) is displayed for a pre-defined period of time on a screen (41) in front of the

person (P) when the head (H) of the person (P) exceeds a certain acceleration, velocity (V) and/or reaches a certain position,

- wherein upon each of said movements (M) of the head (H) of the person (P) the respective movement (M) of the head (H) as well as a respective movement (M', M") of the at least one eye (E, E') of the person (P) trying to fixate the optotype (50) when the head (H) undergoes the respective movement (M) is detected, wherein particularly the movements (M', M") of the at least one eye (E, E') and said movements (M) of the head (H) are detected by means of a sensor means (10, 20),
- determining the dynamic visual acuity with help of the displayed optotypes (50),
- estimating the vestibulo-ocular reflex of the at least one eye (E, E') with respect to said movements (M) of the head (H) by means of a processing means (30) connected to said sensor means (10, 20), particularly by comparing detected movements (M) of the head (H) with associated detected movements (M', M") of the at least one eye (E, E') trying to fixate the respectively displayed optotype (50) when the head (H) undergoes the respective movement (M).

21. Method as claimed in claim 20, **characterized in that** upon each movement (M) of the head (H) an optotype (50) having an orientation that is randomly chosen out of a finite number of possible orientations is displayed when the head (H) of the person (P) exceeds a certain acceleration, velocity (V) and/or reaches a certain position, wherein particularly the optotype (50) comprises a structure (51), wherein particularly said orientations correspond to different positions of the structure (51) obtained by rotating the optotype (50) in the plane of the screen (41), wherein particularly the optotype is a Landolt ring having a break (51) as said structure (51), wherein the break (51) comprises a length (h) that is one-fifth of the outer diameter (D) of the ring (50), and wherein particularly said orientations correspond to the break (51) being positioned at 0°, 45°, 90°, 135°, 180°, 225°, 270°, or 315° with respect to the vertical (Z).

22. Method as claimed in claim 21, **characterized in that** to each orientation of the optotype (50) an actuating element (61) of an input means (60) connected to the processing means (30) is associated, wherein the person (P) is advised to actuate the actuating element (61) that corresponds to the respectively displayed

optotype (50), wherein particularly the processing means (30) determines from the respectively actuated actuating element (61) whether the respective orientation was recognized correctly by the person (P).

23. Method as claimed in one of the claims 20 to 22, **characterized in that** the outer diameter (D) of the displayed optotypes (50) is stepwise reduced between two successive movements (M) of the head (H) of the person (P) in order to determine the dynamic visual acuity.

24. Method as claimed in one of the claims 20 to 23, **characterized in that** the dynamic visual acuity is determined from the smallest optotype (50) that can be correctly recognized by the person (P), wherein particularly in case of an optotype (50) in form of a Landolt ring the dynamic visual acuity corresponds to the reciprocal value of the length of the break of the smallest Landolt ring in angular minutes that can be perceived by the person (P).

25. Method as claimed in one of the claims 20 to 24, **characterized in that** said movements (M) of the head (H) of the person (P) are generated by another person or are automatically generated, particularly such that the person (P) is not able to anticipate the respective movement (M) of its head (H) in beforehand.

Figure 1

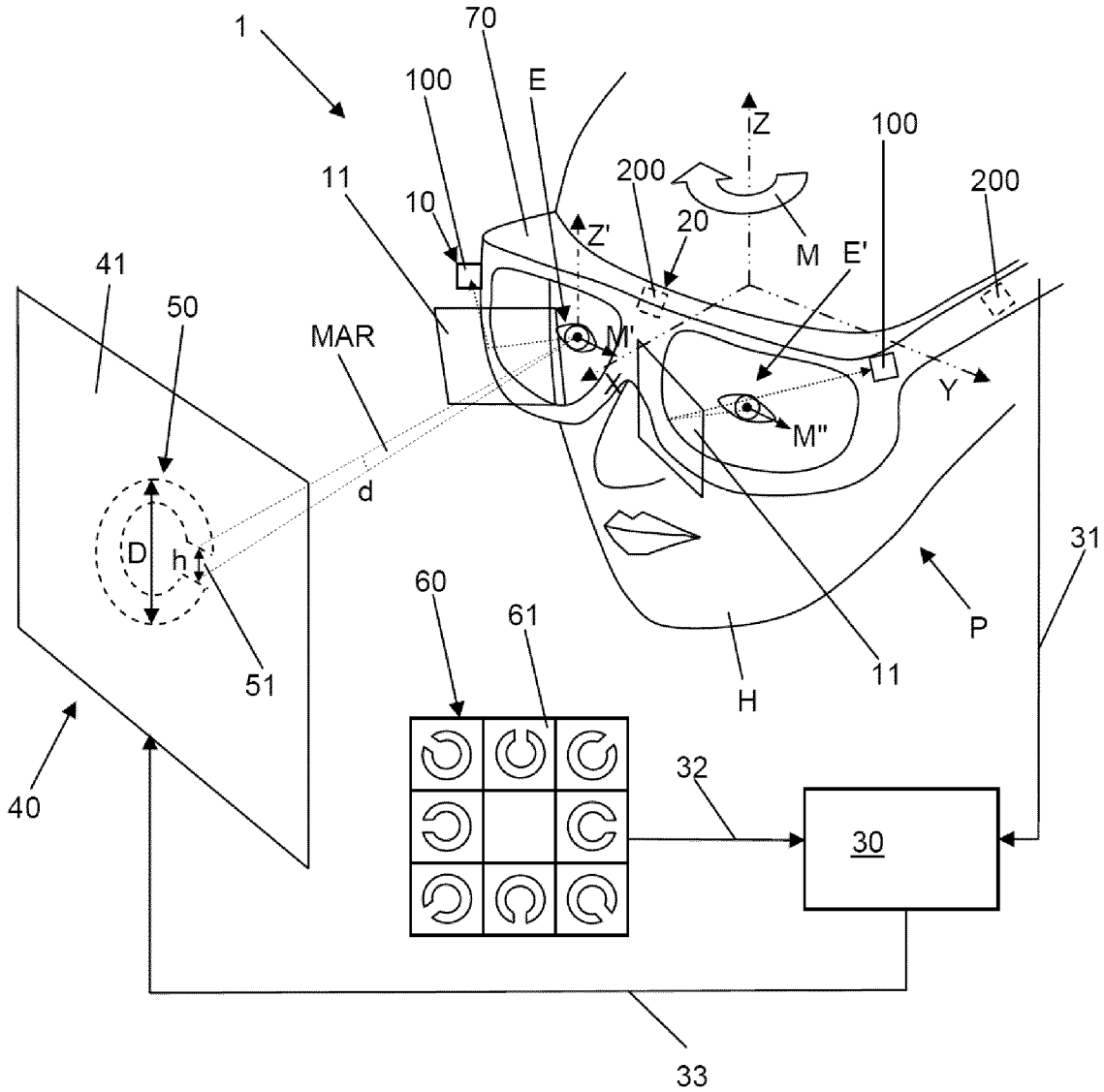
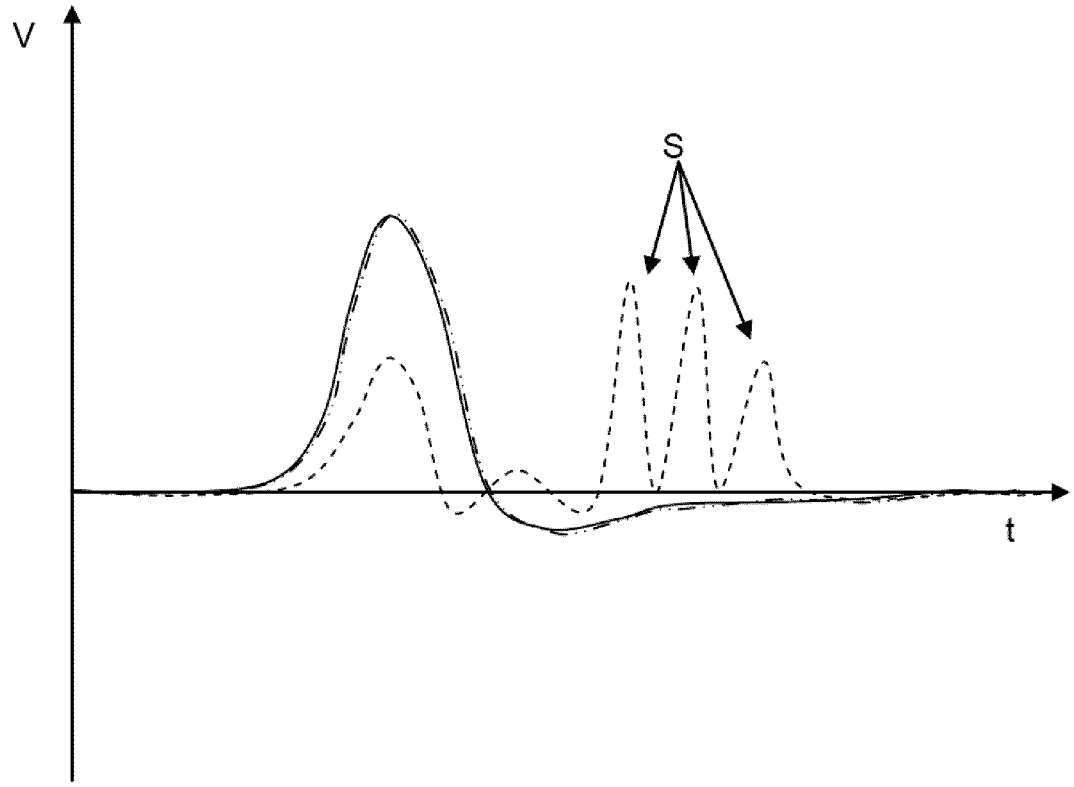

1
70
100
E
Z
100
11
10
200
20
200
Z'
M
E'
41
50
MAR
M'
Y
M"
d
D
h
31
60
61
P
51
H
11
40
32
30
33

Figure 2



INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/052595

A. CLASSIFICATION OF SUBJECT MATTER
INV. A61B3/00 A61B3/113 A61B5/11
ADD. A61B5/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
A61B G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	TIAN J R ET AL: "Dynamic visual acuity during transient and sinusoidal yaw rotation in normal and unilaterally vestibulopathic humans", EXPERIMENTAL BRAIN RESEARCH, SPRINGER INTERNATIONAL, DE, vol. 137, no. 1, 1 March 2001 (2001-03-01) , pages 12-25, XP002526120, ISSN: 0014-4819, DOI: 10.1007/S002210000640	1-5, 7-11,13, 14,16, 20-25
Y	abstract	6,12,15
A	page 12, paragraph Introduction - page 15, paragraph Data analysis figures 1A,1B	17-19
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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 May 2013	24/05/2013

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Artikis, T

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2013/052595

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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INTERNATIONAL SEARCH REPORT

Information on patent family members

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PCT/EP2013/052595

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