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(54) **DEVICE FOR STIMULATING AND TRAINING VISUMOTOR, AUDITIVE, COGNITIVE AND POSTURE FUNCTIONS OF AN INDIVIDUAL**

(57) The invention concerns a device for stimulating and training visumotor, auditive, cognitive and posture functions of an individual in integrative way. Such integrative physiologic approach is a must in order to better understand symptoms in patients, orient treatment and evaluate progress. Together with eye movement capture and analysis it provides objective measurement and data on patients' functionalities, which is essential for evidence-based medicine, also for communicating with the patient and its environment, for pedagogic aspect, e.g. communicating between different medical and paramedical professionals following up the patient. Neuro cognitive functions such as those of selective attention (e.g. Stroop) are up to now based on verbal reports; the methods provides additional time, space measures based on eye movements. The invention also relates to uses and methods of using the device for functional exploration, follow-up or training of individuals in need thereof.

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Description

TECHNICAL FIELD OF THE INVENTION

[0001] The invention concerns a device for stimulating and training visumotor, auditive, cognitive and posture functions of an individual. In particular, the invention concerns a device for evaluating and training visumotor, auditive, cognitive and posture deficits due to physiologic ageing, trauma or neurologic, neuro-otologic, or ophthalmic pathologies.

BACKGROUND ART

[0002] Binocular stimulations are often used to detect various neurological pathologies and are often used to cure these pathologies by the training these stimulations.

[0003] Document US 8 851 669 B1 describes a device called REMOBI device. REMOBI is a device enabling audio-visual stimulation and training of eye movements in 2D, i.e., horizontal and depth.

[0004] However, there is a need to improve such a device in order to:

- permit complete 3D (i.e., not only horizontal and depth, but also vertical and combined horizontal, vertical and depth) stimulation and training of eye movements,
- improve adherence to functional exploration and training protocols of individuals, and
- further add easily other types of stimulations, including postural and cognitive stimulations.

SUMMARY OF THE INVENTION

[0005] The invention responds to these needs.

[0006] To this end, the invention provides a device for stimulating and training visumotor, auditive, cognitive and posture functions of an individual, the device comprising:

- a flat support comprising a lower surface and an upper surface, the flat support being adapted to be positioned in front of an individual;
- a plurality of light diffusion means for visual stimulation arranged on the upper surface, a light diffusion means being configured to diffuse a light according to an intensity and a color;
- a plurality of sound diffusion means arranged on the upper surface, each sound diffusion means being configured to diffuse a sound according to a sound level and a frequency; one light diffusion means and one sound diffusion means defining an audio-visual set;

  the audio-visual sets being arranged regularly along iso-vergence arcs symmetrical with respect to a longitudinal axis of the flat support and positioned along the upper surface, and along the longitudinal axis between the iso-vergence arcs; for each audio-visual set one light diffusion means being adjacent to a sound diffusion means;
  the device comprising a control system configured to control the intensity and the color of each light diffusion means and/or to control the sound level and the frequency of each sound diffusion means and to control a spatio-temporal activation of the light diffusion means and the sound diffusion means according to several predefined protocols.

[0007] The invention according to the first aspect may comprise by the following features, alone or in combination technically possible:

- the predefined protocols comprise a duration of activation of each light diffusion means and/or each sound diffusion means;
- the color(s) used in the predefined protocol for the light diffusion means is(are) chosen among: red, orange, yellow, green, blue, cyan, purple, white, a mixture of several colors;
- the control system is further configured to count the number of light diffusion means of each selected color during a predetermined protocol;
- the device comprises a foot on which the flat support is mounted, the foot being connected to the lower surface of the flat support;
- the foot is configured to adjust the height of the of the flat support allowing the flat support to be positioned appropriately at the eyes level of an individual positioned in front of the flat support;
- the foot is configured to adjust the tilt of the flat support in horizontal position, in vertical position, or in tilted position in either direction, an upper part being further from the individual than a lower part of the flat support or vice versa;
- the flat support is trapezoidal;

- the device comprises at least three iso-vergence arcs, preferably four isovergence arcs;
- nine light diffusion means and nine sound diffusion means forming nine audiovisual sets are arranged on each iso-vergence arc, preferably one of the nine audio-visual sets is arranged at the intersection of the iso-vergence arc and the longitudinal axis, and four audio-visual sets are arranged on the iso-vergence arc on either side of the longitudinal axis.

[0008] The device of the invention thus proposes a complete technology for evaluating and training vision, audition, and cognition deficits due to physiologic ageing, trauma or neurologic, neuro-otologic, or ophthalmic pathologies. In particular, it is an improved version of the REMOBI (referred to as "REMOBI-NeuroCog"), which permits innovative specific stimulation protocols for functional evaluation and training (also referred to as "reeducation") of individuals in need thereof, enabling to precisely identify their deficiencies by complete functional exploration, and to train them using specific new protocols to decrease their deficiencies and finally improve their quality of life.

[0009] The present invention thus also relates to various uses of and methods of using the device of the invention for functional exploration of vision, audition and/or cognition deficiencies. In particular, the present invention also relates to the use of the device according to the invention, for measuring binocular motricity parameters in an individual.

[0010] The present invention also relates to a method for measuring binocular motricity parameters in an individual, comprising:

a) putting the individual in front of the device according to the invention, and
b) subjecting the individual to a saccade protocol, a vergence protocol, a combined protocol, or any combination thereof, using the device according to the invention, wherein the individual is given eye movement instructions to follow the lighted diffusions means such as diodes of the device with both eyes.

[0011] The present invention also relates to the use of the device according to the invention for decreasing a visual, an auditory, a cognitive deficit and/or a posture instability in an individual in need thereof.

[0012] The present invention also relates to methods for decreasing a visual, an auditory, a cognitive deficit and/or a posture instability in an individual in need thereof, comprising subjecting the individual to training sessions with the device according to the invention.

DESCRIPTION OF THE FIGURES

[0013] Other characteristics, purposes and advantages of the invention will be apparent from the following description, which is purely illustrative and non-limitative, and should be read in conjunction with the attached drawings on which:

Figure 1 illustrates a schematic view of a device according to an embodiment of the invention.
Figures 2, 3, 4, 5 and 6 illustrate several positions of the device of the invention in front of an individual.
Figures 7A, 7A, 7A & 7D illustrate a summary of multiple positions of the device of the invention.
Figure 8 illustrates an upper surface of the flat support of the device of the invention.
Figure 9 illustrates a possible implementation of the device of the invention.
Figure 10: Spatial arrangement of the horizontal saccade test when the flat support 10 is in horizontal position. The targets were randomly interleaved in order to test saccades eye movements in different blocks. Individuals looked successively at different diodes; from the initial (here 100 cm, but the same protocol could be used to test saccades at other depths of 20 or 36 cm) fixation diode to the target diode for saccades (15° to left to target T or to the right to target T'). Each trial starts with the fixation target that appears for a variable period of 1200 to 1800 ms; following this period the target diode lights are on for 2000ms together with a paired buzzer preceding 50 ms and lasting only 100ms.
Figure 11A, **11B & 11C:** saccade tests experiment Set-Up when the flat support 10 is in vertical position.
Figure 12. Spatial arrangement of the vergence test when the flat support 10 is in horizontal position. The targets were randomly interleaved in order to test saccade eye movements in different blocks. Individuals looked successively at different diodes; from the initial (36 cm) fixation diode (F), to the target diode for divergence (100 cm, T) or the target diode for convergence (20 cm, T'). Each trial starts with the fixation target that appears for a variable period of 1200 to 1800 ms; following this period the target diode lights are on for 2000ms together with a paired buzzer preceding 50 ms and lasting only 100ms.
Figure 13. Spatial arrangement of the combined test when the flat support 10 is in horizontal position. The targets were randomly interleaved in order to test saccades eye movements in different blocks. Individuals looked successively at different diodes; from the initial (36 or 100 cm, F1 or F2) fixation diode to the target diode for combined movement (T1' or T1 when starting from F1, T2' or T2 when starting from F2). Each trial starts with the fixation target that appears for a variable period of 1200 to 1800 ms; following this period the target diode lights are on for 2000ms

together with a paired buzzer preceding 50 ms and lasting only 100ms.

Figure 14. Method for saccade analysis, illustrated for saccades of 20° in an individual with vergence disorders (TC). All trials are superimposed at t = 0, the instant of target appearance. The bold lines show an individual trial of saccade to the left (A, B): Onset (I) and offset (P) of eye movements were defined according to velocity threshold (V), traces of velocity being illustrated at the bottom (C). Note that coordination of saccades may be evaluated from the disconjugate amplitude (B).

Figure 15. Exemplary trajectories of the eye movements of a healthy (non-dyslexic, A) and a dyslexic (B) individual during reading of one line of text. In this figure, on the x-axis we have time; in y the conjugate signal of both eyes in degrees, showing the succession of saccades to the right followed by fixations fixing the words one after the other, then the large saccade to the left to start reading the next line. Regression saccades are further present for the dyslexic individual.

Figure 16. Method for vergence analysis: convergence and divergence were obtained by subtraction of right eye (RE) position from the left eye (LE) position (LE - RE). The corresponding velocity trace is shown *below*. Mark of onset and offset of vergence is based on velocity criteria: the time point when the eye velocity respectively exceeded or dropped below 5°/s. The *horizontal dotted lines* indicate the targets' (T for divergence, T' for convergence) position.

Figure 17. Vergence rehabilitation experiment Set-Up. Temporal (A) and spatial (B, C) arrangements of REMOBI divergence (B) and convergence (C) training blocks. Double-step targets used for divergence and convergence rehabilitation are shown in (B, C) from F to T1 or T2, the first target location; then to T'1 or T'2, the final target location.

Figure 18. Analysis of combined eye movements before reeducation in an individual with hemineglect due to stroke. (A) Experimental set-up for analysis of combined eye movements. (B) Conjugate signals (right and left saccades) during combined eye movements before reeducation.

Figure 19. Vestibular test before reeducation in an individual with hemineglect due to stroke. (A) conjugate (left+right eyes positions/2) and (B) disconjugate (left eye position - right eye position) signals measured during the vestibular test.

Figure 20. Reading test before reeducation in an individual with hemineglect due to stroke. (A) conjugate (left+right eyes positions/2) and (B) disconjugate (left eye position - right eye position) signals measured during the reading test.

Figure 21. Saccade tests before reeducation in an individual with hemineglect due to stroke. Saccades measured at (A) far distance (150 cm), (B) intermediate distance (70 cm) and (C) very near distance (20 cm) are presented.

Figure 22. Saccade test after reeducation in an individual with hemineglect due to stroke. Saccades measured at very near distance (20 cm) are presented.

Figure 23. Analysis of combined eye movements after reeducation in an individual with hemineglect due to stroke. (A) Experimental set-up for analysis of combined eye movements. (B) Conjugate signals (right and left saccades) during combined eye movements before reeducation.

Figure 24. Summary of the main and interaction effects of the 3-Way ANOVA with repeated measures for Latency. Latency means and 0,95 confident intervals in function of movement (D for Divergence, C for Convergence, LS for left saccade, RS for right saccade), age group (Y for young group, E for elderly group) and modality target (AV for audiovisual target, V for visual target).

Figure 25. Summary of the main and interaction effects of the 3-Ways ANOVA with repeated measures for Gain amplitude. Gain amplitude means and 0,95 confidence intervals in function of movement (D for Divergence, C for Convergence, LS for left saccade, RS for right saccade), age group (Y for young group, E for elderly group) and modality target (AV for audiovisual target, V for visual target).

Figure 26. Regression lines between convergence AVI and age, for A) AVI(Lat) B) AVI(AVel) and C) AVI(Amp), regarding the whole population (YG+EG) and EG alone. Square points represent the participants of the YG; triangle points represent the participants of the EG. The black solid line represents the regression line for the whole population (YG+EG) and the red dashed line represents the regression line for the EG. The "r" represents the Pearson correlation coefficient and the "p" represents the significance of the slope of the regression line.

Figure 27. Regression lines between saccades AVI(Lat) and Stroop_D/I, for the YG+EG. Square points represent the participants of the YG; triangle points represent the participants of the EG. The black solid line represents the regression line for the whole population (YG+EG). The "r" represents the Pearson correlation coefficient and the "p" represents the significance of the slope of the regression line.

Figure 28. Saccades of a presbycusis individual at very low light intensity and variable sound intensity (A) very low light intensity, no sound (B) very low light intensity, 10% of 75 decibels (subliminal) (C) very low light intensity, 100% of 75 decibels.

Figure 29. Vergence test an individual with concussion before reeducation.

Figure 30. Reading test of an individual with concussion before reeducation.

Figure 31. Saccade test an individual with concussion before reeducation.

Figure 32. Vergence test a dyslexic individual before (A) and after (B) training with REMOBI-NeuroCog.

Figure 33. Reading test of a dyslexic individual before training with REMOBI-NeuroCog.

Figure 34. Reading test of a dyslexic individual after training with REMOBI-NeuroCog.
Figure 35. Eye traces when using the REVA training period for a dyslexic individual, during a first random block mixing 5 colours (A), 2 random blocks mixing 3 colours (B, C) and a regular block (D).
Figure 36. Eye movement traces during the three Stroop conditions (A, D: reading, B, E: naming colour, C, F: interference) before (A, B, C) and after (D, E, F) the REVA training for a dyslexic individual.
Figure 37. Eyes traces during REVA protocols in an autist child. The child was subjected to (A) a random protocol with sound, (B) a regular protocol with visual stimulation only, in which the diodes were presented regularly, step by step, from left to right, going from the upper to down series of diodes, but with no sound, or (C) a regular protocol with audio-visual stimulation, in which the diodes were presented regularly from left to right, going from the upper to down series of diodes, with sound now present before each diode. The child was asked to speak up the colours. The speed of diodes lightening was 1000 ms in all conditions.

DETAILED DESCRIPTION OF THE INVENTION

Device

[0014] **Figure 1** illustrates a device 1 for stimulating cognition and audition of an individual or a patient based on one or more predefined protocol(s) according to an embodiment of the invention.
[0015] The device 1 includes a flat support 10 comprising an upper surface 10a and a lower surface 10b to be positioned in front of the individual.
[0016] The flat support 10 comprises a longitudinal axis AA (also referred to as a "central axis") which is an axis of symmetry for the flat support 10. On Figure 1 the longitudinal axis AA is shown on the upper surface 10a. Also, the flat support 10 comprises an upper part 10c opposite to a lower part 10d.
[0017] The flat support 10 may have several shapes: trapezoidal, rectangular, triangular, etc.
[0018] The flat support 10 is preferably supported by a foot 2 mounted on a base 3. The base 3 can comprise wheels 31 for moving the flat support 10 allowing a good positioning of the device 1. Alternatively, the flat support 10 can be placed on a table (not shown). In that case, the device does not comprise a foot, the foot 2 can be detachable from the flat support 10. The base 3 is intended to be positioned on a plane surface such as a floor. The foot 2 is advantageously configured to adjust the height and the tilt of the flat support 10. This permits to adjust the height of the flat support 10 so that it is positioned at eyes level in front of an individual that may be either in seated position or in standing position. The possibility of using the device in standing position permits to include postural stimulation during the protocols.
[0019] In particular, the foot 2 permits to place the flat support 10 at eye level at a height going from 120 cm to 180 cm for instance or less depending on the individual's height.
[0020] The foot 2 is also configured to adjust the tilt of the flat support 10 from a horizontal position (if the foot is vertical, then the flat support 10 will be perpendicular it) to a vertical position. To this end, the foot 2 comprises a mechanism known from the person skilled in the art that enables the flat support 10 to be positioned in several directions from a horizontal position to a vertical position relative to the base or the individual (for instance at 45 degrees or completely verticalized in relation to the base 3). In addition, the flat support 10 can be positioned in a tilted position in either direction (upper part 10c being further from the individual than the lower part 10d of the support 10 or vice versa). As it will be described in the following, the device 1 is preferably used with an eye tracker ET (also referred to as an eye movement acquisition and recording system).
[0021] **Figure 2** shows an individual P in a seated position in front of the device with the flat support 10 in horizontal position relative to the foot 2. **Figure 3** shows an individual P in a standing position in the front of the device with the flat support 10 in horizontal position relative to the foot 2. **Figure 4** shows the device with the flat support 10 in vertical position relative to the foot 2 in front of an individual P in a standing position (it is also possible to have the device in this vertical position with the individual in a seated position). **Figure 5** shows the device in a tilted position with the upper part 10c further from the individual P and **Figure 6** shows the device in another tilted position with the lower part 10d further from the individual P. **Figures 7A, 7B, 7C** and **7D** illustrate the various position of the flat support 10 in relation to the foot 2 by showing the longitudinal axis AA of the support in relation to the foot 2: horizontal, vertical and tilted. Therefore, due to the multiple positions provided by the foot 2, the device 1 can be used either in the seated or standing position, and with the flat support 10 in horizontal, tilted or vertical position relative to the individual or the base 3.
[0022] In case the flat support 10 is trapezoidal, an individual is intended to be positioned toward the narrow base (i.e., the lower part 10c) of the flat support 10 (see **Figures 2, 3 and 4).** In case the flat support 10 is a triangle, an individual is intended to be positioned toward a summit of the triangle, the point of the triangle being thus the lower part 10d of the support 10.
[0023] The device 1 is configured to stimulate vision, audition and/or cognition of an individual P in front of the flat support 10 by means of audio-visual sets D, S arranged on the upper surface 10a of the flat support 10. Each audio-visual set D, S comprises a light diffusion means or diode D and sound diffusing means S (for instance a speaker).

[0024] **Figure 8** shows the upper surface 10a of the flat support 10 on which a plurality of diodes D and a plurality of sound diffusion means S are arranged.

[0025] The upper surface 10a comprises several iso-vergence arcs 11, 12, 13, 14 on which audiovisual sets D, S are arranged.

[0026] By means of iso-vergence arcs it is meant arcs such that the vergence angle of the eyes of an individual required to see each diode D on one arc is the same for each diode D on the considered arc. This angle is obviously defined with respect to the position of the individual in front of the device 1. The iso-vergence arcs 11, 12, 13, 14 are therefore positioned in a symmetric manner with respect to the longitudinal axis, and the individual put in front of the longitudinal axis.

[0027] In other words, the diodes D and the sound diffusion means S are arranged regularly along iso-vergence arcs 11, 12, 13, 14 that are symmetrical with respect to the longitudinal axis. The device 1 preferably comprises three or four iso-vergence arcs 11, 12, 13, 14. The first arc 11 is for instance at distance from 60 to 90 cm, preferably 80 cm to the fourth arc 14. Preferably, up to nine diodes D and sound diffusion means are arranged on each iso-vergence arc. Of course, these numbers can be set to other values.

[0028] The iso-vergence arcs 11, 12, 13, 14 are increasingly larger as they move away from the side in front of which the patient is seated or standing when the flat support 10 is in a horizontal position or as they move upwards from the base 3 when the flat support 10 is in a vertical position.

[0029] The size of the flat support 10 and the number of iso-vergence arcs 11, 12, 13, 14 enable to stimulate the essential range of physiological eye movement (e.g., 15 degrees of eccentricities left, right, 15 degrees of vergence eye movements). For instance, the flat support 10, when in horizontal position, has a depth L of 90 cm and a width l of 65 cm. Preferably, an audio-visual set D, S is arranged at the intersection of each iso-vergence arc 11, 12, 13, 14 and the longitudinal axis AA. On each iso-vergence arc 11, 12, 13, 14, the same number (up to 4, such as 1, 2, 3 or 4, preferably 4) of audio-visual sets D, S are further preferably arranged on either side of the longitudinal axis AA. Moreover, in order to be able to stimulate the same degrees of eccentricities for saccades on the left and on the right on each iso-vergence arc when the flat support 10 is in horizontal position, the same spaces between two audio-visual sets D, S are used on either side of the longitudinal axis AA. Preferably, the audio-visual sets D, S are regularly spaced on either side of the longitudinal axis AA.

[0030] Moreover, in order to be able to stimulate the same degrees of eccentricities for saccades on each iso-vergence arc, the i^{th} audio-visual sets D, S of all iso-vergence arcs on one side of the longitudinal axis AA are preferably aligned (see **Figure 8).** These audio-visual sets D, S arranged on the iso-vergence arcs are useful for stimulating horizontal right or left saccades when the flat support 10 is in horizontal, tilted or vertical position. They are also useful for stimulating combined eye movements when the flat support 10 is in horizontal or tilted position, and for stimulating oblique saccades when the flat support 10 is in vertical position.

[0031] Additionally, audio-visual sets D, S are also arranged along the longitudinal axis of the support between the iso-vergence arcs 11, 12, 13, 14. These additional audio-visual sets D, S are notably useful for stimulating vergence movements when the flat support 10 of the device according to the invention is put in horizontal position, and for stimulating vertical upward or downward saccades when the flat support 10 of the device according to the invention is put in vertical position.

[0032] Therefore, audio-visual set D, S are both arranged on the iso-vergence arcs 11, 12, 13, 14 and on the longitudinal axis AA of the flat support 10.

[0033] One diode D is always located adjacent to one sound diffusion means S. For each position of a diode, a sound diffusion means is also positioned.

[0034] **Figure 9** shows a possible implementation of the flat support 10. As can be seen on this figure, the audio-visual sets D, S are supported on electronic cards. The audio-visual sets D, S are grouped in several manner. For instance, a card 21 for an iso-vergence arc 11, 12 and the corresponding audio-visual sets D, S. A card 22 for the audio-visual set D, S along the longitudinal axis A, a card 24, 25 for both the iso-vergence arcs 13, 14 and the corresponding audio-visual sets D, S and the audio-visual sets D, S along the longitudinal axis. The different cards 21, 22, 23, 24, 25 are linked together to the control system 4 by means on a communication and supply link connected the control system 4. The implementation of the support 10 cannot be limited to this implementation.

[0035] The various positions of the support 10 along with the audio-visual sets D, S permit to increase the possibilities in the predetermined protocols for stimulating additional movements compared to REMOBI as disclosed in US 8 851 669 B1. In particular, the possibility of putting the flat support 10 in vertical position permits to further stimulate vertical saccades. It also permits to stimulate all types of saccades (horizontal, vertical and oblique) in the same protocol. The new possibilities of functional exploration and reeducation of oblique and vertical saccades possibility offered by the device according to the invention will be important in many pathologies. For instance, Example 1 shows that functional exploration of vertical saccades in patients with early diagnosis of dementia allowed to establish correlations between several vertical saccades parameters and early dementia.

[0036] The device 1 further comprises a control 4 system for controlling the audio-visual sets D, S. In particular, each diode D is configured to diffuse a light according to an intensity and a color and each sound diffusion means S is

configured to diffuse a sound according to a sound level and a frequency. These parameters are all controlled by the control system 4.

[0037] Thus, the control system 4 is configured to control the intensity and the color of each diode D and/or to control the sound level and the frequency of each diffusion means S and to control a spatio-temporal activation of the diodes D and the sound diffusion means S according to several predefined protocols.

[0038] The diodes D and the sound diffusion means S are controlled by the control system 4 connected to the flat support 10 for instance by means of a USB cable. The control system 4 is for instance a computer with a display allowing a user to control the device 10 and to set the parameters of each protocol. The control system 4 can support android™ operating system or other type of operating system.

[0039] Each diode D is in particular configured to diffuse a light having a color that may be selected from several distinct colors. In particular, the control system 4 can control the color and the intensity of the light diffused by each diode D. The color (s) used in the predefined protocol may be chosen among: red, orange, yellow, green, blue, cyan, purple, white, a mixture of several colors (in this case, each diode uses a single color, but distinct diodes use distinct colors, resulting in a mixture or several colors being used in the predefined protocol). The diodes D are harmless to the eye of the individual. It is possible to choose the percentage of the different colors to be mixed up. For instance, 33% red, 33% blue, 33% green.

[0040] Each sound diffusing means S is configured to diffuse an adjustable sound level (from 0 to 100 % of a maximal intensity of 75 dB) and an adjustable frequency. Here again, the sound diffused is harmless for the patient. The sound level can be tuned to be more or less acute for the individual (for instance, the sound has a full intensity of 70 dB SPL and a frequency close to 2000 Hz).

[0041] It is possible to modulate the intensity of the color going from very low medium to very bright. Similarly, it is possible to choose to modulate the intensity of the sound during the protocol.

[0042] It is also possible to run any protocol either with a single color or with a variety of colors for the diodes (for instance, 2, 3 or 4 distinct colors may be used in the same protocol). Furthermore, the control system 4 is configured to count the number of diodes of each selected color appeared in the protocol and the stimulated individual may be asked to count the number of occurrences of a specific color or of multiple colors (to increase the cognitive and attentional load of the test). This information can be verified.

[0043] It is also possible to render one or many of the colors used silent i.e., no sound is emitted when the light is on. If such is the choice, there is also a counter implemented by the control system 4 on the silent occurrences of the diodes of each selected color and the stimulated individual may be asked to count the silent red diodes (i.e., the red diodes that are not accompanied by sound). For this, the control system 4 is configured so that the user may enter the proportion of the diodes of each color that is wished to be made silent.

[0044] Therefore, the control system 4 is configured so that:

- the user may define a protocol by selecting:
  - a number of distinct colors for the diodes and the proportion of diodes of each selected color, and
  - for each color:
    - the intensity of the light, and
    - the proportion of silent diodes (from 0 to 100%),
    - the frequency and intensity of the associated sound for non-silent diodes;
- for each color, the control system 4 counts the number of silent and non-silent diodes during the protocol.

[0045] Based on the defined protocol, in addition to eye movements instructions (follow the lighted diodes with your eyes), cognitive instructions may further be given to the individual by asking him/her to count all diodes, or only silent diodes or only non-silent diodes of one or more specific color(s).

[0046] The new functionalities (programmable color and intensity of light, programmable frequency and intensity of sound) give an infinite number of possibilities to render the test (for functional exploration) or training (for reeducation) task more or less difficult for the individual (depending on the more or less difficult cognitive instructions given to the individual).

[0047] No matter their difficulty, adding cognitive instructions to the eye movements instructions permits to:

- improve adherence of individuals to the eye movements instructions by making the test or training more like a game (as the count made by the individual will be compared to the count of the control system 4 at the end of the protocol), which may be particularly useful for adolescent individuals; and
- add a new cognitive dimension to the functional exploration or training, which is very important because many

deficiencies, no matter whether they are due to physiologic ageing, trauma or other pathologies are known to involve both physical and cognitive aspects.

[0048] By engaging multiple physiologic functionalities, including physical functionalities such as motricity of eye movement, color vision, and sound perception (when at least a proportion of the diodes are non-silent), but also cognitive functionalities (attention, memory inhibitory capacity (ability to inhibit a routine response and name or count selectively), the device of the invention permits to implement new protocols for testing and training eye movements, including the new REVA protocols (see below) specifically designed for training individuals with neurocognitive deficits, no matter whether such deficits are due to physiologic ageing, trauma or other pathologies (see below). The new REVA protocol is the name of one of the predetermined protocol(s) that can run on the device 1 above described. This REVA protocol will be further detailed in the following. With the device of the invention, it also possible to follow up the counter during the execution of a program, indicating how many diodes are done from the total included in the defined protocol.

[0049] Thus, further to audio and visual stimulation, the device of the invention also permits to stimulate cognition, this new device is named REMOBI-Neurocog and is therefore an improvement of the already disclosed REMOBI device (US 8 851 669 B1).

Uses of/methods of using the device according to the invention

[0050] The present invention also relates to various uses of the device according to the invention. Such uses may be primarily divided into two types of uses: those relating to functional exploration of various deficiencies and those relating to reeducation (also referred to as "training") of such deficiencies.

Uses relating to functional exploration or follow-up of various deficiencies

[0051] As its previous version (REMOBI, see WO2011/073288 and US 8 851 669 B1), REMOBI-Neurocog may be used for measuring binocular motricity parameters in any individual.

[0052] For instance, REMOBI has been shown to be useful for measuring binocular motricity parameters (such as saccades, vergences, and/or combined eye movements) in individuals suffering from a learning disorder (in particular dyslexia, but also other learning disorders, such as dyspraxia, dysphasia, dyscalculia, dysgraphia, and attention-deficit/hyperactivity disorder (ADHD), see application PCT/EP2021/077718 filed on October 7, 2021 and El Hmimdi AE, Ward LM, Palpanas T, Kapoula Z. Predicting Dyslexia and Reading Speed in Adolescents from Eye Movements in Reading and Non-Reading Tasks: A Machine Learning Approach. Brain Sci. 2021 Oct 11;11(10):1337. doi:10.3390/brainsci11101337; Ward LM, Kapoula Z. Dyslexics' Fragile Oculomotor Control Is Further Destabilized by Increased Text Difficulty. Brain Sci. 2021 Jul 27;11(8):990. doi: 10.3390/brainsci11080990. Ward LM, Kapoula Z. Differential diagnosis of vergence and saccade disorders in dyslexia. Sci Rep. 2020 Dec 17;10(1):22116. doi: 10.1038/s41598-020-79089-1), and vertigo (see application PCT/EP2021/077721 filed on October 7, 2021).

[0053] Moreover, Examples below shows that REMOBI-Neurocog may be useful for measuring binocular motricity parameters in individuals suffering from visual deficits following a brain lesion (such as visual neglect after a stroke, see Example 1), auditive deficits (such as presbycusis, see Examples 2-3), visual and balance deficits after brain lesion (such as concussion, see Example 4), cognitive and visual deficits due to learning disorder (such as dyslexia, see Example 5), and cognitive and visual deficits due to autism (see Example 6).

[0054] These results support the use of the device according to the invention for functional exploration, follow-up (in order to assess efficiency of training or medication) and training of individuals suffering from cognitive deficits due to brain lesions or developmental disorders (including learning disorders and autism spectrum disorders), visual or auditive deficits (no matter their origin, for instance due to physiological ageing or to a bran lesion), balance disorders (including but not limited to vertigo), and any activity necessitating cognitive and multisensory integration.

[0055] Moreover, eye movements represent an important component of the perception-action loop. Consequently, neurodegenerative disorders, including Alzheimer's (AD), Lewybody (LBD), Parkinson's (PD), and Huntington's disease (HD), present during progression abnormalities of eye movements. The utility of eye movement tests is multiple for assessing cognitive executive functions, for evaluating the evolution of the disease or of a treatment.

[0056] In particular, it is often assumed that people with dementia suffer primarily from a deficit of working memory, however there is increasing evidence that people with early AD have subtle impairments in attentional eye-tracking that are often undetected by traditional cognitive assessments.

[0057] LBD is the second leading cause of neurodegenerative dementia after AD. Three types of pathological forms are recognized: pure brainstem, limbic and diffuse neocortical types. Usually, lesions of LB types are not in occipital regions and are less numerous in parietal cortices than in temporal and frontal cortices. Study of different types of saccades (voluntary versus reflexive) and of different parameters (time of initiation, variability, speed, accuracy) provide important information on brain function at the level of cortical oculomotor areas, sub-cortical areas (ganglia, superior

colliculus) and brainstem. Kapoula and collaborators have shown that patients with LBD at the advanced stage spread abnormal variability of all parameters (Kapoula Z, Yang Q, Vernet M, Dieudonné B, Greffard S, Verny M. Spread deficits in initiation, speed and accuracy of horizontal and vertical automatic saccades in dementia with lewy bodies. Front Neurol. 2010 Nov 22;1:138).

[0058] Similarly, in patients with AD at the advanced stage abnormalities of saccades have been reported particularly for more voluntary saccades tested with the overlap paradigm; in contrast no saccade abnormality has been found in patients with Moderate Cognitive Impairment (Yang Q, Wang T, Su N, Xiao S, Kapoula Z. Specific saccade deficits in patients with Alzheimer's disease at mild to moderate stage and in patients with amnestic mild cognitive impairment. Age (Dordr). 2013 Aug;35(4):1287-98); abnormal variability microsaccades during fixation was found in patients with AD at the moderate or advanced stage of the disease (Kapoula Z, Yang Q, Otero-Millan J, Xiao S, Macknik SL, Lang A, Verny M, Martinez-Conde S. Distinctive features of microsaccades in Alzheimer's disease and in mild cognitive impairment. Age (Dordr). 2014 Apr;36(2):535-43).

[0059] This further supports the use of the device according to the invention for functional exploration, follow-up (in order to assess efficiency of training or medication) and training of individuals suffering from cognitive deficits due to neurodegenerative diseases.

[0060] Therefore, in a first aspect of functional exploration, the invention also relates to the use of the device according to the invention for measuring binocular motricity parameters in an individual. Preferably, the measured binocular motricity parameters comprise saccades, vergences, and/or combined movements.

[0061] The present invention also relates to a method for measuring binocular motricity parameters in an individual, comprising:

a) putting the individual in front of the device according to the invention, and
b) subjecting the individual to a saccade test, a vergence test, a combined test, or any combination thereof, using the device according to the invention, wherein the individual is given eye movement instructions to follow the lighted diodes of the device with both eyes.

[0062] Types of eyes movements for which binocular motricity parameters are measured

[0063] There are three main types of eye movements that may be measured: saccades, vergences and combined movements.

[0064] A "vergence" is the simultaneous movement of both eyes in opposite directions to increase or decrease the angle of the optic axes (the vergence angle) to obtain or maintain single binocular vision of objects located at different depths. To look at an object closer by, the eyes rotate towards each other (convergence), while for an object farther away they rotate away from each other (divergence). Vergence is always connected with some vertical movements, upward saccade for diverging and downward saccade for converging. This vertical component is however minimized when using the device according to the invention in horizontal position but intrinsically the physiologic synergy is always present.

[0065] A "saccade" is a quick, simultaneous movement of both eyes between two or more phases of fixation in the same direction, horizontally, vertically or in oblique, i.e. horizontally and vertically at the same time e.g. looking up and right, down and left etc.

[0066] A saccade may be horizontal (it is then referred to a "horizontal saccade"), when both eyes move from one location to another location at the same height on the right (it is then referred to a "right saccade" or "rightward saccade") or on the left (it is then referred to a "left saccade" or "leftward saccade"). Horizontal saccades are thus a first type of saccade, left and right saccades being each a subtype of horizontal saccade. Horizontal saccades can be made with the eyes at different level of elevation: position of the eyes at the straight ahead and saccading left or right, eyes elevated and saccading left or right, eyes down and saccading left or right

[0067] A saccade may also be vertical (it is then referred to a "vertical saccade"), when both eyes move from one location to another location at the same lateral position but at a distinct height, either above (it is then referred to an "upward saccade") or below (it is then referred to a "downward saccade") the initial position. Vertical saccades are thus a second type of saccade, upward and downward saccades being each a subtype of vertical saccade. Vertical saccades can also start from different gaze positions e.g. eyes at the straight head position saccade up or down, or from eye fixating at a lateral left or right position and saccading up or down.

[0068] A saccade may also be oblique (it is then referred to an "oblique saccade"), when both eyes move from one location to another location at another height on the right or on the left. Depending on the specific initial and final locations, it may be referred to an "upward right saccade", an "upward left saccade", a "downward right saccade", or a "downward left saccade". Oblique saccades are thus a second type of saccade, upward right, upward left, downward right and downward left saccades being each a subtype of oblique saccade.

combined movements involve both a saccade movement (i.e. both eyes simultaneously move horizontally (on the right or on the left) and/or vertically (upward or downward) depending on the type of saccade) and a vergence movement

(i.e. both eyes simultaneously move in opposite directions in depth to obtain or maintain single binocular vision). Two types of combined eye movements may be made: horizontal saccades combined with vergence (when device is in horizontal position, see **Figure 13),** or combined along all 3 dimensions when oblique saccades are combined with vergence (when the device is tilted). Noteworthy, the device according to the invention enables stimulating all types of eye movements.

[0069] In real life, e.g. while exploring the visual environment vergence almost always occurs together with a saccade (horizontal, vertical, or both). That is the eyes move at the same time in depth and in verticality and/or horizontality: ex: alternating gaze from a working screen in front of a person to look at a visitor arriving to the right involves divergence and rightward and upward saccades at the same time. These eye movement commands are transmitted at the same time to the eye muscles and to the neck muscles, no matter if the head is moving or not. From the neck projections there is a strong influence to the whole body posture and equilibrium of the eye movement commands. For instance, in many dyslexic and vertigo individuals symptoms such as visual instability, stress and lack of concentration result from poor synergy of all these components of movements of the two eyes in depth, in verticality and in horizontality in the head and body.

[0070] For each movement, a number of parameters may be measured, including duration parameters, amplitude parameters, velocity parameters (see below). The quality of synchronization of different components can be also evaluated as well as their interactions.

Protocols stimulating the eye movements for which parameters are measured

[0071] The device according to the invention is used to stimulate saccades, vergences or combined movements.

[0072] A protocol stimulating saccade movements is referred to as a "saccade test" or a "saccade protocol" (both expressions are used interchangeably). A protocol stimulating vergence movements is referred to as a "vergence test" a "vergence protocol" (both expressions are used interchangeably). A protocol stimulating combined movements is referred to as a "combined test" a "combined protocol" (both expressions are used interchangeably).

Saccade tests/protocols

[0073] The type of saccades that may be stimulated depends on the tilt of the device according to the invention. Indeed, thanks to its foot 2 configured to adjust the tilt of the flat support 10, said flat support 10 may be easily put in horizontal position (see **Figures 2-3),** in vertical position (see **Figure 4),** or in any tilted position (see **Figures 5, 6 and 7).**

[0074] When the flat support 10 of the device according to the invention is put in horizontal position, at the eye level, only horizontal saccades may be stimulated, but at various depths. This thus permits to perform one or more "horizontal saccade test(s)" at varying distances from the eyes of the individual.

[0075] Therefore, the invention also relates to the use of the device according to the invention, with the flat support 10 put in horizontal position, for measuring horizontal saccades parameters in an individual.

[0076] The invention also relates to a method for measuring horizontal saccades parameters in an individual, comprising:

a) Putting the flat support 10 of the device according to the invention in horizontal position at the eyes level of the individual,
b) Subjecting the individual to a horizontal saccade test with the flat support 10 of the device according to the invention in horizontal position,
c) Recording eye movements during the horizontal saccade test (see below), and
d) Calculating of one or more horizontal saccades parameters (see below).

[0077] With the flat support 10 of the device according to the invention put in horizontal position, the saccade test may only be a "horizontal saccade test" (i.e. stimulating only horizontal saccades).

[0078] A horizontal saccade test with the flat support 10 of the device according to the invention in horizontal position preferably comprises 30 to 50 trials of:

- visually and/or audiovisually stimulating the individual at a point located at the eyes level, in the central axis between the left eye and the right eye (illustrated for instance by point F in **Figure 10),** and
- visually and/or audiovisually stimulating the individual at another point located at the eyes level at the same isovergence arc, on the left (illustrated for instance by point T' in **Figure 10)** or on the right (illustrated for instance by point T in **Figure 10)** of the previous point, half of the trials being on the left, the other half on the right, the trials on the left and on the right being interleaved.

[0079] A horizontal saccade test with the flat support 10 of the device according to the invention in horizontal position comprises 30 to 50 trials, preferably an even number of trials between 30 and 50, more preferably between 36 and 44 trials, such as 36, 38, 40, 42 or 44 trials, in particular 40 trials.

[0080] Each trial of a horizontal saccade test with the flat support 10 of the device according to the invention in horizontal position more preferably comprises:

- visually and/or audiovisually stimulating the individual at a point located at the eyes level, in the central axis between the left eye and the right eye, at a distance of 20, 36, 56 or 100 cm (see point F in **Figure 10)** for a period varying from 1400ms to 2000 ms, and
- visually and/or audiovisually stimulating the individual at another point located at the eyes level at the same isovergence arc, at 10° to 20°, preferably 15° of eccentricity on the left (see point T' in **Figure 10)** or on the right (see point T in **Figure 10)** during 1500 ms to 2000ms, preferably 2000 ms, half of the trials being on the left, the other half on the right, the trials on the left and on the right being interleaved.

[0081] When the flat support 10 of the device according to the invention is put in vertical position, all of horizontal saccades with the eyes at different levels of elevation or depression(see **Figure 11A),** vertical saccades (see **Figure 11B)** and oblique saccades (see **Figure 11C)** may be stimulated.

[0082] Therefore, the invention also relates to the use of the device according to the invention, with the flat support 10 put in vertical position, for measuring horizontal saccades parameters, vertical saccades parameters, oblique saccades parameters, or any combination thereof, in an individual.

[0083] The invention also relates to a method for measuring horizontal saccades parameters, vertical saccades parameters, oblique saccades parameters, or any combination thereof in an individual, comprising:

a) Putting the flat support 10 of the device according to the invention in vertical position at the eyes level of the individual,
b) Subjecting the individual to a saccade test with the flat support 10 of the device according to the invention in vertical position,
c) Recording eye movements during the saccade test (see below), and
d) Calculating of one or more parameters of horizontal saccades, vertical saccades, and/or oblique saccades (see below).

[0084] With the flat support 10 of the device according to the invention put in vertical position, the saccade test may be a "horizontal saccade test" (i.e. stimulating only horizontal saccades), a "vertical saccade test" (i.e. stimulating only vertical saccades), an "oblique saccade test" (i.e. stimulating only oblique saccades), or a "mixed saccade test" (i.e. stimulating several types of saccades, such as horizontal + vertical, horizontal + oblique, vertical + oblique, or horizontal + vertical + oblique). As putting the flat support 10 of the device according to the invention put in vertical position allows to stimulate several distinct types of saccades, the saccade test is preferably a mixed saccade test.

[0085] With the flat support 10 of the device according to the invention put in vertical position, horizontal right saccades may be stimulated by (referred to as a "trial of right saccade stimulation" or "trial on the right"):

- visually and/or audiovisually stimulating the individual at a first point located on an isovergence arc and on the left of longitudinal axis (illustrated for instance by point F1 in **Figure 11A)** or at the intersection of the longitudinal axis and an isovergence arc (illustrated for instance by point F1' in **Figure 11A),** and
- visually and/or audiovisually stimulating the individual at a second point on the right of the same isovergence arc (illustrated for instance by point T1 in **Figure 11A).** When starting from a first point located on an isovergence arc and on the left of longitudinal axis, the second point is preferably symmetrical to the first point with respect to the longitudinal axis.

[0086] Similarly, horizontal left saccades may be stimulated by (referred to as a "trial of left saccade stimulation" or "trial on the left"):

- visually and/or audiovisually stimulating the individual at a first point located on an isovergence arc and on the right of longitudinal axis (illustrated for instance by point F2 in **Figure 11A)** or at the intersection of the longitudinal axis and an isovergence arc (illustrated for instance by point F2' in **Figure 8A**), and
- visually and/or audiovisually stimulating the individual at a second point on the left of the same isovergence arc (illustrated for instance by point T2 in **Figure 11A).** When starting from a first point located on an isovergence arc and on the right of longitudinal axis, the second point is preferably symmetrical to the first point with respect to the longitudinal axis.

[0087] A horizontal saccade test with the flat support 10 of the device according to the invention in vertical position preferably comprises a similar or equal number of trials on the left and of trials on the right, with preferably 15 to 25 trials of each. In particular, a horizontal saccade test with the flat support 10 of the device according to the invention in vertical position preferably comprises 30 to 50 trials on the left and on the right, half of the trials being trials on the left, the other half being trials on the left, the trials on the left and on the right being interleaved.

[0088] A horizontal saccade test with the flat support 10 of the device according to the invention in vertical position comprises 30 to 50 trials, preferably an even number of trials between 30 and 50, more preferably between 36 and 44 trials, such as 36, 38, 40, 42 or 44 trials, in particular 40 trials. In each case, preferably, half of the trials are trials on the left, the other half are trials on the left, and the trials on the left and on the right are interleaved.

[0089] With the flat support 10 of the device according to the invention put in vertical position, vertical upward saccades may be stimulated by (referred to as a "trial of upward saccade stimulation" or "upward trial"):

- visually and/or audiovisually stimulating the individual at a first point located on the central axis (illustrated for instance by point F1 in **Figure 11B),** and
- visually and/or audiovisually stimulating the individual at a second point located higher on the central axis (illustrated for instance by point T1 in **Figure 11B).**

[0090] Similarly, vertical downward saccades may be stimulated by (referred to as a "trial of downward saccades stimulation" or "downward trial"):

- visually and/or audiovisually stimulating the individual at a first point located on the central axis (illustrated for instance by point F2 in **Figure 11B),** and
- visually and/or audiovisually stimulating the individual at a second point located lower on the central axis (illustrated for instance by point T2 in **Figure 11B).**

[0091] A vertical saccade test with the flat support 10 of the device according to the invention in vertical position preferably comprises a similar or equal number of upward trials and of downward trials, with preferably 15 to 25 trials of each. In particular, a vertical saccade test with the flat support 10 of the device according to the invention in vertical position preferably comprises 30 to 50 upward and downward trials, half of the trials being upward trials, the other half being downward trials, the upward and downward trials being interleaved.

[0092] A vertical saccade test with the flat support 10 of the device according to the invention in vertical position comprises 30 to 50 trials, preferably an even number of trials between 30 and 50, more preferably between 36 and 44 trials, such as 36, 38, 40, 42 or 44 trials, in particular 40 trials. In each case, preferably, half of the trials are upward trials, the other half are downward trials, and the upward trials and downward trials are interleaved.

[0093] With the flat support 10 of the device according to the invention put in vertical position, oblique upward right saccades may be stimulated by (referred to as a "trial of upward right saccade stimulation" or "upward right trial"):

- visually and/or audiovisually stimulating the individual at a first point (illustrated for instance by point F1 in **Figure 11C),** and
- visually and/or audiovisually stimulating the individual at a second point located higher than and on the right of the first point (illustrated for instance by point T1 in **Figure 11C).**

[0094] Similarly, vertical upward left saccades may be stimulated by (referred to as a "trial of upward left saccades stimulation" or "upward left trial"):

- visually and/or audiovisually stimulating the individual at a first point (illustrated for instance by point F2 in **Figure 11C),** and
- visually and/or audiovisually stimulating the individual at a second point located higher than and on the left of the first point (illustrated for instance by point T2 in **Figure 11C**).

[0095] Similarly, oblique downward right saccades may be stimulated by (referred to as a "trial of downward right saccade stimulation" or "downward right trial"):

- visually and/or audiovisually stimulating the individual at a first point (illustrated for instance by point F3 in **Figure 11C),** and
- visually and/or audiovisually stimulating the individual at a second point located lower than and on the right of the first point (illustrated for instance by point T3 in **Figure 11C**).

[0096] Similarly, vertical downward left saccades may be stimulated by (referred to as a "trial of downward left saccades stimulation" or "downward left trial"):

- visually and/or audiovisually stimulating the individual at a first point (illustrated for instance by point F4 in **Figure 11C),** and
- visually and/or audiovisually stimulating the individual at a second point located lower than and on the left of the first point (illustrated for instance by point T4 in **Figure 11C**).

[0097] An oblique saccade test with the flat support 10 of the device according to the invention in vertical position preferably comprises a similar or equal number of the various types (upward right, upward left, downward right and downward left) oblique saccades, with preferably 15 to 25 trials of each, such as 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 trials of each. 20 trials of each may notably be used.

[0098] In addition to the new possibility of testing vertical and oblique saccades, compared to REMOBI, the device according to the invention, thanks to its tiltable flat support 10 that makes easy to put it in vertical position, makes it possible to assess several types of saccades in a single test.

[0099] Preferably, when the flat support 10 of the device according to the invention put in vertical position, a mixed saccade test is performed, assessing at least two types of saccades (such as horizontal + vertical, horizontal + oblique, vertical + oblique, or horizontal + vertical + oblique).

[0100] Such a mixed test preferably comprises 15 to 25 trials, such as 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25 trials, of each saccade subtype tested. 20 trials of each may notably be used.

[0101] Moreover, the trials corresponding to different subtypes of saccades are preferably interleaved.

[0102] When the flat support 10 of the device according to the invention is put in tilted position, horizontal left and right saccades may be stimulated using the same protocols as described above when the flat support 10 of the device according to the invention is put in vertical position. However, purely vertical or oblique saccades cannot be stimulated. Vertical and oblique saccades in such case will also integrate a vergence component, and thus will represent combined movements; e.g. if the device is tilted so that the upward part is further away from the observer than the lower part, then any upward saccade or oblique (e.g. include a divergence component and vice versa any downward saccade will include a convergence component. The device enables this way to stimulate eye movements in all three axis, horizontal, vertical and depth.

Vergence tests/protocols

[0103] A vergence test involves vergence movement (i.e. both eyes simultaneously move in opposite directions in depth only to obtain or maintain single binocular vision), and may thus be performed only when the flat support 10 of the device according to the invention is put in horizontal position (in vertical position, no movement in depth is possible, and in oblique position, movements only in depth are not possible).

[0104] When the flat support 10 of the device according to the invention is put in horizontal position (which is preferred), at the eyes level, a vergence test preferably comprises 30 to 50 trials of:

- visually and/or audiovisually stimulating the individual at a point located at the eyes level, in the central axis between the left eye and the right eye, at a first distance (illustrated for instance by point F in **Figure 12),** and
- visually and/or audiovisually stimulating the individual at another point located at the eyes's level, in the central axis between the left eye and the right eye, at another distance calling for a convergence movement (illustrated for instance by point T' in **Figure 12)** or a divergence movement (illustrated for instance by point T in **Figure 12**), half of the trials calling for a convergence movement, the other half for a divergence movement, the trials calling for convergence and divergence movements being interleaved.

[0105] The vergence test comprises 30 to 50 trials, preferably an even number of trials between 30 and 50, more preferably between 36 and 44 trials, such as 36, 38, 40, 42 or 44 trials, in particular 40 trials.

[0106] Each trial of a vergence test preferably comprises:

- visually and/or audiovisually stimulating the individual at a point located at the eyes level, in the central axis between the left eye and the right eye, at a distance of 36 cm ± 5 cm (i.e. between 31 and 41 cm, preferably between 32 and 40 cm, between 33 and 39 cm, between 34 and 38 cm, between 35 and 37 cm, more preferably 36 cm, see point F in **Figure 12)** for a period varying from 1400ms to 2000ms, and
- visually and/or audiovisually stimulating the individual at another point located at the eyes level, in the central axis between the left eye and the right eye, at a distance of 20 cm ± 5 cm (i.e. between 15 and 25 cm, preferably between 16 and 24 cm, between 17 and 23 cm, between 18 and 22 cm, between 19 and 21 cm, more preferably 20 cm, see

point T' in **Figure 12)** calling for a convergence movement or at a distance of 56 to 100 cm (in particular 56 cm ± 5 cm, i.e. between 51 and 61 cm, preferably between 52 and 60 cm, between 53 and 59 cm, between 54 and 58 cm, between 55 and 57 cm, more preferably 56 cm; or 100 cm ± 5 cm, i.e. between 95 and 105 cm, preferably between 96 and 104 cm, between 97 and 103 cm, between 98 and 102 cm, between 99 and 101 cm, more preferably 100 cm; see point T in **Figure 12)** calling for a divergence movement during 1500 to 2500 ms, preferably 2000 ms, half of the trials calling for a convergence movement, the other half for a divergence movement, the trials calling for convergence and divergence movements being interleaved.

Combined tests/protocols

[0107] A combined test stimulates combined movements involving both a saccade movement (i.e. both eyes simultaneously move between two or more phases of fixation in the same direction laterally (on the right or on the left) and/or vertically (upward or downward) depending on the type of saccade) and a vergence movement (i.e. both eyes simultaneously move in opposite directions in depth to obtain or maintain single binocular vision). Such a combined test may thus be performed only when the flat support 10 of the device according to the invention is put in horizontal or tilted position (in vertical position, no movement in depth is possible).

[0108] When the flat support 10 of the device according to the invention is put in horizontal position, at the eyes level, a combined test preferably comprises 70 to 90 trials of:

- visually and/or audiovisually stimulating the individual at a point located at the eyes level, in the central axis between the left eye and the right eye, at a distance of 36 cm ± 5 cm (i.e. between 31 and 41 cm, preferably between 32 and 40 cm, between 33 and 39 cm, between 34 and 38 cm, between 35 and 37 cm, more preferably 36 cm, see point F1 in **Figure 13)** or at a distance of 100 cm ± 5 cm (i.e. between 95 and 105 cm, preferably between 96 and 104 cm, between 97 and 103 cm, between 98 and 102 cm, between 99 and 101 cm, more preferably 100 cm, see point F2 in **Figure 13)** for a period varying from 1400ms to 2000ms, and
- visually and/or audiovisually stimulating the individual during 1500 ms to 2000ms, preferably 2000 ms at another point located at the eyes level, either

    - when starting from fixation point F1: at a distance of 100 cm ± 5 cm (i.e. between 95 and 105 cm, preferably between 96 and 104 cm, between 97 and 103 cm, between 98 and 102 cm, between 99 and 101 cm, more preferably 100 cm) and at 10° to 20°, preferably 15° of eccentricity on the left (see point T1' in **Figure 13)** or on the right (see point T1 in **Figure 13),**
    - when starting from fixation point F2: at a distance of 36 cm ± 5 cm (i.e. between 31 and 41 cm, preferably between 32 and 40 cm, between 33 and 39 cm, between 34 and 38 cm, between 35 and 37 cm, more preferably 36 cm) and at 10° to 20°, preferably 15° of eccentricity on the left (see point T2' in **Figure 13)** or on the right (see point T2 in **Figure 13),**

wherein a quarter of the trials combine convergence and left saccade, a quarter of the trials combine convergence and right saccade, a quarter of the trials combine divergence and left saccade, and a quarter of the trials combine divergence and right saccade, the trials being (preferably randomly) interleaved.

[0109] When the flat support 10 of the device according to the invention is put in oblique position, all the stimulations explained for the vertical positions are valid but in addition there is a vergence stimulation together e.g. Vertical and oblique saccades in such case will also integrate a vergence component thus resulting in combined movements e.g. if the device is tilted so that the upward part is further away from the observer than the lower part, then any upward saccade or oblique will include a divergence component and vice versa any downward saccade will include a convergence component. The device enables this way to stimulate eye movements in all three axis, horizontal, vertical and depth. Vergence testing along the longitudinal axis will also be associated with downward saccade - depression of the eye for convergence and upward saccade for divergence. In the tilted position stimulation is 3D i.e. horizontal vertical and in depth). When stimulating horizontal saccades along the same arc with the device at the tilted position the eyes will be more converging for the lower arcs than the upper arcs. If the device is tilted in the other direction the opposite occurs the eyes will be more convergent for the upper arcs than the lower ones. Thus, all combinations are possible. Note however that the tilt that corresponds to more physiologic conditions is the first one, i.e. the upward part being further from the observer than the lower part.

REVA test protocols

[0110] REVA stands for "REeducation Visuomotor Attention" and uses all or almost all (i.e. at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, preferably all) of the audio-visual sets D, S arranged on the upper surface 10a

of the flat support 10 combined with the modulations of color type, color intensity, sound on/off and intensity.

[0111] This allows to cause eye movement exploration of the total surface of the device of the invention with a variety of size direction and depth eye movements. Diodes are switched on in either pseudorandom way (each position appearing 5 times, corresponding to the "random REVA protocol" described in more details below) or in sequential predictive way (corresponding to the "regular REVA protocol" described in more details below). Moreover, the flat support 10 of the device of the invention can be used either at the horizontal position at eye level, or inclined or completely in vertical position. The position of the tested individual may be either seated or standing. The rhythm of diodes lighting is also variable (very fast 250 msec, or very slow 1500 msec).

[0112] For functional exploration, it is preferable to record eye movements and to substantiate the fixation patterns of eye movements and their degree of fluctuation in addition to the responses given by the person to the cognitive instruction (e.g. how many red colors were presented). A map superimposing diodes and eye fixations patterns objectivizes the quality of responses, attentional capacity and readiness to respond to stimuli (see for instance **Figures 35 and 37).**

Random REVA protocols

[0113] In these protocols, all or almost all (i.e. at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, preferably all) of the diodes D arranged on the upper surface 10a of the flat support 10 are switched on and then off one after another, and the order in which the diodes are switched on is random.

[0114] The delay between each diode is the same during the whole protocol, but different random REVA protocols may be used, each with a distinct delay between diodes. Such delay may be selected by the user thanks to the control system 4. Values between 250 and 1500 ms may be selected. Five predefined random REVA protocols (with a delay between diodes of 250, 500, 750, 1000 and 1500 ms, respectively) are available to the user.

Regular REVA protocols

[0115] In these protocols, all or almost all (i.e. at least 75%, at least 80%, at least 85%, at least 90%, at least 95%, preferably all) of the diodes D arranged on the upper surface 10a of the flat support 10 are switched on and then off one after another, and the order in which the diodes are switched on is not random, but instead follows a regular predefined scheme.

[0116] Three schemes are preferred:

- Scheme 1:
  In the first scheme, the flat support 10 of the device of the invention is in horizontal position, and the diodes D are switched on and then off one after another from near to far and left to right. In this case the stimulations concern vergence and horizontal saccades.
- Scheme 2:
  In the second scheme, the flat support 10 of the device of the invention is in vertical position, with the largest part up and the smaller down (i.e. with the smaller width of the device at the bottom), and the diodes D are switched on and then off one after another from top to bottom and left to right or vice versa from up and left to right. In this case the stimulations concern horizontal, vertical and oblique saccades.
- Scheme 3:
  In the second scheme, the flat support 10 of the device of the invention is in tilted position, with the largest part up and the smaller down and preferably with the upward part further from the observer than the lower part, and the diodes D are switched on and then off one after another from top to bottom and left to right or vice versa from up and left to right. In this case the stimulations concern vergence and horizontal, vertical and oblique saccades.

[0117] For all three schemes, the delay between each diode is the same during the whole protocol, but different regular REVA protocols may be used, each with a distinct delay between diodes. Such delay may be selected by the user thanks to the control system 4. Values between 250 and 1500 ms may be selected. Six predefined regular REVA protocols (with a delay between diodes of 250, 350, 500, 750, 1000 and 1500 ms, respectively) are available to the user for each of scheme 1 and scheme 2.

Specific additional REVA protocols for individuals suffering from on autist spectrum disorder

[0118] Autist individuals are known not to fixate the eyes of other individuals. Even when looking at a picture or painting (e.g. painting *Girl with pearl earring* by J Vermeer) with a face, they tend not to fixate the eyes (see Example 6).

[0119] On this basis, for individuals suffering from an autist spectrum disorder, the REVA regular and random protocols as described above can be used with an image containing one or more faces such as a painting (e.g. *Girl with pearl*

earring or other) placed upon the flat support 10. Noticeably, both diodes and sounds are perceived when using tissue prints of the paintings covering the surface of the flat support 10.

[0120] In addition, slightly modified protocols based on the REVA regular and random protocols as described above can be defined, in which the diodes that correspond to the location of the eyes, nose and mouth of the face(s) may be made more frequent among the other diodes. The avoidance or increase with exerting of fixations to such locations is measured.

Instructions

[0121] For each REVA protocol, the individual is given eye movement instructions (follow the lighted diodes with both eyes) and also with cognitive instructions. Optionally, the protocol, may further comprise postural instructions (when the individual is in standing position).

[0122] Inspired by the Stroop test, which is a golden neurologic test for testing the selective attention and the inhibitory cognitive executive function, the trained individual is given cognitive instructions, as described below.

Gap and overlap paradigms

[0123] Any of the saccade, vergence or combined test/protocol described above may be performed using a "gap paradigm" or an "overlap paradigm".

[0124] In the "gap paradigm", the initial diode is switched off and the next diode is switched on after a gap period of 200 msec. In such paradigm, the fixation and attention being normally released during the gap period, eye movement preparation is done in a shorter latency or preparation time than in the overlap paradigm.

[0125] In the "overlap paradigm", the initial fixation diode is kept on and extinguishes 200 msec after the onset of the next diode for the movement to be made. In such case, the release of fixation and attention from the fixation diode has to be done voluntarily and this involves hypothetically a larger cortical circuit, namely the posterior parietal and the frontal cortices (see Kapoula, Z., Yang, Q., Sabbah, N., & Vernet, M. (2011). Different effects of double-pulse TMS of the posterior parietal cortex on reflexive and voluntary saccades. Frontiers in Human Neuroscience, 5, Article 114).

Further instructions that may be added to saccade, vergence or combined tests

[0126] In all of the above-described saccade, vergence and combined tests, the individual is given eye movement instructions to follow the lighted diodes of the device with both eyes.

[0127] When only such eye movement instructions are given to the individual, the tests engage/stimulate binocular motricity, visual perception and, if the stimulation is audiovisual (at least some of the diodes are non-silent), auditive perception.

[0128] However, further instructions may be given to the individual, in order to further engage/stimulate posture and/or cognition.

Postural instructions

[0129] In order to further engage posture during measure of binocular motricity parameters (and thus possibly observe an influence of posture on the identified binocular motricity deficits), the same test(s) may be performed once in seated position (which does not engage significant posture influence) and once in standing position (which does engage significant posture influence), with and without shoes, with fine inserts under the feet, or on a dynamic rocking plate typically used in posturology.

[0130] In this case, when the test(s) is(are) performed in standing position, postural parameters (for instance body sway parameters or head rotations parameters) may further be measured during the test.

[0131] Such posture instructions and optional additional measure of postural parameters may particularly be used for individual suffering from a disease or deficit known to involve posture elements, such as balance disorders (including vertigo, vestibular pathologies, elderly with falling history or fear to fall), but also neurodegenerative diseases (such as Parkinson's disease), brain lesions (concussion, stroke), developmental motor coordination disorders concerning children with learning difficulties and particularly children with dyspraxia, , or for individuals involved in any activity necessitating cognitive, posture and multisensory integration.

Cognitive instructions

[0132] In order to further engage cognition during measure of binocular motricity parameters (and thus possibly observe an influence of posture on the identified binocular motricity deficits), the individual may further be given cognitive instruc-

tions for the test(s).

[0133] As explained above in the section relating to the device, thanks to the control system 4, the user may:

- define a protocol by selecting:
    - a number of distinct colors for the diodes and the proportion of diodes of each selected color, and
    - for each color:
        - the intensity of the light, and
        - the proportion of silent diodes (from 0 to 100%),
        - the frequency and intensity of the associated sound for non-silent diodes; and
- Ask the individual, in addition to its primary task to follow the lighted diodes with both eyes, to perform an additional cognitive task.

[0134] Such cognitive task may be to count the number of all diodes, silent diodes only, or non-silent diodes only of one or more particular color(s). The user may check the accuracy of the response of the individual at the end of the protocol as the control system 4 counts the number of silent and non-silent diodes of each selected color during the protocol. Asking to count sets up an automatic cognitive routine that has to be inhibited voluntarily by the individual whenever the color or the sound does not match with the instructed targets.

[0135] The complexity and difficulty for the individual depends on the matching mis-matching between congruent and incongruent elements requiring attention, inhibition and mental flexibility in addition to capacity for fine color identification and sound perception.

[0136] For instance, it is more difficult to count two colors among 3 or four than one color. It is more difficult to count only the colors with sound than the ones without sound (it is easier to detect the absence than the presence of sound).

[0137] Alternatively, for easier version, e.g. for elderly individuals with cognitive impairment or attention limitations, the user may ask the individual to name loudly the target color, e.g. red; or instead of naming the real color to give an opposite color, e.g. say "green" when a red diode lights up.

[0138] Examples of cognitive instructions include:

- Count only the blue diodes (or any other color used during the protocol),
- Count only the blue silent (or any other color used during the protocol),
- Count only the blue non-silent (or any other color used during the protocol),
- Count only the blue (or any other color used during the protocol) appearing left (or right or up or down),
- Count the blue and the white (or any other couple of colors used during the protocol),
- Count the blue, the red silent, and the green
  For each of the above counts, the individual may be asked to count loudly or silently.
- When you see a blue diode tell red (or any other couple of colors used during the protocol),
- Etc.

[0139] The fact that the light and sound intensity may be varied by the user also contributes to the fact that more or less difficult cognition instructions may be given to the individual. For instance, using a low light intensity may make the cognitive task harder for an individual with visual deficits. Similarly, using a low sound intensity may make the cognitive task harder for an individual with auditive deficits.

[0140] Based on the high versatility conferred by the presence of programmable diodes D and programmable sound diffusion means S and by the control system 4, there is a large repertoire of possible combinations for cognitive instructions.

Recording of eye movements during tests performed with the device according to the invention

[0141] For all tests performed using the device according to the invention, the eye movements of the left eye and the right eye of the individual are recorded.

[0142] This may be performed using any appropriate eye tracker (also referred to as an eye movement acquisition and recording system). The eye movement acquisition and recording system works advantageously with a video-oculography system, i.e. micro-cameras that focus their lenses on both eyes and record their movements when the person is looking at the device according to the invention to stimulate binocular motricity (vergence, saccade or combined tests).

[0143] Such a system is for example an eyetracker from the company Pupil Labs™, such as the head mounted device Pupil Core, enabling binocular recording at 200 Hz per eye (https://pupil-labs.com/products/core/)

[0144] Another type of eye movement acquisition system is the Powref III from the company PlusOptix™. Such a type of system is placed at a distance from the person, for example in front of the person on the REMOBI support. This system allows to measure the eye movement but also, at a distance, the change of eye accommodation for and to plot eye positions but also the plot of the change of eye accommodation. In this regard, one can refer to the document (https://www.medicus.ua/eng/product/ophthalmic-equipment/plusoptiX-R09-PowerRef-3/manufacturer:, 8 "HSOA Journal of Clinical Studies and Medical Case Reports", Kapoula Z, et al, J Clin Stud Med Case Rep 2019, 6: 74). Other examples of suitable eye trackers include the EyeSeeCam system (University of Munich Hospital, Clinical Neuroscience, Munich, Germany, available in the public domain at http://eyeseecam.com/,) or other remote devices e.g. Tobbii (https://www.tobii.com/), Powref (https://plusoptix.com/home).

[0145] The same type of eye tracker may be used for recording eye movements during a reading test, when such test is combined with tests involving the device according to the invention (see below).

Calculation of binocular motricity parameters

Calculating saccade parameters during saccade and combined tests

[0146] As already indicated above, a saccade is a quick, simultaneous movement of both eyes between two or more phases of fixation in the same direction, horizontally and/or vertically.

[0147] Based on the recording of eye movements made by the eye tracker, the effective trajectory corresponding to a saccade is obtained by calculating a conjugate signal defined by the average of the position of the left eye with the position of the right eye (i.e. left+right eyes positions/2).

[0148] Each saccade effective trajectory is calculated between the time point when a visual or audiovisual stimulation inducing saccade movement starts and the time point when a next visual or audiovisual stimulation inducing saccade movement starts.

[0149] In any saccade test, a representative saccade trajectory corresponding to a mean trajectory of all effective trajectories is calculated, and effective trajectory at too much variance with the representative trajectory may be discarded for further analysis.

[0150] For each saccade effective trajectory, a corresponding effective velocity trajectory is further calculated by conventional calculation (see **Figure 14,** illustrating this for an individual with a vergence disorder tested for saccades).

[0151] Each effective velocity trajectory first permits to calculate the peak velocity of saccade (right or left), which is defined as the highest velocity value of the effective velocity trajectory (see **Figure 14).**

[0152] For each saccade effective trajectory and corresponding velocity trajectory, several parts of the saccade effective trajectory and specific time points may then be calculated (see **Figure 14):**

- Onset of saccade (right or left):
  This parameter is defined as the time point when the saccade velocity, initially close to zero has increased to reach 8-12%, preferably 10%, of the peak velocity (highest velocity in the effective trajectory), or when the saccade velocity initially close to zero has increased to reach a predefined velocity. For instance, when using a saccade test involving a right or left saccade of about 20°, onset of saccade may be defined as the time point when the saccade velocity reaches 40-50°/s, preferably 45°/s.
- Offset of saccade (right or left):
  This parameter is defined as the time point when the saccade velocity, after decreasing from the peak velocity reaches only 8-12%, preferably 10%, of the peak velocity, or when the saccade velocity after decreasing from the peak velocity reaches a predefined velocity. For instance, when using a saccade test involving a right or left saccade of about 20°, offset of saccade may be defined as the time point when the saccade velocity once more reaches 40-50°/s , preferably 45°/s after decreasing from peak velocity.
- Latency trajectory part (right or left):
  This part of the effective saccade trajectory corresponds to the part between the time point when the visual or audiovisual stimulation starts (beginning of the trajectory) and right or left saccade onset.
- Initial phasic trajectory part of saccade or "initial phasic component":
  This part of the effective saccade trajectory corresponds to the part between right or left saccade onset and offset.
- 80 ms drift trajectory part of saccade or "80 ms component":
  This part of the effective saccade trajectory corresponds to the 80 ms after right or left saccade offset.
- 160 ms drift trajectory part of saccade or "160 ms component":
  This part of the effective saccade trajectory corresponds to the 160 ms after right or left saccade offset.

[0153] Based on the above-defined time points and trajectory parts, saccade parameters may be calculated. Saccade parameters include:

- Duration parameters:

  ◦ Latency duration of saccade (right or left):
  This parameter is defined as the duration between the time point when the visual or audiovisual stimulation starts and right or left saccade onset.
  ◦ Initial phasic duration of saccade (right or left):
  This parameter is defined as the duration of the initial phasic trajectory part of saccade, i.e. the duration between right or left saccade onset and offset.
  ◦ Total duration:
  This parameter is defined as the sum of the initial phasic duration of saccade and the following 160 ms.

- Amplitude parameters:

  ◦ Amplitude of the initial phasic component:
  This parameter is defined as (conjugated signal at offset - conjugated at signal onset).
  ◦ Amplitude of the 80 ms component:
  This parameter is defined as (conjugated signal 80 ms after offset - conjugated signal at offset).
  ◦ Amplitude of the 160 ms component:
  This parameter is defined as (conjugated signal 160 ms after offset - conjugated signal at offset).
  ◦ Total amplitude:
  This parameter is defined as the sum of the amplitude of the initial phasic component and the amplitude of the 160 ms component.

- Velocity parameters:

  ◦ Peak velocity:

  As mentioned above, peak velocity is the highest velocity value of the effective velocity trajectory.
  Peak velocity of specific parts of each vergence effective trajectory may also be calculated, including the peak velocity of the initial phasic component. However, it should be noted that peak velocity is clearly found during the initial phasic component and is thus equal to the peak velocity of the initial phasic component

  ◦ Average velocity of the initial phasic component:
  This parameter is defined as the ratio between the amplitude and the duration of the initial phasic component.
  ◦ Total average velocity:
  This parameter is defined as the ratio between the total amplitude and the total duration, as defined above.

[0154] For saccades, to evaluate binocular coordination of saccades, a disconjugate signal (i.e., left eye - right eye, see **Figure 14)** may also be first calculated and a disconjugacy parameter may then be calculated, defined as the difference in saccade amplitude between the left and right eye signal may be calculated in the initial phasic component (referred to as "disconjugacy during saccade" parameter), or after the initial phasic component (referred to as "disconjugacy after saccade" or "post-saccadic drift disconjugacy"), in particular in the 80 ms component (referred to as "disconjugacy 80 ms after saccade" parameter), in the 160 ms component (referred to as "disconjugacy 160 ms after saccade" parameter).

[0155] Saccade (conjugate and disconjugate) parameters are preferably calculated separately for each subtype of saccades trajectories (horizontal right, horizontal left, vertical upward, vertical downward, oblique upward right, oblique upward left, oblique downward right and oblique downward left).

[0156] No matter which saccade parameter(s) is(are) calculated, the calculation may be made using any suitable software able to compute saccade effective trajectories from the recordings made by the eye tracker and calculate saccade parameters. Such software may preferably be the AIDEAL® software disclosed in WO2021228724A1, the content of which is herein incorporated by reference.

Calculating saccade parameters during reading

[0157] In the case of a reading test, the saccades are treated in the same way as the saccades obtained during a saccade test (after stimulation by means of the REMOBI device for stimulating binocular motricity). The only difference concerning saccade parameters is that the latency is not measurable since there is no target signal and it is the reader himself who decides when to trigger the next saccade.

[0158] On the other hand, the duration of fixation, that is, the duration between saccades, is an additional measured parameter. Reading speed, i.e. the number of words read per minute, is also measured as an additional parameter.

[0159] In addition, while in the saccade test, only left saccades and right saccades are distinguished, in the case of a reading test, saccades are categorized as saccades to the right (also referred to as "saccades of progression"), saccades to the left on the same line (saccades of regression) and large saccades to the left back to the next line.

[0160] **Figure 15A** illustrates the exploration of the eyes of a reader who does not suffer from any pathology during the reading of a line of text. In this figure, on the x-axis we have time; in y the conjugate signal of both eyes in degrees, showing the succession of saccades to the right (small vertical lines from bottom to top) followed by fixations (horizontal lines) fixing the words one after the other, then the large saccade to the left (large vertical line from top to bottom) to start reading the next line. The trajectory corresponds to the horizontal conjugate signal (left eye + right eye / 2). **Figure 15B** shows an example of the exploration of the eyes of a dyslexic reader during the reading of a line of text. In addition to the alternance of normal right saccades and fixations followed by a large saccade to the left to start reading the next line, the trajectory further comprises regression saccades (saccades to the left, small vertical lines from top to bottom) during reading of the line of text.

Calculating vergence parameters during vergence tests

[0161] As already indicated above, a vergence is the simultaneous movement of both eyes in opposite directions enabling to increase or decrease the angle of the optic axes (the vergence angle) to obtain or maintain single binocular vision of objects located at different depths. To look at an object closer by, the eyes rotate towards each other (convergence), while for an object farther away they rotate away from each other (divergence).

[0162] Based on the recording of eye movements made by the eye tracker, the effective trajectory corresponding to each vergence is obtained by calculating an unconjugated signal defined by the difference of the position of the left eye with the position of the right eye (i.e., left eye - right eye).

[0163] Each vergence effective trajectory is calculated between the time point when a visual or audiovisual stimulation inducing vergence movement starts and the time point when a next visual or audiovisual stimulation inducing vergence movement starts.

[0164] In any vergence test, a representative vergence trajectory corresponding to a mean trajectory of all effective trajectories is calculated, and effective trajectory at too much variance with the representative trajectory may be discarded for further analysis.

[0165] For each vergence effective trajectory, a corresponding effective velocity trajectory is further calculated by conventional calculation (see **Figure 16).**

[0166] Each effective velocity trajectory first permits to calculate the peak velocity of vergence (divergence or convergence), which is defined as the highest velocity value of the effective velocity trajectory (see **Figure 16).**

[0167] For each vergence effective trajectory and corresponding velocity trajectory, several parts of the vergence effective trajectory and specific time points may then be calculated (see **Figure 16):**

- Onset of vergence (convergence or divergence):
  This parameter is defined as the time point when the vergence velocity, initially close to zero has increased to reach 8-12%, preferably 10%, of the peak velocity (highest velocity in the effective trajectory), or when the vergence velocity initially close to zero has increased to reach a predefined velocity. For instance, when using a vergence test involving a convergence or divergence of about 7-9°, onset of vergence may be defined as the time point when the vergence velocity reaches 4-6°/s, preferably 5°/s.
- Offset of vergence (convergence or divergence):
  This parameter is defined as the time point when the vergence velocity, after decreasing from the peak velocity reaches only 8-12%, preferably 10%, of the peak velocity, or when the vergence velocity after decreasing from the peak velocity reaches a predefined velocity. For instance, when using a vergence test involving a convergence or divergence of about 7-9°, offset of vergence may be defined as the time point when the vergence velocity once more reaches 4-6° /s, preferably 5° /s after decreasing from peak velocity.
- Latency trajectory part (convergence or divergence):
  This part of the effective vergence trajectory corresponds to the part between the time point when the visual or audiovisual stimulation starts (beginning of the trajectory) and convergence or divergence onset.
- Initial phasic trajectory part of vergence or "initial phasic component":
  This part of the effective vergence trajectory corresponds to the part between convergence or divergence onset and offset.
- 80 ms slower trajectory part of vergence or "80 ms component":
  This part of the effective vergence trajectory corresponds to the 80 ms after convergence or divergence offset.
- 160 ms slower trajectory part of vergence or "160 ms component":

This part of the effective vergence trajectory corresponds to the 160 ms after convergence or divergence offset.

[0168] Based on the above-defined time points and trajectory parts, vergence parameters may be calculated. Vergence parameters include:

- Duration parameters:
  - ◦ Latency duration of vergence (convergence or divergence):
    This parameter is defined as the duration between the time point when the visual or audiovisual stimulation starts and convergence or divergence onset.
  - ◦ Initial phasic duration of vergence (convergence or divergence):
    This parameter is defined as the duration of the initial phasic trajectory part of vergence, i.e. the duration between convergence or divergence onset and offset.
  - ◦ Total duration:
    This parameter is defined as the sum of the initial phasic duration of vergence and the following 160 ms.
- Amplitude parameters:
  - ◦ Amplitude of the initial phasic component:
    This parameter is defined as (unconjugated signal at offset - unconjugated at signal onset).
  - ◦ Amplitude of the 80 ms component:
    This parameter is defined as (unconjugated signal 80 ms after offset-unconjugated signal at offset).
  - ◦ Amplitude of the 160 ms component:
    This parameter is defined as (unconjugated signal 160 ms after offset-unconjugated signal at offset).
  - ◦ Total amplitude:
    This parameter is defined as the sum of the amplitude of the initial phasic component and the amplitude of the 160 ms component.
- Velocity parameters:
  - ◦ Peak velocity:

    As mentioned above, peak velocity is the highest velocity value of the effective velocity trajectory.
    Peak velocity of specific parts of each vergence effective trajectory may also be calculated, including the peak velocity of the initial phasic component. However, it should be noted that peak velocity is clearly found during the initial phasic component and is thus equal to the peak velocity of the initial phasic component.
  - ◦ Average velocity of the initial phasic component:
    This parameter is defined as the ratio between the amplitude and the duration of the initial phasic component.
  - ◦ Total average velocity:
    This parameter is defined as the ratio between the total amplitude and the total duration, as defined above.

[0169] Vergence parameters are preferably calculated separately for divergence and convergence trajectories.

[0170] No matter which vergence parameter(s) is(are) calculated, the calculation may be made using any suitable software able to compute vergence effective trajectories from the recordings made by the eye tracker and calculate vergence parameters. Such software may preferably be the AIDEAL® software disclosed in WO2021228724A1, the content of which is herein incorporated by reference.

Individual

[0171] The device according to the invention may be used for functional exploration or follow-up (for assessing efficiency of training and/or medication, e.g. ritaline for ADHD) of various deficiencies in any individual.

[0172] However, based on known uses of REMOBI and further uses of REMOBI-Neurocog illustrated in Examples below, the individual in which binocular motricity parameters are measured is preferably selected from individuals suffering from:

- Cognitive deficits, in particular due to:

- ◦ neurodegenerative diseases, including but not limited to Alzheimer's disease (AD), Lewy Body disease (LBD), Parkinson's disease (PD), Huntington's disease (HD),
- ◦ Age-related cognitive decline,
- ◦ Brain lesions, in particular due to stroke, surgery, or trauma (e.g. concussion),
- ◦ Developmental disorders, including but not limited to:
  - ▪ learning disorders, including but not limited to dyslexia, dyspraxia, dysphasia, dyscalculia, dysgraphia, and attention-deficit/hyperactivity disorder (ADHD), in particular dyslexia (see PCT/EP2021/077718 and Example 5), and
  - ▪ autism spectrum disorders (see Example 6, in this case, the device according to the invention may even be used for pre-screening before starting school)

- Visual or auditory deficits, in particular due to:
  - ◦ physiological ageing (presbyopia, presbycusis, see Examples 2-3),
  - ◦ brain lesions, in particular due to stroke (such as visual neglect or auditive neglect, see Example 1), surgery, or trauma,
  - ◦ developmental disorders, including but not limited to:
    - ▪ learning disorders, including but not limited to dyslexia, dyspraxia, dysphasia, dyscalculia, dysgraphia, and attention-deficit/hyperactivity disorder (ADHD), in particular dyslexia (see PCT/EP2021/077718 and Example 5), and
    - ▪ autism spectrum disorders (see Example 6, in this case, the device according to the invention may even be used for pre-screening before starting school)
  - ◦ eye or ear surgery,
  - ◦ genetic diseases (including Ehlers-Danlos syndrome),
  - ◦ any other reason (e.g. tinnitus)

- Balance disorders, including but not limited to vertigo (see PCT/EP2021/077721), elderlies with falling history.

[0173] The device according to the invention may also be used for functional exploration or follow-up of individuals involved in any activity necessitating cognitive, posture and multisensory integration.

Preferred binocular motricity parameters depending on individuals

[0174] While some binocular motricity parameters may be more relevant to certain deficits, the first functional exploration of an individual will preferably comprise at least a saccade and a vergence test (and optionally a combined test), and all duration, amplitude and velocity parameters will preferably be calculated.

[0175] Several saccade tests may also be performed, in particular when there is an interest for testing saccades at various distances (for instance in the case of visual neglect, as neglect of the visual field can be depth specific).

[0176] However, for further follow-up of the individual, once specific deficits of binocular motricity have been identified, and in order to assess the efficiency of training (or reeducation) sessions performed by the individual, the follow-up may be focused on eye movements initially found to be deficient.

Uses relating to reeducation/training of various deficiencies

[0177] Once specific binocular motricity deficits have been identified in an individual by using the device of the invention (or possibly REMOBI device as described in WO2011 /073288 and US 8 851 669 B1), the patient may further be trained/reeducated (both terms are herein considered synonymous) using the device of the invention, in order to alleviate and hopefully suppress the identified deficits and improve the individual's quality of life. Therefore, the present invention also relates to methods for decreasing a visual, an auditive, a cognitive deficit and/or a posture instability in an individual in need thereof, comprising subjecting the individual to training sessions with the device according to the invention.

[0178] The present invention also relates to the use of the device according to the invention for decreasing a visual, an auditive, a cognitive deficit and/or a posture instability in an individual in need thereof.

[0179] For this purpose, the individual is preferably subjected to regular training sessions during a few weeks.

[0180] In particular, the individual is preferably subjected to training sessions with the device according to the invention once or twice a week between 2 to 6 weeks, preferably 3 to 5 weeks, such as 3, 4 or 5 weeks. Preferably, the individual

is subjected to at least 4 (or at least 5, at least 6, at least 7, at least 8, such as 4, 5, 6, 7, 8, 9 or 10) training sessions (also referred to as "reeducation sessions" or "rehabilitation sessions"). The period between two successive training sessions is preferably of 2 to 7 days, such as 2, 3, 4, 5, 6 or 7 days. The period between different successive training sessions may vary, depending on the availabilities of the individual and visual health professional. However, the training sessions are preferably regularly spaced.

[0181] The training sessions may comprise vergence double step training sessions (preferably combined with the new functionalities (use of many colours and instruction to count one) and/or REVA training sessions. For each training session, the individual may be subjected to vergence double step training sessions only, to REVA training sessions only or to both vergence double step training sessions and REVA training sessions, depending on the type of deficit identified during functional exploration. However, during the whole set of training sessions, the individual will preferably be subjected to both vergence double step training sessions and REVA training sessions.

[0182] When the whole set of training sessions comprises both vergence double step training sessions and REVA training sessions, each training session (on a specific day) may comprise a vergence double step training session only, a REVA training session only or both a vergence double step training session and a REVA training session. However, each training session (on a specific day) preferably comprises both a vergence double step training session and a REVA training session, as the variety of protocols renders training more engaging for the person.

[0183] Both types of training sessions use the device according to the invention, but with different protocols.

Vergence double step training sessions

[0184] Vergence double step training sessions stimulate vergence movements, similarly to vergence tests/protocols for functional exploration. However, the protocol is slightly different, using the double step protocol, as this has been found to improve training/reeducation.

[0185] Each vergence double step training session comprises 1 or 2 repetitions of 1 or 2 block(s) of divergence followed by 3 to 5 blocks of convergence. For instance, a vergence double step training session may comprise:

- 1 block of divergence, followed by 4 blocks of convergence. When each block contains 40 trials, each block is about 2-3 minutes and such a training session has a duration of about 15 minutes.

- 2 blocks of divergence, 3 blocks of convergence, 2 blocks of divergence, 3 blocks of convergence, and a final block of divergence. When each block contains 40 trials, each block is about 2-3 minutes and such a training session has a duration of about 35 minutes.

[0186] While all vergence double step training sessions to which the individual is subjected may be identical, it is also possible for the visual health professional to change the precise content of vergence double step training sessions in some sessions.

[0187] Each block of a vergence double step training session comprises 30 to 50 trials, preferably an even number of trials between 30 and 50, more preferably between 36 and 44 trials, such as 36, 38, 40, 42 or 44 trials, in particular 40 trials.

[0188] The trials of the vergence double step training sessions are not the same as in the vergence tests/protocols for functional exploration. In the functional exploration, single step protocols are used while in the training protocols double step is used (double step: following the fixation period a target diode appears towards which the brain starts initiating a convergence or divergence movement; before ending this movement the target diode steps to a more converging or more diverging location depending on the paradigm).

[0189] With the flat support 10 in horizontal position, after an initial fixation of a diode presented at various depths along the longitudinal axis of the flat support 10, the first target diode stimulus is only activated for a short period (between 150 and 200 ms); following this period, another target stimulus is activated for a period of 800 to 1800 ms. preferably 1300 ms. The vergence training protocol based on sequences of the double step type is more drastic and very effective because it triggers the implementation by the central nervous system of a new adaptive control (generation of a motor command in response to the final stimulus and not in response to the initial transitory stimulus). The technique can be particularly useful as it stimulates natural ocular motor plasticity. During convergence training blocks the second target is closer to the individual's eyes that the first one, and the opposite during the divergence training trials.

[0190] Each trial of each block of a vergence training session comprises:

- visually and/or audiovisually stimulating the individual suffering from a learning disorder at a first point located at the eyes level, in the longitudinal axis between the left eye and the right eye for a period varying from 1000 to 1600 ms, at a first distance (for instance illustrated by point F in **Figures 17B and 17C)**,
- visually and/or audiovisually stimulating the individual suffering from a learning disorder at a second point located

at the eyes level, in the longitudinal axis between the left eye and the right eye for a period of 150 to 200 ms, preferably 200 ms, at a second distance calling for a convergence movement in convergence blocks (for instance illustrated by point T1 or T1' in **Figure 17C)** or a divergence movement in divergence blocks (for instance illustrated by point T1 or T1' in **Figure 17B)**, and

- visually and/or audiovisually stimulating the individual suffering from a learning disorder at a third point located at the eyes level, in the longitudinal axis between the left eye and the right eye for a period varying from 800 to 1800 ms, preferably 1000 to 1600 ms, in particular 1300 ms, at a third distance calling for a further convergence movement in convergence blocks (for instance illustrated by point T2 or T2' in **Figure 17C)** or a further divergence movement in divergence blocks (for instance illustrated by point T2 or T2' in **Figure 17B).**

[0191] This type of protocol is referred to as a "vergence double-step protocol", and is based on the fact that the target steps to a second position before the vergence movement completion. Given that the vergence latency is between 160 and 250 ms, and vergence execution lasts between 350 and 550 ms, it is almost certain that the second step of the target occurred before the initial vergence eye movement has been made. This type of protocol is designed to expose the visuo-motor system to an error that cannot be corrected online and leads to adaptive readjustment of the gain of the motor control.

[0192] As described above for vergence tests/protocols for functional exploration, vergence training sessions may use the new functionalities of the device according to the invention. In particular, while all vergence training sessions comprise eye movement instructions, one or more (including all) of vergence training sessions may further comprise postural and/or cognitive instructions.

[0193] With respect to cognitive instructions, thanks to the control system 4, in addition to defining double step vergence movements as defined above, the user may:

- further define the double step vergence protocol by selecting:
    - a number of distinct colors for the diodes and the proportion of diodes of each selected color, and
    - for each color:
        - the intensity of the light, and
        - the proportion of silent diodes (from 0 to 100%),
        - the frequency and intensity of the associated sound for non-silent diodes; and
- Ask the individual, in addition to its primary task to follow the lighted diodes with both eyes, to perform an additional cognitive task.

[0194] Examples of cognitive instructions/tasks that may be given to the individual are the same as those described above in the section relating to functional exploration.

REVA training sessions

[0195] Protocols for REVA training sessions are similar to REVA test protocols described above in the section relating to functional exploration.

[0196] The same REVA protocols can be used for functional exploration and training. For training, eye movements may also be recorded to substantiate the fixation patterns of eye movements and their degree of fluctuation in addition to the responses given by the person to the cognitive instruction (e.g. how many red colors were presented). It is however not necessary, and REVA training sessions may thus be performed without recording eye movements.

Individual

[0197] Any individual may be trained/reeducated using the device according to the invention. However, the trained/reeducated individual will preferably be selected from those already mentioned as preferred in the section relating to functional exploration using the device according to the invention.

[0198] The REVA protocols are of high relevance for all types of individuals with:

- attention and cognitive deficits, no matter their age (children, adolescents, adults, or elderly) or the origin of the cognitive deficits,
- visual and/or auditory deficit(s), no matter their age (children, adolescents, adults, or elderly) or the origin of the visual and/or auditive deficits ,

- activities necessitating cognitive, posture and multisensory integration.

[0199] The vergence double step training protocol is necessary only when vergence deficits have been assessed in the functional exploration session. However, as vergence is physiologically the most fragile eye movement, such training is also almost always needed.

[0200] The following examples merely intend to illustrate the present invention.

EXAMPLES

Example 1: Post-stroke reeducation with REMOBI-Neurocog improves hemineglect due to stroke

[0201] REMOBI was used for initial functional exploration of an individual with hemineglect due to stroke, despite previous rehabilitation with conventional methods. The individual was then submitted to training with REMOBI-Neurocog and final functional exploration confirmed significant improvement in defects detected in the initial functional exploration.

Patients, Materials and Methods

Patient

[0202] The individual is 35 years old man and has previously suffered an ischemic hemorrhagic stroke in the right occipital lobe by dissection of the right posterior cerebral artery resulting in a clot that resolved.

[0203] Since then, the subject suffers from a left hemineglect despite a lot of rehabilitation (speech therapy, orthoptic therapy and video games). Cognitive tests did not reveal any other after-effects except for a slight difficulty in recognizing new people and finding one's way around in new places.

[0204] The individual works and lives normally, except for driving, which is forbidden, and cycling in the city, which he prefers not to perform.

Eye movement recording device

[0205] For each test involving recording of eye movements, eye movements were recorded binocularly with a head-mounted video-oculography device, Pupil Core, enabling binocular recording at 200 Hz per eye (Pupil Labs, Berlin).

Vestibular test

[0206] The individual performs left and right head rotations while fixating the central diode of the REMOBI device, and eyes' movements were recorded. The lighted diode progressivelly moves for near to far (from 20 to 100 cms from the eyes of the individual).

[0207] Based on these measurements, the conjugate (left+right eyes positions/2) and disconjugate (left eye position - right eye position) signals were calculated using the AIDEAL software (as described in details in WO2021228724A1, the content of which is herein incorporated by reference).

Reading test

[0208] For the reading test, the individual was seated, and his r eyes' movements were recorded during reading of the text L'Alouette, a French text of 265 words that does not make sense and that is routinely used in dyslexia diagnosis by orthophonists.

[0209] Based on these measurements, curves of the conjugate (left+right eyes positions/2) and disconjugate (left eye position - right eye position) signals were generated using the AIDEAL software.

Initial and final tests with REMOBI

Combined movements

[0210] Using visual targets alone (no sound), the combined eye movements left or right from near to far (see arrows on **Figure 18A)** were tested using the following protocol: the site of target appearance was unpredictable as well as the depth (far or near).

[0211] Based on these measurements, curves of the conjugate signal (left+right eyes positions/2, i.e. left and right sacades) were generated using the AIDEAL software.

Saccades at different depths on the same arc

[0212] In order to determine if visual neglect on the left side occurs at all distances in depth, saccades of the individual were measured at various distances (far: 150 cm, intermediate: 70 cm and very near: 20 cm), using the following protool: using the saccade protocol under the overlap paradigm.

[0213] Based on these measurements, curves of saccades (conjugate signal, i.e. left+right eyes positions/2) were generated using the AIDEAL software.

Reeducation/training with REMOBI-Neurocog

Vergence training with the double step in depth paradigm

[0214] Vergence training was done using the double step paradigm with sound described previously

REVA protocol

[0215] A prototype version of the random REVA protocol was used, by setting the tablet in slightly tilted position and using the random REVA protocol presenting diodes at different positions left or right and near or far randomly; the sound was made more or less high to stimulate use of the visual input.

Results

[0216] The individual was first subjected to a detailed functional exploration using various tests: a vestibular test, a reading test and saccades and vergence tests using the REMOBI device.

Initial functional exploration

Vestibular test

[0217] The conjugate (left+right eyes positions/2) and disconjugate (left eye position - right eye position) signals measured during the vestibular test are presented in **Figure 19.**

[0218] The conjugate signal indicates the vestibulo-ocular compensating eye movements (eyes turn right, upward reflexion when the head turns left, and vice versa). Large compensatory vestibulo-ocular eye movements of about 30 degrees are observed.

[0219] The disconjugate signal indicates the dis-conjugacy (difference between the two eyes) during the head's rotations. The disconjugacy is abnormally high (about 20% of the conjugate signal, normal value should be below 10%). This means that in natural conditions with head or body movements, the individual might experience transiently blurred or double vision, which can compromise his visual stability, justifying absence of driving or cycling in the city.

Reading test

[0220] The conjugate (left+right eyes positions/2) and disconjugate (left eye position - right eye position) signals measured during the reading test are presented in **Figure 20.**

[0221] The conjugate signal shows that the eyes saccade from left to right across the 5 text lines read.

[0222] The disconjugate signal during reading shows as major deficit a large divergent disconjugacy of the two eyes, about 5 degrees, at the moment when the eyes move left to read the beginning of the next line.

REMOBI tests (before reeducation with REMOBI-Neurocoq)

[0223] Results obtained for the test of combined movements are presented in **Figure 18B.**

[0224] The curves show that the individual was missing completely the targets to the left, indicating that visual neglect for this side and depth was still there.

[0225] Combined eye movements are the most frequent movements we make in everyday life; they are complex as the brain has to calculate and synchronize both directions (left and right) and depth.

[0226] In order to determine if visual neglect on the left side occurs at all distances, saccades of the individual were measured at various distances (150 cm, 70 cm and 20 cm). Saccades measured at far distance (150 cm) are presented in **Figure 21A,** and show that the individual makes saccades to both fields (right and left) at far distance; but those to the left are less accurate followed by multiple corrective saccades.

[0227] Saccades measured at intermediate distance (70 cm) are presented in **Figure 21B,** and show larger differences between the right and left at intermediate distance compared to far distance; leftward saccades are more perturbed with multiple saccades made to reach the target.

[0228] Saccades measured at very near distance (20 cm) are presented in **Figure 21C,** and show that the problem is majored at very near distance. With sgnificant difficulty in initiating stimulus driven saccades.

[0229] Because of the difficulty with the very near space and convergence of the eyes the patient tries to anticipate target location, giving rise to errors or inappropriate movements. This analysis indicates that the patient has problems with visual activities at the very near space requiring sustained convergence of the eyes.

Conclusion

[0230] Overall, the examination of the individual with the REMOBI device enabled to identify persisting problems specific in side and depth; namely problems in dealing with the very near space and with the left side for intermediate distances, despite 3,5 years of previous reeducation using conventional rehabilitation (speech therapy, orthoptic therapy and video games).

Final test with REMOBI (after reeducation with REMOBI-Neurocog)

[0231] Such persisting problems could be alleviated with REMOBI-Neurocog training, and the individual was thus subjected to REMOBI-Neurocog training (or reeducation). Two types of training were performed:

- Three sessions of training of 30 minutes each were performed, during which the individual performed a few blocks of vergence training along the median plane using the double step in depth paradigm (with sound) of the REMOBI (see Materials and methods),
- One session of training with the REVA protocol (see Materials and methods) was also performed.

[0232] After reeducation, the individual was once more subjected to analysis
of saccades at very near distance (20 cm) and combined movements using REMOBI device. Results for saccades at very near distance (20 cm) are presented in **Figure 22,** and show clear improvement of both left and right saccades at very near distance.

[0233] Tests were done with visual targets alone with no sound, to compare with those obtained before. Also the importance here is to evaluate how much the person's behavior relies on attention and visual processing *per se,* rather than on multisensory compensatory audiovisual integration.

[0234] Results for combined movements to visual targets (no sound) are presented in **Figure 23,** and also show clear improvement of combined movements to the left.

Conclusion

[0235] Overall, the REMOBI testing enabled to identify persisting problems in the specific parts of the visual field. Training of the eye movement with the vergence and REVA protocols together with visual and auditory stimuli improved the capacity of the patient to orient his eyes successfully to visual targets alone appearing in either visual field.

[0236] This case illustrates the interest of reeducation protocols using the new REMOBI-Neurocog device, both for vergence training and using the new REVA protocol, for decreasing hemineglect in subjects after a stroke. The possibility to modulate sound and vision intensity is a major asset to improve functional orienting eye movements in all parts of the visual field in such patients. Further developments include the possibility to render more or less frequent the occurrence of targets in the neglected site of the visual field.

Example 2: functional exploration of binocular motricity parameters in healthy young subjects and in elderly individuals suffering from presbycusis reveals correlations between binocular motricity, audition and cognition

[0237] Various participants (young or elderly) were tested for:

- their binocular motricity (vergence and saccade tests) with the device of the invention, using visual or audiovisual stimulation,
- their auditive perception (hearing tests), and
- their cognitive perception (Stroop test).

[0238] Then, correlations between various binocular motricity parameters, auditive perception parameters, and cog-

nitive perception parameters were analyzed, either in the total population (young + elderly) or specifically in the elderly population.

Participants, materials and methods

Participants - studies 1 and 2

[0239] Participants were divided into two groups: an elderly group (Group E), composed of 69 participants aged between 51 and 84 years (mean 66.7 +8.4, 18 M and 51 W) and a young group (Group Y) composed of 30 participants aged between 21 and 30 years (mean 25.3 +-2.68, 17M and 13 W). Group E was recruited by the RISC (relai d'information des sciences cognitives, France) platform of the CNRS or by contacting associations likely to have people of appropriate ages. Some of them were retired while others were still working. All participants were autonomous and came to the laboratory without assistance. We can consider this sample as an average elderly population. Group Y was composed of people working in the same building.

[0240] All these participants had good sight or wore visual correction. No participants showed neurological or psychiatric disorders nor did they receive any medication that could affect their sensory and motor functions. Finally, none had auditory or oculomotor pathologies. Amongst the participants of Group E, 5% of them are treated for diabetes, 17% are treated for blood pressure, none have renal failure and 14% have vascular issues (60% of them treated).

[0241] Informed consent was obtained from all participants after the nature of the procedure had been explained.

[0242] Rather than focusing on the elderly group, which became smaller than planned due to the COVID 19 pandemic, we sought useful to add a group of young participants enabling us to evaluate aging both relative to performances of young persons, and progressive aging withing the elderly group itself.

[0243] The study was approved by the ethic committee "Ile de France II".

Participants - study 3

[0244] An elderly group (EG) and a young group (YG) were tested. The YG was composed of 30 participants aged between 21 and 30 years (mean 25.3 +-2.68). They were mostly students working in neighbouring laboratories. The EG was composed of 69 participants, aged between 51 and 84 years (mean 66.7 +8.4). They were essentially recruited on the RISC (relai d'information des sciences cognitives, France) platform of the CNRS and were autonomous. Thus, they are considered to be a normal representing aging population. They all passed a short questionnaire at the beginning of the tests in order to check if they had a good vision in their daily life (with or without correction), if they took medications which could damage their sensory and motor functions, if they had neurologic, psychiatric, auditory or oculomotor disorders. They all sign an informed consent.

Binocular motricity tests

[0245] The different oculomotor movements (divergence, convergence, left saccade and right saccade) were tested via the REMOBI device.

[0246] The REMOBI device is a visio-acoustic surface composed of 48 diodes (with nominal frequency 626 nm, 180 mCd, and a diameter of 3 mm) embedded at 4 isovergence arcs. The device includes different sequences, lighting up the diodes in different patterns. The participants were sitting in front of the REMOBI device, placed at eye level, and were instructed to fixate as quickly and as accurately as possible the activated diode and to maintain the fixation. The sequence chosen on the REMOBI device enables the testing of a specific kind of eye movement. Two sequences were used in this study: the saccade sequence, measuring left and right saccades (see **Figure 10),** and the vergence sequence, measuring divergence and convergence (see **Figure 12).**

Eye movement analysis

[0247] Data recorded with the Pupil Labs eye tracker was analyzed with the AIDEAL software (pending international patent application: WO2021228724A1). The signal is derived by calculating the difference between the two eyes from the individual calibrated eye position signals (i.e., left eye - right eye). The onset and the offset of the saccades were defined as the moments where the velocity went above or below 10% of the peak velocity. The onset and the offset of the vergences were defined as the moments where the velocity went above or below 5°/s. These criteria are standard and were applied automatically by the AIDEAL software. Trials with blinks were excluded.

Hearing tests

[0248] All the hearing tests were assessed by an audiometrist with an audiometer of the brand Interacoustics (model AD629) in a sound booth calibrated cabin. These tests were composed of a pure-tone hearing threshold audiometry and by two speech recognition tests, one in silence and one in noise. An otoscopic evaluation was first performed in order to detect any foreign body in the outer ear canal that could bias the audiometric results.

[0249] The pure-tone hearing threshold audiometry (also known as tonal audiometry) is measuring the audibility, e.g., the minimum intensity required to detect a sound. It was realized with a headset (audiometric TDH-39P), with one ear tested at the time. The score extracted from the pure-tone hearing threshold audiometry is the PTA (pure-tone average) of the best ear. Hearing thresholds in dB HL for pure-tones of 250, 500, 750, 1000, 2000, 3000 and 4000 Hz were determined with 5-dB steps. Then the PTA was calculated by meaning all these thresholds. We decided to keep the PTA of the better ear in order to follow the hearing loss definition of the world health organization (WHO) (Cruickshanks, K. J.; Wiley, T. L.; Tweed, T. S.; Klein, B. E. K.; Klein, R.; Mares-Perlman, J. A.; Nondahl, D. M. Prevalence of Hearing Loss in Older Adults in Beaver Dam, Wisconsin: The Epidemiology of Hearing Loss Study. Am. J. Epidemiol. 1998, 148 (9), 879-886. https://doi.org/10.1093/oxfordjournals.aje.a009713), which is when the better PTA of the two ears is above 20 dB HL.

[0250] The speech audiometry in silence was realized with a loudspeaker situated at 1 m in front of the participant (azimuth 90°). From this loudspeaker (brand Tangent, model EVO) were sent different lists of words with different step intensity levels: either 70, 60, 50, 40, 30, 20 or 10 dB SPL. The lists were the Lafon cochlear lists, which are composed of 17 monosyllabic words of 3 phonemes (51 phonemes) (Gordon, -Salant Sandra; Fitzgibbons, P. J. Temporal Factors and Speech Recognition Performance in Young and Elderly Listeners. J. Speech Lang. Hear. Res. 1993, 36 (6), 1276-1285. https://doi.org/10.1044/jshr.3606.1276). Each list was assigned a score of comprehension, representing the percentage of phonemes correctly repeated, out of the 51 phonemes of a list. The intensity level of the first list was chosen with respect to the PTA scores (assessed just before) to be well heard by the participant. Each following list was then sent with a lower step-intensity. The score extracted from the speech audiometry in silence was the SRT50 (speech recognition threshold 50%), representing the intensity required in dB SPL (sound pressure level) such that the participant repeats 50% of the phonemes. In this study, the SRT50 was estimated by a cross product between the intensity needed to obtain the score above 50% and the intensity needed to obtain the score under 50%.

[0251] The speech audiometry in noise was realized with three loudspeakers loudspeaker (brand Tangent, model EVO) situated at 1 m of the participant: one in behind him (azimuth 270°), one to his right (azimuth 180°) and one to his left (azimuth 0°). From the two loudspeakers on the right and left, were sent the Lafon cochlear lists (same speech signal as for the speech audiometry in silence). From the loudspeaker situated behind the participant was sent a noise signal called the OVG (Onde Vocale Globale in French) (Plack, C. J.; Barker, D.; Prendergast, G. Perceptual Consequences of "Hidden" Hearing Loss. Trends Hear. 2014, 18, 2331216514550621. https://doi.org/10.1177/2331216514550621). This noise is composed of a mix of two couples, one French and one English, speaking at the same time, resulting in an incomprehensible babble noise. Similarly, to the audiometry in silence, each Lafon cochlear list was assigned a score of comprehension, representing the percentage of phonemes correctly repeated, out of the 51 phonemes. The score extracted from the speech audiometry in noise was based on the Signal to Noise Ratio (SNR). The SNR represents the extent to which the speech signal is higher or lower in intensity compared to the noise intensity. It is calculated by deducting the intensities in dB SPL of the speech list and the noise (SNR=signal intensity - noise intensity). The SNR varied for each new Lafon cochlear list by changing the noise intensity while the intensity of Lafon cochlear lists remained unaltered. Thus, each participant had during all their speech audiometry in noise, a specific unchanged intensity for all their Lafon cochlear lists. For each participant, the intensity of the Lafon cochlear lists was chosen by taking the lower intensity in the speech audiometry in silence giving the best score (example: if in speech in silence test, participant A had a recognition score of 100% for the list at 60 dB SPL, 100% for the list at 50 dB SPL and 82% for the list at 40 dB SPL, then the intensity of the lists for the whole speech audiometry in noise would be set at 50 dB SPL). The first Lafon cochlear list of this test was sent with a SNR at 0 (speech and noise at the same intensity level). We then we decreased the SNR by 5 for each list (by increasing the noise level by steps of 5 dB SPL). The variable extracted from speech in noise test was the SNR50 (signal to noise ratio 50%), representing the SNR required to have a phoneme discrimination score of 50%. As for the speech comprehension in silence test, the SNR50 was estimated by a cross product between the SNR needed to obtain the score above 50% and the SNR needed to obtain the score under 50%. Consequently, this test assessed the degradation of comprehension by the noise for a signal completely understood in silence.

Stroop tests

[0252] The Stroop test is a cognitive test assessing executive functions such as selective attention or inhibition capacities. It consists of orally enumerating the font colors of a list of words that have a different meaning than their color (ex: the word "blue" printed in red). The brain has to inhibit the information given by the meaning of the word, which is

the most protruding and intuitive, in order to focus on the information given by the printed colors. In other words, it has to focus on a specific information while ignoring another information.

[0253] The Stroop test was first described in 1935 by J.R STROOP (Salthouse, T. A. Speed of Behavior and Its Implications for Cognition. In Handbook of the psychology of aging, 2nd ed; The handbooks of aging; Van Nostrand Reinhold Co: New York, NY, US, 1985; pp 400-426). A lot of variations of this original test were created, but they followed the same principle. The different Stroop tests are always composed of three or four parts, from simple tasks such as reading words printed in black or color recognition of colored dots to the final and more complex task, cited above, of color enumeration with incongruent words.

[0254] The selected version of Stroop in this article is the French Stroop Victoria (Dubno, J. R.; Dirks, D. D.; Morgan, D. E. Effects of Age and Mild Hearing Loss on Speech Recognition in Noise. J. Acoust. Soc. Am. 1984, 76 (1), 87-96. https://doi.org/10.1121/1.391011). This version of Stroop test was chosen because of its short administration time; appropriate for usage on an elderly population and the provision of a normative database on 244 healthy community-dwelling adults living in Montpellier and Lille (mean age 65.83 SD=10.71).

[0255] In this version, the participant has to list the color of 24 items as quickly as possible (6 lines of 4 items) in three different conditions. The possible colors of the items are blue, green, yellow or red. The first condition is the "Dot" condition, where the items are dots. The second condition is the "Word" condition, where the items are the words *mais* (but), *pour* (for), *donc* (thus) and *quand* (when). The third condition is the "Interference" condition, where the items are the words bleu (blue), *vert* (green), *jaune* (yellow) and *rouge* (red). Words in this last condition are incongruent, i.e. the color ink of the word is not the same as the word signification (example: the word *rouge* (red) printed in green). In this article, Stroop_D represents the time to perform the "Dot" condition, Stroop_W represents the time to perform the "Word" condition, and Stroop_I represent the time to perform the "Interference" condition. From these variables are also calculated Stroop_I/D, which represents the ratio between Stroop_I over Stroop_D; and Stroop_W/D, which represents the ratio between Stroop_W over Stroop_D.

[0256] Thus, the Stroop Victoria first assesses the speed of color denomination (Stroop_D). Then it assesses the same variable but in presence of a distracting information, i.e the meaning of the words (Stroop_W and Stroop_I). The ratio Stroop_W/D and Stroop_I/D represent the behavioral impact of these distracting informations on the speed of color denomination. The difference between Stroop_W/D and Stroop_I/D is about the strength of their interference effect. The distracting information given by the "Interference" condition is stronger than those given by the "Word" condition. Thus, the Stroop_W/D assesses the behavioral impact of a weak interference, while the Stroop_I/D assesses the behavioral impact of a strong interference.

[0257] Besides, the study of aging effect on inhibition and selective attention will be more specific with Stroop_I/D than with Stroop_I. Indeed, if the increase of Stroop_I with age could reflect of loss of selective attention capacities, it can also reflect a general slowing due to age (in this last case, Stroop_D will be increased too). The age-related general slowing is a robust finding in studies. This slowing of behavior appears for motor responses and sensory processes and becomes more important with complex tasks (Rajan, R.; Cainer, K. E. Ageing without Hearing Loss or Cognitive Impairment Causes a Decrease in Speech Intelligibility Only in Informational Maskers. Neuroscience 2008, 154 (2), 784-795. https://doi.org/10.1016/j.neuroscience.2008.03.067; Clinard, C. G.; Tremblay, K. L. Aging Degrades the Neural Encoding of Simple and Complex Sounds in the Human Brainstem. J. Am. Acad. Audiol. 2013, 24 (7), 590-599. https://doi.org/10.3766/jaaa.24.7.7). The calculation of this ratio variable (Stroop_I/D) reduces the influence age-related general slowing (King, A.; Hopkins, K.; Plack, C. J. The Effects of Age and Hearing Loss on Interaural Phase Difference Discrimination. J. Acoust. Soc. Am. 2014, 135 (1), 342-351. https://doi.org/10.1121/1.4838995).

Results

Loss of audiovisual facilitation along the depth axis with age (study 1)

[0258] In study 1, a loss with age of audiovisual facilitation also called audio-visual integration along the depth axis was observed, as illustrated by **Figures** 24 **and 25.**

[0259] In particular, **Figure 24** shows that, for convergence and divergence for the elderly group, there is no latency difference between movements toward visual and audiovisual targets.

[0260] **Figure 25** shows that gain amplitude was lower for the elderly group than young group (74 $\pm$ 1.3 % for the young group, and 71.4 $\pm$ 1.3 % for the elderly group; $p < 0.000$); higher for the movement toward audiovisual targets than toward visual targets (78.0 $\pm$ 1.9 % VS 67.4 $\pm$ 1.3 %; $p = 0.033$); and higher for saccades than vergence (52.1 $\pm$ 1.9 % for D; 57.8 $\pm$ 2.4 % for C; 89.9 $\pm$ 1.0 % for LS and 91.1 $\pm$ 1.1 % for RS; $p < 0.000$). Recall that the gain amplitude is estimated as the ratio of eye movement amplitude over the target amplitude requirement. Gain values are thus measured between 0 and 1, with 1 representing 100% accuracy.

[0261] Significant interactions were also found between movement and age ($p=0.002$) and between age, movement and target modality ($p=0.025$). Such significant interactions indicate that audiovisual targets improve gain amplitude only

for vergence eye movements and only in the young group.

In the elderly, audiovisual integration (AVI) along the depth axis increases with age (study 3)

[0262] While audiovisual integration along the depth axis was found in study 1 to decrease with age, when focusing on the elderly population, it was unexpectedly found that audiovisual facilitation along the depth axis increases with age (see Figure 26).

[0263] As shown in Figure 26, the slopes of the regression lines between convergence AVI(Lat) and age are significantly different from 0, regarding either the two groups together (EG+YG), or the EG alone. However, these two effects are different. For the EG alone, convergence AVI(Lat) decreases with age, while it increases with age for the whole population (YG+EG). This means that, for the whole population (YG+EG), the reduction of convergence latency with the auditory signal is more important for the participants of the YG than for the participants of the EG. However, regarding only the participants of the EG, the reduction of the convergence latency with the auditory signal increases with age. In other words, there is a process degrading the AVI of convergence latency between the period of young adults to senior. Then, another process inverses this trend and improves the AVI of convergence latency with age.

In the elderly, audiovisual integration (AVI) or facilitation along the depth axis increases when Stroop score decreases (study 3)

[0264] This section assessed the relation between Stroop performances and AVI of eye movements in study 3. In order to avoid a potential confound effect of age, the analyses methods used here are multiple regressions analysis. AVI is the dependent, explained variable. Stroop_W/D and age are the independent, explanatory variables.

[0265] Results are shown in **Table 1** and **Figure 27.**

			AVI(Lat)~Stroop_I/D +Age			AVI(PVel)~Stroop_I/D+Age			AVI(AVel)~Stroop_I/D +Age			AVI(Amp)~Stroop_I/D +Age		
Movement			a	StdError	tvalue	a	StdError	tvalue	a	StdError	tvalue	a	StdError	tvalue
D	*For EG+YG*	Stroop_I/D	7,101	13,323	0,533	4,006	7,225	0,554	-1,52	1,318	-1,153	-2,12	4,88	-0,434
		Age	0,039	0,338	0,114	-0,163	0,175	-0,935	0,006	0,032	0,192	-0,033	0,118	-0,281
	For EG	Stroop_I/D	-1,36	13,423	-0,101	4,928	8,756	0,563	-1,552	1,377	-1,127	-2,362	5,017	-0,471
		Age	-0,646	0,787	-0,822	0,191	0,503	0,38	0,092	0,079	1,162	0,324	0,288	1,126
C	*For EG+YG i*	Stroop_I/D	-15,334	15,781	-0,972	6,247	11,935	0,523	0,355	1,787	0,199	1,346	6,552	0,205
		Age	0,793.	0,4	1,983	0,013	0,287	0,044	-0,018	0,043	-0,428	-0,06	0,158	-0,384
	For EG	Stroop I/D	-14,084	16,207	-0,869	2,653	14,153	0,187	-0,076	1,854	-0,041	-0,601	6,6	-0,091
		Age	**-2,097***	0,95	-2,207	-0,094	0,81	-0,115	**0,342****	0,106	3,225	**1,107****	0,378	2,93
LS	*For EG+YG*	Stroop_I/D	**-21,831.**	11,307	-1,931	6,7	15,293	0,438	0,59	1,6	0,369	0,813	1,797	0,452
		Age	0,002	0,286	0,005	0,037	0,361	0,103	0,001	0,038	0,014	0,016	0,042	0,377
	For EG	Stroop_I/D	-21,625	12,948	-1,67	6,432	14,719	0,437	0,742	1,754	0,423	0,88	1,93	0,456
		Age	0,361	0,759	0,475	-0,323	0,812	-0,398	0,086	0,097	0,89	0,039	0,106	0,367
RS	*For EG+YG*	Stroop_I/D	**-25,842***	12,271	-2,106	-11,902	18,094	-0,658	1,6	1,8	0,889	1,556	1,845	0,843
		Age	0,149	0,311	0,478	-0,152	0,431	-0,353	-0,053	0,043	-1,228	-0,046	0,044	-1,038
	For EG	Stroop_I/D	-21,045	14,139	-1,488	-18,819	21,155	-0,89	1,554	1,915	0,811	1,394	1,97	0,707
		Age	-0,363	0,829	-0,438	0,973	1,151	0,845	0,089	0,104	0,856	0,047	0,107	0,436

[0266] **Table 1.** Effect of Stroop scores on AVI independently of age, multiple regressions. Multiple regressions analysis of eye movements AVI explained by Stroop_W/D and age, for YG+EG and for EG alone. AVI are the explained variable; Stroop_W/D and age are the explanatory variables. "a" is the slope of the regression line. D for divergence, C for convergence, LS for left saccade, RS for right saccade. ***: p<0.000// **: 0.000 < p < 0.00 // *: 0.00 < p <0.05//.: 0.01 < p < 0.05.

[0267] There are no significant effects of Stroop scores on the AVI(PVel), AVI(AVel) or AVI(Amp), for any kind of eye movements and considering YG+EG or EG alone.

[0268] Regarding the AVI(Lat), there are significant effects of Stroop_I/D independently of age, for the whole population (YG+EG): AVI(Lat) of saccades decreases when the Stroop_I/D is increasing. This means that, for the whole population (YG+EG), the reduction of saccade latency with the auditory signal becomes more important with the reduction of the inhibition capacities measured with the Stroop.

Speech comprehension decrease is correlated to an increase of reaction time to initiate (latency) saccades (study 2)

[0269] In this part, are presented the results of different multiple regressions analyses, all assessing the effect of eye movement latency and age on hearing in study 2.

[0270] In **Table 2** are aggregated the results of different multiple regressions analyses, for the whole population (Group Y + Group E), assessing the effect of eye movement latency and age on hearing in study 2. The first row assesses the effect of eye movements latency and age on PTA (PTA ~Latency+Age), the second row on SRT50 (SRT50~Latency+Age) and the third row on SNR50 (SNR50~Latency+Age). For each row, the first line shows the results for the effect of latency on the hearing variable, independently of age. The second line shows the results for the effect of age on the hearing variable, independently of latency. The columns indicate the eye movement tested (divergence, convergence, left and right saccade).

Table 2: Multiple regressions; hearing results as a function of eye movement latency and age. Hearing - Latency+age *Group Y and Group E*

Divergence				**Convergence**			
	A	*StdError*	*tvalue*		*a*	*StdError*	*tvalue*
Latency	-0,013	0,014	-0,894	*Latency*	-0,005	0,014	-0,327
Age	**0,367*** **	0,044	8,346	*Age*	**0,353*** **	0,041	8,639
Latency	-0,012	0,014	-0,838	*Latency*	0,003	0,014	0,178
Age	**0,279*** **	0,044	6,394	*Age*	**0,261*** **	0,04	6,44
Latency	0,008	0,006	1,218	*Latency*	0,005	0,006	0,832
Age	0,03	0,02	1,504	*Age*	**0,039***	0,017	2,294
Left saccade				**Right saccade**			
	A	*StdError*	*tvalue*		*a*	*StdError*	*tvalue*
Latency	0,015	0,016	0,976	*Latency*	0,02	0,016	1,268
Age	**0,329*** **	0,045	7,366	*Age*	**0,322*** **	0,045	7,173
Latency	**0,033***	0,015	2,175	*Latency*	**0,043****	0,015	2,85
Age	**0,218*** **	0,043	5,045	*Age*	**0,203*** **	0,043	4,754
Latency	0,009	0,007	1,343	*Latency*	0,005	0,008	0,685
Age	**0,032.**	0,018	1,743	*Age*	**0,037.**	0,019	1,914

[0271] The results show a significant relationship between SRT50 and saccade latency independently from age. By looking at the third and fourth column, second line, the slopes of the regression lines for the left and right saccades are significant and positive. They indicate that the SRT50 of left saccade increase of 0.033 dB SPL and the SRT50 of right saccade increase of 0.043 when the latency increases of 1 ms. In other words, the speech comprehension decrease is associated with the increase of reaction time to initiate saccades. This effect remains when focusing on Group E only.

[0272] Thus, these results suggest that saccade latency may be a tool to target the cognitive consequences of presbycusis.

Conclusion

[0273] All these results show the existence of multiple interactions between auditive perception, its cognitive processing, and binocular motricity and the importance of a good communication between these different elements for a good speech understanding. Thus, they illustrate all the interest of the device according to the invention, which makes it possible to stimulate all these elements simultaneously.

Example 3: use of REMOBI-Neurocog for functional exploration of a presbycusis individual

Participant, materials and methods

[0274] The individual was a presbycusis individual.

[0275] Three saccade tests were performed at 36 m with the flat support 10 in horizontal position using the overlap protocol, using 3 colors (red, blue, green or RBG) presented randomly and instructions to count one of them, and with the following specifications for light colors, and light and sound intensity:

- Test 1: very low light intensity, no sound
- Test 2: very low light intensity, sound intensity at 10% of its maximal value (75 dB)
- Test 3: very low light intensity, sound intensity 100% (of its maximal value 75 dB)

Results

[0276] Results are presented in **Figure 28** and Table 3 below.

Table 3. Saccades latency of a presbycusis individual at very low light intensity and variable sound intensity.

Conditions	Right saccades latency	Left saccades latency
Test 1 (very low light intensity, no sound)	284+- 91 ms	295+-91 ms
Test 2 (very low light intensity, sound intensity 10% of 75 decibels (subliminal)	252+- 94 ms	231+-56 ms
Test 3 (very low light intensity, sound intensity 100% of 75 decibels)	169+- 36 ms	196+-49 ms

[0277] The results show that sound is very important. In particular, when the visual stimuli is of low intensity; even though not consciously perceived, a sound at 10% permits to improve saccades latency, in such presbycusis subject.

Conclusion

[0278] Such protocol is useful for the functional evaluation of presbycusis individuals. The protocol can also be used in connection with hearing aids, testing the one that brings better results.

Example 4: REMOBI - NeuroCog use in an individual with concussion

[0279] The patient was recruited by Alain Bauwens, Vestibular Orthoptist at Université Catholique de Louvain, Namur, site Dinant, Rue Saint Jacques 501-5500, Dinant Belgique) 56 years old, male, accident occurred 3 years ago.

[0280] Concussion occurred by accident where a stone fell on his head in a construction site, fortunately he was wearing a helmet. He has been followed for several years with marked improvements but despite this problems and discomfort persist; he cannot read, watch tv, and feels unstable.

[0281] An examination of the vergences shows significant deficits (see **Figure 29);** Vergence eye movements are also very poor, both in amplitude, slowness of initiation, slowness of the trajectories, hypometric and highly variable during vestibular ocular tests the maintenance of the binocular alignment of the eyes is compromised, during reading, one observes discoordinated saccades and unstable fixations (see Figure 30, during reading after a few lines he loses vergence control).

[0282] Saccades show high variability in latency and amplitude and left/right asymmetry, e.g. very few good saccades to the left (see **Figure 31).** Amplitude and the time of initiation of the saccades are highly variable from one second to next.

[0283] The patient presents persisting problems of binocular motor control that presumably deteriorate the quality of

his vision attention and concentration.

[0284] To go further along this functional evaluation a REVA test was also applied for 3 min. The patient was standing and the REMOBI - NeuroCog device was inclined in a oblique position so that movements of the eyes were stimulated simultaneously in all 3 dimensions (horizontally, vertically and in depth). Diodes targets (high visible of 5 different colors red, blue, green, yellow, white interleaved randomly) accompanied by sound (100% of 75 dB) were lighted on randomly at different locations (48 possible positions, in a random way). Lighting of different diodes was done at very high speed, e.g. every 250-300 msec. The patients was instructed to count only the red and green diodes and ignore the rest. The patient was highly engaged to the task; still made many errors 40% presumably due to the inefficiency of his eye movements in the 3D space.

[0285] The patient will be trained with RERMOBI Neurocog, combining the double step multicolor vergence training protocol and the random REVA protocol.

Example 5: Testing and training functionalities in a dyslexic individual with REMOBI-NeuroCog

Introduction:

[0286] 29-year-old HT presents dyslexia of mixed type (phonologic and visual), that was diagnosed and followed up during school years by speech therapy and orthoptic treatment. Today her binocular visual motor capacities are almost normal, yet optimization is still possible.

Study:

[0287] Day 1: she performed saccade, vergence and reading tests with the REMOBI-NeuroCog using multicolour (3 colours) and was given instruction to count one of these colours. Following this test, 10 minutes training was applied using the double step vergence paradigm with three colours and the instruction to count one of the colours; the training program consisted in 3 blocks of vergence double step, and 1 block of the REVA random task.

[0288] Day 2: saccade, vergence and reading tests were repeated using the same protocols to evaluate whether noticeable optimization progress could be visible after only one session.

Results:

Impact of training on binocular motricity

[0289] Results of vergence tests performed before and after training are presented in **Figures 32A** and **32B** and in **Table 4** below, and show significant improvements after training: reduction of latency (415 vs 271, 336 vs 267 msec for convergence and divergence respectively), increase of the amplitude at 160 msec 2.74 vs 4.02, 2.53 vs 2.92 for convergence and divergence respectively), increase of the mean velocity of this period (14.34 vs 18.89, 12.69 vs 14.36).

Table 4. Vergences parameters before and after training with REMOBI-NeuroCog.

Before training	
Convergence	
Number of convergences	18/20
Initial amplitude (deg)	1.26 ± 0.09
Latency	**415** ± 91
Duration (ms)	34 ± 3
Average velocity (deg/s)	40 ± **16**
Amplitude (80 ms) (deg)	1.01 ± 0.41
Amplitude (160 ms) (deg)	1.48 ± 0.8
Amplitude initial + 160 ms (deg)	2.74 ± 0.89
M(initial velocity + 160) (deg/s)	14.14 ± 5.47
Divergence	
Number of divergences	17/20

(continued)

Divergence	
Initial amplitude (deg)	1.03 ± 0.02
Latency	**336** ± 94
Duration (ms)	39 ± 3
Average velocity (deg/s)	33 ± 11
Amplitude (80 ms) (deg)	0.84 ± 0.26
Amplitude (160 ms) (deg)	1.5 ± 0.6
Amplitude initial + 160 ms (deg)	2.53 ± 0.61
M(initial velocity + 160) (deg/s)	12.69 ± 3.76
After training	
Convergence	
Number of convergences	14/20
Initial amplitude (deg)	2.08 ± 0.49
Latency	271 ± 53
Duration (ms)	53 ± 12
Average velocity (deg/s)	36 ± 11
Amplitude (80 ms) (deg)	1.17 ± 0.25
Amplitude (160 ms) (deg)	1.94 ± 0.49
Amplitude initial + 160 ms (deg)	4.02 ± 0.98
M(initial velocity + 160) (deg/s)	18.89 ± 5.68
Divergence	
Number of divergences	19/20
Initial amplitude (deg)	1.46 ± 0.38
Latency	267 ± 107
Duration (ms)	43 ± 17
Average velocity (deg/s)	28 ± 19
Amplitude (80 ms) (deg)	0.83 ± 0.56
Amplitude (160 ms) (deg)	1.46 ± 0.96
Amplitude initial + 160 ms (deg)	2.92 ± 1.34
M(initial velocity + 160) (deg/s)	14.36 ± 7.56

[0290] In addition, **Figures 33** and **34** show traces of the eyes movements during reading at day 1 (before training) and day 2 (after training). Reading speed in day 2 increased from 147 to 189 words per minute (the total time of reading decreased from 45 to 35 sec). In day 2, HT made fewer rightward saccades (43 vs 53), but the amplitude of the saccades was larger in day 2 relative to day 1 (2.21 +- 0.86 degrees vs 1.79 +- 0.66 degrees), the fixation duration increased in day 2 (430 +- 184 msec vs 368 +- 170 msec). Thus, reading speeding up was mediated by making fewer larger saccades and longer fixations, presumably treating more letters within the same fixation and fixating more selectively some of the words. Note also in the figure above the green traces that show better control of the disconjugacy of the eyes in day 2, i.e. smaller fluctuations while reading.

[0291] The above shows that REMOBI NeuroCog functionalities enable efficient optimization of vergence eye movements that impact positively reading scores.

Impact of REVA training on Cognitive executive functions

[0292] The Stroop test is widely used in neurology, including for assessing dyslexia. This test investigates capacity of selective attention and of inhibition. Literature reports poor Stroop scores in dyslexic individuals (Protopapas A, Archonti A, Skaloumbakas C (2007) Reading ability is negatively related to Stroop interference. Cogn Psychol 54:251-282).

[0293] REVA training protocols exercise visio-motor and attention capacities. In this study, the dyslexic individual HT performed the following protocol: the classic neurologic Stroop test was performed, i.e. three tasks, reading a text of colour names written in black, naming colour of dots successively, the cognitive interference task in which colour words displayed in a colour that does not match the word-for instance, the word "RED" written in the colour blue; the person is asked to identify not the word, but its colour.

[0294] Following the Stroop test, a 10-12-min training was done with the REVA protocol as follows: the REMOBI tablet was at the upright position slightly inclined, HT was at the standing position. The REVA random protocol was used for 2 min mixing 5 colours at different locations and asked to count one of them; this task was felt very difficult and in the subsequent 2 blocks only three colours were mixed and one of them should be counted; the rate of changing diodes positions was very rapid (250 msec) corresponding to average fixation duration in real life. Following these blocks, a final REVA block was done using the regular protocol presenting diodes successively from left to right, going from up to down, also mixing 3 colours at high speed (250 msec). Successful scores of colour naming varied (64/94, 43/44, 70/52 in the random blocks).

[0295] **Figures 35A** to **35D** below show eye traces during the REVA training period. When confronted to 5 colours in the first random block (A), she focuses at the centre trying to identify colours mostly in the visual periphery; exploration of the diodes is wider in the following 2 random blocks (B, C) as well as during the regular block (D).

[0296] Following this short training period, the Stroop test was run again. **Figure 36** shows eye movement traces during the three Stroop conditions (A, D: reading, B, E: naming colour, C, F: interference) before (A, B, C) and after (D, E, F) the REVA training.

[0297] Noteworthy, the time in both cases, before and after training, increases with the difficulty of the task: 14, 17.5 and 25 seconds for the reading, colour naming and cognitive interference tasks.

[0298] As in the past, we evaluate fixation durations during each task, and evaluate the cognitive interference by subtracting from fixation duration task interference fixation duration in the colour naming task (see Daniel F., Kapoula Z., Induced vergence-accommodation conflict reduces cognitive performance in the Stroop test, Sci Rep. 2019 Feb 4; 9(1): 1247). The results in Table 5 below show a significant reduction of the cognitive interference effect from 235 msec to 124 msec.

Table 5. Effect of REVA training on interference effect.

Fixation duration in msec			Interference effect 3-2
Stroop1 read black	Stroop2 name colours	Stroop 3 interference	
420+-98	314+-128	549+-119	**235**
349 +-117	378+-62	509+-62	**131 msec**

[0299] The above shows that REVA training protocols can be used to improve cognitive executive functions such as selective attention and cognitive interference as evaluated by the Stroop test. REVA training can be applied in individuals of any age with attention difficulties, learning disabilities, cognitive decline, neurodegenerative diseases, neurologic insults (strokes, concussions etc.)

[0300] REVA provides a powerful eye movement stimulation and the evidence for improvement of the cognitive interference on dyslexic adult after REVA training is shown here for the first time.

Example 6: Testing and training functionalities in an autistic individual with REMOBI-NeuroCog

Testing and training of visio-motor attention deployment using REMOBI-NeuroCog

Introduction

[0301] N. is a 4,5-year-old girl, presenting autism spectrum disorder, with a family history and hyperactivity. Her situation is improving with age.

[0302] During eye-movement functional exploration, the child was highly unstable and had difficulties to fix her attention for long periods. However, she found amusing to name the colours of the LEDs on the REMOBI tablet.

Protocol

[0303] The REVA protocol was as followed: the tablet was set in the upright slightly inclined position; LEDs targets of variable colours with full intensity and quick lighting, preceded by the buzzer were presented in:

(A) a random protocol with sound at full intensity,
(B) a regular protocol with visual stimulation only, in which the diodes were presented regularly, step by step, from left to right, going from the upper to down series of diodes; but with no sound,
(C) a regular protocol with audio-visual stimulation, in which the diodes were presented regularly from left to right, going from the upper to down series of diodes, with sound now present before each diode.

[0304] In all conditions, the speed was set at 1000 ms, i.e. next Led lighted on every second. The child was asked to speak up the colours. She did so with emphasis and sometimes trying to touch the tablet.

Results

[0305] Colour naming was always correct.
[0306] The child was engaged for 60 sec in the condition (A), 30 sec in condition (B) and 80 seconds in condition (C). In all cases the child quit the task before the end, that was supposed to last 89 seconds. Eyes traces during REVA protocols (A) to (C) are presented in **Figure 37.**
[0307] The child was very responsive to music that was appeasing her, and the much longer engagement for regular protocol (C) with sound (80 s) compared to regular protocol (B) without sound (only 30 s) confirms the interest of audiovisual stimulation in autist children.
[0308] An attempt to measure vergence eye movement (with the flat support 10 in horizontal position and using sounds) failed as the child showed no interest at all to do this test. Yet, there is literature with clinical subjective tests suggesting higher frequency of vergence accommodation problems in autism (Anketell PM, Saunders KJ, Gallagher SM, Bailey C, Little JA. Accommodative Function in Individuals with Autism Spectrum Disorder. Optom Vis Sci. 2018 Mar;95(3):193-201. doi: 10.1097/OPX.0000000000001190. PMID: 29424829). Future developments of the vergence test with the REMOBI tablet at the horizontal position will consist in modulating the sound e.g. triple buzzer beep, double beep and single one or vice versa, for the near, intermediate and far LED target positions.
[0309] Additionally, the use of the REVA paradigms with the REMOBI tablet in a slightly tilted position so that the upper part of the tablet being further away from the child than the lower part, will help to train vergence eye movements combined with the saccades.

Conclusion

[0310] Regularity (diodes lighting on progressively from left to right) together with audio-visual stimulation with a variety of colours was the most challenging task for the child to capture and train her visio-motor attention deployment.
[0311] This shows that the above-described protocols can be used for training autistic children. Using the flat support 10 in vertical or tilted position and the child in the standing position helps to engage the child more in such training.
[0312] Visio-motor training, particularly with the REVA regular protocol, is particularly relevant for sequential eye movements as needed during reading and school activities.
[0313] The REVA protocol with regular left to right diodes lighting and from up to down, can be also be used to pre-screen developmental disorders of binocular visio-motor control for any child before starting school.
[0314] The measure of the number of colours correctly named or counted, and of the number of diodes actually fixated helps to characterize the maturation of visuomotor capacities.

REMOBI NeuroCog to increase eye contact and social gaze.

[0315] The child was also asked to look at images with faces or various personages. Her eye movement exploration over time analysed with the EyescanArt shows, in line with existing literature (see Ma X, Gu H, Zhao J. Atypical gaze patterns to facial feature areas in autism spectrum disorders reveal age and culture effects: A meta-analysis of eye-tracking studies. Autism Res. 2021 Dec;14(12):2625-2639. doi: 10.1002/aur.2607. Epub 2021 Sep 20. PMID: 34542246), the child did not fixate the eyes of the painting *Girl with pearl earring* by J Vermeer. Similarly, when looking at the image *"the thief of cookies"* almost all her eye movement exploration was focused on the right bottom corner, with no exploration on mother's face or of the children.
[0316] Yet, a surprising additional information followed up: the child was given these two images and a pencil; she immediately doodled selectively the eyes of the girl and the face of the mother.

[0317] This inspiring accidental observation leads to another use of the REMOBI-NeuroCog for autist children. The REVA regular and random protocols can be used with an image containing faces such as a painting *(Girl with pearl earring* or other) placed upon the flat support 10. Noticeably, both diodes and sounds are perceived when using tissue prints of the paintings covering the surface of the flat support. The diodes that correspond to the location of the eyes, nose and mouth of the face may be made more frequent among the other diodes. The avoidance or increase with exerting of fixations to such locations is measured.

Conclusion

[0318] REMOBI NeuroCog is useful in autism, for evaluating and improving vergence/accommodation deficits, and also for improving the child's capacity to maintain visuomotor attention and focusing on external stimulation thereby improving also social gaze and interaction.

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[0332] PCT/EP2021/077721

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Claims

1. A device for stimulating and training visumotor, auditive, cognitive and posture functions of an individual, the device comprising:

- a flat support (10) comprising a lower surface (10b) and an upper surface (10a), the flat support (10) being adapted to be positioned in front of an individual (P);
- a plurality of light diffusion means (D) for visual stimulation arranged on the upper surface, a light diffusion means (D) being configured to diffuse a light according to an intensity and a color;
- a plurality of sound diffusion means (S) arranged on the upper surface (10a), each sound diffusion means (S) being configured to diffuse a sound according to a sound level and a frequency; one light diffusion means (D) and one sound diffusion means (S) defining an audio-visual set (D, S);

the audio-visual sets (D, S) being arranged regularly along iso-vergence arcs (11, 12, 13, 14) symmetrical with respect to a longitudinal axis (AA) of the flat support (10) and positioned along the upper surface (10a), and along the longitudinal axis (AA) between the iso-vergence arcs (11, 12, 13, 14); for each audio-visual set (D, S) one light diffusion means (D) being adjacent to a sound diffusion means (S);

the device comprising a control system (4) configured to control the intensity and the color of each light diffusion means (D) and/or to control the sound level and the frequency of each sound diffusion means (S) and to control a spatio-temporal activation of the light diffusion means (D) and the sound diffusion means (S) according to several predefined protocols.

2. The device according to claim 1, wherein the predefined protocols comprise a duration of activation of each light diffusion means (D) and/or each sound diffusion means (S).

3. The device according any one of the preceding claims, wherein the color(s) used in the predefined protocol for the light diffusion means (D) is(are) chosen among: red, orange, yellow, green, blue, cyan, purple, white, a mixture of several colors.

4. The device according to any one of the preceding claims, wherein the control system (4) is further configured to count the number of light diffusion means (D) of each selected color during a predetermined protocol.

5. The device according to any one of the preceding claims, comprising a foot (2) on which the flat support (10) is mounted, the foot (2) being connected to the lower surface (10b) of the flat support (10).

6. The device according to the preceding claim, wherein the foot (2) is configured to adjust the height of the of the flat support (10) allowing the flat support (10) to be positioned appropriately at the eyes level of an individual (P)positioned in front of the flat support (10).

7. The device according to any one of claims 5 to 6, wherein the foot (2) is configured to adjust the tilt of the flat support (10) in horizontal position, in vertical position, or in tilted position in either direction, an upper part (10c) being further from the individual (P) than a lower part (10d) of the flat support (10) or vice versa.

8. The device according to any one of the preceding claims, wherein the flat support (10) is trapezoidal.

9. The device according to any one of the preceding claims, comprising at least three isovergence arcs (11, 12, 13), preferably four iso-vergence arcs (11, 12, 13, 14).

10. The device according to any one the preceding claims, wherein nine light diffusion means (D) and nine sound diffusion means (S) forming nine audio-visual sets (D, S) are arranged on each iso-vergence arc (11, 12, 13, 14), preferably one of the nine audiovisual sets is arranged at the intersection of the iso-vergence arc and the longitudinal

axis (AA), and four audio-visual sets are arranged on the iso-vergence arc on either side of the longitudinal axis (AA).

11. Use of the device according to any one of claims 1 to 10, for measuring binocular motricity parameters in an individual (P).

12. A method for measuring binocular motricity parameters in an individual, comprising:

c) putting the individual (P) in front of the device according to any one of claims 1 to 10, and
d) subjecting the individual (P) to a saccade protocol, a vergence protocol, a combined protocol, or any combination thereof, using the device according to any one of claims 1 to 10, wherein the individual (P) is given eye movement instructions to follow the lighted diffusions means (D) such as diodes of the device with both eyes.

13. The use according to claim 11 or the method according to claim 12, wherein the individual is selected from individuals:

- suffering from:
  - Cognitive deficits, in particular due to:
    - neurodegenerative diseases,
    - age-related cognitive decline,
    - brain lesions, in particular due to stroke, surgery, or trauma,
    - o developmental disorders, including but not limited to:
      - learning disorders, and
      - autism spectrum disorders,
  - Visual or auditory deficits, in particular due to:
    - physiological ageing,
    - brain lesions, in particular due to stroke, surgery, or trauma,
    - developmental disorders, including but not limited to:
      - learning disorders, and
      - autism spectrum disorders
    - eye or ear surgery,
    - genetic diseases,
  - balance disorders, or
- involved in any activity necessitating cognitive, posture and multisensory integration.

14. The use according to claim 12 or claim 13 or the method according to claim 12 or claim 13, wherein the flat support of the device is put in horizontal, vertical or tilted position.

15. The method according to any one of claims 12 to 14, wherein the individual is further given postural instructions and/or cognitive instructions.

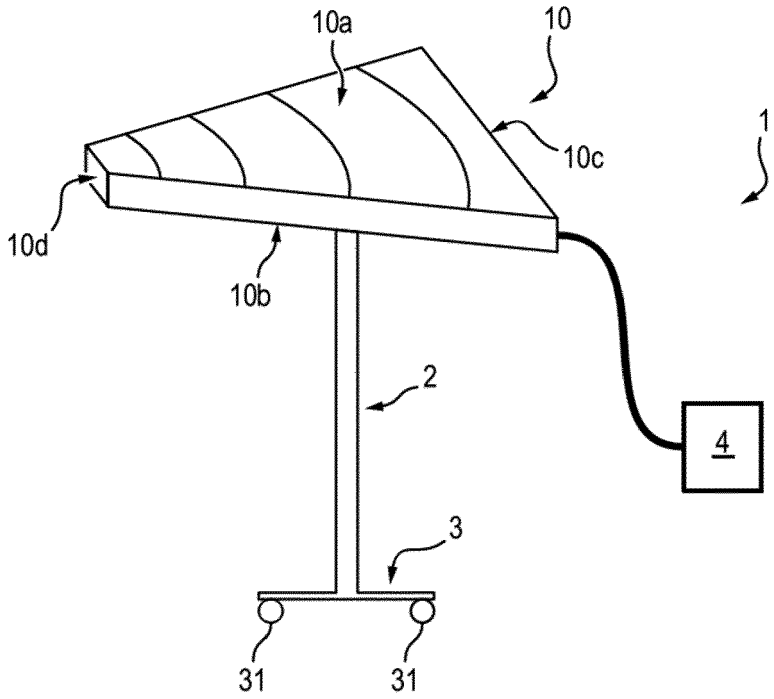


Figure 1

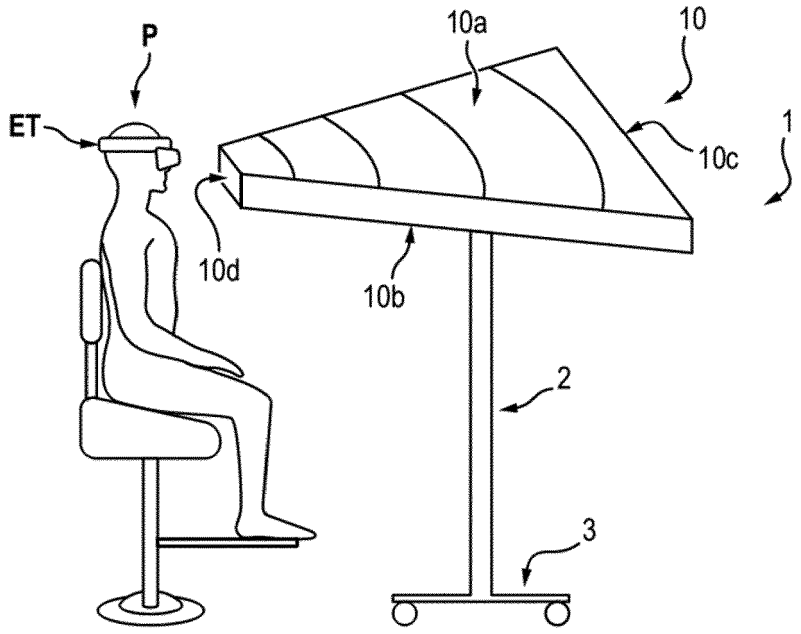


Figure 2

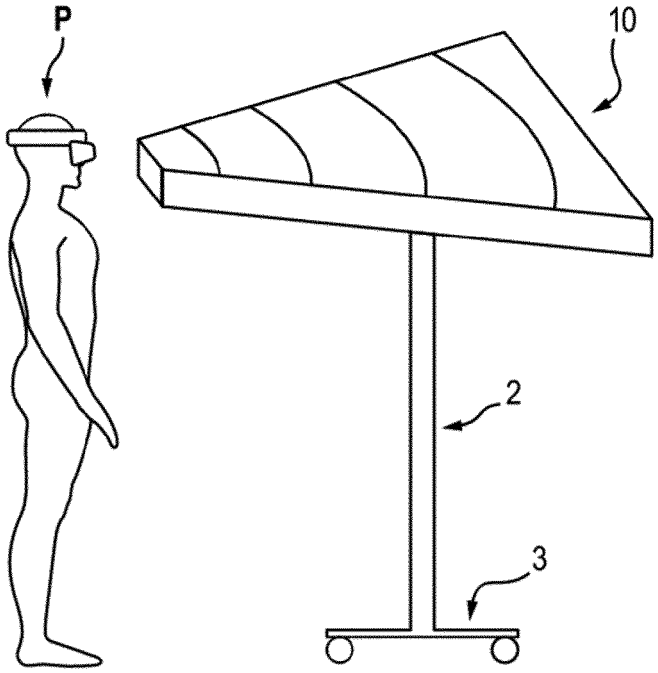


Figure 3

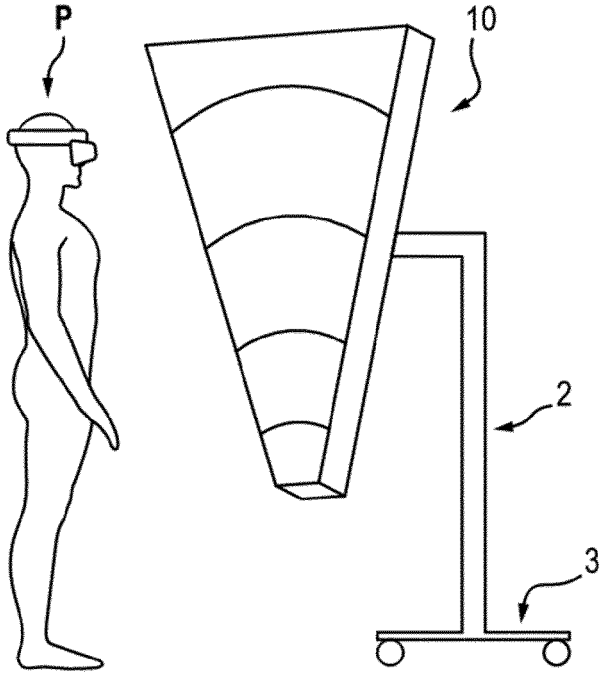


Figure 4

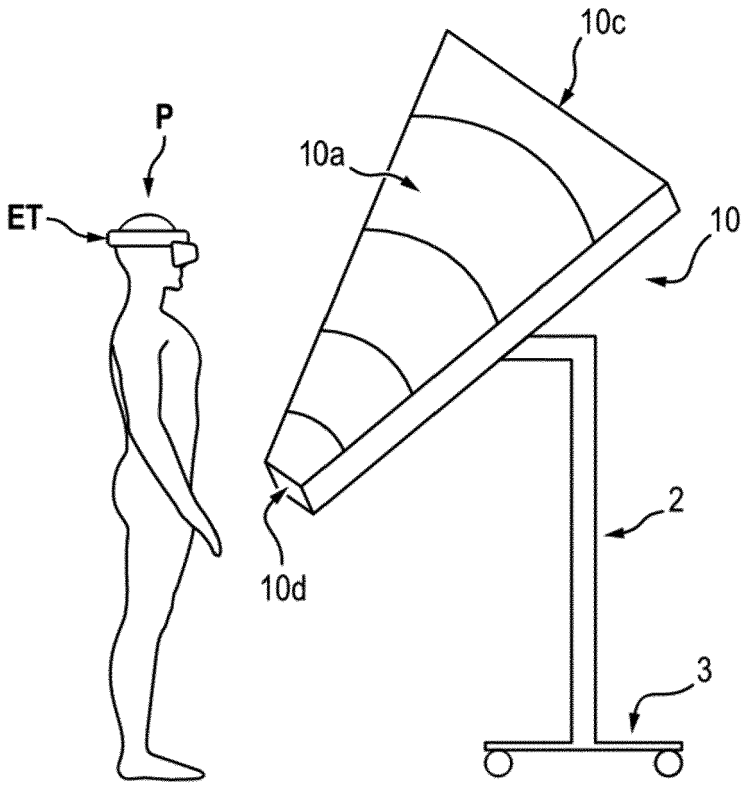


Figure 5

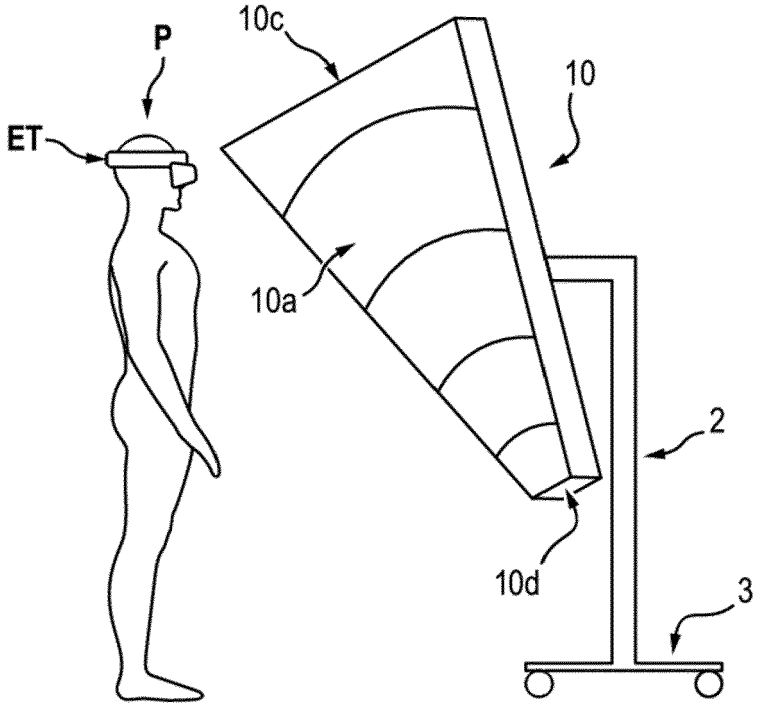


Figure 6

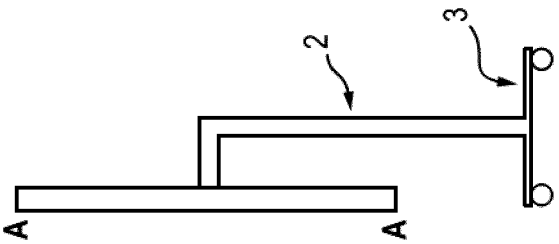


FIG. 7b

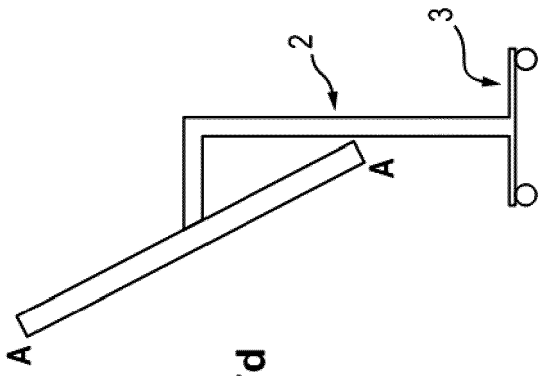


FIG. 7d

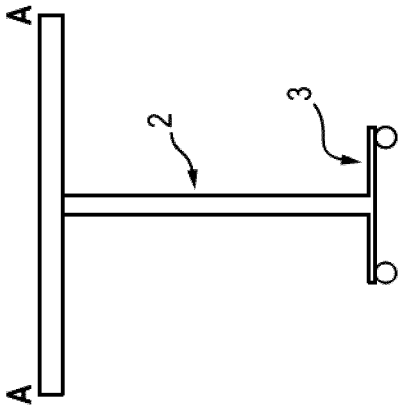


FIG. 7a

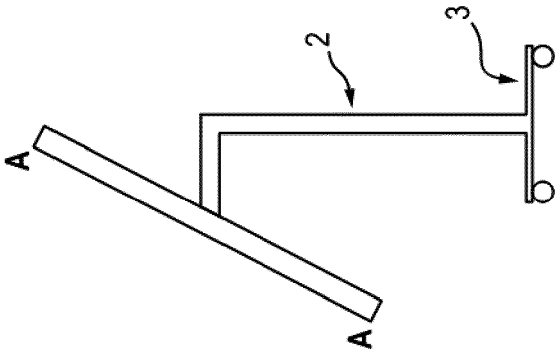


FIG. 7c

Figure 7

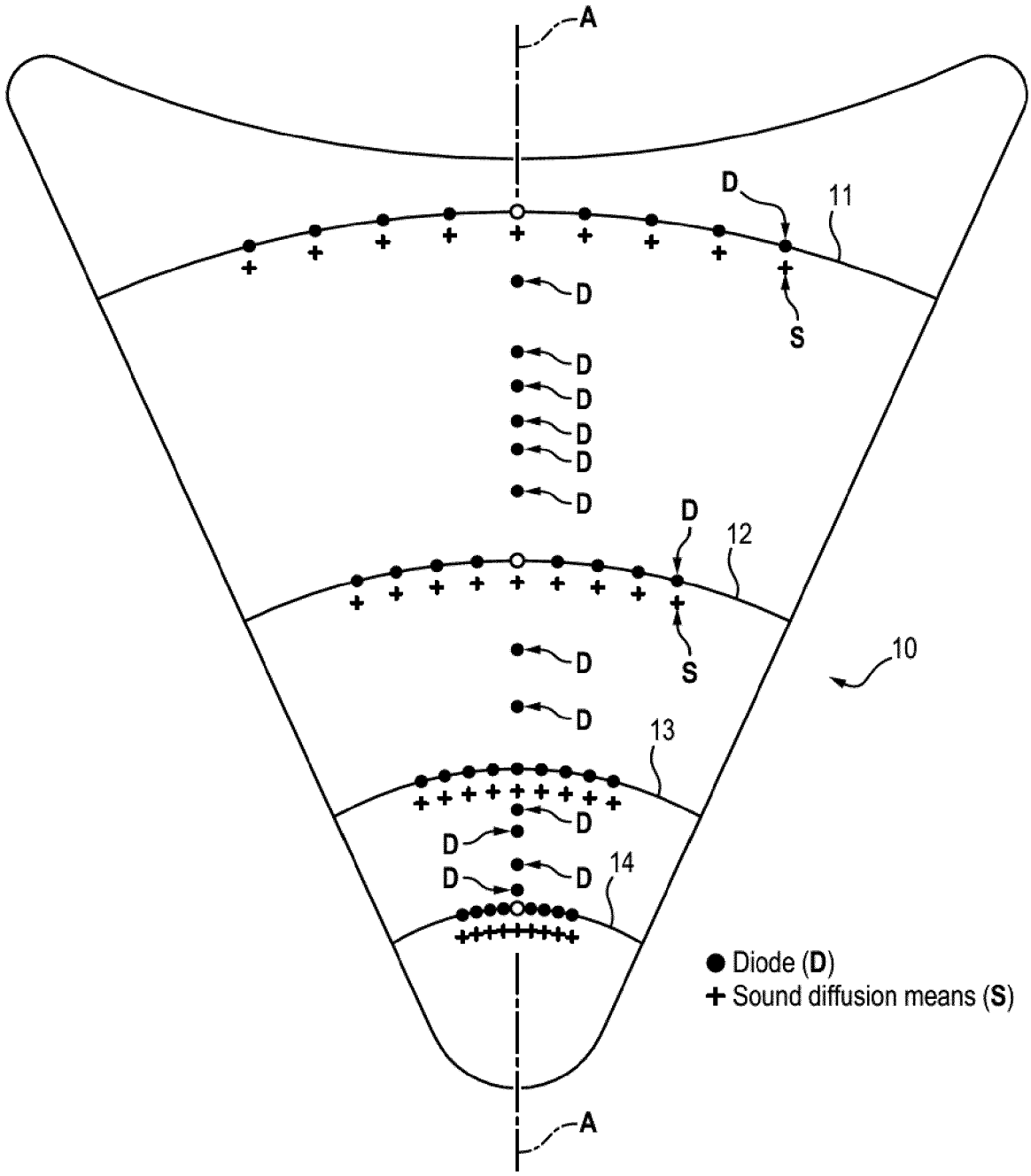

A
D
11
S
D
D
D
D
D
D
D
12
S
10
D
D
13
D
D
D
D
14
A
Diode (D)
Sound diffusion means (S)

Figure 8

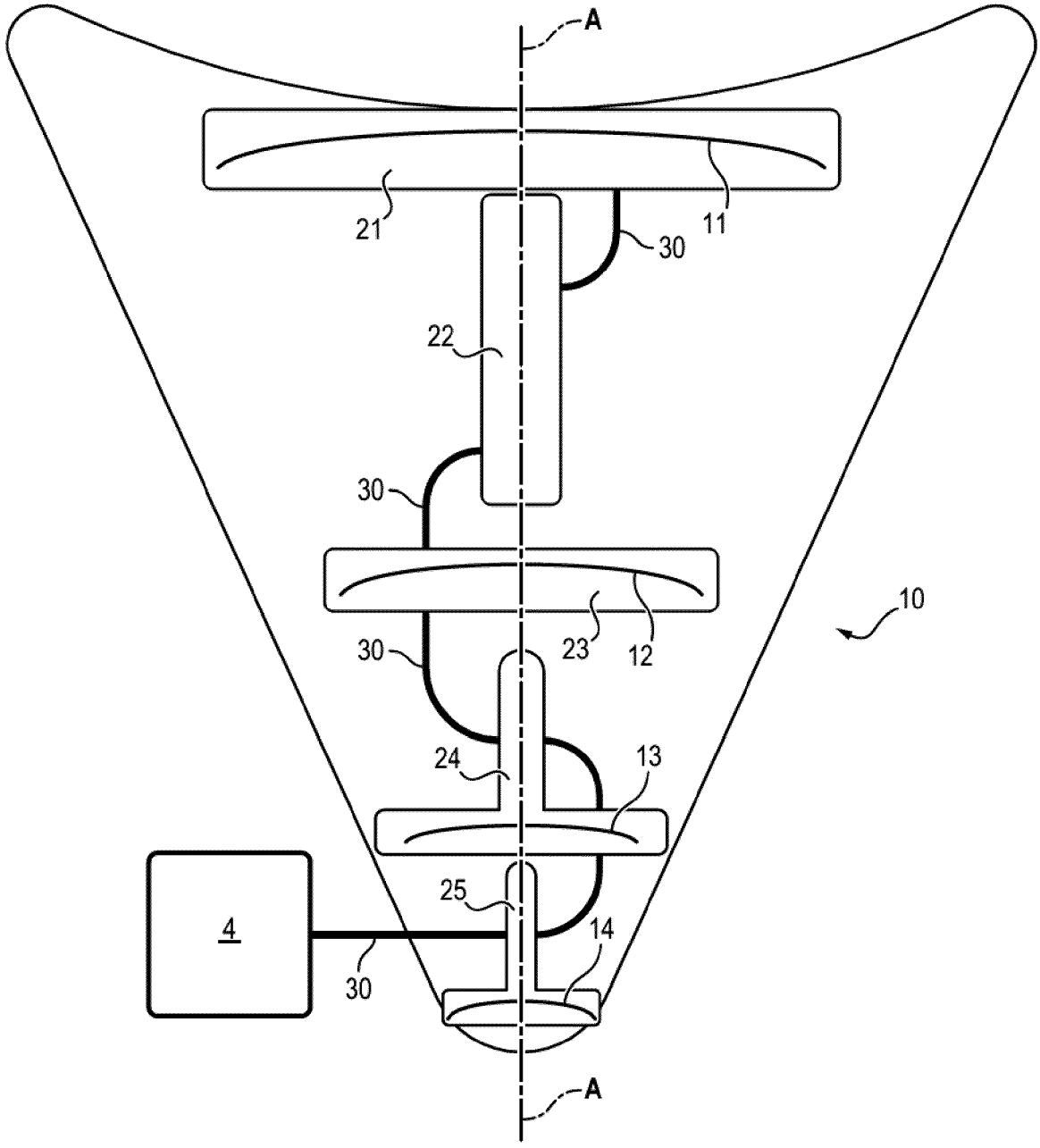


Figure 9

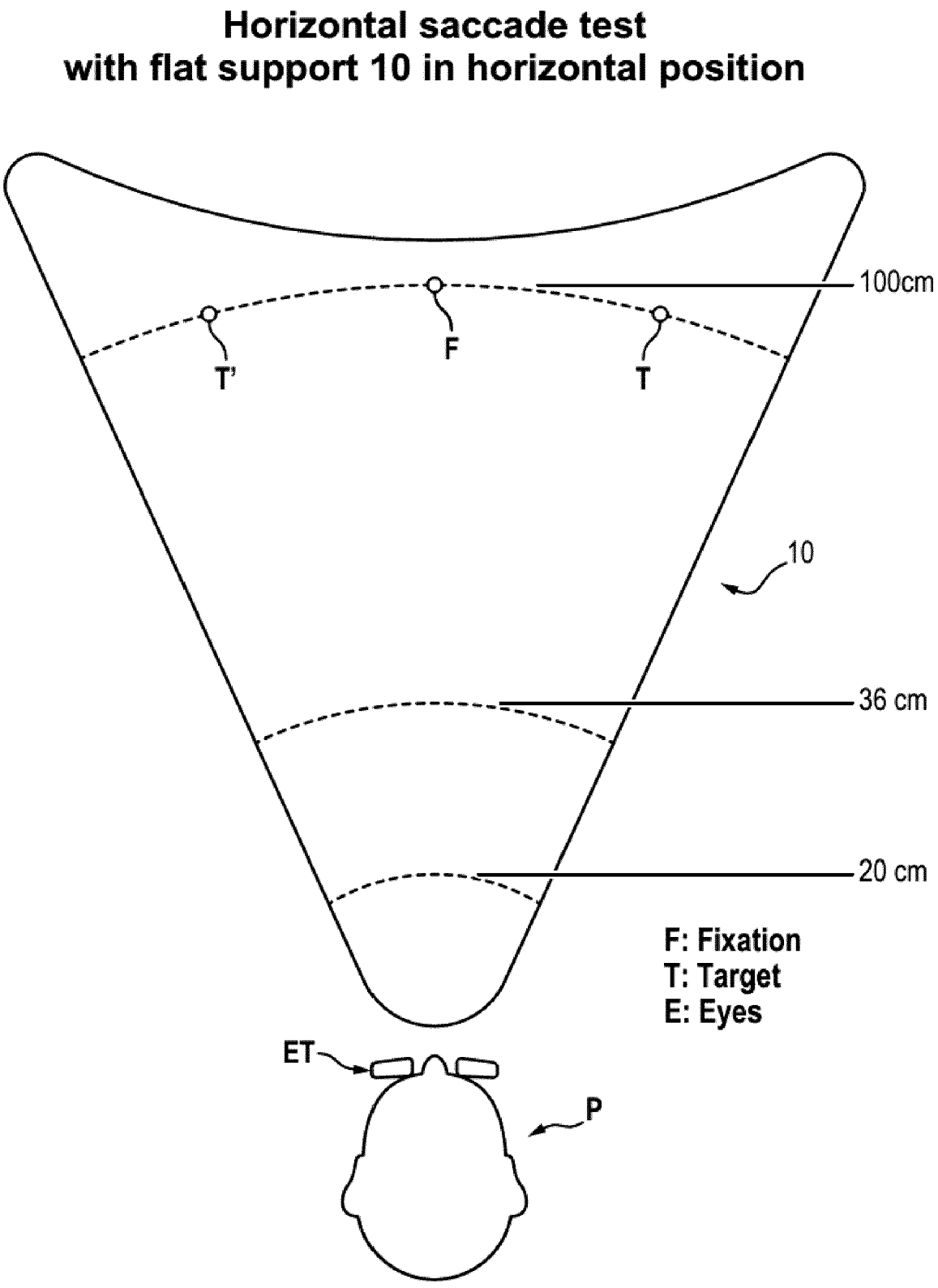

Horizontal saccade test
with flat support 10 in horizontal position
100cm
T'
F
T
10
36 cm
20 cm
F: Fixation
T: Target
E: Eyes
ET
P

Figure 10

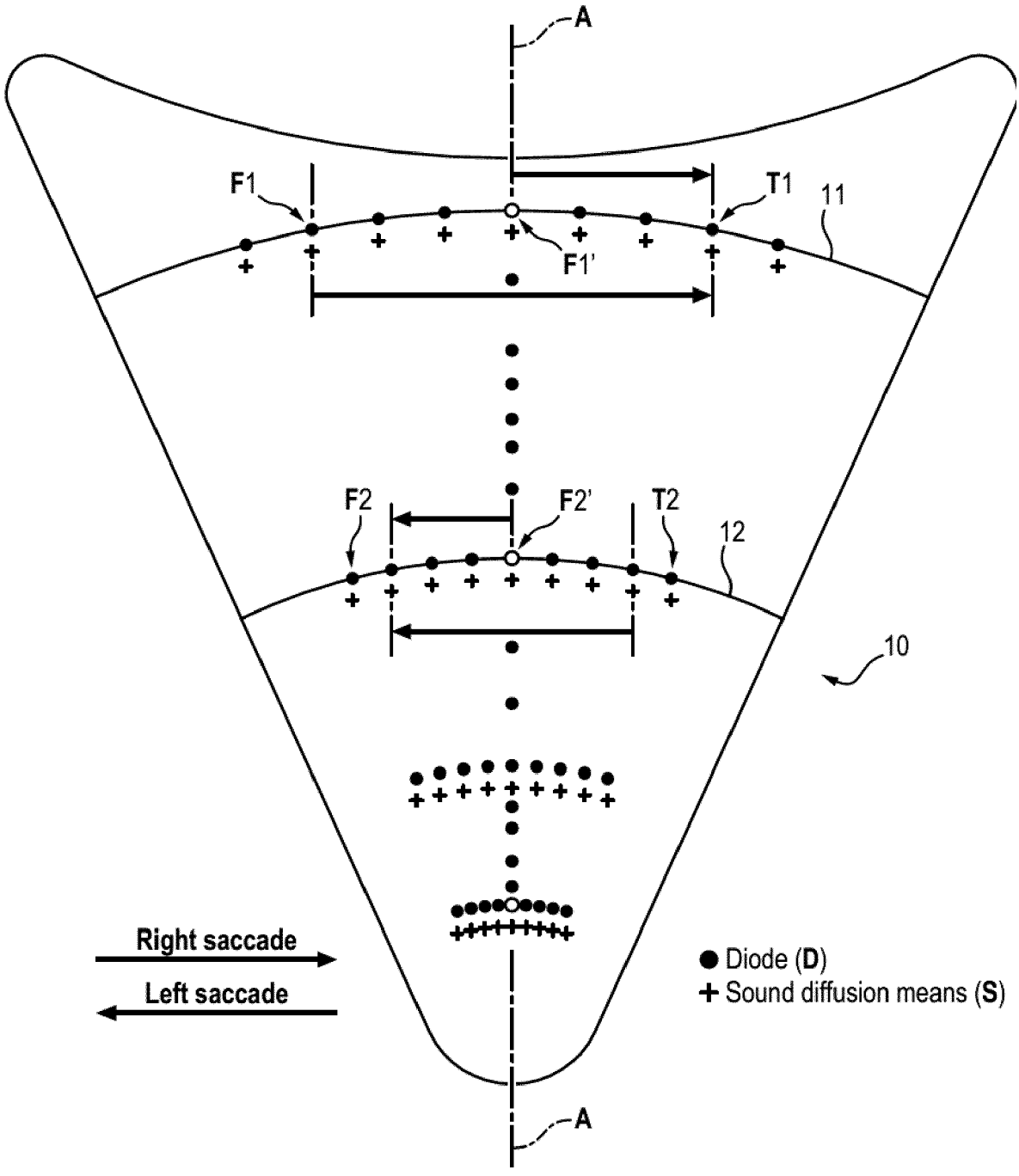

A
F1
T1
11
F1'
F2
F2'
T2
12
10
Right saccade
Left saccade
Diode (D)
Sound diffusion means (S)
A

Figure 11A

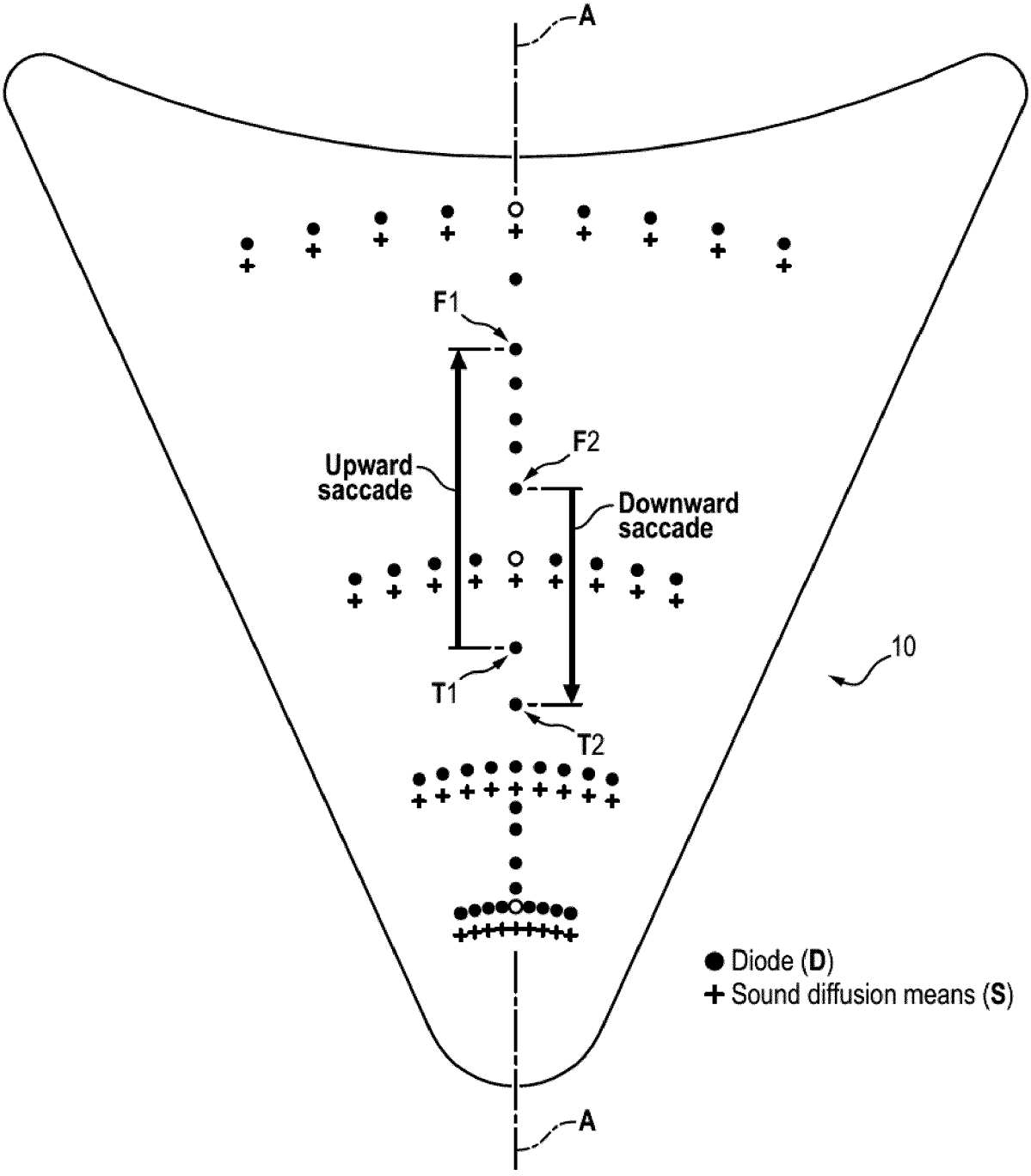

A
F1
F2
Upward saccade
Downward saccade
T1
T2
10
Diode (D)
Sound diffusion means (S)
A

Figure 11B

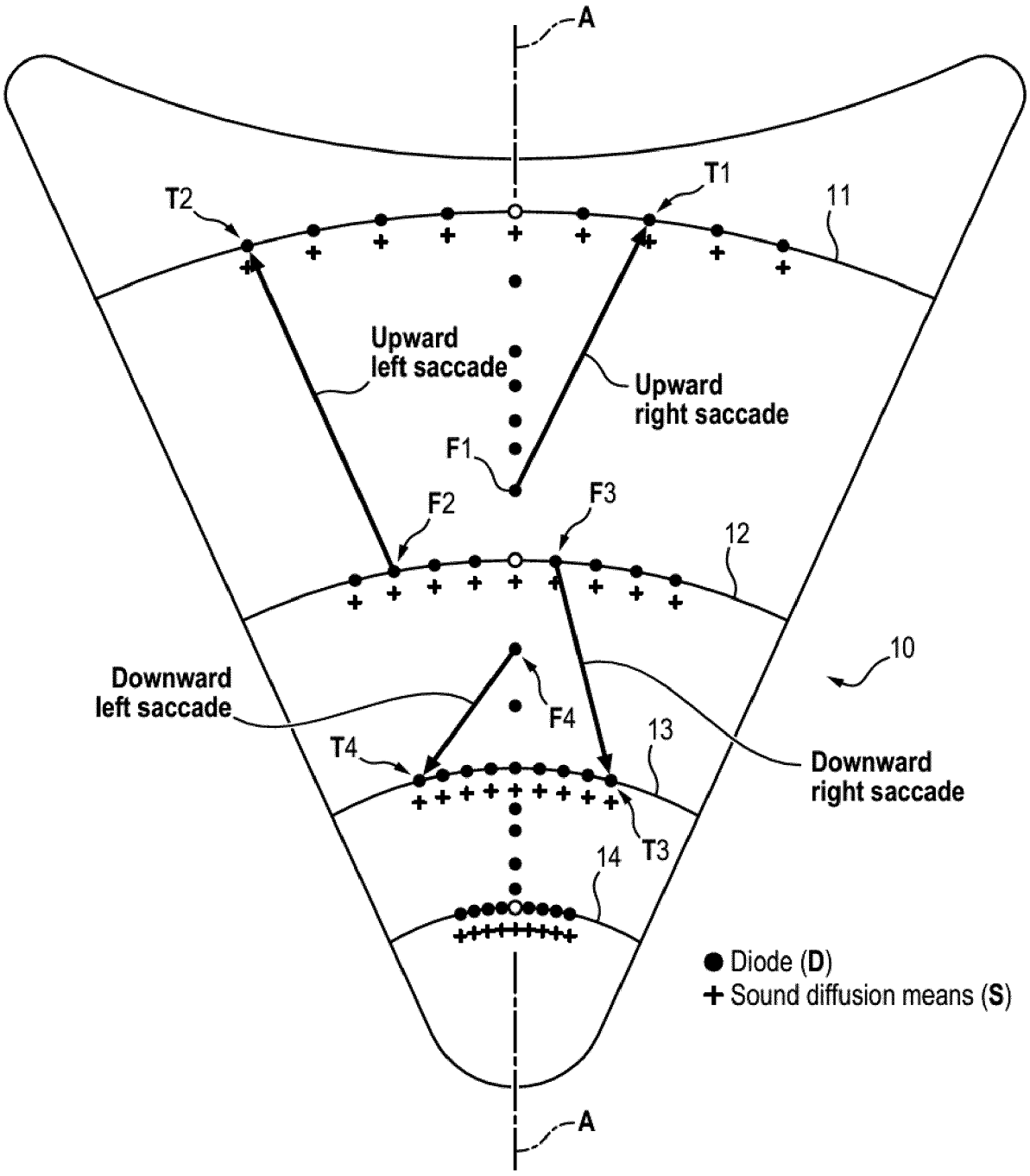

A
T1
T2
11
Upward
left saccade
Upward
right saccade
F1
F2
F3
12
10
Downward
left saccade
F4
T4
13
Downward
right saccade
T3
14
A
● Diode (D)
+ Sound diffusion means (S)

Figure 11C

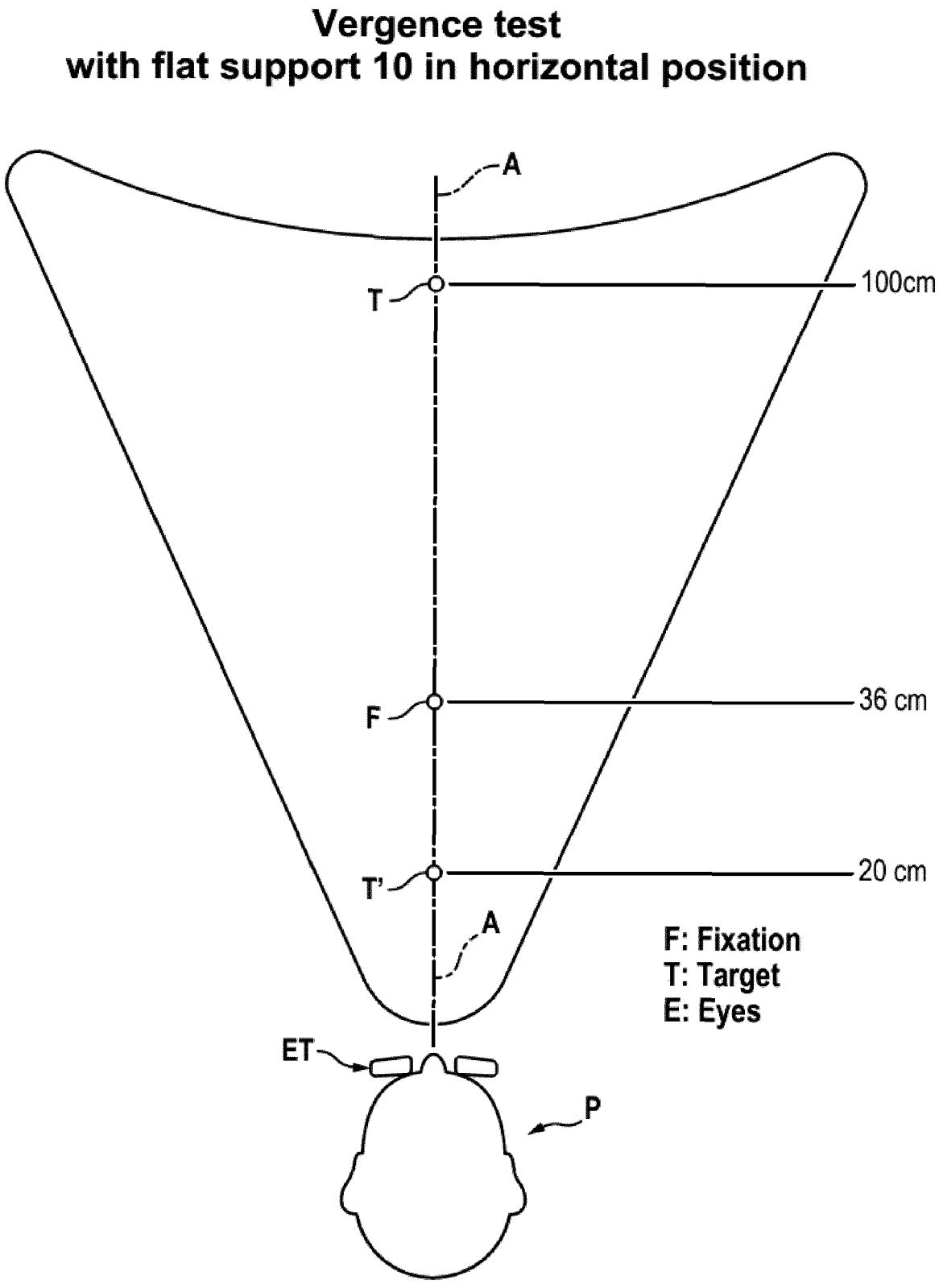

Vergence test
with flat support 10 in horizontal position
A
T
100cm
F
36 cm
T'
20 cm
A
F: Fixation
T: Target
E: Eyes
ET
P

Figure 12

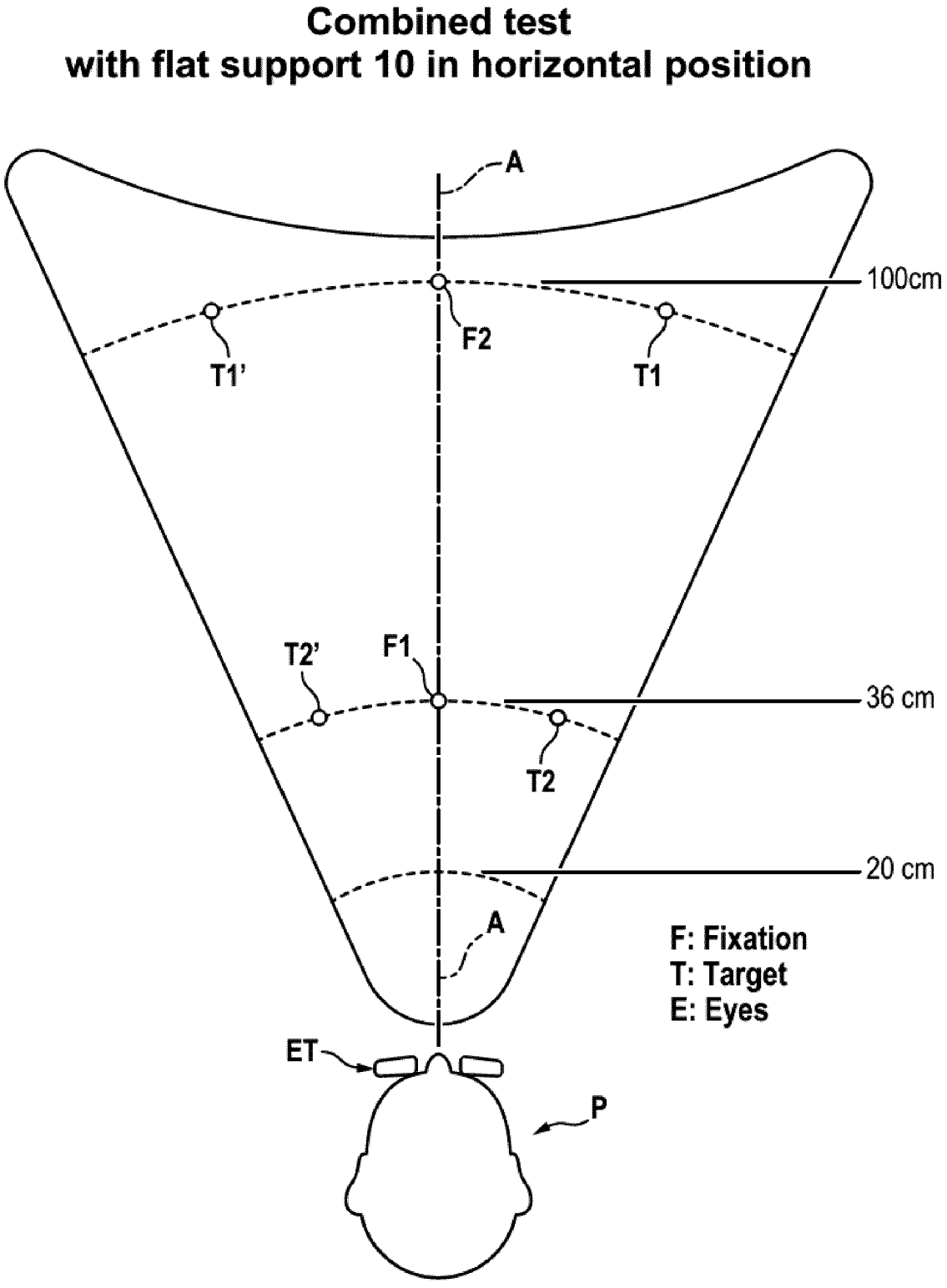

Combined test
with flat support 10 in horizontal position
A
100cm
F2
T1'
T1
T2'
F1
36 cm
T2
20 cm
A
F: Fixation
T: Target
E: Eyes
ET
P

Figure 13

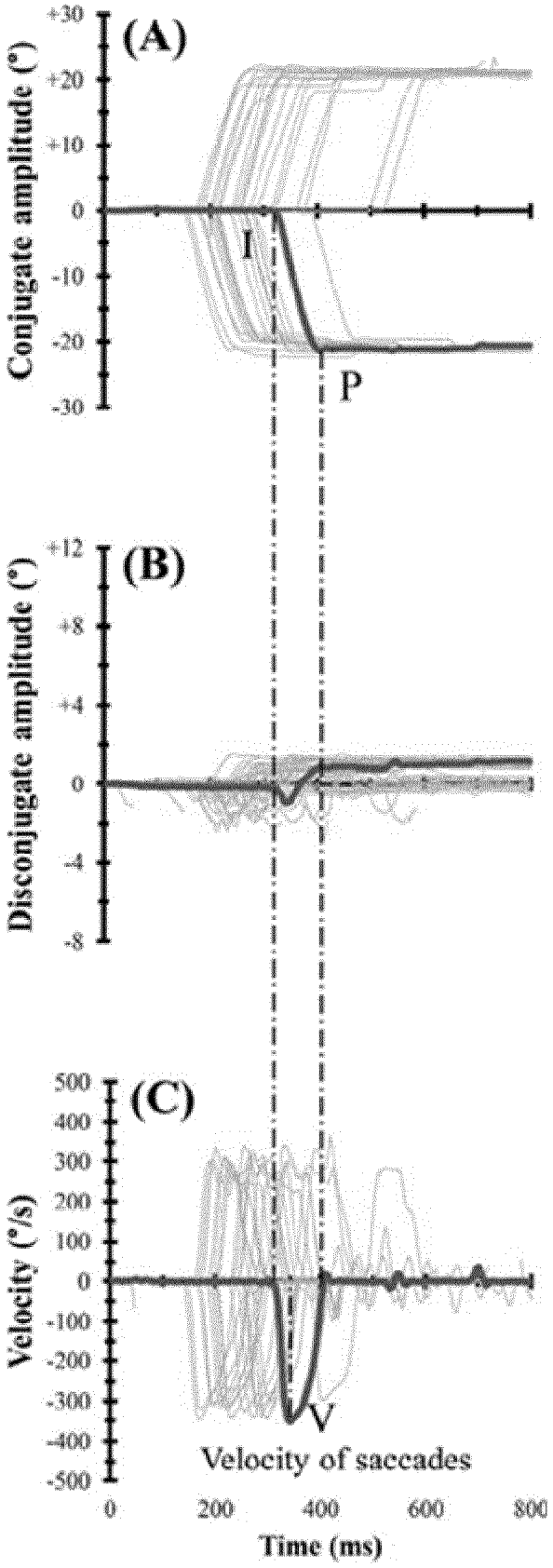

(A)
Conjugate amplitude (°)
+30
+20
+10
0
-10
-20
-30
I
P
(B)
Disconjugate amplitude (°)
+12
+8
+4
0
-4
-8
(C)
Velocity (°/s)
500
400
300
200
100
0
-100
-200
-300
-400
-500
V
Velocity of saccades
0
200
400
600
800
Time (ms)

Figure 14

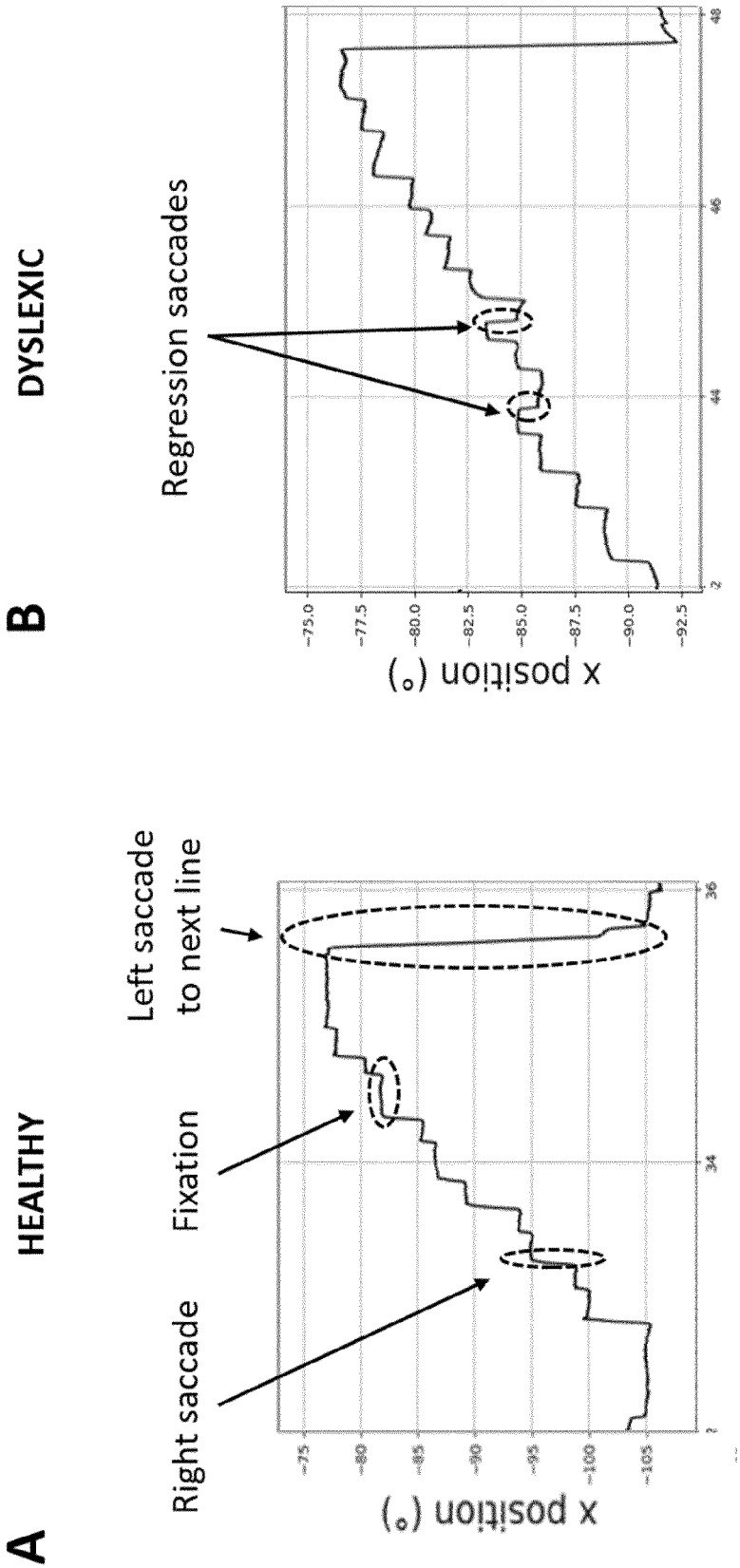

A
HEALTHY
Right saccade
Fixation
Left saccade
to next line
x position (°)
B
DYSLEXIC
Regression saccades
x position (°)

Figure 15

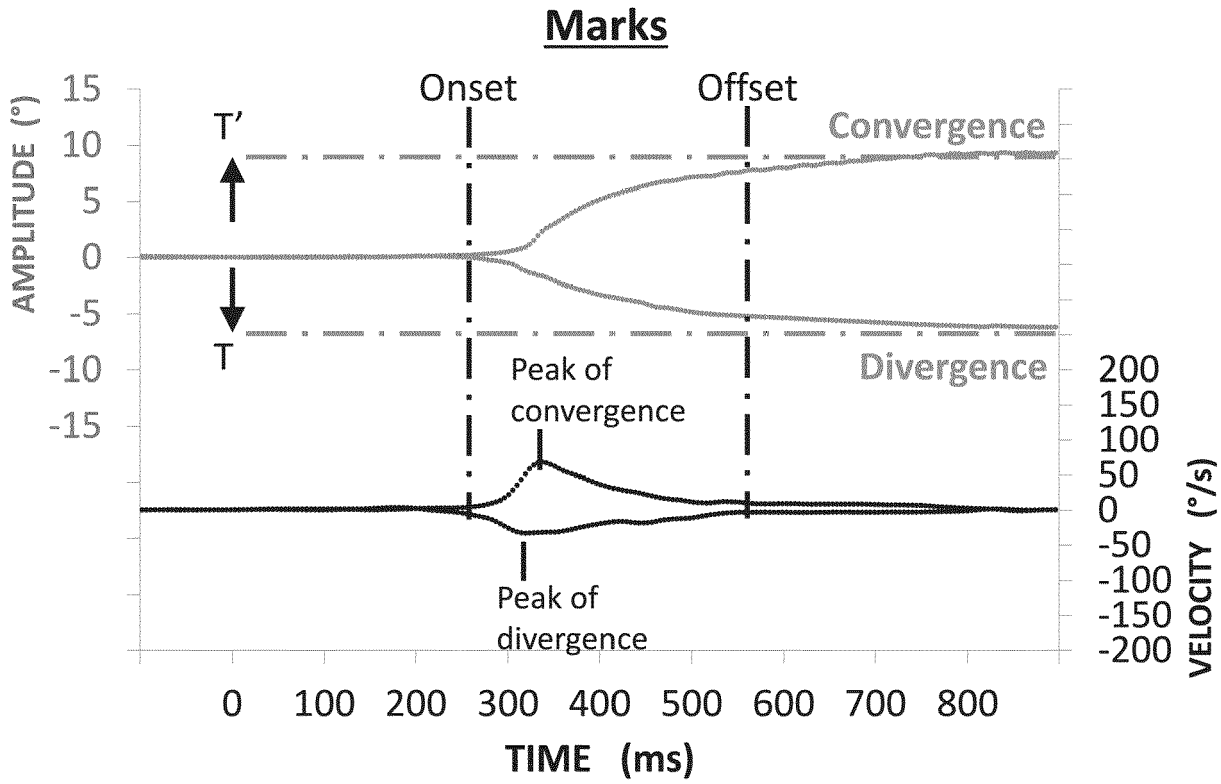

Marks
Onset
Offset
T'
T
Convergence
Divergence
Peak of convergence
Peak of divergence
AMPLITUDE (°)
15
10
5
0
-5
-10
-15
200
150
100
50
0
-50
-100
-150
-200
VELOCITY (°/s)
0
100
200
300
400
500
600
700
800
TIME (ms)

Figure 16

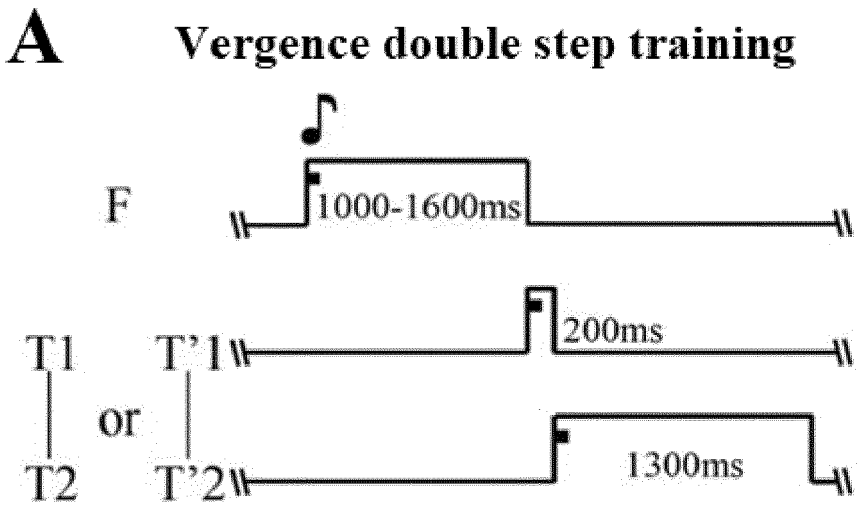


Figure 17A

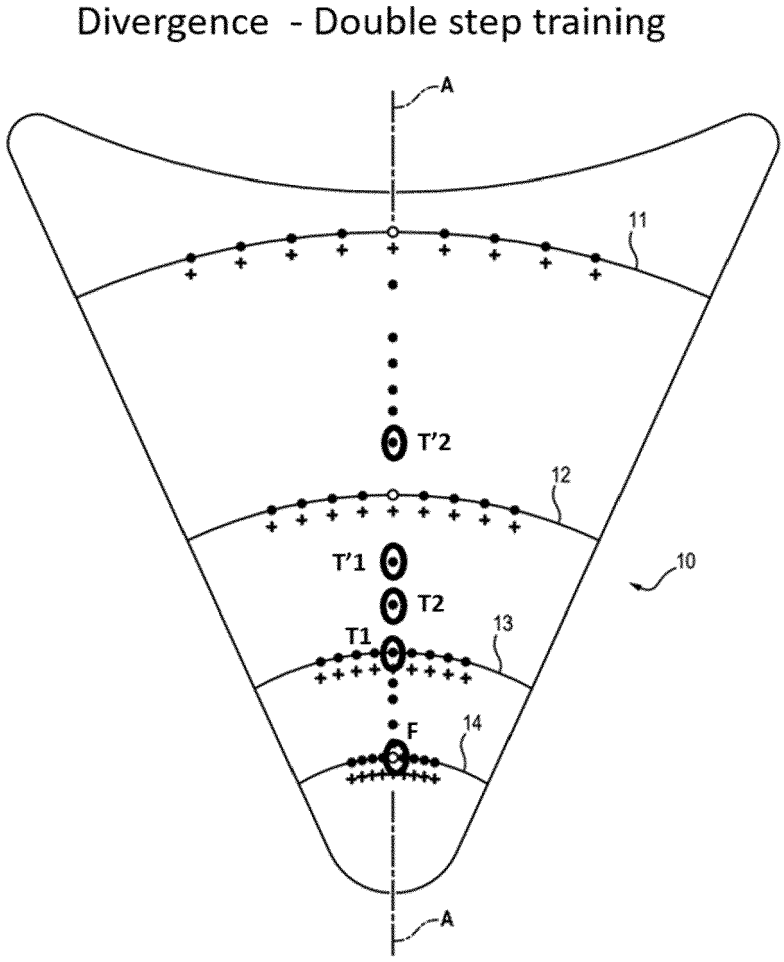


Figure 17B

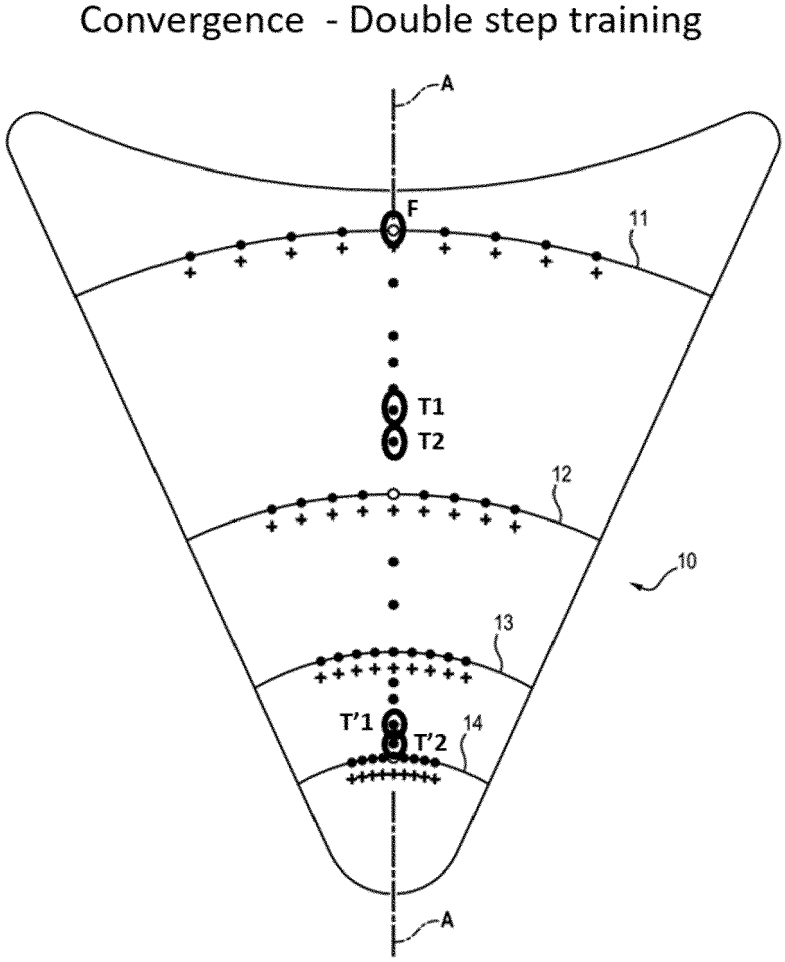
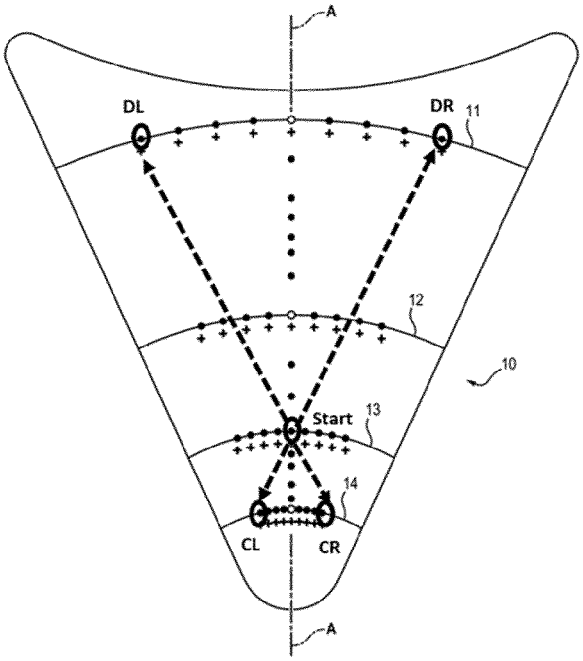

Convergence - Double step training
A
F
11
T1
T2
12
10
13
T'1
T'2
14
A

Figure 17C

Combined movements before reeducation

A



B

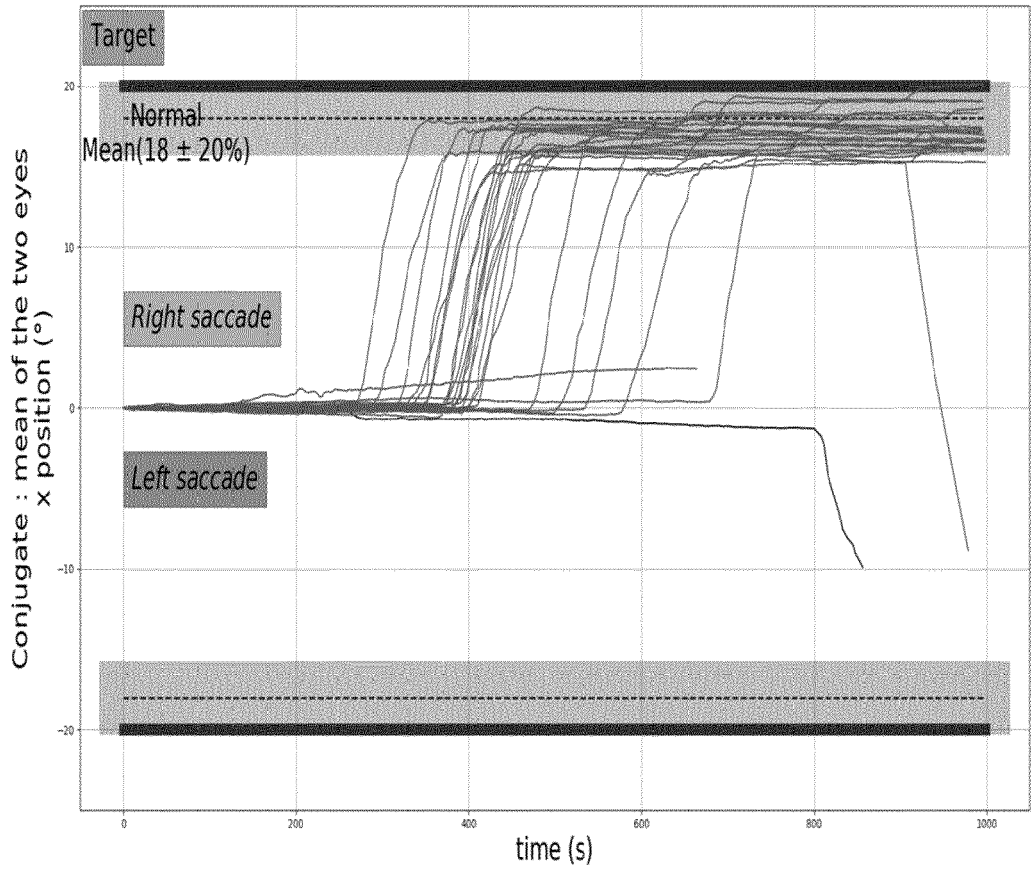


Figure 18

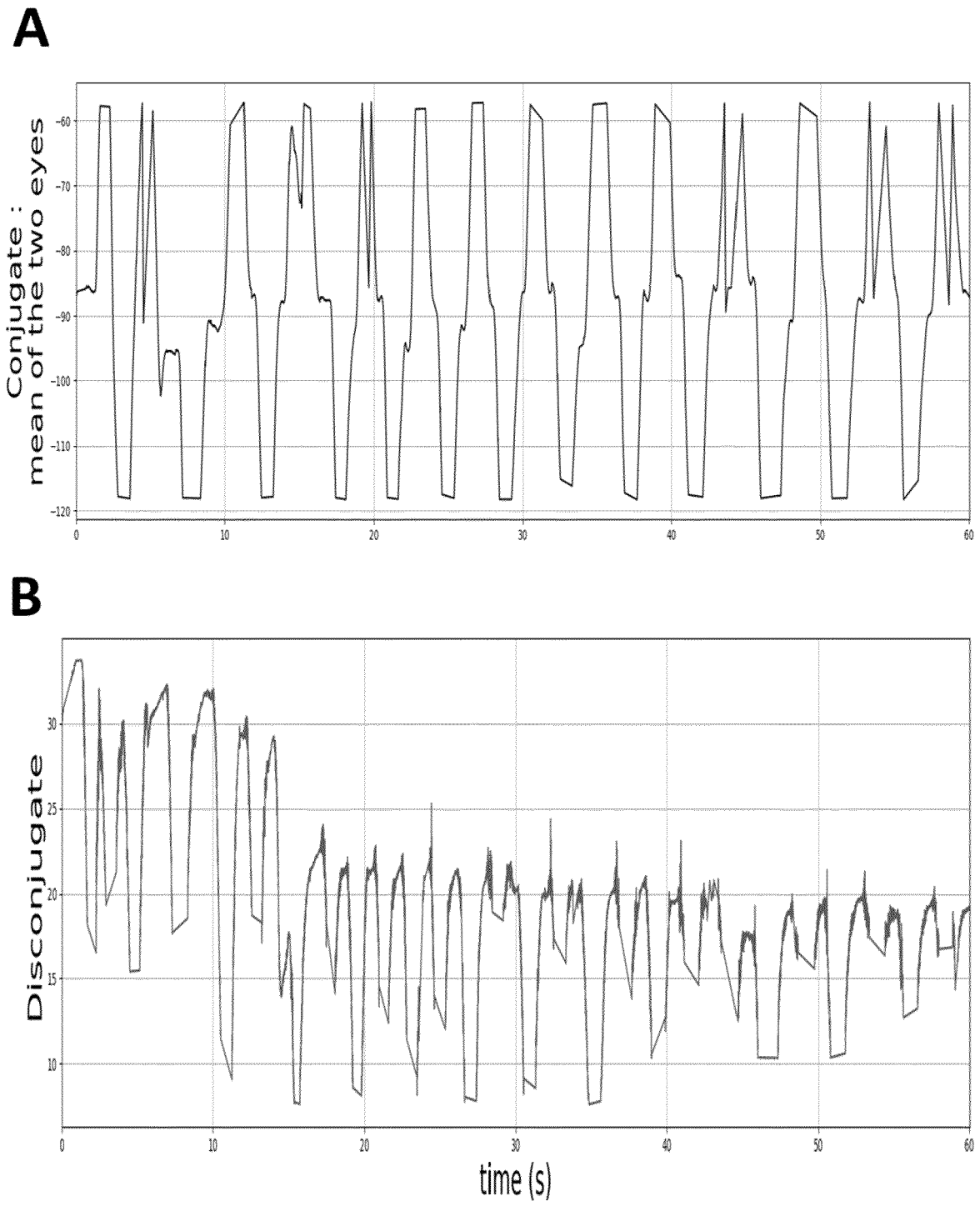

A
Conjugate :
mean of the two eyes
-60
-70
-80
-90
-100
-110
-120
0
10
20
30
40
50
60
B
Disconjugate
30
25
20
15
10
0
10
20
30
40
50
60
time (s)

Figure 19

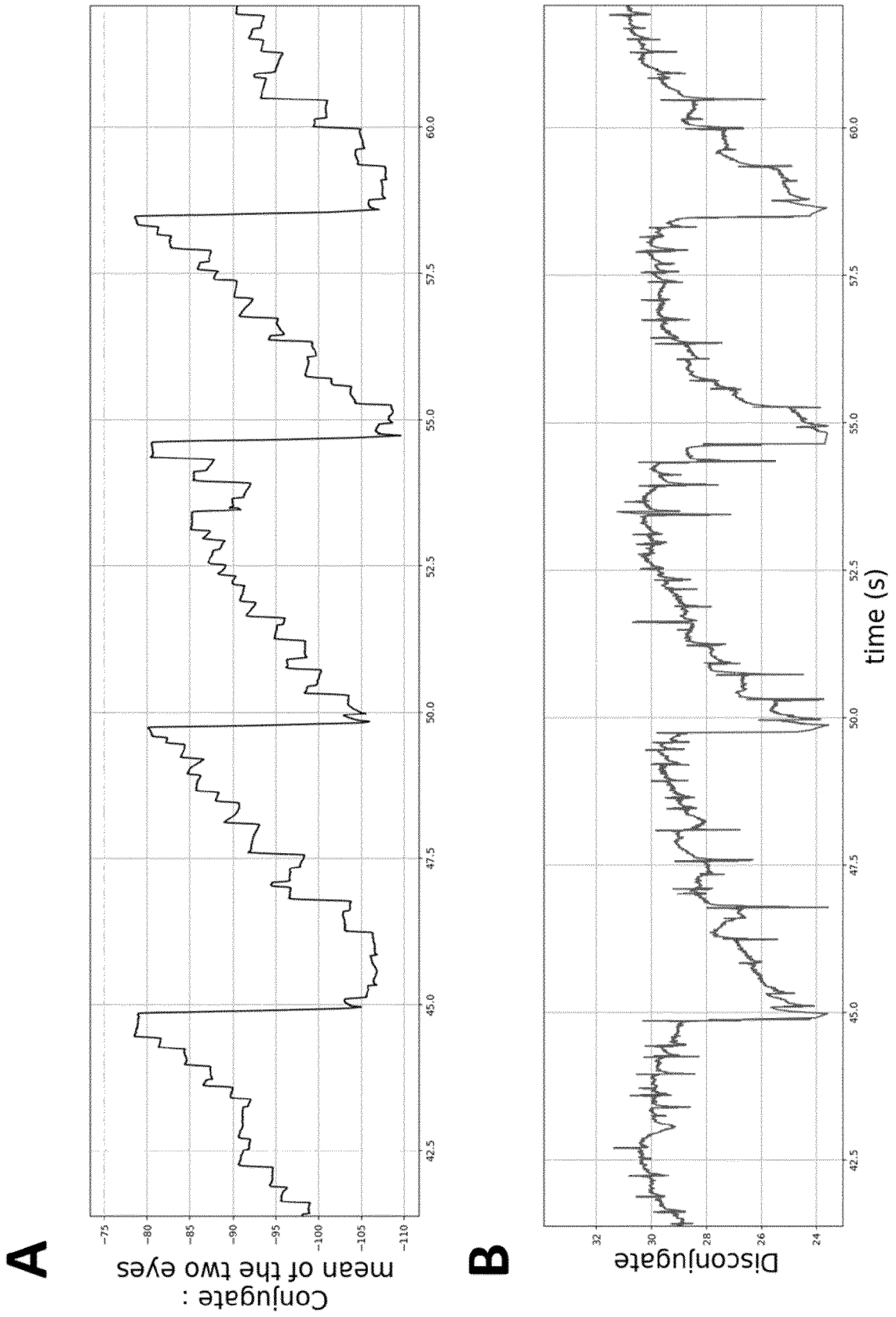

A
Conjugate :
mean of the two eyes
−75
−80
−85
−90
−95
−100
−105
−110
42.5
45.0
47.5
50.0
52.5
55.0
57.5
60.0
B
Disconjugate
32
30
28
26
24
42.5
45.0
47.5
50.0
52.5
55.0
57.5
60.0
time (s)

Figure 20

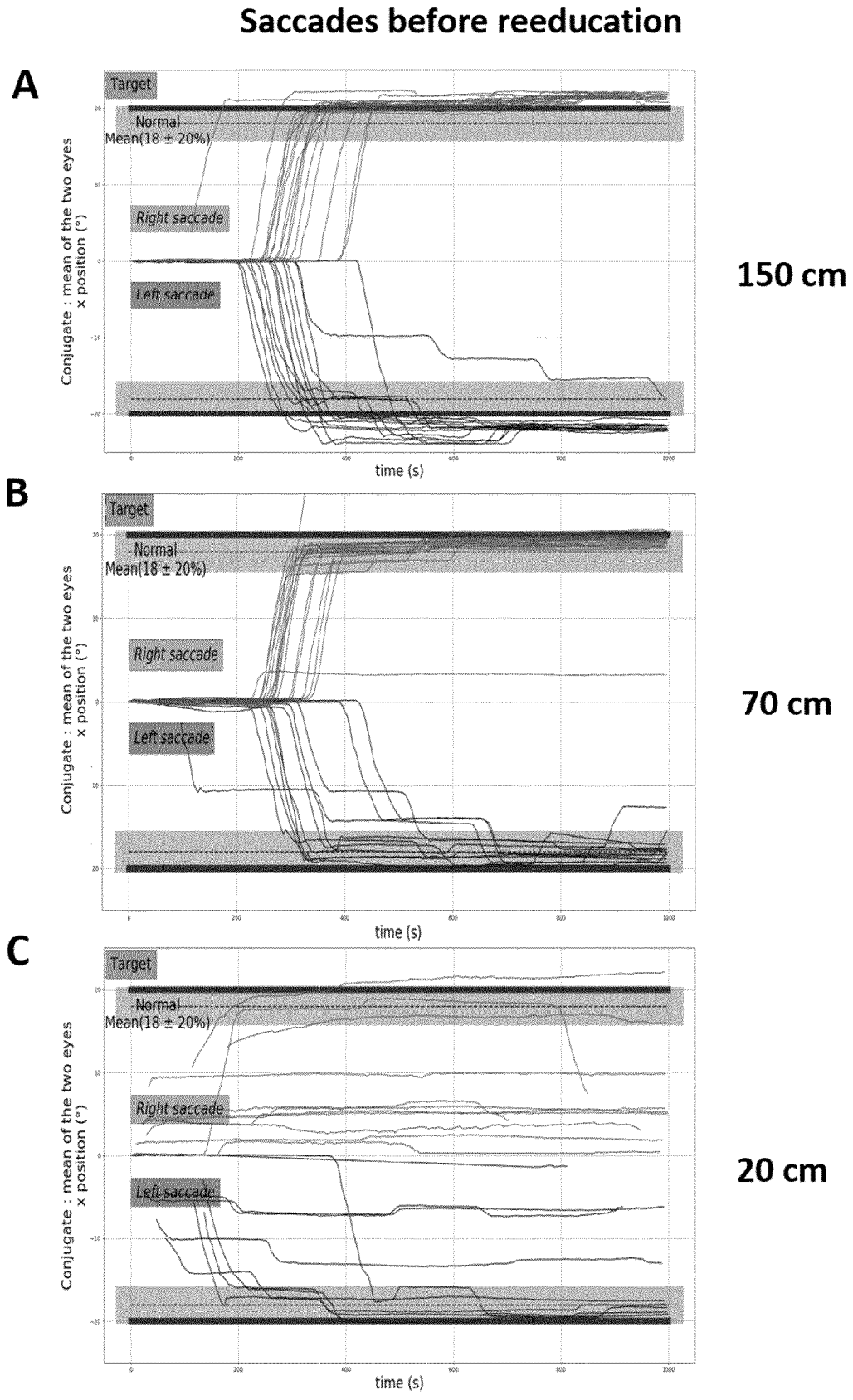

Saccades before reeducation
A
Target
Normal
Mean(18 ± 20%)
Right saccade
Left saccade
Conjugate : mean of the two eyes
x position (°)
time (s)
150 cm
B
Target
Normal
Mean(18 ± 20%)
Right saccade
Left saccade
Conjugate : mean of the two eyes
x position (°)
time (s)
70 cm
C
Target
Normal
Mean(18 ± 20%)
Right saccade
Left saccade
Conjugate : mean of the two eyes
x position (°)
time (s)
20 cm

Figure 21

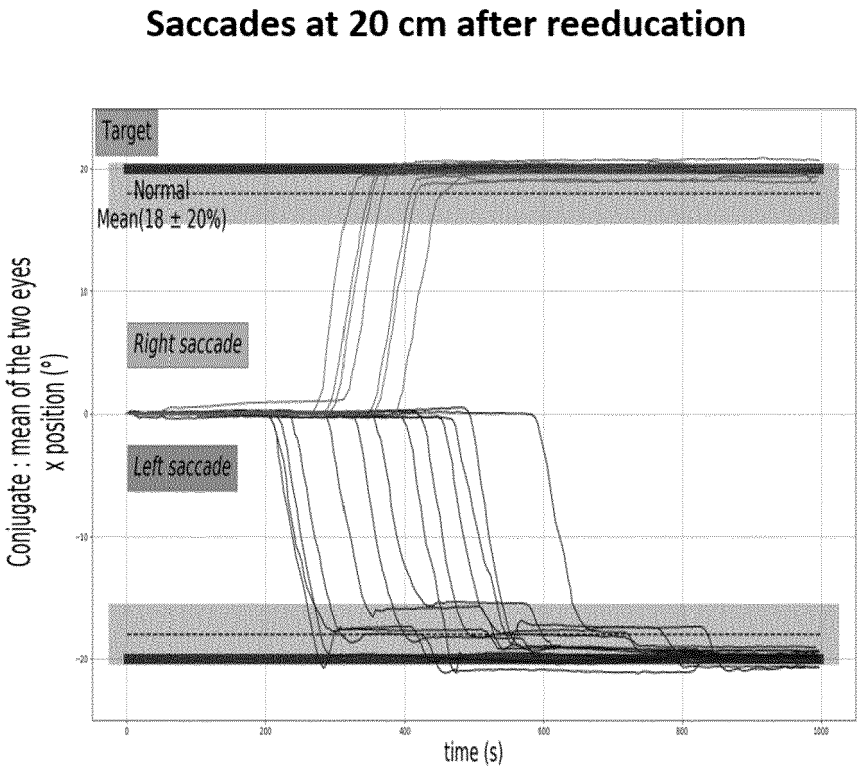
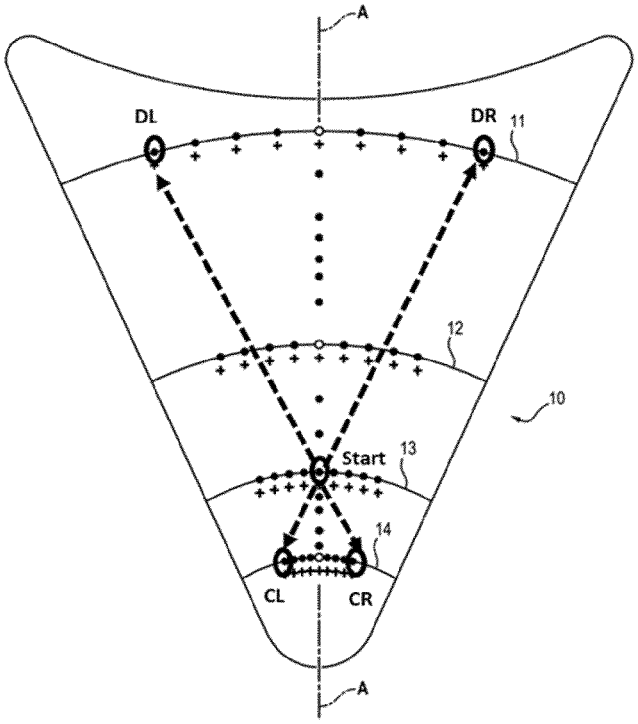

Saccades at 20 cm after reeducation
Target
Normal
Mean(18 ± 20%)
Right saccade
Left saccade
Conjugate : mean of the two eyes
x position (°)
time (s)

Figure 22

Combined movements after reeducation

A



B

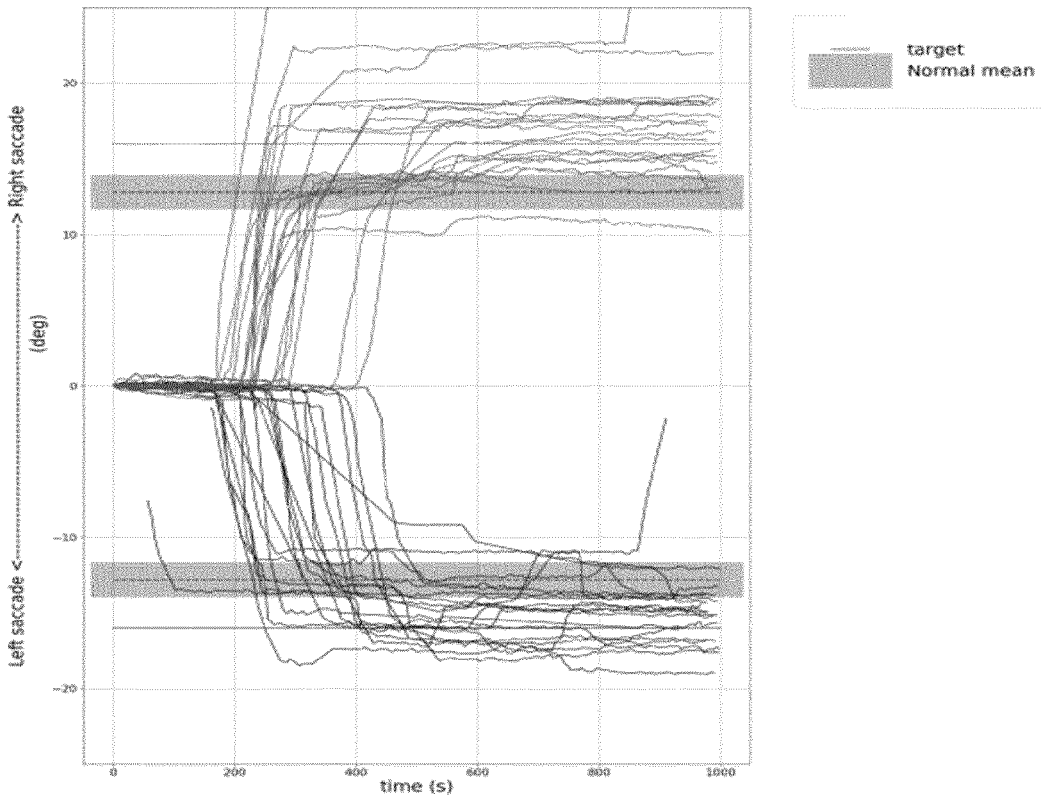
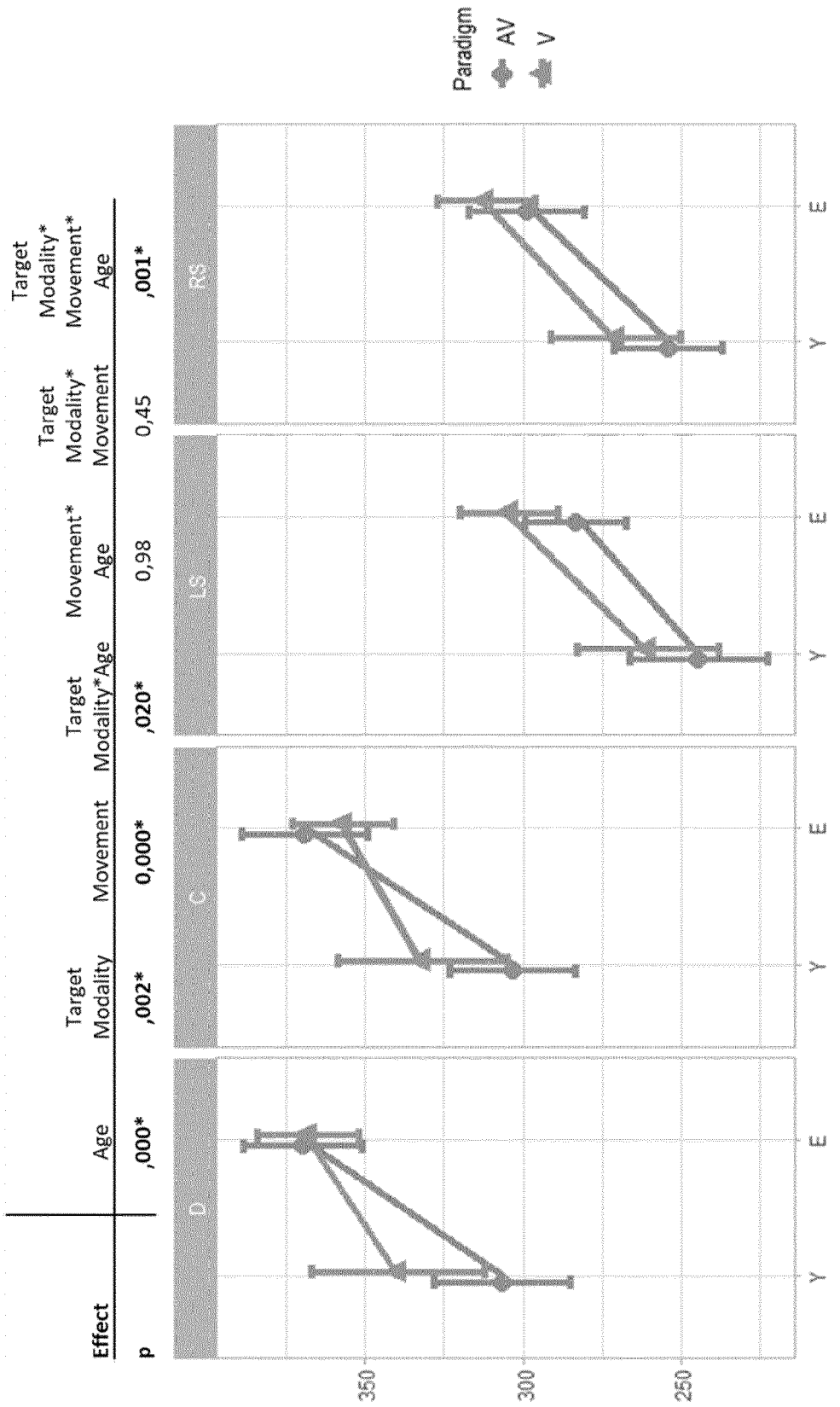
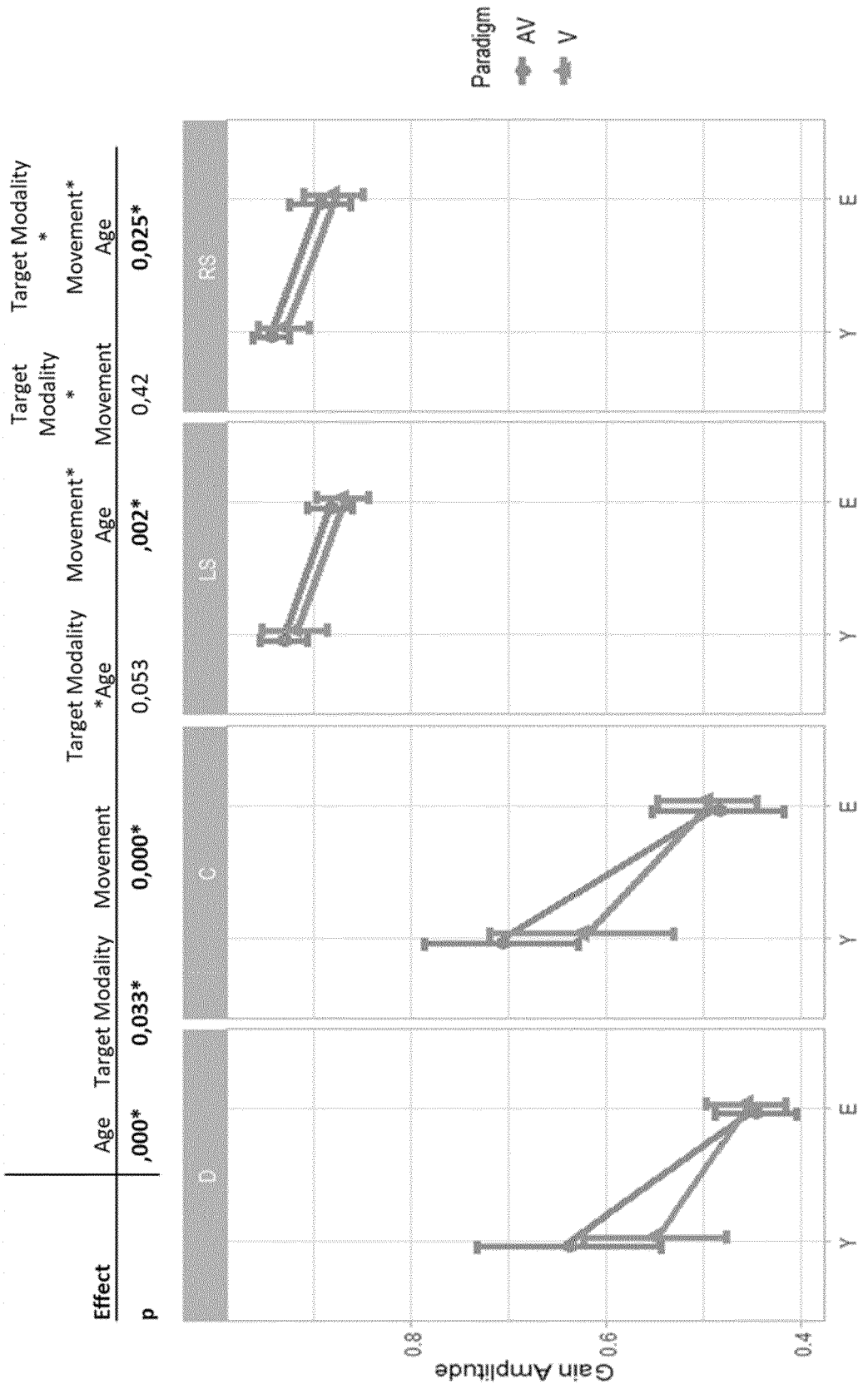


Figure 23



Effect	Age	Target Modality	Movement	Target Modality*Age	Movement*Age	Target Modality*Movement	Target Modality*Movement*Age
p	,000*	,002*	0,000*	,020*	0,98	0,45	,001*

Figure 24



Effect	Age	Target Modality	Movement	Target Modality *Age	Movement* Age	Target Modality * Movement	Target Modality * Movement* Age
p	**,000***	**0,033***	**0,000***	0,053	**,002***	0,42	**0,025***

Figure 25

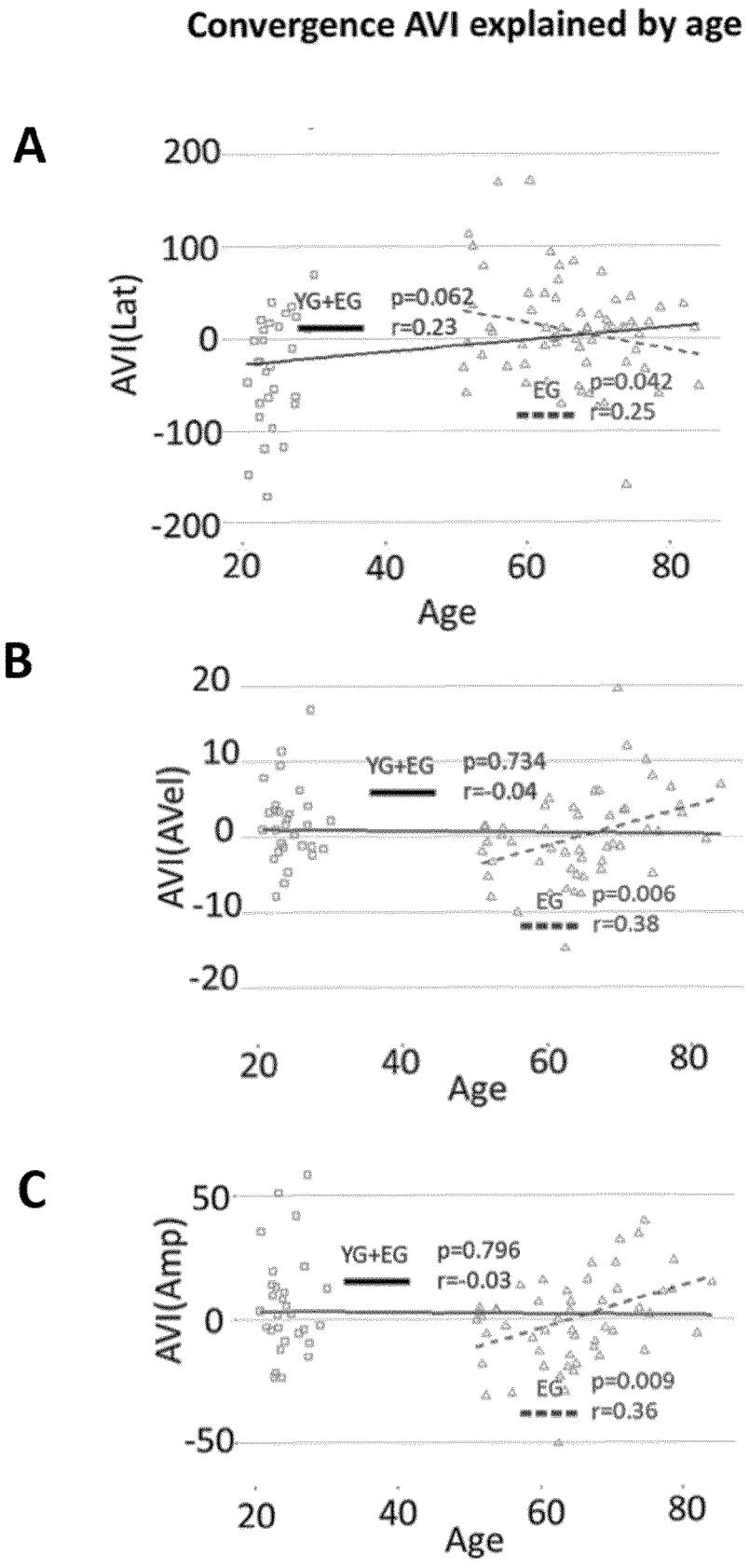

Convergence AVI explained by age
A
200
100
0
-100
-200
AVI(Lat)
YG+EG
p=0.062
r=0.23
EG
p=0.042
r=0.25
20
40
60
80
Age
B
20
10
0
-10
-20
AVI(AVel)
YG+EG
p=0.734
r=-0.04
EG
p=0.006
r=0.38
20
40
60
80
Age
C
50
0
-50
AVI(Amp)
YG+EG
p=0.796
r=-0.03
EG
p=0.009
r=0.36
20
40
60
80
Age

Figure 26

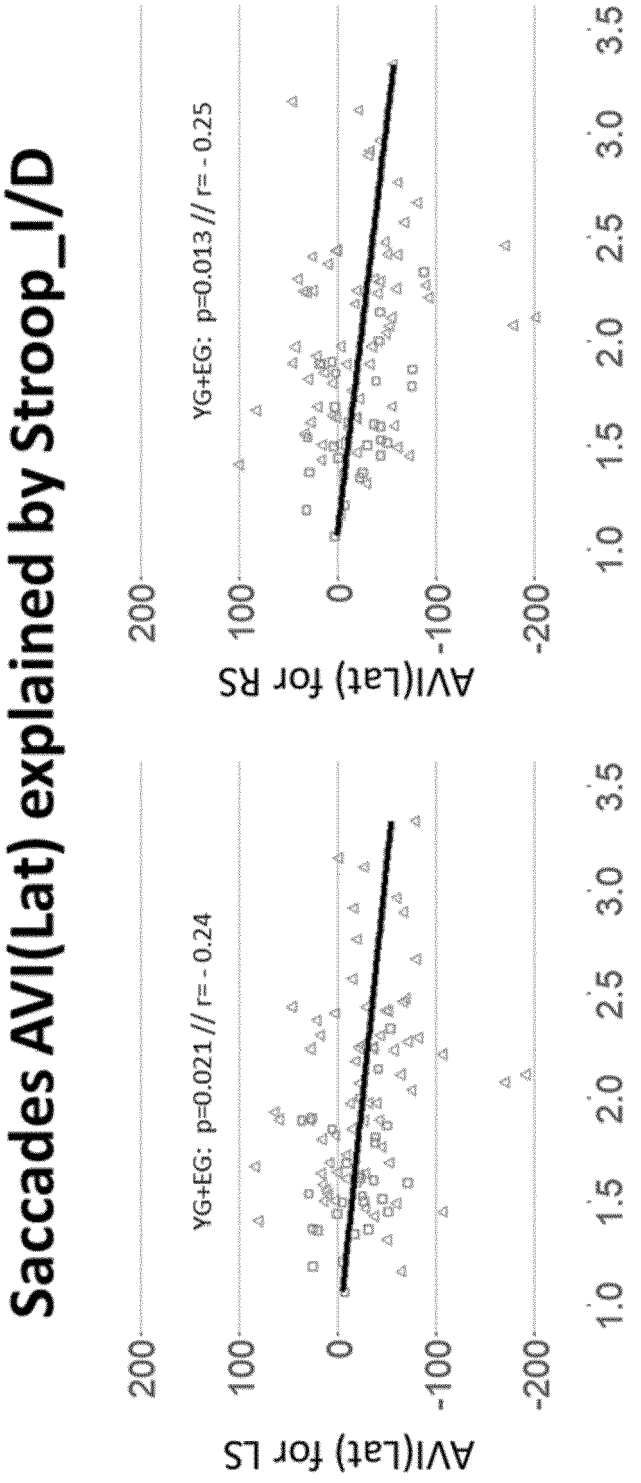

Saccades AVI(Lat) explained by Stroop_I/D
YG+EG: p=0.013 // r= - 0.25
YG+EG: p=0.021 // r= - 0.24
AVI(Lat) for RS
AVI(Lat) for LS
Stroop_I/D
200
100
0
-100
-200
1.0
1.5
2.0
2.5
3.0
3.5

Figure 27

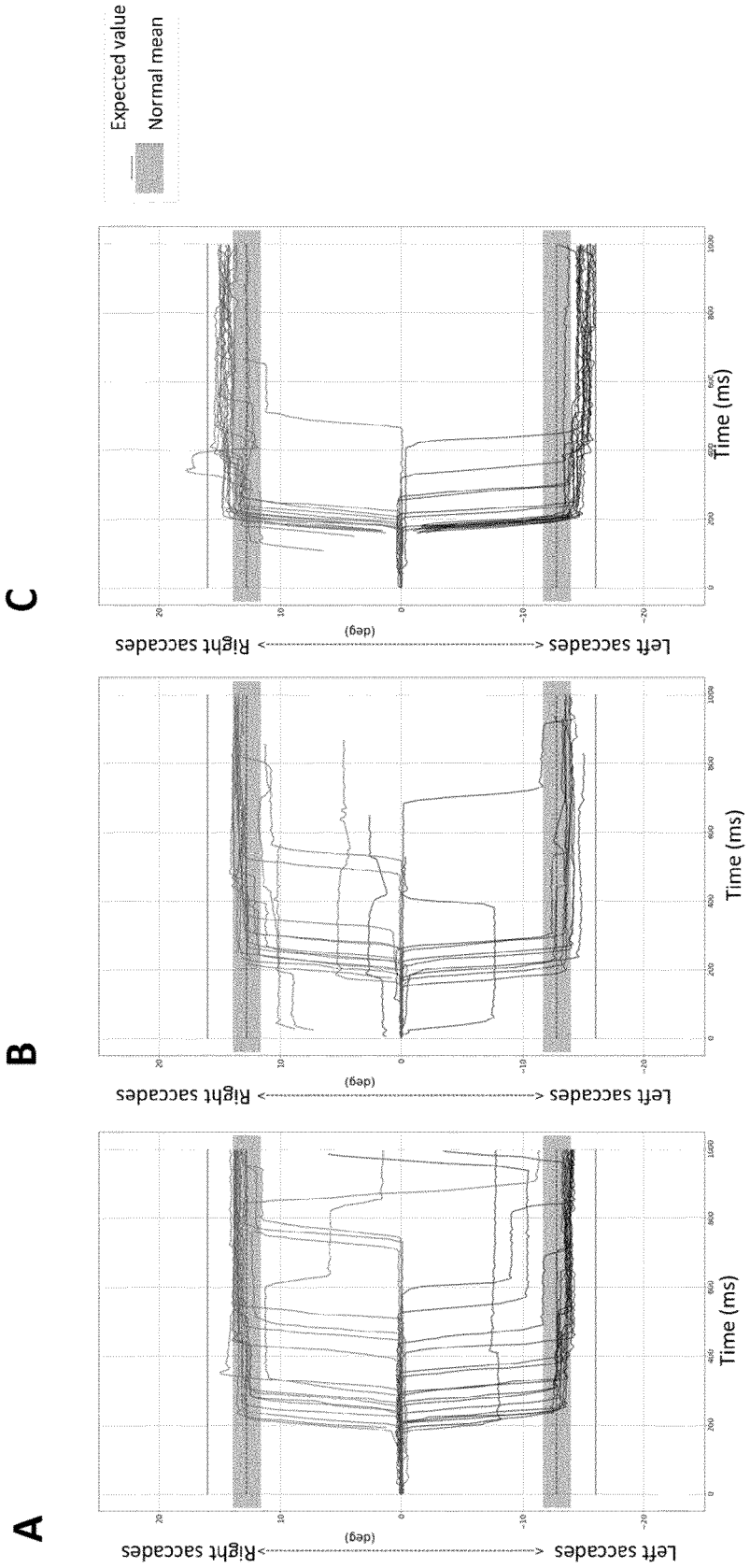

A
B
C
Expected value
Normal mean
Left saccades
Right saccades
(deg)
Time (ms)

Figure 28

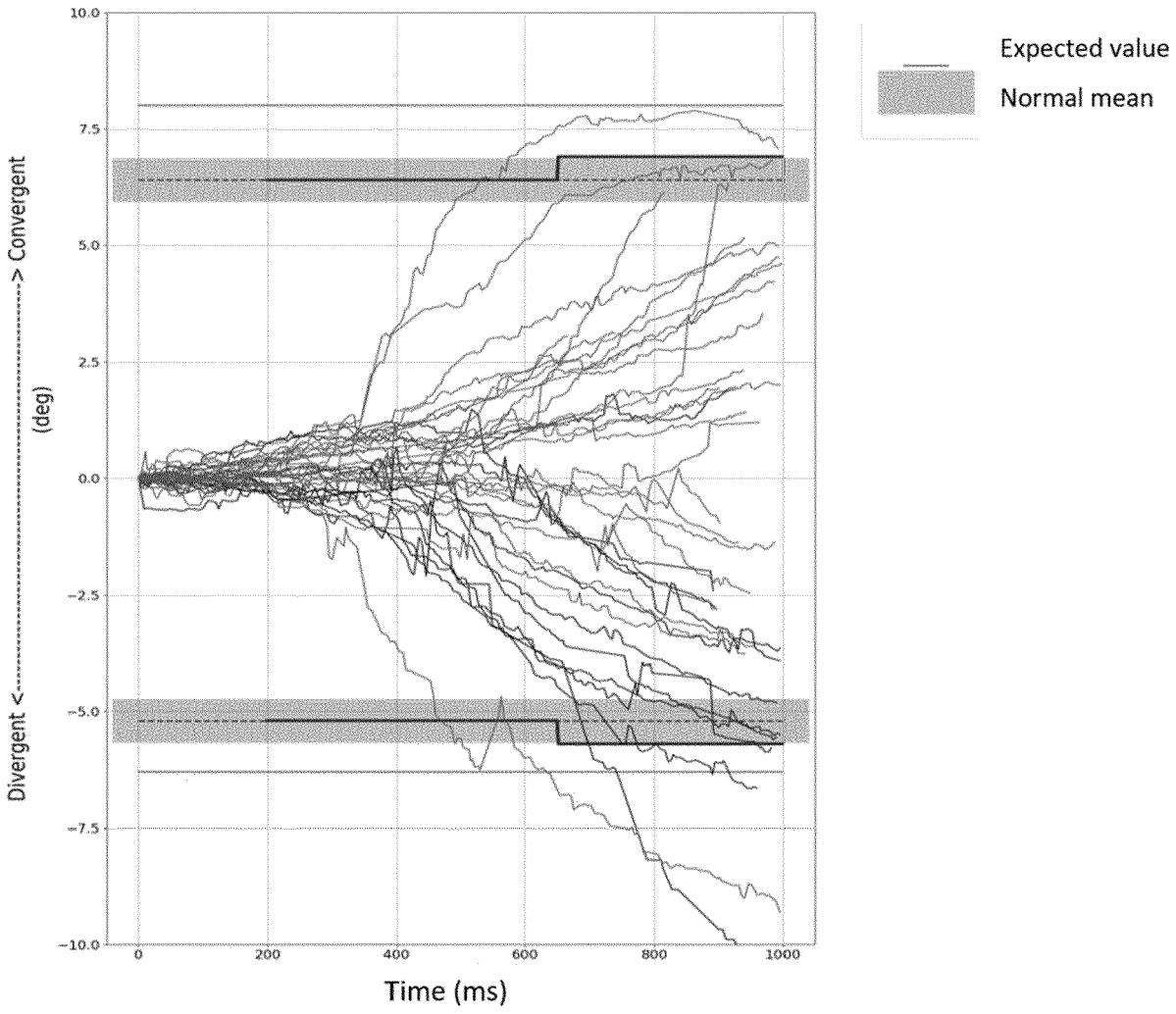

Expected value
Normal mean
Divergent <---------- (deg) ----------> Convergent
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
0
200
400
600
800
1000
Time (ms)

Figure 29

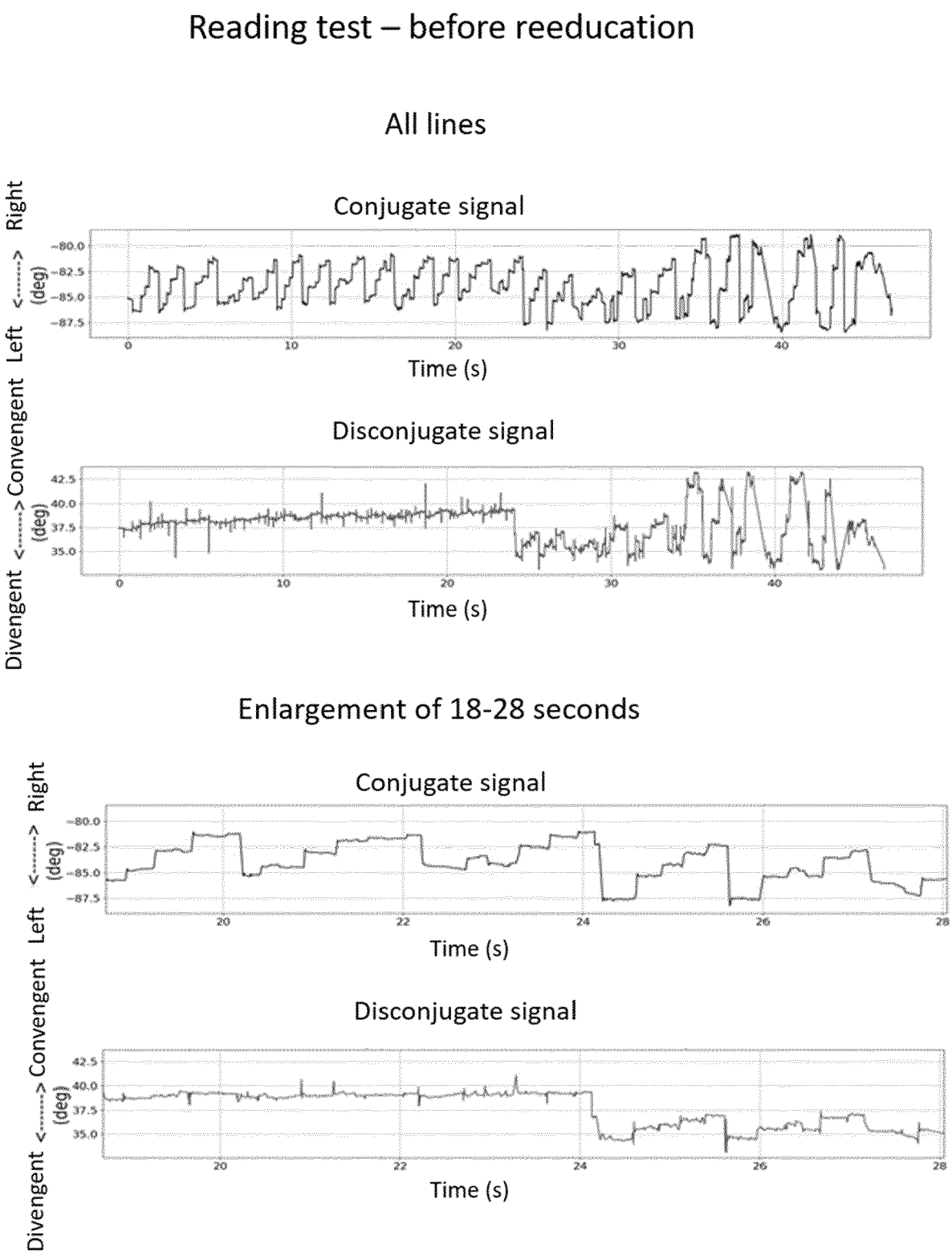

Reading test – before reeducation
All lines
Conjugate signal
Right <------> Left
(deg)
-80.0
-82.5
-85.0
-87.5
0
10
20
30
40
Time (s)
Disconjugate signal
Divergent <------> Convergent
(deg)
42.5
40.0
37.5
35.0
0
10
20
30
40
Time (s)
Enlargement of 18-28 seconds
Conjugate signal
Right <------> Left
(deg)
-80.0
-82.5
-85.0
-87.5
20
22
24
26
28
Time (s)
Disconjugate signal
Divergent <------> Convergent
(deg)
42.5
40.0
37.5
35.0
20
22
24
26
28
Time (s)

Figure 30

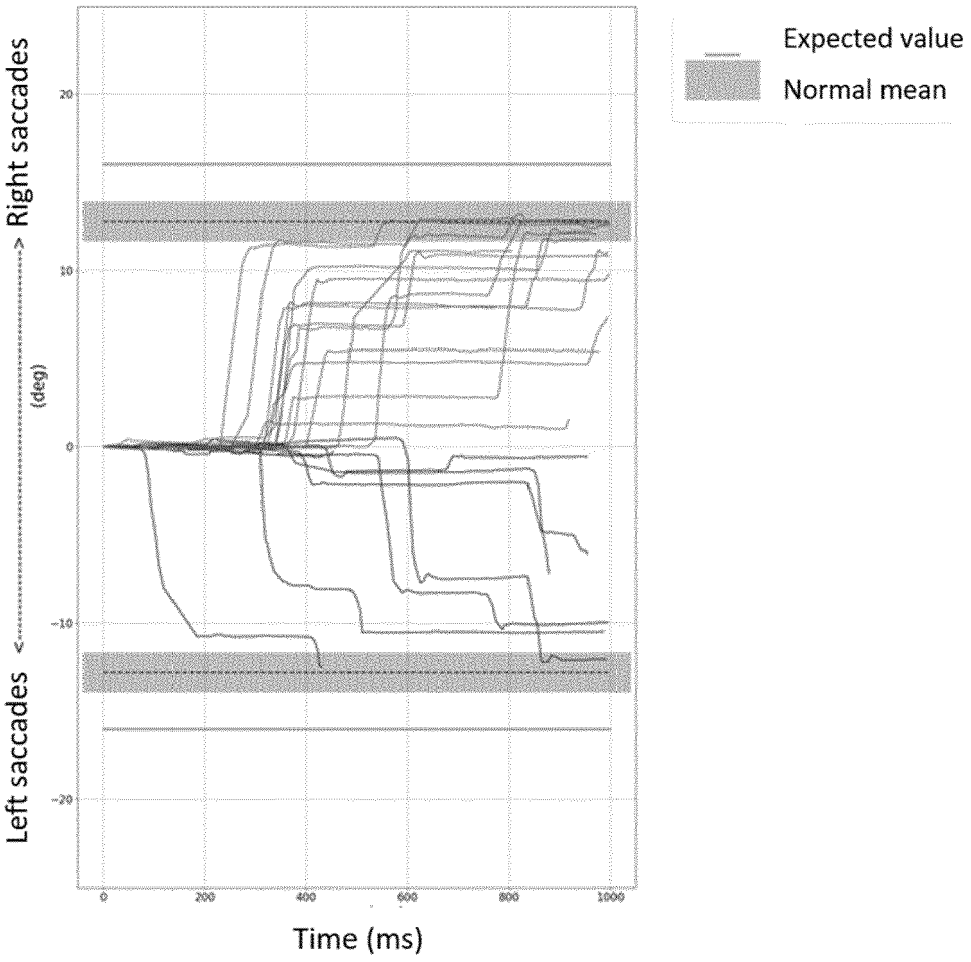

Expected value
Normal mean
Right saccades
Left saccades
(deg)
20
10
0
-10
-20
0
200
400
600
800
1000
Time (ms)

Figure 31

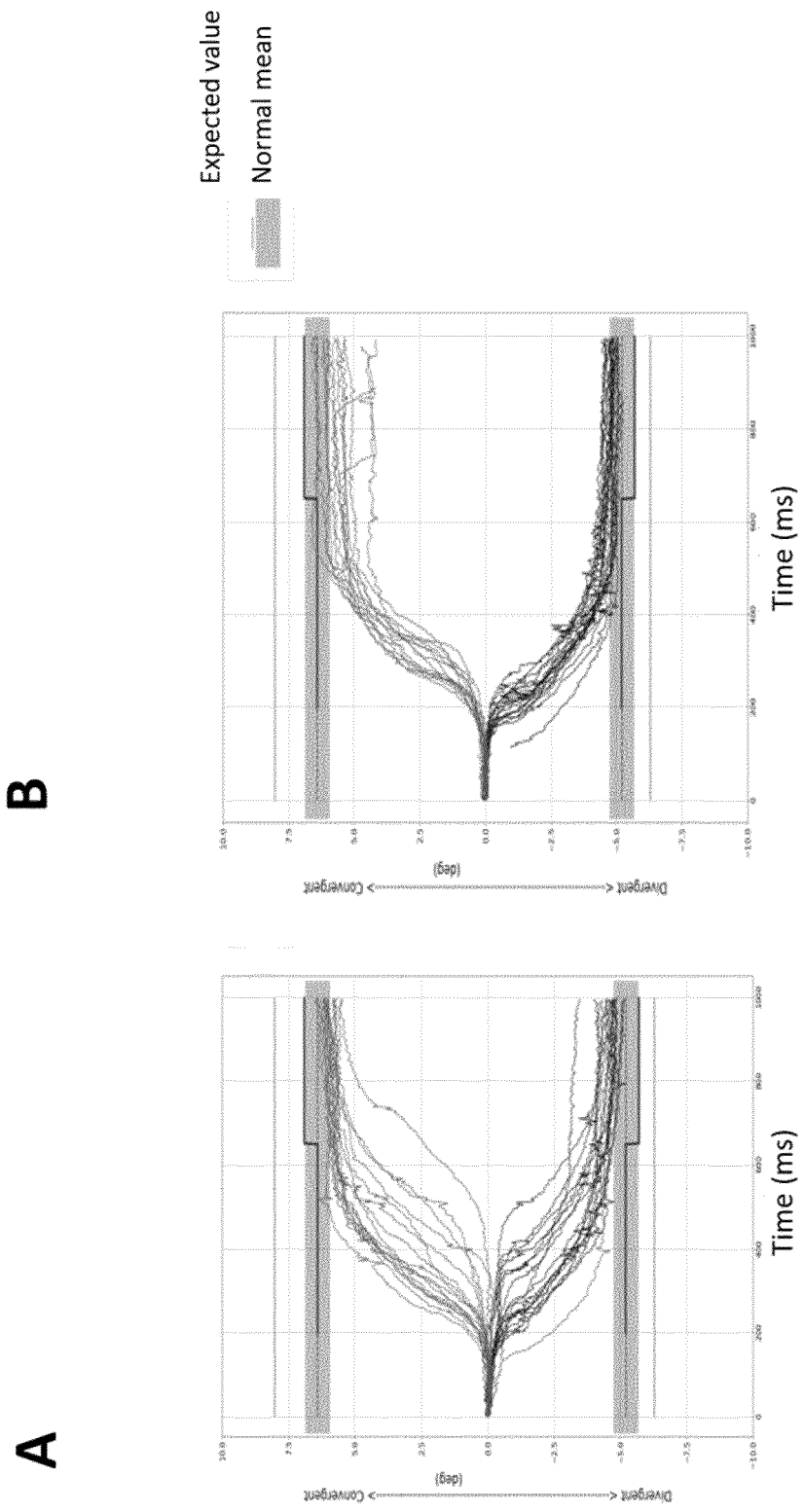

Expected value
Normal mean
B
A
Time (ms)
Time (ms)
Divergent <----------> Convergent
Divergent <----------> Convergent
(deg)
(deg)

Figure 32

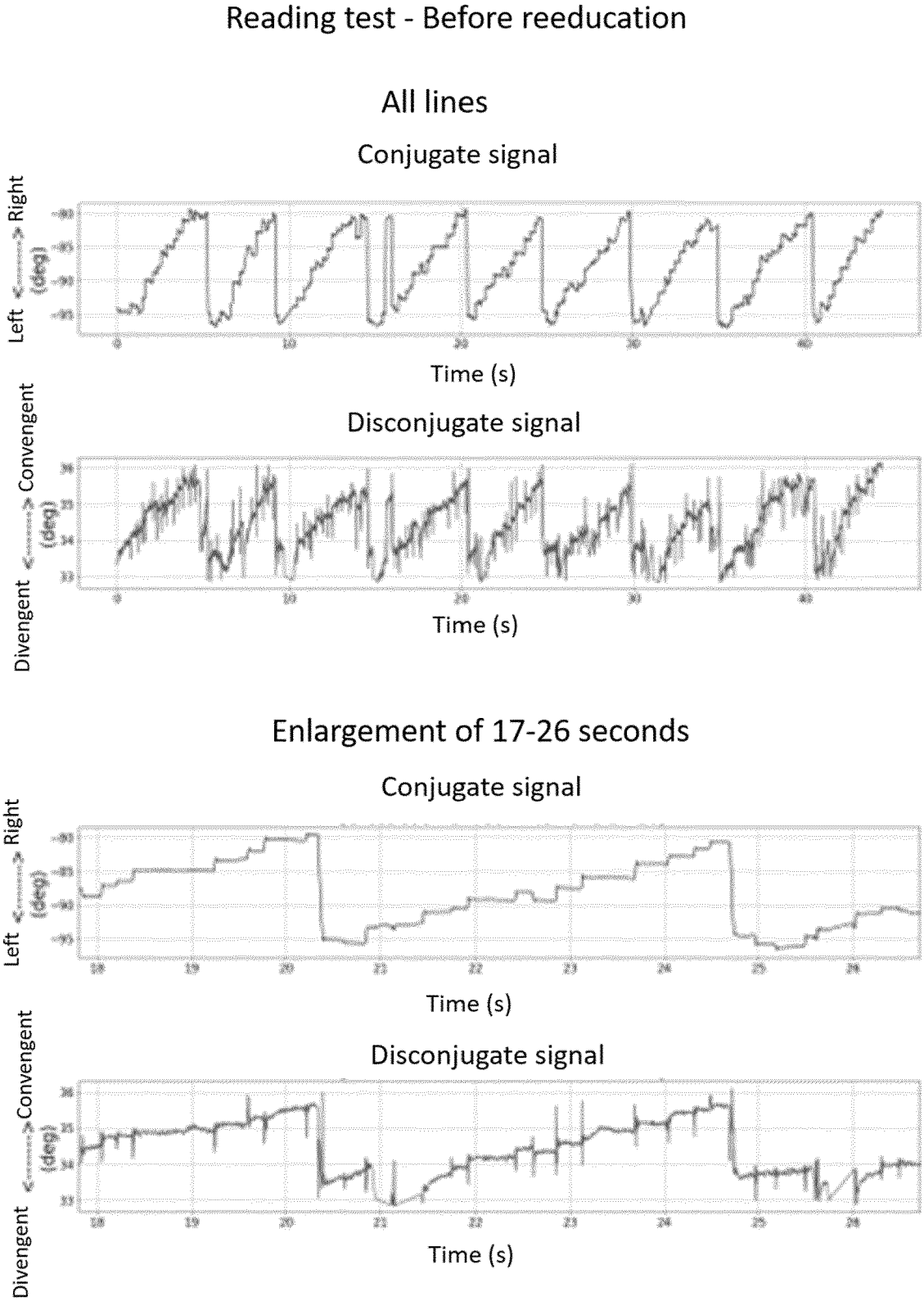

Reading test - Before reeducation
All lines
Conjugate signal
Left
Right
(deg)
Time (s)
Disconjugate signal
Divengent
Convengent
(deg)
Time (s)
Enlargement of 17-26 seconds
Conjugate signal
Left
Right
(deg)
Time (s)
Disconjugate signal
Divengent
Convengent
(deg)
Time (s)

Figure 33

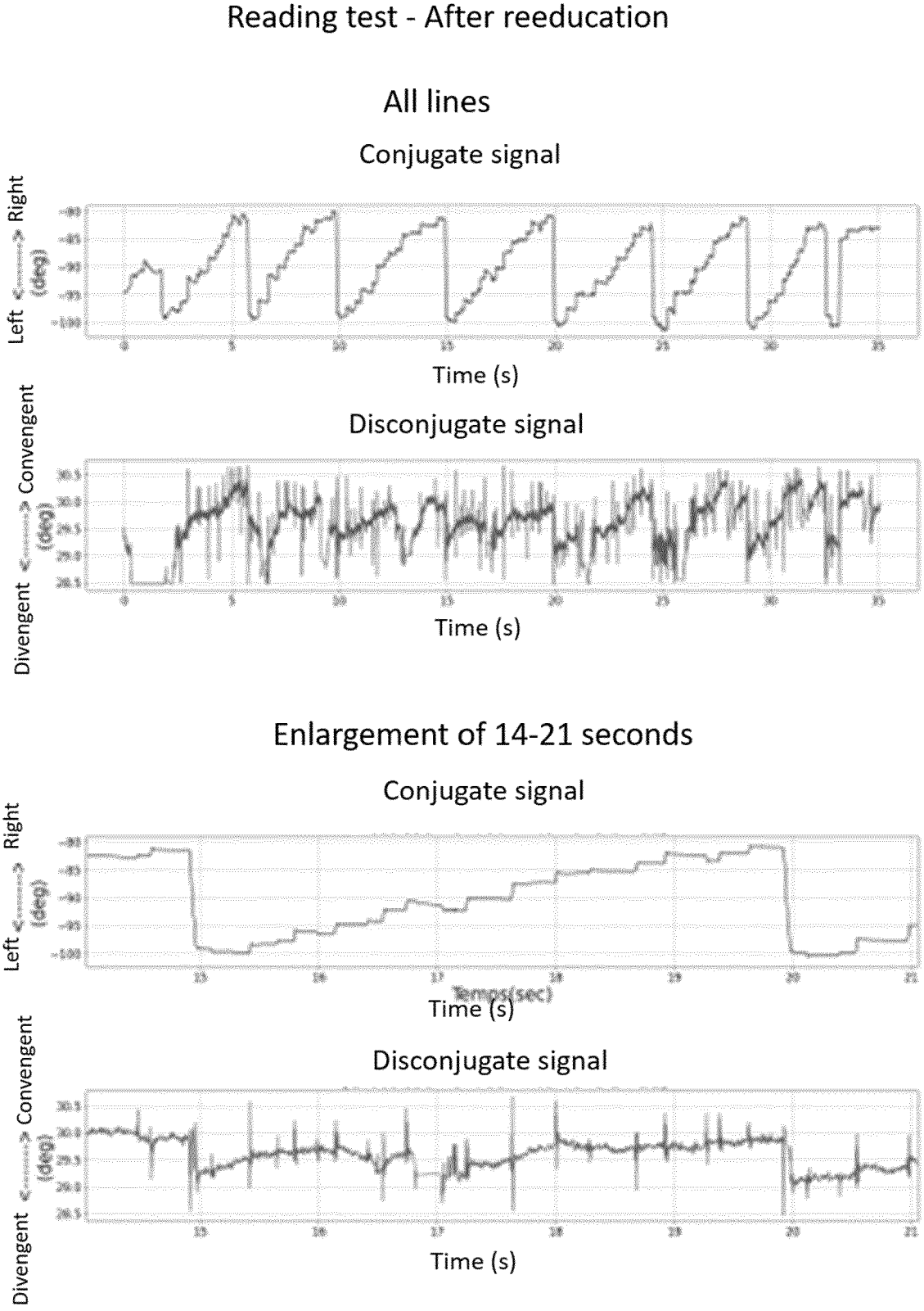

Reading test - After reeducation
All lines
Conjugate signal
Left
Right
(deg)
Time (s)
Disconjugate signal
Divengent
Convengent
(deg)
Time (s)
Enlargement of 14-21 seconds
Conjugate signal
Left
Right
(deg)
Temps(sec)
Time (s)
Disconjugate signal
Divengent
Convengent
(deg)
Time (s)

Figure 34

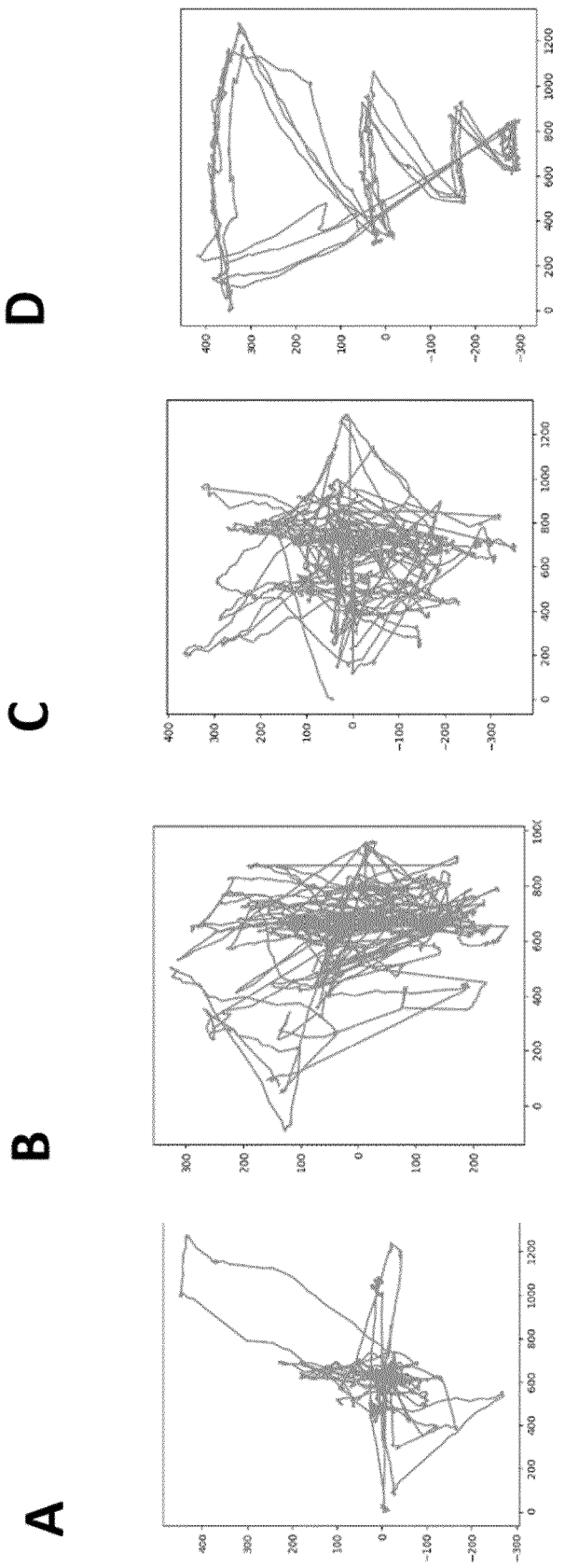


Figure 35

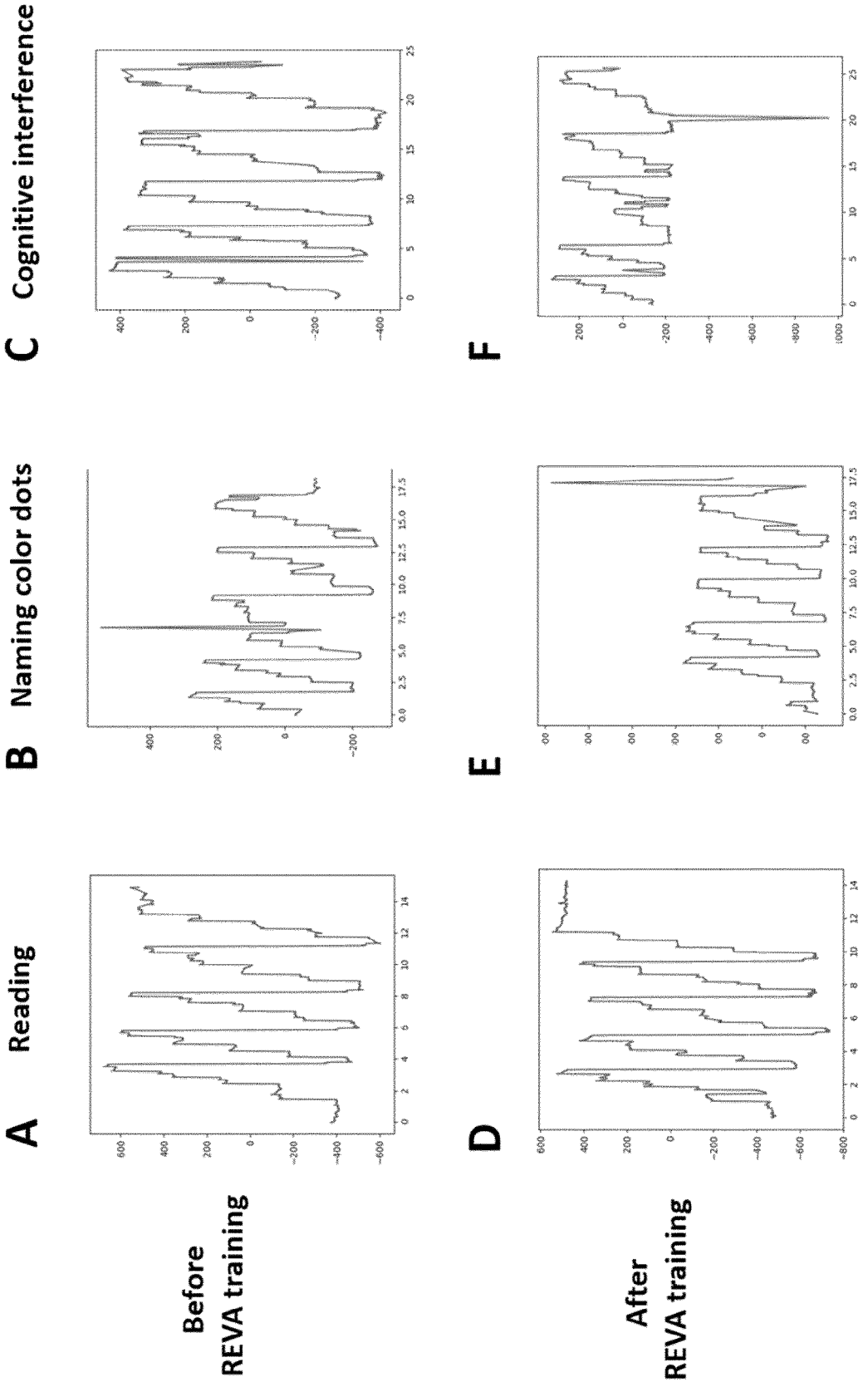

A
Reading
B
Naming color dots
C
Cognitive interference
D
E
F
Before
REVA training
After
REVA training

Figure 36

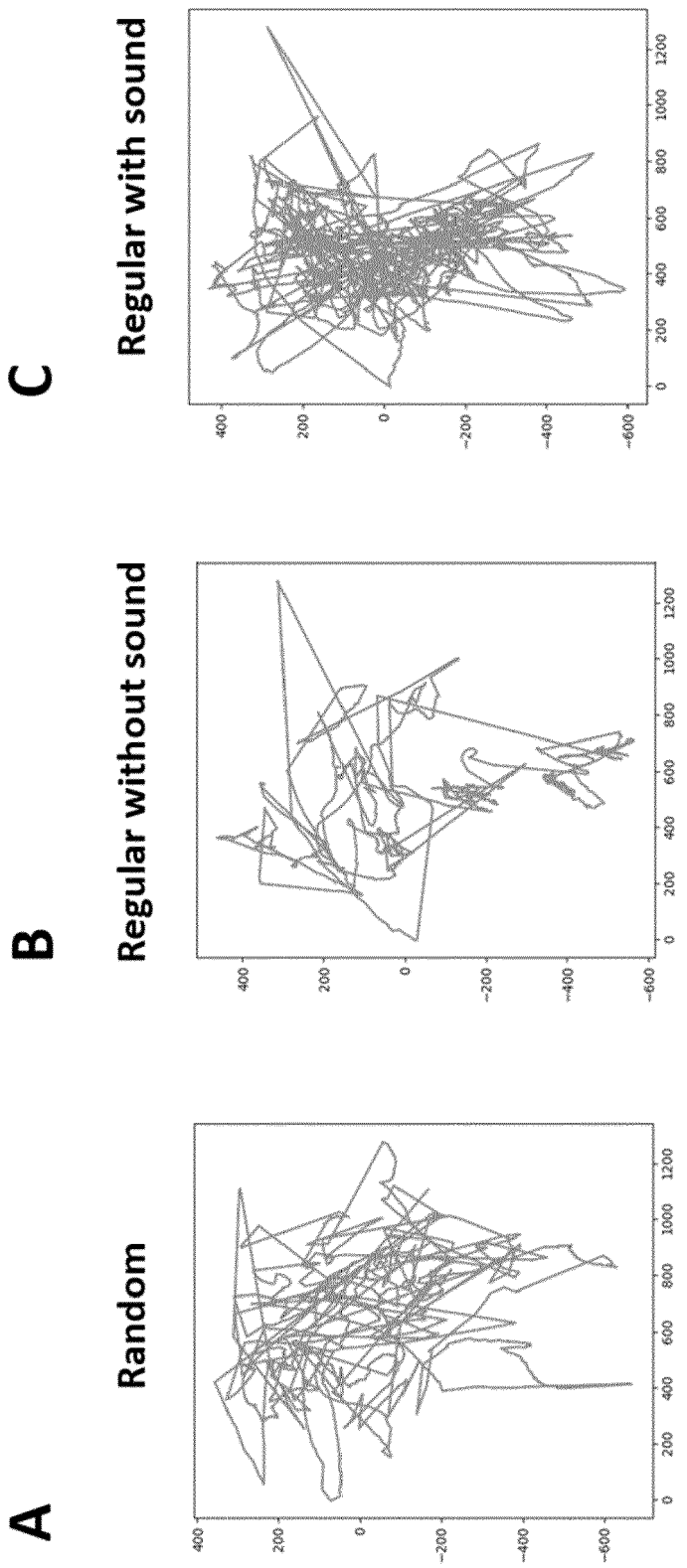

A
Random
B
Regular without sound
C
Regular with sound
400
200
0
-200
-400
-600
0
200
400
600
800
1000
1200

Figure 37

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EUROPEAN SEARCH REPORT

Application Number
EP 22 30 5061

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X,D	US 8 851 669 B2 (KAPOULA ZOI [FR]; YANG QING [FR] ET AL.) 7 October 2014 (2014-10-07) * column 3, line 50 - column 6, line 25; claims; figures *	1-15	INV. A61H5/00 A61B3/00
X,D	WO 2021/228724 A1 (CENTRE NAT RECH SCIENT [FR]; UNIV PARIS DESCARTES [FR]) 18 November 2021 (2021-11-18) * claims; figures *	1-15	
A	TW 201 034 651 A (UNIV NAN KAI TECHNOLOGY [TW]) 1 October 2010 (2010-10-01) * claims; figures *	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

A61H
A61B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	29 June 2022	Shmonin, Vladimir

CATEGORY OF CITED DOCUMENTS

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29-06-2022

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