(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
30 August 2018 (30.08.2018)

WIPO | PCT

(10) International Publication Number
WO 2018/154289 A2

(51) International Patent Classification:
*A61B 5/0484* (2006.01) *A61B 5/00* (2006.01)
*A61B 5/12* (2006.01)

(21) International Application Number:
PCT/GB2018/050441

(22) International Filing Date:
20 February 2018 (20.02.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1702915.8 23 February 2017 (23.02.2017) GB

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,

**(54) Title:** SYSTEM, METHOD, COMPUTER PROGRAM AND COMPUTER PROGRAM PRODUCT FOR DETECTING A CHANGE IN HEARING RESPONSE

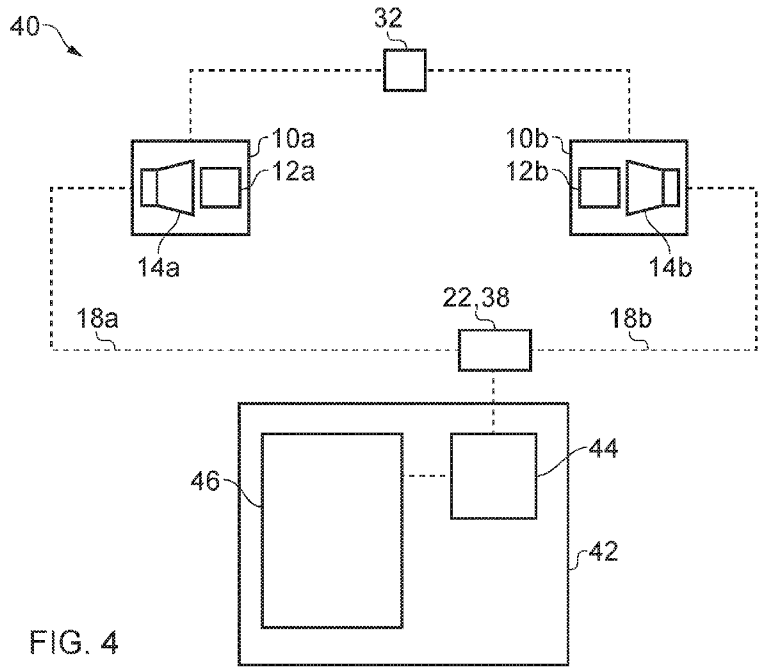


FIG. 4

**(57) Abstract:** A system is provided. The system comprises a processing system and a headphone system comprising an electrode and a transducer. The processing system is configured to carry out a method for determining a change in hearing response. The method comprises causing the transducer to output an auditory stimulus, detecting a first electrical characteristic representing a particular individual's response to the auditory stimulus at a first time, and recording first data associated with the first electrical characteristic. The method further comprises retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time. The method further comprises comparing at least one feature of the first data with at least one feature of the second data and determining, based on the comparison, that there has been a change in hearing response.

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SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

**(84) Designated States** *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

**Published:**

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

# SYSTEM, METHOD, COMPUTER PROGRAM AND COMPUTER PROGRAM PRODUCT FOR DETECTING A CHANGE IN HEARING RESPONSE

## Technical Field

The present invention relates to a system and a method for detecting signals evoked in an auditory system as part of the hearing process.

## Background

Electrical signals are generated by the auditory system as part of the hearing process. They are a result of various physiological processes in the body from areas such as, but not limited to, the cochlea, auditory brainstem, and cortex. When an auditory stimulus is applied to an ear of subject, an electrical signal or characteristic, such as a potential, is generated in various parts of the Cochlea, auditory brainstem and cortex of the subject. These signals/potentials can be detected using electrodes and may be observed as voltage against time after the stimulus. These signals are commonly known as Auditory Evoked Potentials (AEP). The observed measurement against time may be known as a waveform.

Hearing tests are commonly performed using Pure Tone Audiometry (PTA), where the subject is prompted to indicate if they are able to hear a sound, for example by pressing a button. Varying the frequency and amplitude of the test signals allows the threshold of hearing to be determined for a subject at a set of different frequencies.

AEPs may also be used to determine hearing thresholds, but without requiring a response from the subject. This may be useful if a subject is unable to indicate when they have heard a sound. For example, young children may be particularly suited to hearing tests measuring AEPs. An AEP measurement may also provide a greater wealth of information which cannot be attained from PTA results.

It is often difficult to compare AEP results between different subjects due to the great inter-subject variability. In addition, both AEP and PTA testing tend to require expensive equipment, expert supervision and interpretation of results, and typically a visit to a specialist facility. For this reason, testing is only likely to occur if a problem has already been noticed by the subject, a healthcare professional, or if the subject is at high risk.

Summary

According to a first embodiment of the present invention, a headphone system is provided. The headphone system comprises: a first earpiece comprising a first electrode and a first transducer; and a second earpiece comprising a second electrode and a second transducer. At least one of the first and second transducers is configured to output an auditory stimulus, and the first and second electrodes are configured to measure an electrical signal generated by a user as a result of the auditory stimulus.

Such a headphone system allows the detection of electrical signals, such as AEPs in a user. In one example, the headphone system is similar in form to standard audio headphones, meaning that that AEP hearing tests can be performed without the need for expensive dedicated devices. To begin an AEP test, a user can quickly and simply place the left and right earpieces on, in, or over their left and right ears. The user is then ready to perform the AEP test, and is not required to separately affix multiple electrodes or use invasive electrodes, for example trans-tympanic needle electrodes. The headphone system provides an effective solution to apply electrodes and provide an auditory stimulus to the ear(s) of a user without reduced electrode placement complexity.

In existing systems an electrode may be placed in an ear of the user and a separate means for supplying an auditory stimulus is used. The headphone system provides an all-in-one system including both electrodes and transducers meaning that the user is not required to attach an electrode system to separate transducers.

Such a headphone system may be portable, meaning that hearing tests can be initiated outside of a clinical environment, possibly the user themselves. This may allow tests to be repeated over time, providing data that cannot readily be obtained in a single medical appointment.

The headphone system may be used in conjunction with an audio device. For example the headphones can be connected to a portable media player, a computer, a laptop or a mobile phone. The headphone system can be used with standard audio devices therefore providing a low cost solution for performing AEP tests on a user. The headphone system may be a standard set of headphones adapted for AEP tests.

In some embodiments, the first earpiece is a left earpiece and the second earpiece is a right earpiece.

The headphone system may further comprise a third electrode. The third electrode may be used to measure a reference signal in some examples. However in other examples, the first or second electrode may be used as a reference electrode. An electrode, when being used as a reference electrode, is used to anchor a location to a certain potential relative to the measuring equipment, for example 0V. A reference electrode has several functions, for example it helps stop the voltage floating relative to the measuring equipment, it helps keep the voltages at the measurement point within the voltage range of the equipment, and can help to reduce common mode noise in the subject. The reference electrode may be known as “a common electrode”.

The reference electrode, for example the third electrode, in the headphone system can be used to provide a reference measurement and/or to reduce noise/interference. The reference may be a ground, a virtual ground or a Driven Right Leg (DRL) signal, produced from the inverse of the common mode noise. A DRL signal can be used to attenuate common mode noise. Measurements made by the first and second electrodes may be defined with respect to the reference measurement detected by the third electrode for example. Unwanted, global changes experienced by the first and second electrodes can be eliminated or reduced by subtracting these changes from measured data using the data measured by the third electrode. Accordingly, use of a third electrode allows accurate, comparable data to be recorded.

The headphone system comprises three electrodes meaning that measurements between one or more pairs of electrodes can be recorded. For example, measurements can be recorded between the first and third electrodes and the second and third electrodes. The headphone system also allows ear-to-ear measurements to be taken between the first and second electrodes. For example, the first electrode may be placed nearest to the ear being tested, and an electrical signal can be measured between the first and second electrodes, where the third electrode is used as a reference electrode. Alternatively, an electrical signal can be measured between the first and third electrode, and the second electrode may be used as a reference. Similarly, the second electrode may be placed nearest to the ear being tested, and an electrical signal can be measured between the second and first electrodes, where the third electrode is used as a reference electrode. Alternatively, an electrical signal can be measured between the second and third electrode, and the first electrode may be used as a reference.

The transducers may be drivers or speakers. For example, they may be speakers found within standard headphones. The transducers are used to output an auditory stimulus to the user's ears.

The electrical signals measured by the electrodes can include potential measurements, impedance measurements and current measurements. For example, impedance measurements can be used to determine whether the electrodes are making a sufficient connection with the user. The electrical signals may be recorded as a waveform.

The auditory stimulus output by the first and/or second transducers may be the same stimulus each time an AEP test is performed. This may improve reliability and provide consistency between each test.

An AEP test may be performed for each ear separately, or an AEP test may be performed at the same time for each ear. For example, the first transducer may be configured to output the auditory stimulus and the first and second electrodes detect an electrical signal. Next, the second transducer may then be configured to output the same or different auditory stimulus and the first and second electrodes detect an electrical signal. Alternatively, the first and second transducers may both be configured to output the auditory stimulus at substantially the same time and the first and second electrodes detect the electrical signal.

The third electrode may be located such that the signal measured by the third electrode is not substantially affected by the electrical signals generated by the user as a result of the auditory stimulus. In other words the third electrode may located so as to minimise any detection of the signals generated by the user as a result of the auditory stimulus.

The third electrode may be configured to be held by the user in use. For example, when the electrodes are being used to take a measurement, the user may be required to grip/hold the third electrode. This can provide an effective way of providing a ground reference signal without requiring the user to attach an electrode to their skin as is common in existing systems. In one example the third electrode is attached to a cord or wire of the headphone system.

In another example, the third electrode may be configured to be attached to the user via a clip in use. In a further example, the third electrode may be attached to a cord or wire of the headphone system and the third electrode is configured to rest against the user in use.

The first electrode may be configured to be disposed inside a first ear of a user in use and the second electrode may be configured to be disposed inside a second ear of a user in use. The first and second electrodes may be identical or different. For example, the first electrode may be specifically shaped to provide good contact with the inside of a user's first ear canal and the second electrode may be specifically shaped to provide good contact with the inside of a user's second ear canal. In one example, the first and second earpieces may also be specifically shaped depending upon the particular ear to which they are provided.

The headphone system may be a circum-aural or supra-aural headphone system. For example, the first earpiece may comprise a first pad and the second earpiece may comprise a second pad, where the first pad comprises the first electrode and the second pad comprises the second electrode. The first pad may be configured to be placed on, or over, a user's first ear in use and the second pad may be configured to be placed on, or over, the user's second ear in use. The electrodes may be integrated within the pads themselves. For example, conductive material may be woven throughout the fabric of the pads. In an example the pads are cushions and the electrodes may be integrated within the cushions to provide comfort while still enabling contact between the user's skin and the electrodes. Having first and second pads comprising the electrodes means that the electrodes are fixed in place, for example they can be positioned to obtain reliable electrical signal measurements.

In another example, the first earpiece may comprise a first pad and the second earpiece may comprise a second pad, wherein the first electrode is located on the first pad and the second electrode is located on second pad. Similarly, the first pad is configured to be placed on, or over, the user's first ear in use and the second pad is configured to be placed on, or over, the user's second ear in use. Thus the electrodes may be separate to the pads themselves. This may allow the electrodes to be removed so that they can be cleaned or replaced, without requiring replacement of the pads themselves. Furthermore, this may allow an electrode to be moved relative to the pad so that they can be placed in desired locations. Having separate electrodes may also mean that it the headphone system is easier and cheaper to manufacture, for example the whole pad need not be electrically conductive. In addition, the electrodes can be sold separately and may be retro-fitted to existing headphones.

These circum-aural or supra-aural headphone systems allow the first and second electrodes to be easily and conveniently placed in contact with the user. Minimum effort is required by the user to place the electrodes. Furthermore, pressure applied by the first and second pads can mean that good electrical contact is maintained with the user, while at the same time allowing the auditory stimulus to be provided via the substantially co-located transducers.

The first and second electrodes may be positioned to allow contact with the ear or a region surrounding the ear of the user, in use. For example, when a pad comprises an electrode or when an electrode is placed on a pad, the electrodes can be configured to contact specific locations on or in the vicinity of the user's ear. In one example the electrodes are configured to be in contact with the user's concha or mastoid locations. At these positions, reliable and/or strong electrical signals can be detected. The electrodes may also be sized and shaped appropriately to provide contact over a required area on the user's skin.

The headphone system may further comprise a headband joining the left earpiece to the right earpiece. The headband may be configured to be placed around the user's head in use. For example, it may pass around the back of the users head or may pass over the top of the user's head. The headband may provide resilience, thereby causing the first and second electrodes to be held against the user to provide improved contact with the user's skin.

In one example the headband comprises the third electrode. For example, the headband may comprise the third electrode as an integral part of the headband or the third electrode may be affixed to the headband. This means that the third electrode can be located in a position where a reliable measurement can be detected. The third electrode may be situated at a midpoint between the left and right earpieces.

The headband may comprise at least two third electrodes. When being used as reference electrodes, an average reference signal could be measured using signals measured by each of the third electrodes to provide an improved reference signal measurement. Alternatively one or more of the third electrodes can be selected based on its location. For example a third electrode may be selected because it provides the greatest signal when considering interference (“cross-talk”) and impedance.

The third electrode may comprise one or more protrusions configured to be in contact with a scalp of the user in use. For example, when the headband comprises the third electrode, the protrusions allow the third electrode to contact the scalp through a user’s hair. The provision of one or more protrusions may therefore improve the electrical connection.

The first and second electrodes may comprise flexible and conductive material. For example, when the first and second electrodes are configured to be disposed inside an ear of the user in use, the electrodes can be made from a flexible conductive material such as, but not limited to: conductive rubber, foam, or cloth. The first and second electrodes may be provided in range of different sizes to ensure a good fit with the user. For a supra-aural or circum-aural headphone system, the first and second electrodes may be made from, but not limited to: conductive rubber, cloth, or a metal or metallic material. The materials may have a high conductivity, and have good bio-compatibility in the electrical and physical interface they form with the user.

Having flexible electrodes allows good contact to be made with the contours of ear canal or ear and its surrounding areas.

According to another embodiment of the present invention there is provided a method of determining a change in a hearing response of a particular individual. The method comprises:

providing an auditory stimulus to an ear of the particular individual;

detecting a first electrical characteristic representing the particular individual’s response to the auditory stimulus at a first time;

recording first data associated with the first electrical characteristic;

retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual’s response to the auditory stimulus at a second time, earlier than the first time;

comparing at least one feature of the first data with at least one feature of the second data; and determining, based on the comparing, that there has been a change in hearing response.

Such a method allows a determination to be made as to whether there has been a change in the hearing response of a particular individual over time. The method therefore allows the individual's hearing response to be compared with an earlier hearing response determined for the same individual.

It has been found that by comparing responses for a particular individual over time, changes can be detected that might otherwise have been missed. For example, these changes may have otherwise been attributed to typical variations between individuals. Current methods compare an individual's AEP test results with those of a "standard" individual who is known not to have any particular hearing problem. However due to great inter-subject variability hearing problems are particularly difficult to characterise and detect by comparison with measurements with other subjects.

It has been found that although different individuals may have widely differing responses to an auditory stimulus, the range for a particular individual is smaller, allowing a meaningful comparison to be made over time. Therefore, unlike prior methods and devices which seek to provide a diagnosis or analysis based on a single test and comparison with "standard" result or known indicators derived from a sample of the population as a while, the method compares at least two tests separated in time for the same individual.

In an example, a hearing test is performed at a first time and the results are compared to results obtained from an earlier hearing test. This may be repeated multiple times, for example over a period of days, months or years. Gradual, minor changes to an individual's hearing response may not be detected from one day to the next, but comparison of data from earlier times can determine change. This repeated monitoring and comparison may be useful to provide a baseline for that particular user to which later results can be compared.

A change in an individual's hearing response may be related to a number of conditions. For example a change may be due to tinnitus or age-related hearing loss. Such changes are typically long-term, lasting for periods longer than a week, a month or a year, for example. The difference in time between when the first data and the second data are recorded may be at least one day, at least one week, at least one month, at least two months or at least three months.

Such a method may be performed using the headphone system described above. For example, a test is performed wherein an auditory stimulus is output by one or more transducers and the auditory stimulus generates an electrical signal within the particular user. Electrical characteristics of the individual's response to the auditory stimulus may be detected by one or more electrodes.

The auditory stimulus provided to an ear of the individual may be a pure tone, white noise, pink noise, a multiple tone, a click, a chirp, a toneburst or any other sound suitable evoking an auditory response in a user. The auditory stimulus may have a constant or varying sound pressure level.

The auditory stimulus may be provided to one ear, both ears, or to alternating ears of the particular individual. For example, the stimulus may be first applied to one ear then subsequently provided to the other ear. The stimulus may also be applied to both ears at substantially the same time. The auditory stimulus may be the same stimulus for each test for consistency and repeatability.

The detected electrical characteristics may be a detected electrical signal. These detected characteristics/signals can include any of an electrical potential/voltage, impedance and current. In one embodiment the electrical characteristic is an Auditory Evoked Potential (AEP). AEPs provide an insight into how the stimulus affects various features within the subject's auditory pathway. The features in the waveform may be classified, for example by name or number, according to how or where they originate from in the body. Metrics such as, but not limited to, amplitude and latency of features, and ratios of amplitude compared to other features may be used to characterise and analyse the waveform. The characteristics of the waveform may vary due to many factors, including but not limited to duration, rate, amplitude and frequency aspects of the stimulus, the subject under test, how and where the signal is measured, and temporary and permanent damage to the auditory system.

Reference to "a first time" may include "a first period of time", and reference to "a second time" may include "a second period of time". Accordingly the electrical characteristics may be detected and/or recorded over a predefined period of time. For example of the order of microseconds, milliseconds, seconds, tens of seconds or minutes. The detected signal/characteristics may be in the form of a waveform. For example, a waveform may be a measure of voltage in the time domain.

The electrical signal or characteristics may be recorded between a pair of electrodes.

The detected electrical characteristics may be processed before being compared or stored/recorded. For example, the detected signals may be sampled at a certain frequency, they may be background subtracted, adjusted to remove noise or interference, amplified, or adjusted with respect to a reference signal. Alternatively the raw detected signal may be stored/recorded. Processing may occur after the raw data has been stored, in addition to storing the raw data, or the detected characteristics may not be subjected to post-processing. Data is recorded which is associated with the detected electrical characteristic.

A first waveform may be recorded, where the waveform is associated with the detected electrical characteristic, and a second waveform associated with a second electrical characteristic may be retrieved.

One or more features, indicia, characteristics or aspects of first data can be compared with corresponding one or more features, indicia, characteristics or aspects of second data. For example, a feature may include a particular voltage value measured at a particular time after the auditory stimulus is provided. This voltage value may be compared to a second voltage value in the second data recorded at the same time after the earlier auditory stimulus was provided. In this way corresponding features from different recorded data is compared. If the data is a waveform, specific peaks and troughs within each waveform may be compared.

A change in a hearing response may be determined based on an absolute difference between the features. For example, a voltage measurement taken at the same time after stimulus may differ between first and second data. A change in hearing response may be determined based on a relative difference between the features, for example a predetermined percentage different between a feature in the first data and a corresponding feature in the second data.

Such a method of comparison may be performed by a system automatically. A particular individual may only be required to initiate the AEP test and the determining whether a change has occurred may be automatic, without further user intervention.

The first data may be recorded or stored on memory. The memory may be a non-transitory computer readable medium. The second data may be retrieved from the memory. The memory may be in a storage device. In one example the storage device is located in an audio device that provides an audio signal to the particular ear of a user. The storage device may alternatively be located remotely from the audio device.

The first data may be a first waveform associated with the first electrical characteristic and the second data may be a second waveform associated with the second electrical characteristic.

The at least one feature of the first data may be a first threshold of hearing and the at least one feature of the second data may be a second threshold of hearing. Hence, the determining, based on the comparing, that there has been a change in hearing response may comprise determining that a difference between the first threshold and second threshold exceeds a predetermined value. This provides a method for calculating whether a user's hearing response is changing over time based on a change in the individual's threshold of hearing.

"Determining" may include "calculating".

An individual's hearing threshold may be determined by varying the frequency and amplitude of the audio stimulus. This may require repeating the step of detecting a first electrical characteristic a plurality of times, where for each time the frequency and/or amplitude of the stimulus is changed. The electrical characteristics detected from these repeated detections may be stored separately or together as first data. The first threshold may be recorded for later retrieval. For example, the first data may be, or may include the first threshold of hearing. Similarly, the retrieved second data may be, or include a second threshold.

The thresholds of hearing may correspond to a threshold for a particular frequency and/or amplitude.

Comparing at least one feature of the first data to at least one feature of the second data may comprise determining a ratio between at least a portion of the first data and at least a portion of the second data. Hence determining, based on the comparing that there has been a change in hearing response may comprise determining whether the ratio exceeds a predetermined value. This provides a method for calculating whether a user's hearing response is changing over time.

The ratio may be a ratio of the first and second data (or waveforms), or a ratio of particular portions of first and second data (or waveforms). Hence certain features from earlier recorded data for the particular individual can be compared to certain features from later recorded data for the same particular individual.

In one example, a potential measurement from the first data may be compared with a potential measurement from the second data. In another example, a ratio is calculated between one peak in the first waveform with another peak in the first waveform. This ratio is compared to the same ratio made in the second waveform.

The recorded data may be compared over time using standard classification, comparison, or machine learning techniques such as mean square error, neural networks, or an heuristic algorithm. The results may be determined automatically without requiring expert intervention.

Comparing at least one feature of the first data to at least one feature of the second data may comprise comparing a first latency of a feature of the first data with a second latency of a feature of the second data. Hence determining, based on the comparing that there has been a change in hearing response may comprise determining that a difference between the first latency and second latency exceeds a predetermined value. This provides a method for determining whether a user's hearing response is changing over the time between the first data and the second data. For example, the time between the first data and the second data may be at least one day, at least one week, at least one month, at least two months or at least three months.

For example, first data may indicate that a particular feature in the data is measured at a particular point in time after a stimulus has been provided. In the second data, the feature may occur at an earlier or later point in time after a stimulus has been provided. If this change in latency is greater than a predetermined value, it may indicate that a user's hearing response has changed. For example, the feature may be a particular wave within the recorded data, such as Wave V. Comparing the latency of particular features may be performed at a particular stimulus level, and may be performed at a plurality of stimulus levels. In a specific example, the latency of Wave V at a stimulus level of 80dBnHL in the first data is compared to the latency of Wave V at a stimulus level of 80dBnHL in the second data. Other stimulus levels may include one or more values between 30-80dBnHL for example.

The step of detecting a first electrical characteristic may be repeated a plurality of times in a period of time and the first data may be an average of the detected electrical characteristics across the plurality of times. By making multiple detections of the electrical characteristics generated, the effect of noise can be reduced by averaging multiple recordings together. This can be particularly effective because the system may be used in an unsupervised manner, outside of a controlled environment. Averaging may also be necessary due to the relatively low potentials/voltages being measured and the relatively high level of noise. For each repetition the stimulus is repeated and the response detected for each repeat.

An "average" may be an average of the plurality of waveforms. Hence the average may also be a waveform.

Instead of the first electrical characteristic being detected at "first time" the detection can be said to have been detected in a "first period of time" in which the repeated detections are made. In other words, in a first period of time the step of detecting a first electrical characteristic representing the particular individual's response to the auditory stimulus may be repeated any desired number of times. For example it may be repeated two, three, five, ten, or fifty times within the first period of time. The number of repetitions may be dependent on a detected signal noise level.

A time difference between a start time of consecutive repetitions of the detecting a first electrical characteristic is random or pseudo-random. In other words, consecutive repeated detection steps may be spaced in time randomly or pseudo-randomly. This can reduce the contamination of periodic signal noise to improve the accuracy of the detected data. Hence the start times of each consecutive repetition is chosen to be uncorrelated with periodic interference. An example source of periodic interference can include mains electricity.

In some examples the noise profile of measured data may be automatically analysed by the system, for example by examining the frequency domain of a representative recording, preferably for long as possible. This can also allow the removal of periodic noise, by filtering to remove periodic components present when there is no stimulus. This may also be performed using an adaptive filter using standard methods.

The method may further comprise detecting a background electrical characteristic when no auditory stimulus is provided to both ears of the particular individual. The method may also comprise recording background data associated with the background electrical characteristic. The background data may be later used to determine whether acceptable signal to noise ratio is achieved. For example the background data could be examined automatically or manually, such as by an expert. This can be used to infer the reliability of the recorded data.

The method may further comprise providing an indication that there has been a change in hearing response. For example the indication could be a visual indication, such as a message displayed on the screen. The indication may be provided to the particular individual or to a third party, such as an audiologist. The indication may prompt the individual to seek professional help to obtain treatment as soon as possible. Data may also be transmitted to the third party for manual assessment. If third party agrees that the data shows the individual's hearing response has changed, a follow up specialist appointment may be scheduled for further tests.

According to another embodiment of the present invention a system is provided. The system comprises the headphone system described above and a processing system. The processing system is configured implement the method described above using the headphone system.

According to another embodiment of the present invention, another system is provided. The system comprises a processing system and a headphone system comprising an electrode and a transducer. The processing system is configured to carry out a method for determining a change in hearing response. The method comprises causing the transducer to output an auditory stimulus, detecting a first electrical characteristic representing a particular individual's response to the auditory stimulus at a first time, and recording first data associated with the first electrical characteristic. The method further comprises retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time. The method further comprises comparing at least one feature of the first data with at least one feature of the second data and determining, based on the comparison, that there has been a change in hearing response.

In some examples the processing systems may be implemented by a processor.

Such systems allow determining whether a particular user's hearing has changed over time. The systems may automatically compare newly obtained results with previously stored results to determine whether a difference has occurred. The systems simply require the individual to wear headphones so that a recording can be made with minimum effort.

The systems may include a communication interface to transmit and receive data recorded with other systems. This may allow tests on one system to be compared with results previously measured on another system. Alternatively, the communication interface may be to provide data recorded for additional, specialist analysis when a change in hearing response is determined.

In some examples the system is portable. This can allow monitoring hearing response without needing a professional appointment at a clinic.

According to another embodiment of the present invention, there is provided a computer program comprising computer-readable instructions that, when executed by a processing system, instruct the processing system to perform a method as described above.

According to another embodiment of the present invention, there is provided a non-transitory computer readable storage medium including instructions stored thereon for execution by a processor, wherein the instructions, when executed by the processor, implement a method as described above.

Further features and advantages of the invention will become apparent from the following description of preferred embodiments of the invention, given by way of example only, which is made with reference to the accompanying drawings.

## Brief Description of the Drawings

Figure 1 shows a diagrammatic representation of a cross section of an earpiece in an example headphone system;

Figure 2 shows a diagrammatic representation of an example headphone system;

Figure 3 shows a diagrammatic representation of a second example headphone system;

Figure 4 shows a diagrammatic representation of an example system;

Figure 5 shows flowchart of an example method for determining a change in a hearing response of a particular individual;

Figure 6 shows an example plot of data recorded using the example system; and

Figure 7 shows a diagrammatic representation of additional features usable in the system depicted in Figure 4.

## Detailed Description

Figure 1 shows a diagrammatic representation of a cross section of a left earpiece 10a in an example headphone system 20. A corresponding right earpiece 10b comprises the same features as the left earpiece 10a. Figure 2 shows a diagrammatic representation of the example headphone system 20. The headphone system 20 may be an “in-ear” headphone system, where an earpiece is disposed within the ear of a user in use.

The headphone system 20 can be used to perform Auditory Evoked Potential (AEP) tests on a user to determine whether there has been a change in a user’s hearing response. A number of tests can be conducted over time and newly recorded data can be compared with previously stored data to determine whether user’s hearing response has changed.

The headphone system 20 comprises a left earpiece 10a and a right earpiece 10b. The left earpiece 10a comprises a first electrode 12a and a first transducer 14a. The right earpiece 10b comprises a second electrode 12b and a second transducer 14b. The headphone system 20 further comprises a third electrode 22. In this example a conducting ring 11a, such as a metal ring, connects the electrode 12a to circuitry 16a. The circuitry 16a may be integrated into the earpiece 10a.

Wires connect the earpieces 10a, 10b to an interface 24. This connection may be a direct connection or may be indirect and may therefore include one or more wires. In the example of Figure 2 the wires 18a, 18b are connected to a third electrode 22 and a wire 26 connects the third electrode 22 to the interface 24. The interface 24 can be used to connect the headphone system 20 to an external audio device 42 (shown in Figure 4). The audio device 42 provides an audio signal to be output by either or both of the first and second transducers 14a, 14b. The interface 24 may include an audio jack, a USB interface or a Lightning connector, for example. Alternatively the earpieces 10a, 10b may be in wireless communication with the audio device 42, for example via Bluetooth.

Audio output by the transducers 14a, 14b may include an auditory stimulus to generate an electrical signal response in a user of the headphone system 20. The electrical signals/characteristics can be detected/measured by the electrodes 12a, 12b. The auditory stimulus may be provided to only one transducer 10a, 10b at a particular time. In this way an AEP test can be conducted on user's ears separately. However both first and second electrodes 12a, 12b can be used to detect an electrical signal generated by the user as a result of the auditory stimulus provided to only one ear. The third electrode 22 may be configured to measure a reference signal.

For example, the first electrode 12a may be placed nearest to the ear being tested, and an electrical signal can be measured between the first 12a and second 12b electrodes, where the third electrode 22 is used as a reference electrode. Alternatively, an electrical signal can be measured between the first 12a and third 22 electrode, and the second electrode 12b may be used as a reference. Similarly, the second electrode 12b may be placed nearest to the ear being tested, and an electrical signal can be measured between the second 12b and first 12a electrodes, where the third electrode 22 is used as a reference electrode. Alternatively, an electrical signal can be measured between the second 12b and third 22 electrode, and the first electrode 12a may be used as a reference.

The detected electrical signals may be manipulated before being stored. For example, the signals may be amplified or adjusted with respect to the reference signal. The electrical signals may be background subtracted and may be adjusted to remove noise and/or interference. These processes may be performed within the headphone system 20 itself, or may be performed on a separate device, such as in the audio device 42. In one example, the electronics for adjusting/amplifying the detected electrical signals is part of the circuitry 16a, 16b.

Data may be transmitted from the earpieces 10a, 10b via the wires 18a, 18b, 26 and via the interface 24 to a storage device. The storage device may be the same device that provides audio to the transducers 14a, 14b. The data may also be stored remotely from the audio device 42. For example, the audio device 42 may transmit the data to a server or other remote storage device (not shown).

A processor 44 (shown in Figure 4) may be communicatively coupled to the headphone system 20 to analyse data measured by the electrodes 12a, 12b. For example, the data may be analysed to determine whether there has been a change in a user's hearing response. The processor 44 may cause the method described above to be implemented. In one example the audio device 42 comprises the processor 44 to analyse the data. A user may use the same audio device 42 to perform multiple tests over time. The data recorded from each test may be stored on the audio device 42 and may be compared to future results.

Figure 3 shows a diagrammatic representation of a second example headphone system 30. Headphone system 30 may be supra-aural or circum-aural headphones configured to be placed on or over the user's ears in use.

The headphone system 30 comprises left and right earpieces 110a, 110b and a headband 34 that connects the left earpiece 110a to the right earpiece 110b. The left earpiece 110a may comprise a left pad 36a and the right earpiece 110b may comprise a right pad 36b. The left pad 36a is configured to be placed on or over the user's left ear in use and the right pad 36b is configured to be placed on or over the user's right ear in use. The pads 36a, 36b may be cushioned to provide comfort for the user.

In one example, the left pad 36a comprises the first electrode 112a and the right pad 36b comprises the second electrode 112b. For example, the pads 36a, 36b may be made from electrically conductive material allowing the pads to act as electrodes 112a, 112b. In another example, the pads 36a, 36b may be formed around the electrodes 112a, 112b such that at least a portion of the electrodes 112a, 112b are recessed within the pads 36a, 36b.

In another example the first electrode 112a is located on the left pad 36a and the second electrode 112b is located on right pad 36b. For example, the electrodes 112a, 112b may be attached to the pads by a hook and loop fastener, adhesive, or stitching.. The electrodes 112a, 112b may be constructed from flexible conductive material to provide comfort for the user when the electrodes 112a, 112b are placed in contact with the user's skin. The electrodes may be integrated with a cushion or a clip to make contact in the concha or mastoid locations. This may be made of but not limited to conductive rubber, cloth, or a metal or metallic material. It may be beneficial that not only do the materials have a high conductivity, but also that they have good bio-compatibility in the electrical and physical interface they form with the user. In one example the electrodes 12a, 12b, 112a, 112b are made from Silver-Aluminium Silicone conductive material, preferably ultra-soft Silver-Aluminium Silicone.

The first and second electrodes 112a, 112b are positioned to allow contact with the ear or a region surrounding the ear of the user, in use.

A third electrode 32 may be integrated with or connected to the headband 34. This third electrode 32 may comprise one or more protrusions 33 to allow the third electrode 32 to contact a user's scalp in use. Where there is no headband, or the designer prefers, third electrodes may be integrated into other elements of the device, such as a lanyard, cord, or enclosures. Alternatively, the third electrode 32 may be similarly located as in the headband system 20 of Figure 2. For example, the third electrode may be located between wires 118a and 118b and may be integrated or connected to housing 38. Housing 38 may alternatively or additionally be used to house electronics, for example circuitry to amplify detected signals.

In both systems 20 and 30, the transducers 14a, 14b and electrodes 12a, 12b, 112a, 112b may be integrated into a conventional set of headphones or earphones. The electrodes 12a, 12b, 112a, 112b depicted in any of Figures 1-3 may come in range of sizes to ensure a good fit with the user. The electrodes 12a, 12b, 112a, 112b may be re-usable, and could be detached for sanitation or replacement. Furthermore, the electrodes 12a, 12b, 112a, 112b may be integrated into the same unit as the transducers 14a, 14b.

Figure 4 shows a diagrammatic representation of an example system 40. Although reference numbers in Figure 4 relate to the headphone system in Figures 1 and 2, it may equally include the headphone system 30. As briefly mentioned above, the headphone systems 20, 30 may be connected to a device 42 with an audio interface and a processor 44, such as a smartphone or other computing device. This computing device may be a general purpose or custom designed device. The audio device 42 and processor 44 may also be fully integrated into the headphone system 20, 30 if standalone operation is required. The audio device 42 will generate the auditory stimuli and process the results detected by the electrodes 12a, 12b.

The system 40 comprises a left headphone earpiece 10a comprising a first electrode 12a and a first transducer 14a. The system 40 further comprises a right headphone earpiece 10b comprising a second electrode 12b and a second transducer 14b. The system further comprises an audio source device 42, which in this embodiment also includes a processor 44 and memory 46. The audio source device may, for example comprise an amplifier (not shown). In the example system 40 of Figure 4, the memory 46 is located on the audio source device 42, however the memory may be located remotely and may be communicatively coupled to the audio device 42. The audio device 42 is configured to provide audio to be output by the transducers 14a, 14b.

The system may further comprise a third electrode 22, 32. For example, this may be connected to, or integral with a headband 34.

In alternative embodiments, the audio source device may be located within the housing 38.

Such a system may allow for regular automated tests to be performed with no greater interaction than a user wearing the device and starting a test.

The memory 46 may have instructions stored thereon that are executable by the processor 44 to cause the system 40 to implement the method of Figure 5. For example, the audio source 42 provides an audio signal (an auditory stimulus) to at least one of the first and second transducers 14a, 14b when a user is wearing the left headphone earpiece 10a and the right headphone earpiece 10b. The first and second electrodes 12a, 12b are configured to detect a first electrical characteristic representing the particular individual's response to the auditory stimulus at a first time. The memory 46 is configured to record first data associated with the first electrical characteristic. The processor 44 is configured to retrieve second data from the memory 46, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time. The processor 44 is configured to compare at least one feature of the first data with at least one feature of the second data and determine, based on the comparing, that there has been a change in hearing response.

The electrode material preferably has low and consistent impedance when in contact with the skin, preferably less than 5kOhm. For example, the electrodes 12a, 12b, 112a, 112b may be made from Silver-Aluminium Silicone conductive material, preferably ultra-soft silver aluminium silicone. The system 40 may further be able to determine whether the electrodes 12a, 12b are making a sufficient connection to the user by, for example, impedance measurement. For example the system may be able to switch in an impedance measurement circuit, to measure the impedance between pairs of electrodes. If the measured impedance is above a predetermined threshold (5kOhm for example), this suggests that contact between the user and the electrodes is poor. An indication may be provided to the user informing them that an insufficient connection is detected. For example a user may be prompted to re-fit the electrodes 12a, 12b until a satisfactory connection is achieved. This will allow some form of feedback, e.g. visual or aural, to enable the user to fit the unit and achieve the required electrode impedance measurements. The impedance measurement shall preferably use low currents, safe for the human body (for example less than 10μA, or less than 10 μA peak to peak).

A system 40 may enhance the utility of AEP measurement, both in detecting small auditory changes and enabling regular records to be kept. The system can analyse the recorded data and may additionally produce records of the results, and provide alerts if abnormal readings or trends are detected. In this way a detailed profile of a user's auditory function can be made over time. This may enable early detection and prevention of hearing conditions such as tinnitus and hearing loss. These profiles may also provide a data resource for future clinical studies, for example for further research to minimise the negative impact of noise exposure.

Figure 5 shows flowchart of an example method 50 for determining a change in a hearing response of a particular individual. The method 50 may be implemented on the system depicted in Figure 4 or 6.

First, at step 51, the method comprises providing an auditory stimulus to an ear of the particular individual.

Next, at step 52, the method comprises detecting a first electrical characteristic representing the particular individual's response to the auditory stimulus at a first time.

Next, at step 53, the method comprises recording first data associated with the first electrical characteristic.

Next, at step 54, the method comprises retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time.

Next, at step 55, the method comprises comparing at least one feature of the first data with at least one feature of the second data.

Finally, at step 56, the method comprises determining, based on the comparing, that there has been a change in hearing response.

The method may also comprise additional steps described above. Such a method can allow an individual to monitor their hearing response over time to determine whether a change has occurred.

Figure 6 shows an example plot of data recorded using the system of Figure 4. The plot shows time (latency) along the x-axis, and voltage along the y-axis. The plot shows the output of the equipment (before any classification) after several runs at various stimulus levels (80, 60, 40, 30 dBnHL). Each trace is the average of around 2000 recordings. It shows the voltage recordings for 20ms after a click stimulus was applied in a single session. For example, the data could be representative of first data detected at a first time.

The plot shows that a particular feature (wave V) consistently occurs at the same latency for a certain stimulus level.

The plot shows how the stimulus is detected as it travels through an auditory system. For example, the wave V may typically occur around the boundary of the Pons and the Midbrain within a subject.

A change in a user's hearing response may be detected if a second plot is recorded at a later time and the wave V latency for a particular stimulus level has shifted.

Figure 7 shows an example overview of the operational elements of the system 40. The audio device 42 may be the same audio device depicted in Figure 4 and may comprise the processor 44 and the memory 46. An audio signal provided by the audio device 42 is received by a Digital to Analogue Converter (DAC) 62. An amplifier 64 may amplify the audio signal in an output gain stage before the audio is output by a transducer 14a, 14b. Electrodes 12a, 12b detect an electrical signal generated by the particular individual which is then amplified by the amplifier 66 in an input gain stage. The amplified signal may be received by an Analogue to Digital Converter (ADC) 68 before being received by the audio device 42. A reference signal from a reference electrode may be a ground, a virtual ground or a Driven Right Leg (DRL) signal. The amplifiers 64, 66, the DAC 62 and the ADC 68 may be located within the system 40 of Figure 4. For example, these features may be located in the headphone earpieces 10a, 10b, in the interface 24, in the housing 38, in the headband 34, or in the audio device 42 itself, or in any combination thereof. The amplifier 66 is a differential amplifier for amplifying a difference in signal levels between pairs of electrodes selected from the electrode 12a, 12b, 22. In other embodiments the amplifier may not be a differential amplifier.

As mentioned, the system 40 measures electrical signals generated as a result of an auditory stimulus. The auditory stimulus can be generated by audio device 42. The stimulus may be generated by an electroacoustic transducer 14a, 14b. The electrical waveform which drives the transducer 14a, 14b may be generated digitally, either from a stored waveform or computed at the time, and then converted into an analogue voltage or current with the digital to analogue converter 62.

The system records the voltage measured between one (or more) pairs of electrodes 12a, 12b, 22; 112a, 112b, 32. In order to achieve the most usable design, focus on a particular type of measurement, or balance electrode impedance, the device may use alternative pairs of electrodes, e.g. left ear to right ear (first and second electrodes) as well as either of the ear electrodes with a third electrode.

In system 20, 30, 40, the signals (e.g. voltages) to be measured may be small, so steps may be taken to isolate the signals from noise at all points. This may be done by placing active buffering close to the electrode site, and by using differential pairs where possible. For example, buffers may be housed within the earpieces 10a, 10b, 110a, 110b. The system ground should be isolated from other grounds where possible, using techniques such as virtual grounds, isolation amplifiers or transformers, and using differential signalling. In one example there are no routes between ground in the analogue path and ground in the rest of the system. In addition to isolation from ground, the differential signal provides common mode rejection, which is essential in this application. Where common mode rejection is required, the channels for inverting and non-inverting signals shall be as balanced as possible, for example for signal traces and component values. The potential across the electrodes are preferably amplified by a differential amplifier 66 to maximise the signal to noise ratio of the analogue to digital converter 68. The initial gain is normally limited by common mode noise. That may be removed with an instrumentation amplifier. Interference which is out of the band of interest may be removed with a band pass filter (for example, a 30Hz-1.5kHz band pass filter), and residual common mode noise removed with a notch filter, for example configured to remove noise within the range of mains frequencies (50-60Hz, or harmonics thereof). If a satisfactory signal to noise ratio can be achieved at the analogue to digital converter 68, it may be preferable to perform this filtering in the digital domain for flexibility. If not, it may be performed in the analogue domain to allow additional gain to be used. For example, a satisfactory signal to noise ratio may be 10dB above the signal to noise ratio of the analogue to digital converter 68.

The electrical signals (e.g. voltages) recorded by the electrodes 12a, 12b, 112a, 112b may be generated as a result of, but not limited to, activity in the Cochlea, auditory brainstem, and cortex, producing recordings such as those used in Electrocochleography (ECochG), Auditory Brainstem Response (ABR) and Electroencephalography (EEG).

Due to the low electrical signal readings (e.g. voltages) which are being measured, and the relatively high level of noise, many recordings of the required response may be taken, to lower the noise level through methods such as averaging. For example, when the system is used outside a controlled environment noise control may be particularly important. During the course of a single test, the auditory stimulus may be repeated, and the response recorded for each repeat. The interval between repeats is determined through a combination of factors. The higher the rate, the more averages may be made in a certain time period, or the total recording time reduced. The interval between repeats should be uncorrelated with periodic interference, such as that from mains electricity. The noise profile may be automatically analysed by the system, for example by examining the frequency domain of a representative recording, preferably for long as possible. This may allow the stimulus interval to be unsynchronised with periodic noise. It can also allow the removal of periodic noise, by filtering to remove periodic components present when there is no stimulus. This may also be performed using an adaptive filter using standard methods. The interval of the stimulus may also be varied randomly or pseudo-randomly to avoid synchronisation with interferers. If the interval is too short, the stimulus may overlap the recording, or the response may be altered due to the behaviour of the auditory system.

Taking multiple recordings also allows large signals such as movements, or other spurious signals to be compensated for. It may be beneficial to stop these signals causing a significant contribution to the result. This may be through methods such as thresholding, or Bayesian weighting. The method of averaging can also be used to discard outlying results, for example using median averaging instead of, or in combination with the mean.

As mentioned, signals could also be obtained without auditory stimulus, to characterise the background noise level. This can be used to determine if an acceptable signal to noise ratio is achieved when a stimulus is present.

To extract information from the results, several techniques are possible. Traditionally, expert manual identification of the characteristic waveforms has been used. This typically requires several output waveforms (to show consistency), at a range of amplitudes (to show characteristic behaviour). Latency, amplitude and ratios can be compared to a normal range. The system can be used to produce waveforms suitable for this purpose, and as such may be useful for visiting audiologists, or other trained medical professionals requiring a low cost, easy to use device. The system may also be configured to automatically classify the waveforms in terms of particular features.

Approximate objective measures are possible with the systems described. A threshold may be employed, using a ratio comparing some measure of recordings after stimulus and stimulus free signals, e.g. using root mean square amplitude or power. Specific waves of interest could be targeted, from their expected latency after the stimulus, using a windowing function. Using stimulus with different frequency content and amplitude, a basic threshold determination may be made. When the ratio of signal, or processed signal with and without stimulus present, reliably exceeds a specific value, an objective threshold for that frequency and amplitude may be recorded.

Signals with a higher latency than the ABR may depend on the user's level of consciousness and brain activity. Due to this, while they may not be particularly useful for detecting subtle physical changes from differences in the waveforms over time, they can identify how alert or relaxed a user is, and hence weight the averaging process accordingly. Better recordings are normally obtained when a subject is relaxed. It may be useful for a subject's hearing to professionally assessed as a baseline before commencing regular recording with the system.

The characteristics of the transducer and its coupling to the subject can affect the recorded electrical signal (waveform). These may include, but are not limited to, received sound pressure level, frequency response, and impulse response. To produce consistent results across different units, the transducers may be calibrated. The calibration may be with an appropriate coupler, head simulator, or if the design allows, an ear canal microphone (not shown).

The data recorded by the device and the metrics it extracts can be stored on the device, and/or uploaded for further diagnostic or record keeping purposes.

Accordingly a system and method for recording and analysing the electrical characteristics in response to an auditory stimulus (for example AEPs) of a subject has been described. The system may be used by a user themselves, outside of a clinical environment and in absence of a trained audiologist. Such a system may be used to determine whether the hearing response of a subject has changed.

Although at least some aspects of the embodiments described herein with reference to the drawings comprise computer processes performed in processing systems or processors, the invention also extends to computer programs, particularly computer programs on or in a carrier, adapted for putting the invention into practice. The program may be in the form of non-transitory source code, object code, a code intermediate source and object code such as in partially compiled form, or in any other non-transitory form suitable for use in the implementation of processes according to the invention. The carrier may be any entity or device capable of carrying the program. For example, the carrier may comprise a storage medium, such as a solid-state drive (SSD) or other semiconductor-based RAM; a ROM, for example a CD ROM or a semiconductor ROM; a magnetic recording medium, for example a floppy disk or hard disk; optical memory devices in general; etc.

It will be understood that the processor or processing system or circuitry referred to herein may in practice be provided by a single chip or integrated circuit or plural chips or integrated circuits, optionally provided as a chipset, an application-specific integrated circuit (ASIC), field-programmable gate array (FPGA), digital signal processor (DSP), Graphics Processing Units (GPUs), etc. The chip or chips may comprise circuitry (as well as possibly firmware) for embodying at least one or more of a data processor or processors, a digital signal processor or processors, baseband circuitry and radio frequency circuitry, which are configurable so as to operate in accordance with the exemplary embodiments. In this regard, the exemplary embodiments may be implemented at least in part by computer software stored in (non-transitory) memory and executable by the processor, or by hardware, or by a combination of tangibly stored software and hardware (and tangibly stored firmware).

The above embodiments are to be understood as illustrative examples of the invention. Further embodiments of the invention are envisaged. It is to be understood that any feature described in relation to any one embodiment may be used alone, or in combination with other features described, and may also be used in combination with one or more features of any other of the embodiments, or any combination of any other of the embodiments. Furthermore, equivalents and modifications not described above may also be employed without departing from the scope of the invention, which is defined in the accompanying claims.

# CLAIMS

1. A system for determining a change in hearing response, the system comprising:

a processing system; and

a headphone system comprising an electrode and a transducer;

wherein the processing system is configured to carry out a method for determining a change in hearing response, comprising:

causing the transducer to output an auditory stimulus;

detecting a first electrical characteristic representing a particular individual's response to the auditory stimulus at a first time;

recording first data associated with the first electrical characteristic;

retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time;

comparing at least one feature of the first data with at least one feature of the second data; and

determining, based on the comparison, that there has been a change in hearing response.

2. A system according to claim 1, wherein the first data is a first waveform associated with the first electrical characteristic and the second data is a second waveform associated with the second electrical characteristic.

3. A system according to any claim 1 or claim 2, wherein:

the at least one feature of the first data is a first threshold of hearing;

the at least one feature of the second data is a second threshold of hearing; and

the determining, based on the comparison, that there has been a change in hearing response comprises determining that a difference between the first threshold and second threshold exceeds a predetermined value.

4. A system according to claim 1 or 2, wherein:

the comparing at least one feature of the first data to at least one feature of the second data comprises determining a ratio between at least a portion of the first data and at least a portion of the second data; and

the determining, based on the comparison that there has been a change in hearing response comprises determining whether the ratio exceeds a predetermined value.

5. A system according to claim 1 or 2, wherein:

the comparing at least one feature of the first data to at least one feature of the second data comprises comparing a first latency of a feature of the first data with a second latency of a feature of the second data; and

the determining, based on the comparison that there has been a change in hearing response comprises determining that a difference between the first latency and second latency exceeds a predetermined value.

6. A system according to any preceding claim, wherein the processing system is configured to:

repeat the step of detecting a first electrical characteristic representing a particular individual’s response to the auditory stimulus a plurality of times in a period of time; and

average the electric characteristics detected across the plurality of times to give the first data.

7. A system according to claim 6, wherein a time difference between a start time of consecutive repetitions of the detecting a first electrical characteristic is random or pseudo-random.

8. A system according to any preceding claim, wherein the processing system is configured to:

detect a background electrical characteristic when no auditory stimulus is provided to both ears of the particular individual; and record background data associated with the background electrical characteristic.

9. A system according to any preceding claim, comprising an indicator for indicating that there has been a change in hearing response; wherein the processing system is configured to provide an indication that there has been a change in hearing response using the indicator when it is determined that there has been a change in hearing response.

10. A system according to any preceding claim comprising a mobile phone, the mobile phone comprising the processing system.

11. A system according to any preceding claim, wherein electrode is a first electrode and the transducer is a first transducer, and wherein the headphone system further comprises a first earpiece, the first earpiece comprising the first electrode and the first transducer.

12. A system according to claim 11, wherein the headphone system further comprises a second earpiece comprising a second electrode and a second transducer, wherein causing the transducer to output the auditory stimulus comprises causing at least one of the first and second transducers to output the auditory stimulus.

13. A headphone system comprising:

a first earpiece comprising a first electrode and a first transducer; and

a second earpiece comprising a second electrode and a second transducer;

wherein at least one of the first and second transducers is configured to output an auditory stimulus, and wherein the first and second electrodes are configured to measure an electrical signal generated by a user as a result of the auditory stimulus.

14. A headphone system according to claim 13, wherein the first earpiece comprises a first pad and the second earpiece comprises a second pad, the first pad

comprising the first electrode and the second pad comprising the second electrode, and wherein the first pad is configured to be placed on or over a user's first ear in use and the right pad is configured to be placed on or over the user's second ear in use.

15. A headphone system according to claim 13, wherein the first earpiece comprises a first pad and the second earpiece comprises a second pad, and wherein the first electrode is located on the first pad and the second electrode is located on second pad, and wherein the left pad is configured to be placed on or over a user's first ear in use and the right pad is configured to be placed on or over the user's second ear in use.

16. A headphone system according to any one of claims 13-15, wherein the first and second electrodes are positioned to allow contact with the ear or a region surrounding the ear of the user, in use.

17. A headphone system according to any of claims 13-16, further comprising a third electrode.

18. A headphone system according to claim 17, wherein the third electrode is configured to be held by the user in use.

19. A headphone system according to claim 17 or 18, further comprising a headband joining the first earpiece to the second earpiece, wherein the headband comprises the third electrode.

20. A headphone system according to claim 19, wherein the third electrode comprises one or more protrusions configured to be in contact with a scalp of the user in use.

21. A headphone system according to any of claims 13-20, wherein the first and second electrodes comprise flexible and conductive material.

22. A computer-implemented method of determining a change in a hearing response of a particular individual, the method comprising:

providing an auditory stimulus to an ear of the particular individual;

detecting a first electrical characteristic representing the particular individual's response to the auditory stimulus at a first time;

recording first data associated with the first electrical characteristic;

retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time;

comparing at least one feature of the first data with at least one feature of the second data; and

determining, based on the comparing, that there has been a change in hearing response.

23. A method according to claim 22, wherein the first data is a first waveform associated with the first electrical characteristic and the second data is a second waveform associated with the second electrical characteristic.

24. A method according to any of claims 22 or 23, wherein:

the at least one feature of the first data is a first threshold of hearing;

the at least one feature of the second data is a second threshold of hearing; and

the determining, based on the comparing, that there has been a change in hearing response comprises determining that a difference between the first threshold and second threshold exceeds a predetermined value.

25. A method according to any of claims 22 or 23, wherein:

comparing at least one feature of the first data to at least one feature of the second data comprises determining a ratio between at least a portion of the first data and at least a portion of the second data; and

determining, based on the comparing that there has been a change in hearing response comprises determining whether the ratio exceeds a predetermined value.

26. A method according to any of claims 22 or 23, wherein:

comparing at least one feature of the first data to at least one feature of the second data comprises comparing a first latency of a feature of the first data with a second latency of a feature of the second data; and

determining, based on the comparing that there has been a change in hearing response comprises determining that a difference between the first latency and second latency exceeds a predetermined value.

27. A method according to any of claims 22-26, wherein the step of detecting a first electrical characteristic is repeated a plurality of times in a period of time and the first data is an average of the detected electrical characteristics across the plurality of times.

28. A method according to claim 27, wherein a time difference between a start time of consecutive repetitions of the detecting a first electrical characteristic is random or pseudo-random.

29. A method according to any of claims 22-28, comprising:

detecting a background electrical characteristic when no auditory stimulus is provided to both ears of the particular individual; and

recording background data associated with the background electrical characteristic.

30. A method according to any of claims 22-29, comprising:

providing an indication that there has been a change in hearing response.

31. A computer program comprising computer-readable instructions that, when executed by a processing system, instruct the processing system to perform the method according to any of claims 22-30.

32. A non-transitory computer readable storage medium including instructions for execution by a processor stored thereon, wherein the instructions, when executed by the processor, implement the method according to any of claims 22-30.

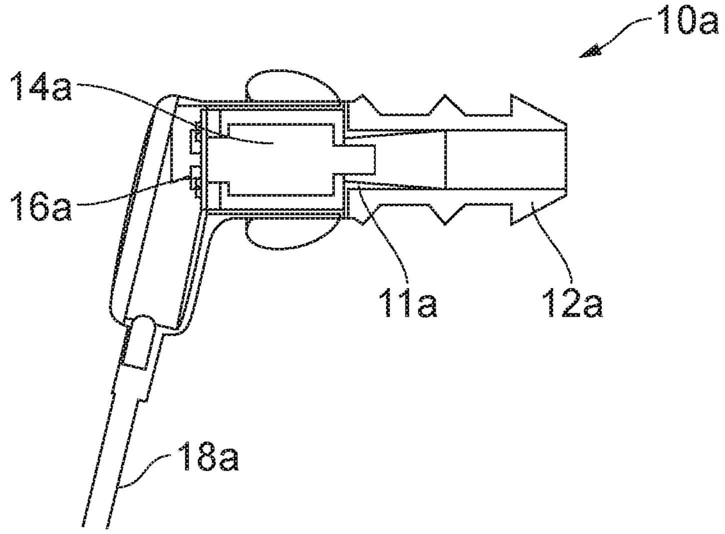


FIG. 1

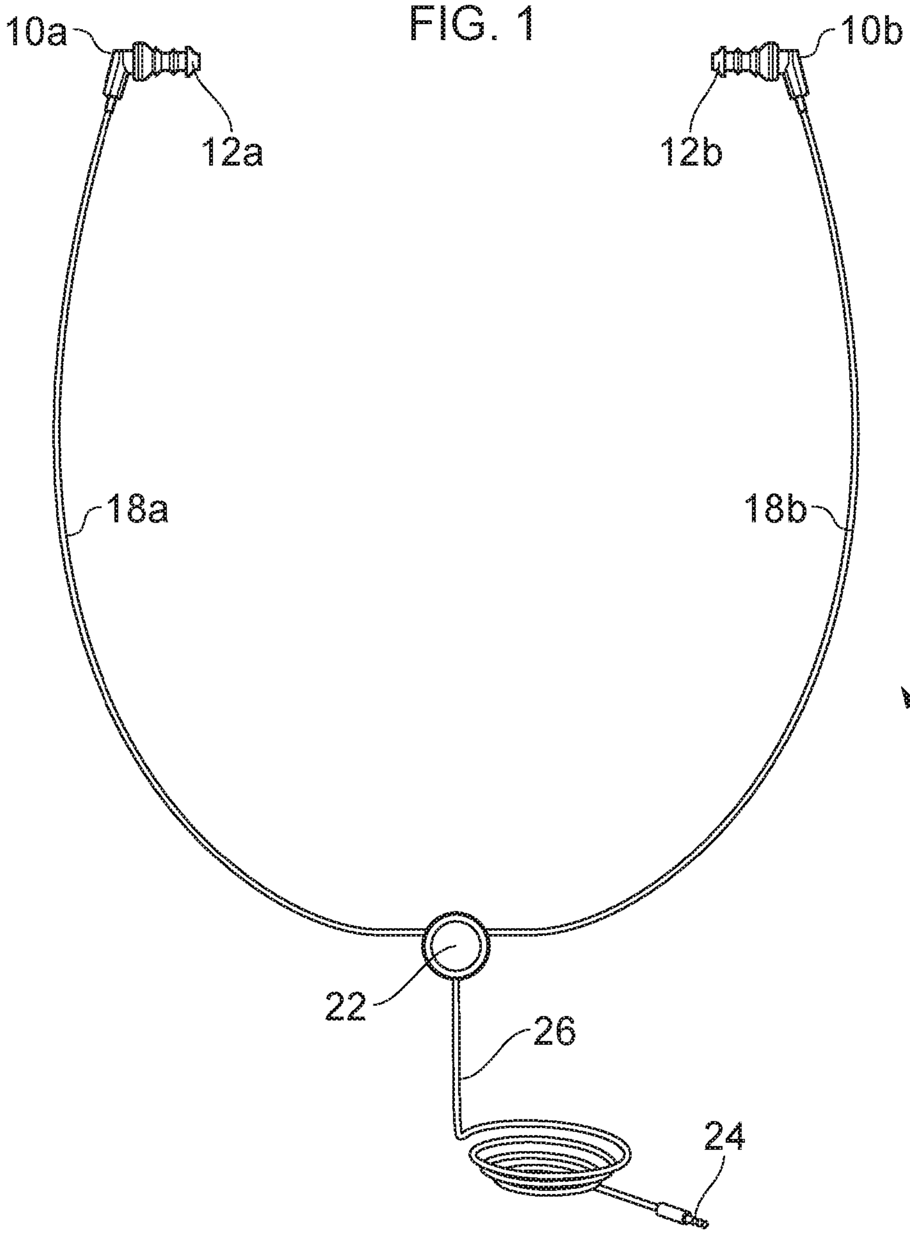


FIG. 2

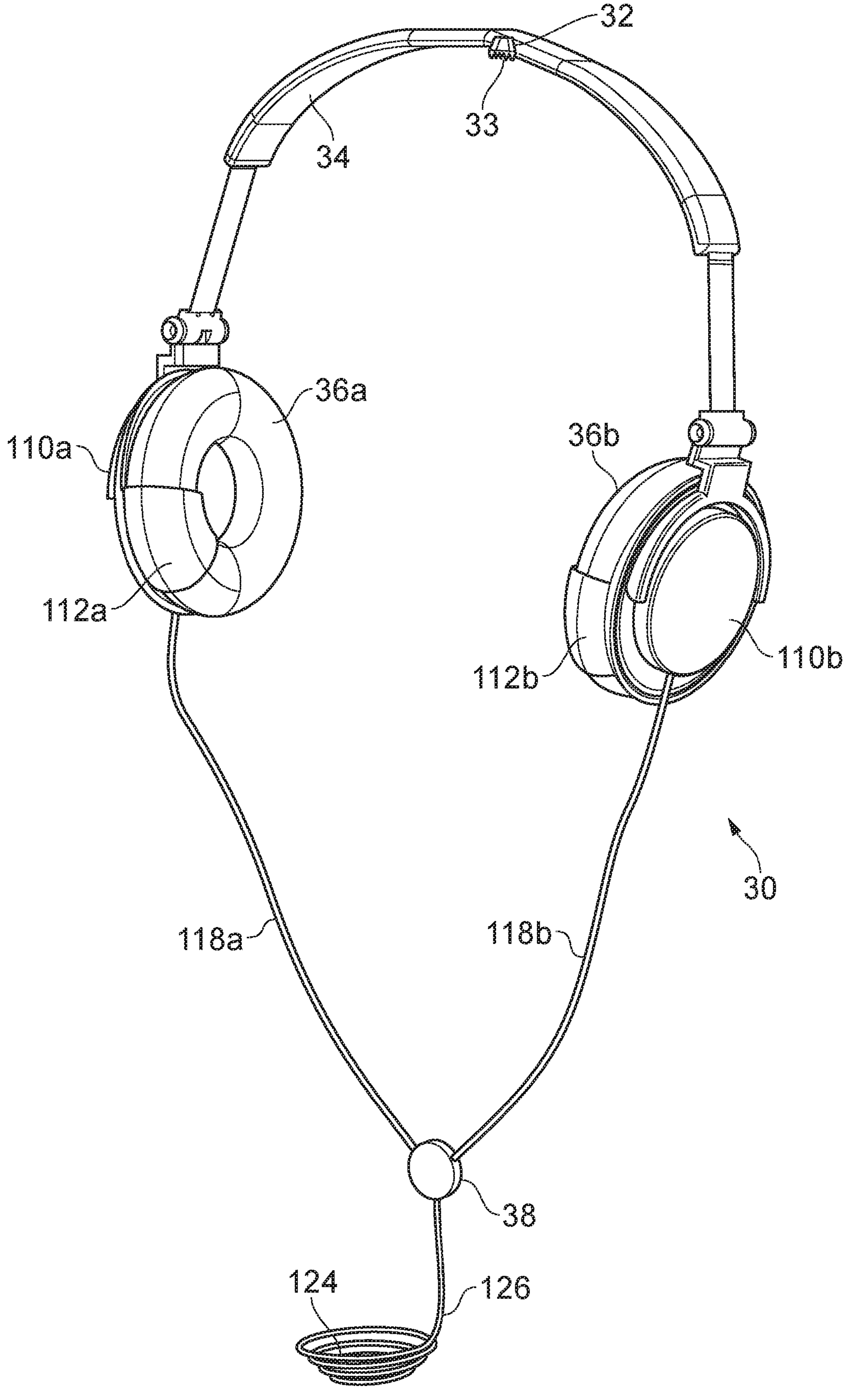


FIG. 3

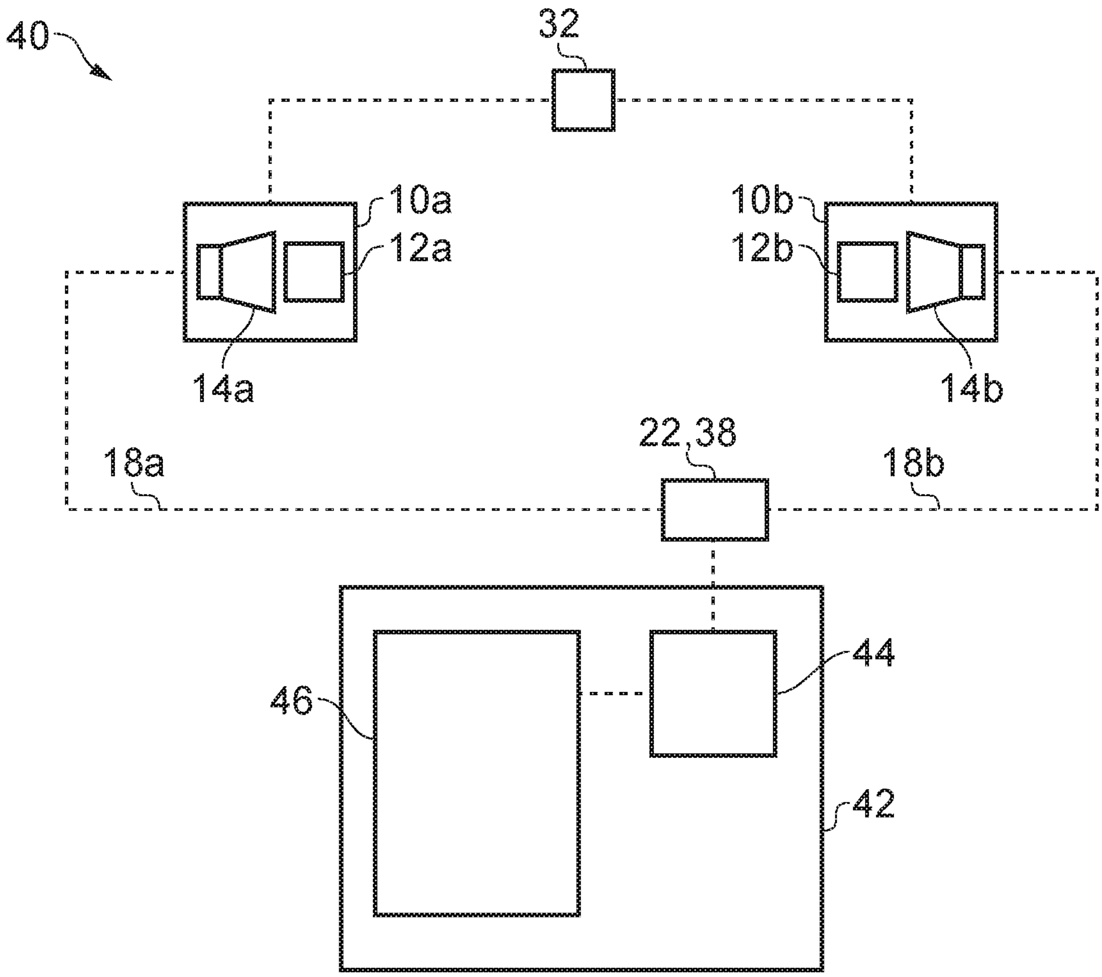


FIG. 4

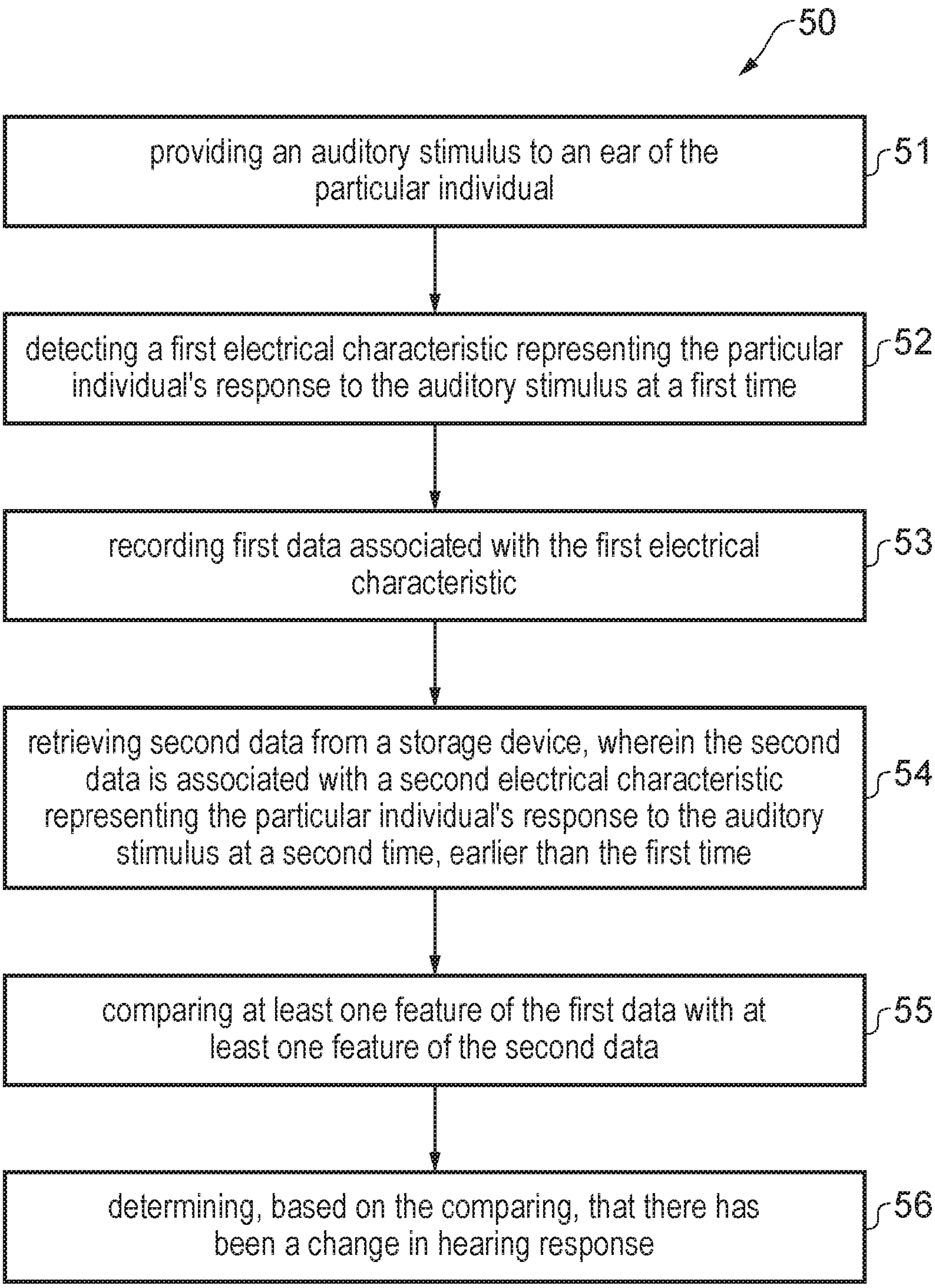
50
providing an auditory stimulus to an ear of the particular individual
51
detecting a first electrical characteristic representing the particular individual's response to the auditory stimulus at a first time
52
recording first data associated with the first electrical characteristic
53
retrieving second data from a storage device, wherein the second data is associated with a second electrical characteristic representing the particular individual's response to the auditory stimulus at a second time, earlier than the first time
54
comparing at least one feature of the first data with at least one feature of the second data
55
determining, based on the comparing, that there has been a change in hearing response
56

FIG. 5

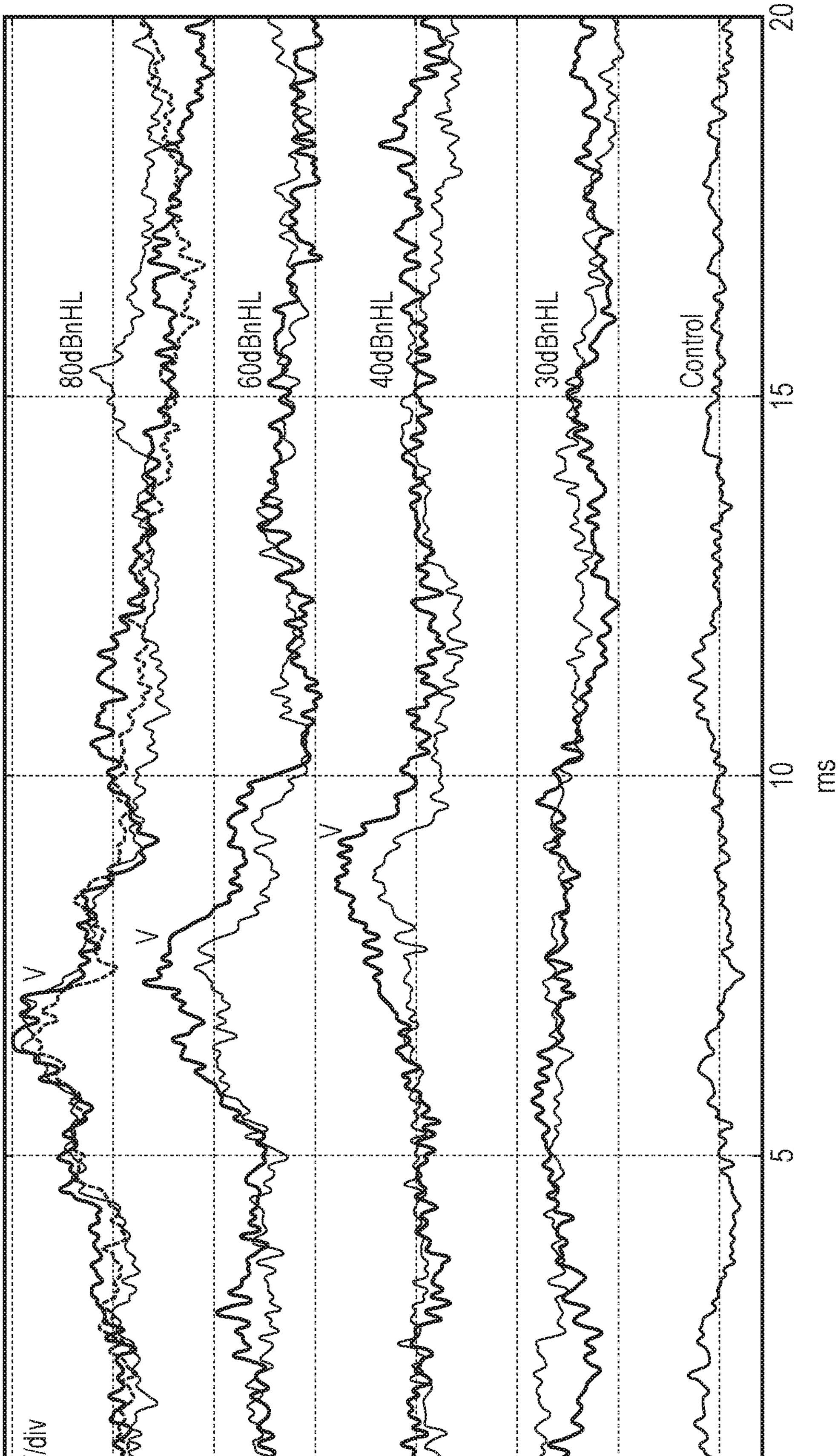
1uV/div
80dBnHL
60dBnHL
40dBnHL
30dBnHL
Control
V
V
V
5
10
15
20
ms

FIG. 6

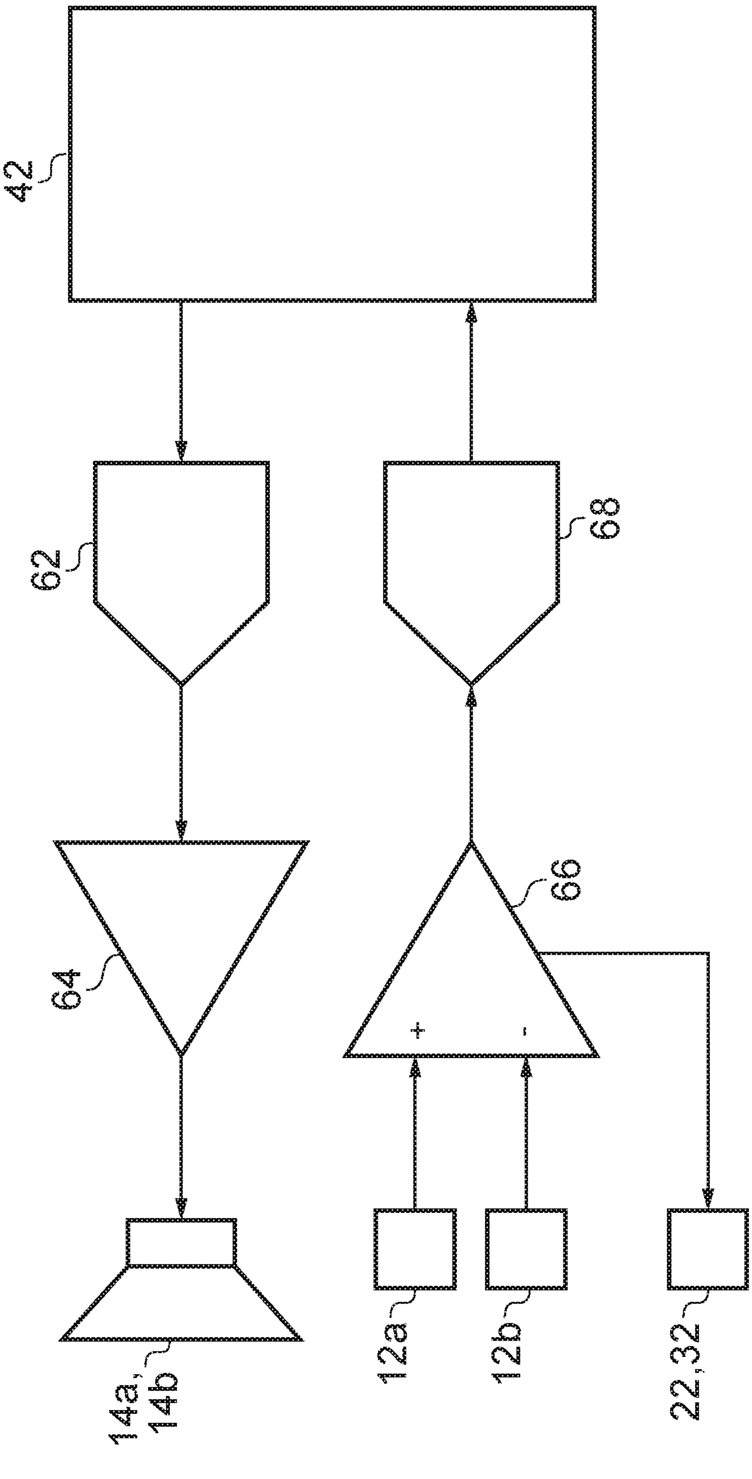


FIG. 7