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(54) Title: SYSTEM AND METHOD FOR SLEEP SESSION MANAGEMENT BASED ON SLOW WAVE SLEEP ACTIVITY IN A SUBJECT

(57) Abstract: The present disclosure pertains to a system
and method for managing a sleep session of a subject.
Managing the sleep session is based on slow wave activity
in the subject during the sleep session. Slow wave activity
is related to sleep pressure. Sleep pressure dissipates
and/or decreases as the subject sleeps. The dissipation dy-
namics depend on a given subject. The manner in which
dissipation occurs regulates the length of the given sleep
session and is linked to the temporal dynamics of slow
wave activity. The system is configured to determine a
metric indicating sleep pressure dissipation and, responsive
to the determined sleep pressure dissipation metric indicat-
ing that sleep pressure dissipation has reached a dissipation
threshold level during the sleep session, wake the subject.

METHOD
700

FIG. 7

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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).

System And Method For Sleep Session Management Based On Slow Wave
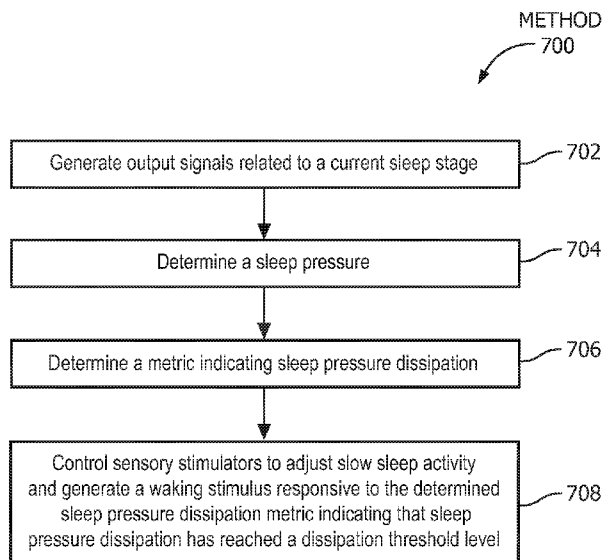Sleep Activity In A Subject

BACKGROUND

1. Field

[01]   The present disclosure pertains to a system and method for managing a sleep session of a subject. Managing the sleep session is based on slow wave activity in the subject prior to and/or during the sleep session.

2. Description of the Related Art

[02]   Systems for monitoring sleep are known. Sensory stimulation during sleep is known. Sensory stimulation during sleep is often applied continuously and/or at intervals that do not correspond to sleeping patterns of a subject. The present disclosure overcomes deficiencies in prior art systems.

SUMMARY

[03]   Accordingly, one or more aspects of the present disclosure relate to a system configured to manage a current sleep session of a subject. The system comprises one or more sensory stimulators, one or more sensors, and one or more processors. The one or more sensory stimulators are configured to provide sensory stimuli to the subject. The one or more sensors are configured to generate output signals conveying information related to a current sleep stage of the subject during the current sleep session. The one or more processors are configured to execute computer program modules. The computer program modules comprise a sleep parameter module, a sleep pressure dissipation module, and a control module. The sleep parameter module may be configured to determine one or more sleep parameters based on the output signals. The one or more parameters include a sleep pressure. The sleep pressure is related to slow wave activity in the subject prior to and/or during the current sleep session. The sleep pressure dissipation module is configured to determine a metric indicating sleep pressure dissipation in the

subject during the current sleep session. The metric is determined based on the sleep pressure determination. The control module is configured such that, responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, the control module controls the one or more sensory stimulators to generate a waking stimulus. The waking stimulus comprises sensory stimulation configured to wake the subject from sleep.

[04]   Yet another aspect of the present disclosure relates to a method for managing a current sleep session of a subject with a management system. The system comprises one or more sensory stimulators, one or more sensors, and one or more processors configured to execute computer program modules. The computer program modules comprise a sleep parameter module, a sleep pressure dissipation module, and a control module. The method comprises generating output signals conveying information related to a current sleep stage of the subject during the current sleep session with the one or more sensors; determining, with the sleep parameter module, one or more sleep parameters based on the output signals, the one or more parameters including a sleep pressure, the sleep pressure being related to slow wave activity in the subject during the current sleep session; determining, with the sleep pressure dissipation module, a metric indicating sleep pressure dissipation in the subject during the current sleep session, the metric determined based on the sleep pressure determination; and, responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, controlling, with the control module, the one or more sensory stimulators to generate a waking stimulus, wherein the waking stimulus comprises sensory stimulation configured to wake the subject from sleep.

[05]   Still another aspect of present disclosure relates to a system configured to manage a current sleep session of a subject. The system comprises means for providing sensory stimuli to the subject; means for generating output signals conveying information related to a current sleep stage of the subject during the current sleep session; means for determining one or more sleep parameters based on the output signals, the one or more

parameters including a sleep pressure, the sleep pressure being related to slow wave activity in the subject during the current sleep session; means for determining a metric indicating sleep pressure dissipation in the subject during the current sleep session, the metric determined based on the sleep pressure determination; and means for, responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, controlling the means for providing sensory stimuli to generate a waking stimulus, wherein the waking stimulus comprises sensory stimulation configured to wake the subject from sleep.

[06]   These and other objects, features, and characteristics of the present disclosure, as well as the methods of operation and functions of the related elements of structure and the combination of parts and economies of manufacture, will become more apparent upon consideration of the following description and the appended claims with reference to the accompanying drawings, all of which form a part of this specification, wherein like reference numerals designate corresponding parts in the various figures. It is to be expressly understood, however, that the drawings are for the purpose of illustration and description only and are not intended as a definition of the limits of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[07]   FIG. 1 is a schematic illustration of a system configured to manage a sleep session of a subject.

[08]   FIG. 2 illustrates a headset worn by a subject and includes sensing electrodes, a bio-signal amplifier, and a wireless audio device.

[09]   FIG. 3 illustrates slow wave activity, a hypnogram showing REM sleep periods and slow wave sleep periods, and sleep pressure as a function of time during a sleep session.

[10]   FIG. 4 illustrates slow wave activity and sleep pressure as a function of time during a sleep session.

[11]   FIG. 5 illustrates a hypnogram and sleep pressure as a function of time during a sleep session.

[12]   FIG. 6 illustrates an example of a relationship between increased and/or decreased slow wave activity and sleep time for a given subject.

[13]   FIG. 7 illustrates a method for managing a sleep session of a subject.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[14]   As used herein, the singular form of "a", "an", and "the" include plural references unless the context clearly dictates otherwise. As used herein, the statement that two or more parts or components are "coupled" shall mean that the parts are joined or operate together either directly or indirectly, i.e., through one or more intermediate parts or components, so long as a link occurs. As used herein, "directly coupled" means that two elements are directly in contact with each other. As used herein, "fixedly coupled" or "fixed" means that two components are coupled so as to move as one while maintaining a constant orientation relative to each other.

[15]   As used herein, the word "unitary" means a component is created as a single piece or unit. That is, a component that includes pieces that are created separately and then coupled together as a unit is not a "unitary" component or body. As employed herein, the statement that two or more parts or components "engage" one another shall mean that the parts exert a force against one another either directly or through one or more intermediate parts or components. As employed herein, the term "number" shall mean one or an integer greater than one (i.e., a plurality).

[16]   Directional phrases used herein, such as, for example and without limitation, top, bottom, left, right, upper, lower, front, back, and derivatives thereof, relate to the orientation of the elements shown in the drawings and are not limiting upon the claims unless expressly recited therein.

[17]   FIG. 1 is a schematic illustration of a system 10 configured to manage a current sleep session of a subject 12. Most people acknowledge the importance of sleep but many people do not get a healthy amount of sleep. The aspiration for healthier sleep

is balanced against demands on time. System 10 manages the current sleep session based
on slow wave activity (SWA) in subject 12 during the current sleep session. SWA
corresponds to the power of the EEG signal in the 0.5-4.5 Hz band. In some
embodiments, this band is set to 0.5-4 Hz. SWA has a typical behavior throughout cyclic
variations of a given sleep session. SWA increases during non-rapid eye movement sleep
(NREM), declines before the onset of rapid-eye-movement (REM) sleep, and remains
low during REM. SWA in successive NREM episodes progressively decreases from one
episode to the next. SWA may be estimated from an electroencephalogram (EEG) for
subject 12 during a given sleep session.

[18]   SWA is related to sleep pressure. Sleep pressure may be thought of as a
need for sleep in a given subject. The higher the SWA is, the higher the need for sleep is.
The decrease in SWA throughout a sleep episode reflects the dissipation of sleep need.
Sleep pressure dissipates and/or decreases as subject 12 sleeps. The dissipation dynamics
depend on the given subject. The manner in which dissipation occurs regulates the length
of a given sleep session and is linked to the temporal dynamics of SWA. System 10 is
configured to determine a metric indicating sleep pressure dissipation and, responsive to
the determined sleep pressure dissipation metric indicating that sleep pressure dissipation
has reached a dissipation threshold level during the current sleep session, wake subject
12.

[19]   In some embodiments, system 10 may comprise one or more of a sensory
stimulator 16, a sensor 18, a processor 20, electronic storage 22, a user interface 24,
and/or other components. In FIG. 1, sensory stimulator 16, sensor 18, processor 20,
electronic storage 22, and user interface 24 are shown as separate entities. This is not
intended to be limiting. Some and/or all of the components of system 10 and/or other
components may be grouped into one or more singular devices. For example, FIG. 2
illustrates a headset 200 worn by a subject 202 and includes sensing electrodes 204, a bio-
signal amplifier 206, and a wireless audio device 208. Sensing electrodes 204 and bio-
signal amplifier 206 may be represented, for example, by sensor 18 in FIG. 1. Wireless

audio device 208 may be represented, for example, by sensory stimulator 16 shown in FIG.1.

[20]   Returning to FIG. 1, sensory stimulator 16 is configured to provide sensory stimuli to subject 12. Sensory stimulator 16 is configured to provide sensory stimulation to subject 12 prior to the current sleep session, during the current sleep session, and/or at other times. For example, sensory stimulator 16 may be configured to provide sensory stimuli to subject 12 during slow wave sleep in the current sleep session. Sensory stimulator 16 may be configured to provide sensory stimulation to subject 12 during the current sleep session to induce and/or adjust SWA in subject 12. In some embodiments, sensory stimulator 16 may be configured such that adjusting includes increasing, decreasing, and/or other adjustment of SWA in subject 12.

[21]   In some embodiments, sensory stimulator 16 may be configured to induce and/or adjust SWA through non-invasive brain stimulation and/or other methods. Sensory stimulator 16 may be configured to induce and/or adjust SWA through non-invasive brain stimulation using sensory stimuli. The sensory stimuli include odors, sounds, visual stimulation, touches, tastes, and/or other stimuli. For example, transcranial magnetic stimulation may be applied to subject 12 to trigger, increase, and/or decrease SWA. As another example, sensory stimulator 16 may be configured to induce and/or adjust SWA via auditory stimulation of subject 12. Examples of sensory stimulator 16 may include one or more of a music player, a tone generator, a collection of electrodes on the scalp of subject 12, a unit to deliver vibratory stimulation (also known as somato-sensory stimulation), a coil generating a magnetic field to directly stimulate the brain's cortex, light generators, a fragrance dispenser, and/or other devices.

[22]   In some embodiments, sensory stimulator 16 is configured to generate a waking stimulus. The waking stimulus includes sensory stimulation configured to wake subject 12 from sleep. For example, sensory stimulator 16 may generate an auditory alarm to wake subject 12. As another example, sensory stimulator 16 may increase an ambient lighting level to wake subject 12.

[23]   Sensor 18 is configured to generate output signals conveying information related to a current sleep stage of subject 12. The current sleep stage of subject 12 may correspond to one or more of non-rapid eye movement (NREM) stage N1, stage N2, or stage N3 sleep, and/or rapid eye movement (REM) sleep. In some embodiments, NREM stage 3 or stage 2 sleep may be slow wave sleep. Sensor 18 may comprise one or more sensors that measure such parameters directly. For example, sensor 18 may include electrodes configured to detect electrical activity along the scalp of subject 12 resulting from current flows within the brain of subject 12. Sensor 18 may comprise one or more sensors that generate output signals conveying information related to a current sleep stage of the subject indirectly. For example, one or more sensors 18 may generate an output based on a heart rate of subject 12 (e.g., sensor 18 may be a heart rate sensor located on the chest of subject 12, and/or be configured as a bracelet on a wrist of subject 12, and/or be located on another limb of subject 12), movement of subject 12 (e.g., sensor 18 may include a bracelet around the wrist and/or ankle of subject 12 with an accelerometer such that sleep may be analyzed using actigraphy signals), respiration of subject 12, and/or other characteristics of subject 12. Although sensor 18 is illustrated at a single location in communication with subject 12, this is not intended to be limiting. Sensor 18 may include sensors disposed in a plurality of locations, such as for example, within (or in communication with) sensory stimulator 16, and/or in other locations.

[24]   Processor 20 is configured to provide information processing capabilities in system 10. As such, processor 20 may comprise one or more of a digital processor, an analog processor, and a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information. Although processor 20 is shown in FIG. 1 as a single entity, this is for illustrative purposes only. In some implementations, processor 20 may comprise a plurality of processing units. These processing units may be physically located within the same device (e.g., sensory stimulator 16), or processor 20 may represent processing functionality of a plurality of devices operating in coordination.

[25]   As shown in FIG. 1, processor 20 is configured to execute one or more computer program modules. The one or more computer program modules may comprise one or more of a sleep parameter module 30, a sleep pressure dissipation module 32, a control module 38, and/or other modules. Processor 20 may be configured to execute modules 30, 32, and/or 38 by software; hardware; firmware; some combination of software, hardware, and/or firmware; and/or other mechanisms for configuring processing capabilities on processor 20.

[26]   It should be appreciated that although modules 30, 32, and 38 are illustrated in FIG. 1 as being co-located within a single processing unit, in implementations in which processor 20 comprises multiple processing units, one or more of modules 30, 32, and/or 38 may be located remotely from the other modules. The description of the functionality provided by the different modules 30, 32, and/or 38 described below is for illustrative purposes, and is not intended to be limiting, as any of modules 30, 32, and/or 38 may provide more or less functionality than is described. For example, one or more of modules 30, 32, and/or 38 may be eliminated, and some or all of its functionality may be provided by other modules 30, 32, and/or 38. As another example, processor 20 may be configured to execute one or more additional modules that may perform some or all of the functionality attributed below to one of modules 30, 32, and/or 38.

[27]   Sleep parameter module 30 is configured to determine one or more sleep parameters based on the output signals from sensor 18. The one or more sleep parameters may include a sleep stage, a timing for delivery of sensory stimulation, a sleep pressure, the power in the slow activity band (0.5-4.5Hz) or other frequency bands, and/or other parameters. The sleep pressure is related to SWA in subject 12. Sleep parameter module 30 may identify SWA in subject 12 based on an analysis of the information conveyed by the output signals of sensor 18. The analysis may include generating and/or monitoring an EEG during a sleep session of subject 12. In some embodiments, SWA may be quantified by sleep parameter module 30 via the EEG spectral power in the 0.5–4.5 Hz frequency range, for example. Sleep parameter module 30 may determine the sleep

pressure based on the SWA. In some embodiments, sleep parameter module 30 may be configured to generate a hypnogram based on the determined parameters. The EEG and/or the hypnogram may be displayed, for example, by user interface 24.

[28]   In some embodiments, sleep parameter module 30 may be configured to identify sleep stages (e.g., N1, N2, N3) while subject 12 is sleeping. In some embodiments, sleep parameter module 30 may determine a timing for delivery of sensory stimulation. In some embodiments, the timing for delivery of sensory stimulation may correspond to sleep stages associated with slow wave activity (e.g., N2, N3). For example, sleep parameter module 30 may be configured to determine a timing for delivery of sensory stimulation such that the determined timing corresponds to sleep stages N2 and N3 while subject 12 is sleeping. Sleep parameter module 30 may be configured to determine a timing for delivery of sensory stimulation such that the determined timing corresponds to sleep stages associated with slow wave activity because the likelihood for slow-wave induction, and/or adjustment during the specific sleep stage may be comparatively higher than in other sleep stages, the user may be less likely to be awakened by the sensory stimuli, and/or for other reasons.

[29]   Sleep pressure dissipation module 32 is configured to determine the metric indicating sleep pressure dissipation in subject 12 during the current sleep session. The metric is determined based on the sleep pressure determination, and/or other information. In some implementations, the metric may be related to the sleep pressure dissipation (e.g., a derivative of the sleep pressure dissipation and/or a final sleep pressure). In some embodiments, the metric may be the sleep pressure dissipation. In some embodiments, sleep pressure dissipation module 32 is configured to determine the sleep pressure dissipation metric based on a model that characterizes the relation between the SWA and the sleep pressure (S) in subject 12. In some embodiments, the model may include equations (1) and (2) shown below.

$$\frac{dS(t)}{dt} = -g_c SWA(t) \tag{1}$$

$$\frac{dSWA(t)}{dt} = r_c \cdot SWA(t) \cdot \left(1 - \frac{SWA(t)}{S(t)}\right) - f_c \cdot SWA(t) \cdot REMT(t) \tag{2}$$

The instantaneous rate of decrease is sleep pressure (dS(t)/dt) is related to SWA by a proportionality constant g_c. The instantaneous rate of change in SWA (dSWA(t)/dt) is, in turn, related to the current value of the sleep pressure (S(t)) and SWA (SWA(t)) as defined in equation (2), where r_c is a SWA-rise constant, f_c is a SWA-fall constant, and REMT(t) is a function related to SWA. In some embodiments, the model that characterizes the relation between the SWA and the sleep pressure may be determined based on previous sleep sessions of subject 12, based on information received via user interface 24, and/or based on other information. In some embodiments, the model may be programmed at manufacture.

[30]   For example, FIG. 3 illustrates SWA 300, a hypnogram 302 showing REM sleep periods 304 and slow wave sleep periods 306, and sleep pressure as a function of time, S(t) 308, during a sleep session. Sleep pressure as a function of time 308 may be determined, for example, according to the model described above by equations 1 and 2. An initial sleep pressure, S_o 310, and a final sleep pressure S_f 312, are also shown in FIG. 3. Sleep pressure as a function of time, S(t) 308, decreases from initial sleep pressure 310 to final sleep pressure 312 during the sleep session. FIG. 3 illustrates that sleep pressure as a function of time 308 decreases faster during periods of SWA 300 and/or slow wave sleep 306.

[31]   Returning to FIG. 1, the description of the model presented herein is not intended to be limiting. The model that characterizes the relation between the SWA and the sleep pressure may include any model configured to establish a relationship between the SWA and the sleep pressure.

[32]   Control module 38 is configured to, responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, control sensory stimulator 16 to generate the waking stimulus. In some embodiments, control module 38 may be configured such that the determined sleep pressure dissipation metric indicates that sleep pressure dissipation has reached the dissipation threshold level during the current sleep session when no further and/or substantial decline in the sleep pressure can be expected.

In some embodiments, control module 38 is configured to determine the dissipation threshold level based on information from one or more previous sleep sessions of subject 12, based on information from the current sleep session, and/or based on other information. In some embodiments, the dissipation threshold level may be considered to be reached as soon as the dissipation threshold level is attained and/or exceeded. In some embodiments, the dissipation threshold level may considered to be reached responsive to the dissipation threshold level being attained and/or exceeded for a predetermined period of time. In some embodiments, the dissipation threshold level may be considered to be reached responsive to an average (and/or other mathematical conglomerations) dissipation threshold level being attained or exceeded over a predetermined period of time. The examples above related to reaching the dissipation threshold level are not intended to be limiting. Reaching the dissipation threshold level may include any event that allows system 10 to function as described herein.

[33]   Information from one or more previous sleep sessions of subject 12 may include the SWA of subject 12 along with the corresponding hypnogram, and/or other information. Information from one or more previous sleep sessions of subject 12 may include typical values of sleep pressure at the beginning (e.g., S_o) and end (e.g., S_f) of a sleep session, information related to the decline of sleep pressure (e.g., $S(t)$) as a function of the SWA, and/or other information. For example, the sleep pressure dissipation metric may be a sleep pressure level at a given time during a sleep session. The dissipation threshold level may be an average value of the final sleep pressure level from two or more previous sleep sessions of subject 12, for example. In some implementations, control module 38 may be configured to determine the dissipation threshold level based on SWA and sleep pressure information from a population of users who correspond to subject 12. For example, age, gender, and/or other factors of users in the population may indicate that the users correspond to subject 12.

[34]   Information from the current sleep session may include the sleep pressure as a function of time, and/or other information. In some implementations, the sleep pressure dissipation metric may be the derivative of the sleep pressure as a function of

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time. The dissipation threshold level may be a value (e.g., a small negative number) of the derivative, for example. Control module 38 may determine that the sleep pressure dissipation metric has reached the dissipation threshold level during the current sleep session responsive to the derivative of the sleep pressure as a function of time reaching the dissipation threshold level.

[35]   For example, FIG. 4 illustrates SWA 400 and sleep pressure as a function of time, S(t) 408, during a sleep session. Sleep pressure as a function of time, S(t) 408, decreases from initial sleep pressure 410 to final sleep pressure 412 during the sleep session. FIG. 4 illustrates a sleep interruption point 414 where no further substantial decline in sleep pressure may be expected (e.g., sleep pressure as a function of time 408 is a flat or slightly negatively sloped line).

[36]   Returning to FIG. 1, in some embodiments, control module 38 is configured to control sensory stimulator 16 to adjust SWA in subject 12 during the current sleep session such that a sleep session duration meets a sleep session duration target. The sleep session duration may be the length of time subject 12 sleeps during a sleep session. Information related to the sleep session duration target may be received from subject 12 and/or other users via user interface 24, for example. The information related to the sleep session duration target may include a time of day, a length of time, and/or other information. Other users may include a doctor, a care-giver, and/or other users. Control module 38 may be configured to determine the sleep session duration target based on the received information related to the sleep session duration target, based on previous sleep sessions of subject 12, and/or based on other information. Control module 38 may be configured to control sensory stimulator 16 to adjust SWA in subject 12 during the current sleep session such that the sleep session duration meets the sleep session duration target based on the determined sleep session duration target, the determined sleep pressure dissipation metric, the dissipation threshold level, the information from one or more previous sleep sessions of subject 12, and/or other information.

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[37]   Adjusting SWA in subject 12 while subject 12 is asleep during the current
sleep session may include controlling sensory stimulator 16 to increase and/or decrease
SWA in subject 12 during sleep. In some embodiments, control module 38 is configured
such that controlling sensory stimulator 16 to increase SWA in subject 12 results in an
increase in the sleep pressure dissipation and controlling sensory stimulator 16 to
decrease slow wave activity in subject 12 results in a decrease in the sleep pressure
dissipation. In some embodiments, control module 38 is configured such that a timing for
delivery of sensory stimulation is the timing determined by sleep parameter module 30
that corresponds to the sleep stages associated with slow wave activity (e.g., N2, N3).

[38]   For example, FIG. 5 illustrates a hypnogram 500 and sleep pressure as a
function of time, S(t) 502. S(t) 502 may be determined based on equations (1) and (2)
described above, for example. SWA may be increased (e.g., a 5% increase) by the system
during periods 504 that correspond to stage N3 sleep. An adjusted sleep pressure as a
function of time S'(t) 506, decays faster than S(t) 502. In the example shown in FIG. 5,
faster decay of S'(t) 506 may indicate faster sleep pressure dissipation and a shorter time
until the sleep pressure dissipation metric reaches the dissipation threshold level.

[39]   Returning to FIG. 1, in some embodiments, control module 38 may cause
information related to sleep pressure as a function of time, the initial sleep pressure, the
final sleep pressure, SWA adjustments, and/or other information from one or more sleep
sessions of subject 12 to be stored in electronic storage 22. In some embodiments,
control module 38 may be configured to estimate a percentage increase and/or decrease in
SWA needed during a current sleep session such that the sleep session duration meets the
sleep session duration target. Control module 38 may be configured to estimate the
percentage based on sleep pressure as a function of time, the initial sleep pressure, the
final sleep pressure, SWA adjustments, and/or other information from the one or more
sleep sessions of subject 12. For example, control module 38 may be configured to
estimate a percentage increase and/or decrease in SWA needed to reach a given final
sleep pressure within a given sleep session duration based on the initial sleep pressure and

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sleep pressure dissipation as a function of time information from previous sleep sessions of subject 12.

[40]   FIG. 6 illustrates an example of a relationship 604 between increased and/or decreased SWA 600 and sleep time 602 for a given subject (e.g., subject 12). In the example shown in FIG. 6, the increase and/or decrease in SWA is relative to a baseline amount of SWA for the given subject determined based on previous sleep sessions of the given subject.

[41]   Returning to FIG. 1, control module 38 may control sensory stimulator 16 to provide the sensory stimulation during the current sleep session such that the sensory stimulation does not wake subject 12. For example, control module 38 may control sensory stimulator 16 to provide the sensory stimulation at a low intensity level. In some embodiments, control module 38 is configured to control sensory stimulator 16 to provide sensory stimulation to subject 12 to adjust slow wave activity in subject 12 in an upcoming sleep session while the subject is awake before the upcoming sleep session.

[42]   Electronic storage 22 comprises electronic storage media that electronically stores information. The electronic storage media of electronic storage 22 may comprise one or both of system storage that is provided integrally (i.e., substantially non-removable) with system 10 and/or removable storage that is removably connectable to system 10 via, for example, a port (e.g., a USB port, a firewire port, etc.) or a drive (e.g., a disk drive, etc.). Electronic storage 22 may comprise one or more of optically readable storage media (e.g., optical disks, etc.), magnetically readable storage media (e.g., magnetic tape, magnetic hard drive, floppy drive, etc.), electrical charge-based storage media (e.g., EPROM, RAM, etc.), solid-state storage media (e.g., flash drive, etc.), and/or other electronically readable storage media. Electronic storage 22 may store software algorithms, information determined by processor 20, information received from subject 12, and/or other information that enables system 10 to function properly. Electronic storage 22 may be (in whole or in part) a separate component within system 10, or electronic storage 22 may be provided (in whole or in part) integrally with one or more other components of system 10 (e.g., processor 20).

[43]   User interface 24 is configured to receive information related to a sleep session duration target for subject 12, and/or other information. User interface 24 is configured to provide an interface between system 10 and subject 12, and/or other users through which subject 12 and/or other users may provide information to and receive information from system 10. This enables data, cues, results, and/or instructions and any other communicable items, collectively referred to as "information," to be communicated between a user (e.g., subject 12) and one or more of sensory stimulator 16, sensor 18, processor 20, and/or other components of system 10. For example, an EEG may be displayed to a caregiver via user interface 24.

[44]   Examples of interface devices suitable for inclusion in user interface 24 comprise a keypad, buttons, switches, a keyboard, knobs, levers, a display screen, a touch screen, speakers, a microphone, an indicator light, an audible alarm, a printer, a tactile feedback device, and/or other interface devices. In some embodiments, user interface 24 comprises a plurality of separate interfaces. In some embodiments, user interface 24 comprises at least one interface that is provided integrally with sensory stimulator 16, sensory stimulator 16, and/or other components of system 10.

[45]   It is to be understood that other communication techniques, either hard-wired or wireless, are also contemplated by the present disclosure as user interface 24. For example, the present disclosure contemplates that user interface 24 may be integrated with a removable storage interface provided by electronic storage 22. In this example, information may be loaded into system 10 from removable storage (e.g., a smart card, a flash drive, a removable disk, etc.) that enables the user(s) to customize the implementation of system 10. Other exemplary input devices and techniques adapted for use with system 10 as user interface 24 comprise, but are not limited to, an RS-232 port, RF link, an IR link, modem (telephone, cable or other). In short, any technique for communicating information with system 10 is contemplated by the present disclosure as user interface 24.

[46]   FIG. 7 illustrates a method 700 for managing a current sleep session of a subject with a management system. The system comprises one or more sensory

stimulators, one or more sensors, and one or more processors configured to execute computer program modules. The computer program modules comprise a sleep parameter module, a sleep pressure dissipation module, and a control module. The operations of method 700 presented below are intended to be illustrative. In some embodiments, method 700 may be accomplished with one or more additional operations not described, and/or without one or more of the operations discussed. Additionally, the order in which the operations of method 700 are illustrated in FIG. 7 and described below is not intended to be limiting.

[47]   In some embodiments, method 700 may be implemented in one or more processing devices (e.g., a digital processor, an analog processor, a digital circuit designed to process information, an analog circuit designed to process information, a state machine, and/or other mechanisms for electronically processing information). The one or more processing devices may include one or more devices executing some or all of the operations of method 700 in response to instructions stored electronically on an electronic storage medium. The one or more processing devices may include one or more devices configured through hardware, firmware, and/or software to be specifically designed for execution of one or more of the operations of method 700.

[48]   At an operation 702, output signals conveying information related to a current sleep stage of the subject during the current sleep session are generated. In some embodiments, operation 702 is performed by one or more sensors the same as or similar to sensors 18 (shown in FIG. 1 and described herein).

[49]   At an operation 704, a sleep pressure is determined. In some embodiments, one or more sleep parameters are determined based on the output signals. The one or more parameters include the sleep pressure. The sleep pressure is related to slow wave activity in the subject during the current sleep session. In some embodiments, operation 704 is performed by a computer program module the same as or similar to sleep parameter module 30 (shown in FIG. 1 and described herein).

[50]   At an operation 706, a metric indicating sleep pressure dissipation is determined. The metric indicates sleep pressure dissipation in the subject during the

current sleep session. The metric is determined based on the sleep pressure determination. In some embodiments, operation 706 is performed by a computer program module the same as or similar to sleep pressure dissipation module 32 (shown in FIG. 1 and described herein).

[51]   At an operation 708, sensory stimulators are controlled to adjust slow wave activity in the subject and generate a waking stimulus responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level. The waking stimulus comprises sensory stimulation configured to wake the subject from sleep. The dissipation threshold level may be determined based on information from one or more previous sleep sessions of the subject, and/or other information.

[52]   In some embodiments, operation 708 may include receiving information related to a sleep session duration target for the subject via a user interface, providing sensory stimulation to the subject during the current sleep session to adjust slow wave activity in the subject, and controlling the one or more sensory stimulators to adjust slow wave activity in the subject such that a sleep session duration meets the sleep session duration target. The controlling is based on the sleep session duration target, the determined sleep pressure dissipation metric, and the dissipation threshold level. In some embodiments, controlling the one or more sensory stimulators to increase slow wave activity in the subject results in an increase in the sleep pressure dissipation metric and controlling the one or more sensory stimulators to decrease slow wave activity in the subject results in a decrease in the sleep pressure dissipation metric. In some embodiments, the one or more sensory stimulators are controlled to provide sensory stimulation to the subject to adjust slow wave activity in the subject while the subject is asleep during the current sleep session and/or while the subject is awake before the current sleep session such that the sleep session duration meets the sleep session duration target for the current sleep session.

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[53]   In some embodiments, operation 708 is performed by sensory stimulators and a computer program module the same as or similar to sensory stimulators 16 and control module 38 (shown in FIG. 1 and described herein).

[54]   In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" or "including" does not exclude the presence of elements or steps other than those listed in a claim. In a device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. In any device claim enumerating several means, several of these means may be embodied by one and the same item of hardware. The mere fact that certain elements are recited in mutually different dependent claims does not indicate that these elements cannot be used in combination.

[55]   Although the description provided above provides detail for the purpose of illustration based on what is currently considered to be the most practical and preferred embodiments, it is to be understood that such detail is solely for that purpose and that the disclosure is not limited to the expressly disclosed embodiments, but, on the contrary, is intended to cover modifications and equivalent arrangements that are within the spirit and scope of the appended claims. For example, it is to be understood that the present disclosure contemplates that, to the extent possible, one or more features of any embodiment can be combined with one or more features of any other embodiment.

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CLAIMS:

1. A system (10) configured to manage a current sleep session of a subject (12), the system comprising:

one or more sensory stimulators (16) configured to provide sensory stimuli to the subject;

one or more sensors (18) configured to generate output signals conveying information related to a current sleep stage of the subject during the current sleep session; and

one or more processors (20) configured to execute computer program modules, the computer program modules comprising:

a sleep parameter module (30) configured to determine one or more sleep parameters based on the output signals, the one or more parameters including a sleep pressure, the sleep pressure being related to slow wave activity in the subject during the current sleep session;

a sleep pressure dissipation module (32) configured to determine a metric indicating sleep pressure dissipation in the subject during the current sleep session, the metric determined based on the sleep pressure determination; and

a control module (38) configured to, responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, control the one or more sensory stimulators to generate a waking stimulus, wherein the waking stimulus comprises sensory stimulation configured to wake the subject from sleep.

2. The system of claim 1, wherein the control module is configured to determine the dissipation threshold level based on information from one or more previous sleep sessions of the subject.

3. The system of claim 1, further comprising a user interface (24) configured to receive information related to a sleep session duration target for the subject;

wherein the one or more sensory stimulators are configured to provide sensory stimulation to the subject during the current sleep session to adjust slow wave activity in the subject; and

wherein the control module is configured to control the one or more sensory stimulators to adjust slow wave activity in the subject such that a sleep session duration meets the sleep session duration target, the control module configured to control the one or more sensory stimulators based on the sleep session duration target, the determined sleep pressure dissipation metric, and the dissipation threshold level.

4. The system of claim 3, wherein the control module is configured such that controlling the one or more sensory stimulators to increase slow wave activity in the subject results in faster sleep pressure dissipation and an increase in the sleep pressure dissipation metric, and controlling the one or more sensory stimulators to decrease slow wave activity in the subject results in slower sleep pressure dissipation and a decrease in the sleep pressure dissipation metric.

5. The system of claim 3, wherein the control module is configured to control the one or more sensory stimulators to provide sensory stimulation to the subject to adjust slow wave activity in the subject while the subject is asleep during the current sleep session and/or while the subject is awake before the current sleep session such that the sleep session duration meets the sleep session duration target for the current sleep session.

6. A method for managing a current sleep session of a subject with a management system (10), the system comprising one or more sensory stimulators (16), one or more sensors (18), and one or more processors (20) configured to execute computer program modules, the computer program modules comprising a sleep parameter

module (30), a sleep pressure dissipation module (32), and a control module (38), the method comprising:

generating output signals conveying information related to a current sleep stage of the subject during the current sleep session with the one or more sensors;

determining, with the sleep parameter module, one or more sleep parameters based on the output signals, the one or more parameters including a sleep pressure, the sleep pressure being related to slow wave activity in the subject during the current sleep session;

determining, with the sleep pressure dissipation module, a metric indicating sleep pressure dissipation in the subject during the current sleep session, the metric determined based on the sleep pressure determination; and

responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, controlling, with the control module, the one or more sensory stimulators to generate a waking stimulus, wherein the waking stimulus comprises sensory stimulation configured to wake the subject from sleep.

7. The method of claim 6, further comprising determining, with the control module, the dissipation threshold level based on information from one or more previous sleep sessions of the subject.

8. The method of claim 6, further comprising receiving information related to a sleep session duration target for the subject via a user interface (24);

providing sensory stimulation to the subject with the one or more sensory stimulators during the current sleep session to adjust slow wave activity in the subject; and

controlling, with the control module, the one or more sensory stimulators to adjust slow wave activity in the subject such that a sleep session duration meets the

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sleep session duration target, the controlling based on the sleep session duration target, the determined sleep pressure dissipation metric, and the dissipation threshold level.

9. The method of claim 8, wherein controlling, with the control module, the one or more sensory stimulators to increase slow wave activity in the subject results in faster sleep pressure dissipation and an increase in the sleep pressure dissipation metric, and controlling the one or more sensory stimulators to decrease slow wave activity in the subject results in slower sleep pressure dissipation and a decrease in the sleep pressure dissipation metric.

10. The method of claim 8, further comprising controlling, with the control module, the one or more sensory stimulators to provide sensory stimulation to the subject to adjust slow wave activity in the subject while the subject is asleep during the current sleep session and/or while the subject is awake before the current sleep session such that the sleep session duration meets the sleep session duration target for the current sleep session.

11. A system (10) configured to manage a current sleep session of a subject (12), the system comprising:

means (16) for providing sensory stimuli to the subject;

means (18) for generating output signals conveying information related to a current sleep stage of the subject during the current sleep session;

means (30) for determining one or more sleep parameters based on the output signals, the one or more parameters including a sleep pressure, the sleep pressure being related to slow wave activity in the subject during the current sleep session;

means (32) for determining a metric indicating sleep pressure dissipation in the subject during the current sleep session, the metric determined based on the sleep pressure determination; and

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means (38) for, responsive to the determined sleep pressure dissipation metric indicating that sleep pressure dissipation has reached a dissipation threshold level during the current sleep session, controlling the means for providing sensory stimuli to generate a waking stimulus, wherein the waking stimulus comprises sensory stimulation configured to wake the subject from sleep.

12. The system of claim 11, wherein the means for controlling is configured to determine the dissipation threshold level based on information from one or more previous sleep sessions of the subject.

13. The system of claim 11, further comprising means (24) for receiving information related to a sleep session duration target for the subject;

wherein the means for providing sensory stimuli is configured to provide sensory stimulation to the subject during the current sleep session to adjust slow wave activity in the subject; and

wherein the means for controlling is configured to control the means for providing sensory stimuli to adjust slow wave activity in the subject such that a sleep session duration meets the sleep session duration target, the means for controlling configured to control the one or more sensory stimulators based on the sleep session duration target, the determined sleep pressure dissipation metric, and the dissipation threshold level.

14. The system of claim 13, wherein the means for controlling is configured such that controlling the means for providing sensory stimuli to increase slow wave activity in the subject results in faster sleep pressure dissipation and an increase in the sleep pressure dissipation metric, and controlling the means for providing sensory stimuli to decrease slow wave activity in the subject results in slower sleep pressure dissipation and a decrease in the sleep pressure dissipation metric.

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15. The system of claim 13, wherein the means for controlling is configured to control the means for providing sensory stimuli to provide sensory stimulation to the subject to adjust slow wave activity in the subject while the subject is asleep during the current sleep session and/or while the subject is awake before the current sleep session such that the sleep session duration meets the sleep session duration target for the current sleep session.
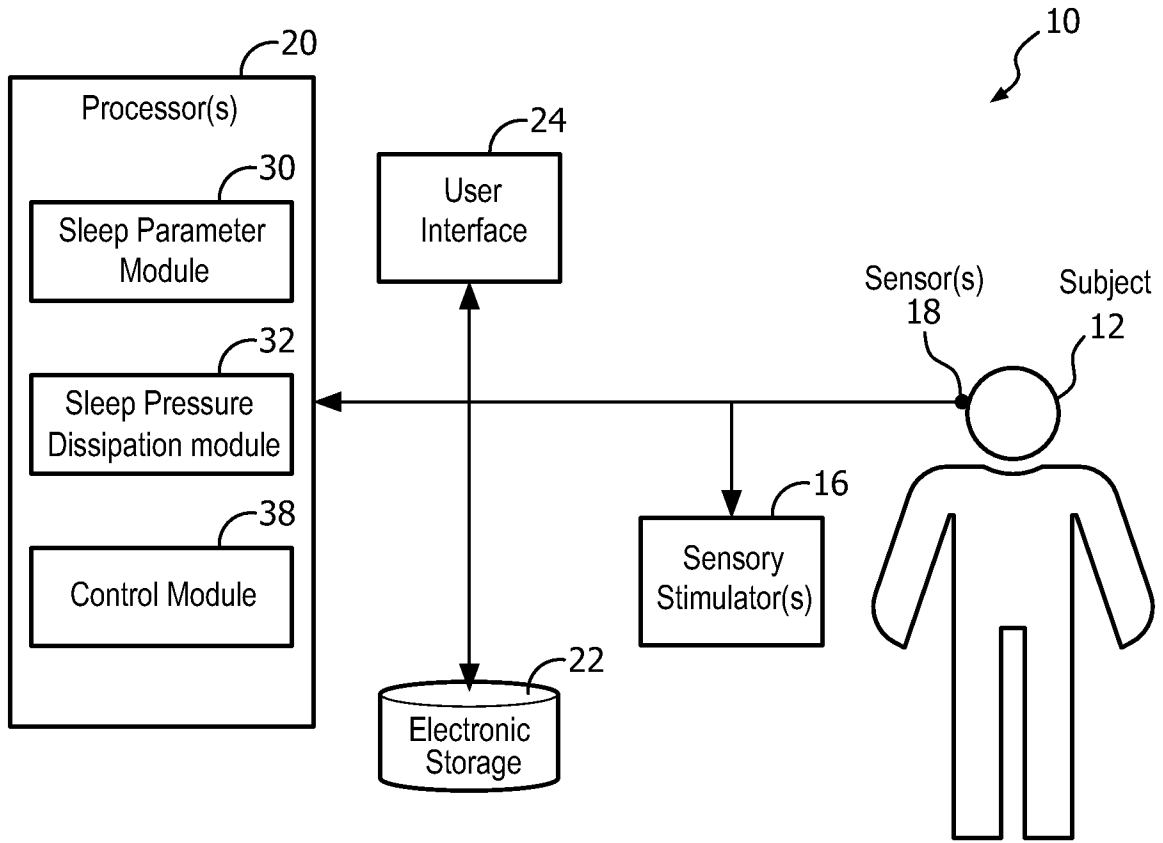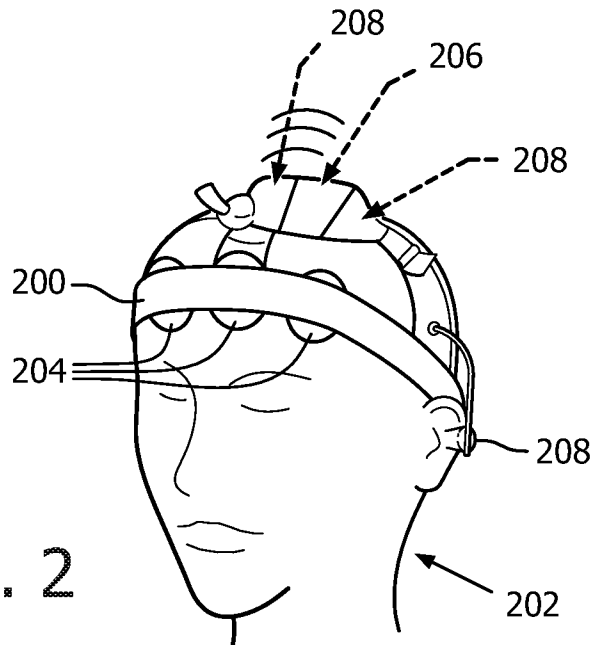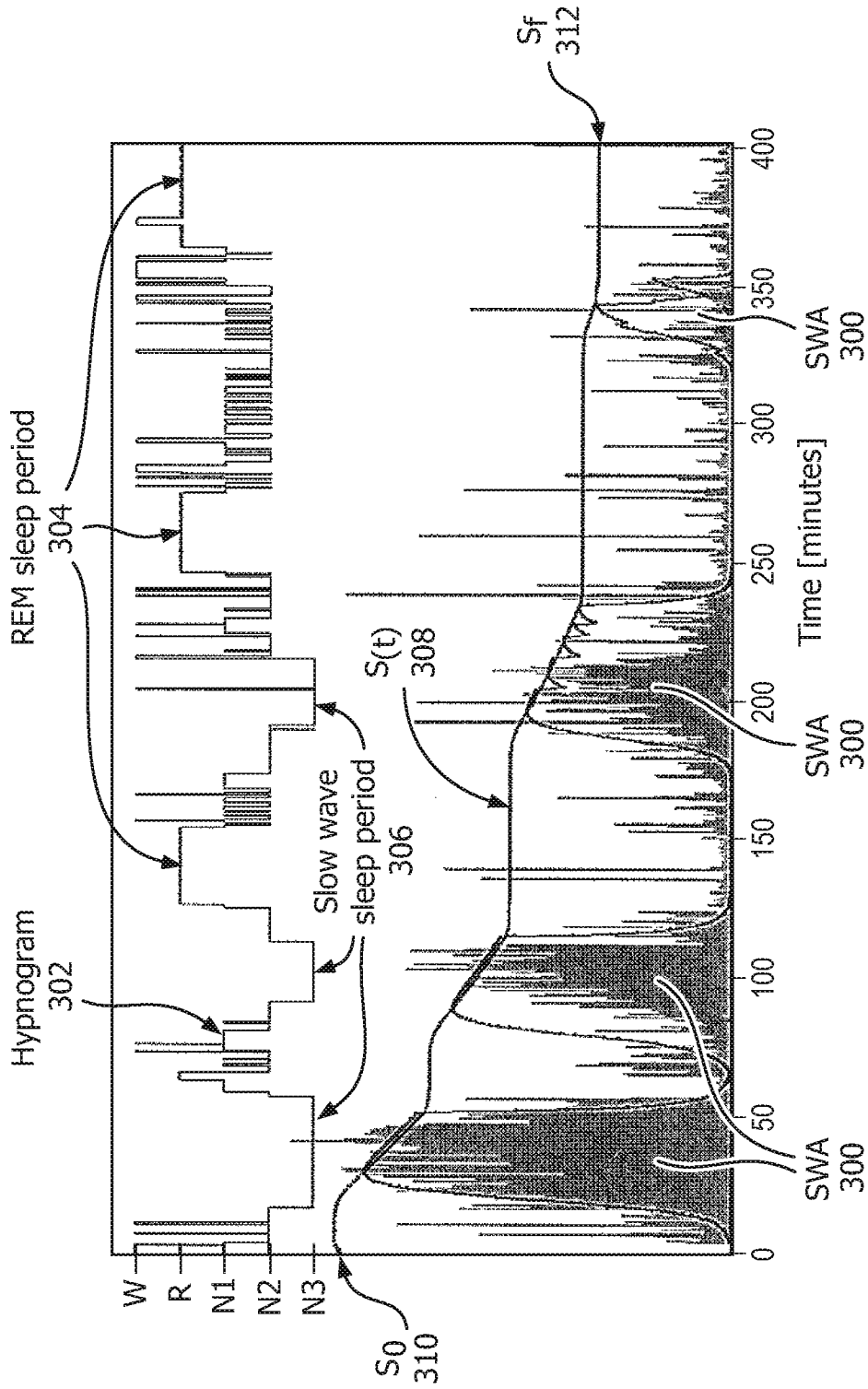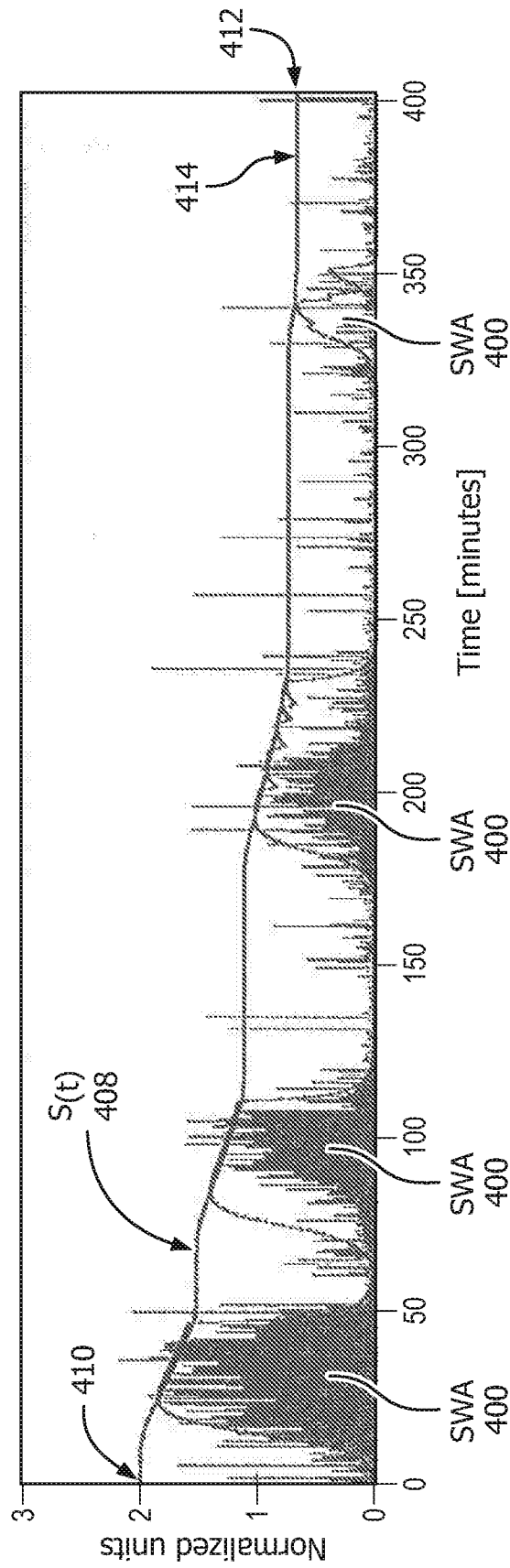
FIG. 1

FIG. 2

FIG. 3

FIG. 4
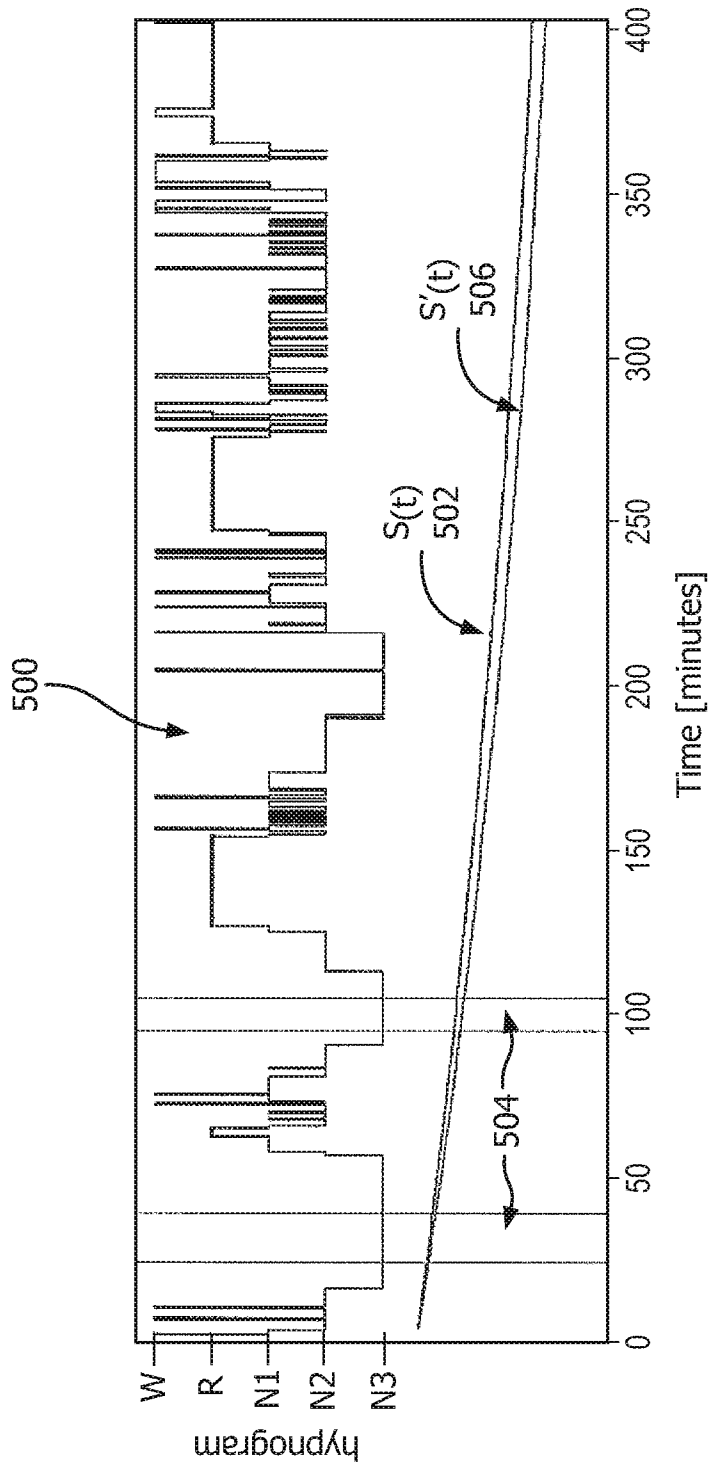
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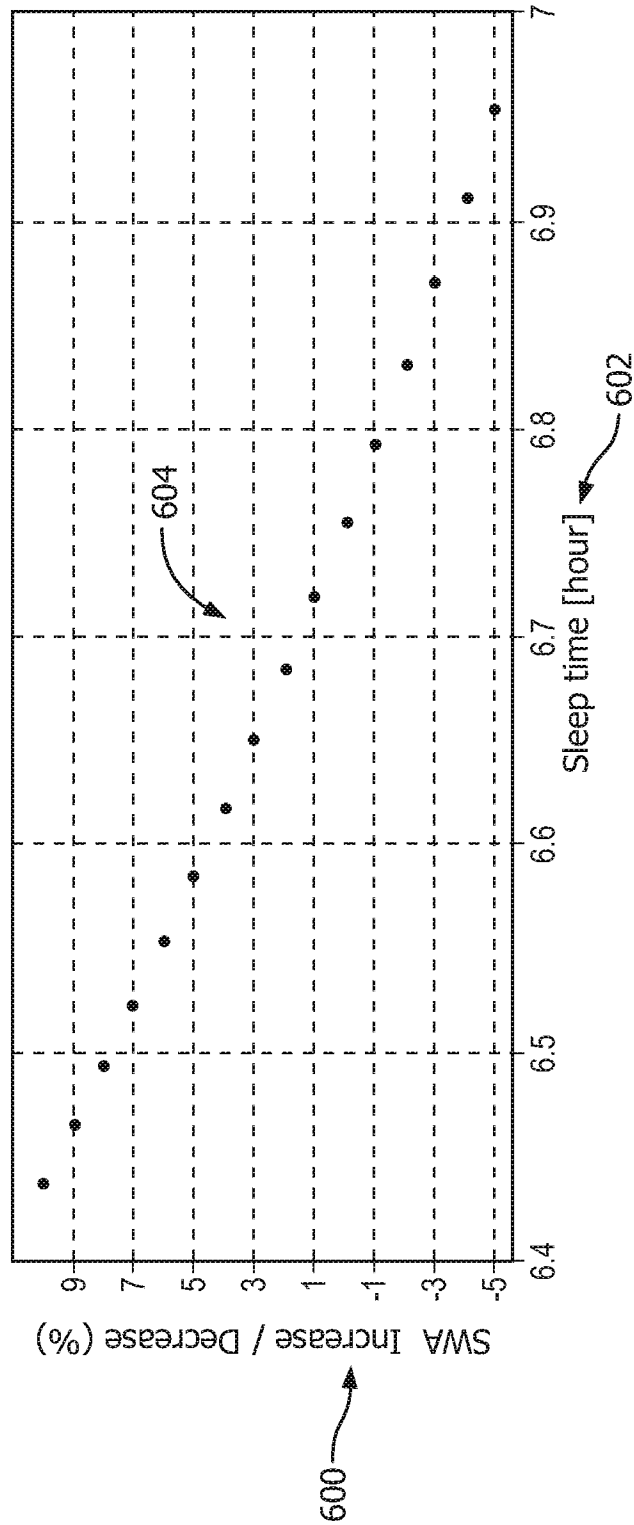
FIG. 6
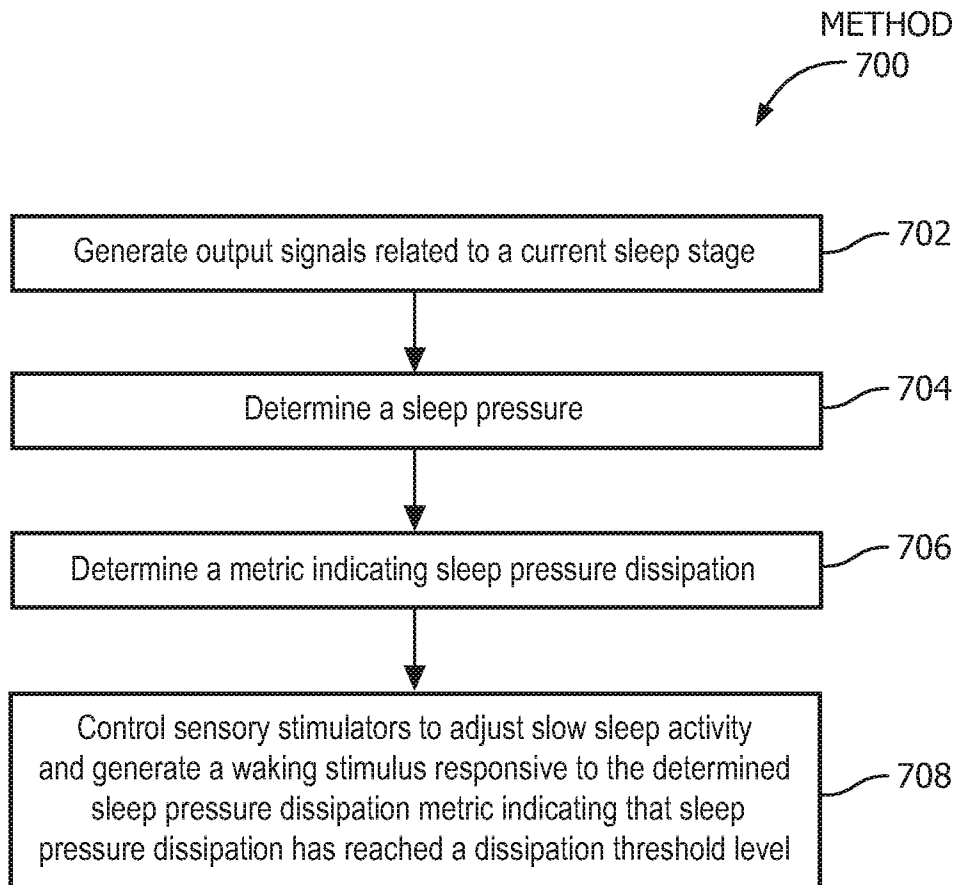
METHOD
700

Generate output signals related to a current sleep stage ———— 702

Determine a sleep pressure ———— 704

Determine a metric indicating sleep pressure dissipation ———— 706

Control sensory stimulators to adjust slow sleep activity
and generate a waking stimulus responsive to the determined
sleep pressure dissipation metric indicating that sleep
pressure dissipation has reached a dissipation threshold level ———— 708

FIG. 7

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

INV. A61B5/0476   A61B5/048   A61B5/00   A61M21/02   A61N1/04
     A61N1/05   A61N1/36
ADD. A61M21/00

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A61B A61M A61N

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008/234785 A1 (NAKAYAMA KANAKO [JP] ET AL) 25 September 2008 (2008-09-25) abstract; figures 1-2, 7-8, 11 paragraphs [0009] - [0010], [0032] - [0052], [0061] - [0066] paragraphs [0084], [0101] - [0103] -----	1-5, 11-15
X	US 2012/251989 A1 (WETMORE DANIEL Z [US] ET AL) 4 October 2012 (2012-10-04) abstract; figures 1-8 paragraphs [0013] - [0015], [0025] - [0028], [0050] - [0056] paragraphs [0125] - [0131], [0138] - [0139], [0146] - [0147], [0151] - [0159] ----- -/--	1-5, 11-15

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 June 2014	30/06/2014

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

Form PCT/ISA/210 (second sheet) (April 2005)

1

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2006/293608 A1 (ROTHMAN DANIEL [US] ET AL) 28 December 2006 (2006-12-28) abstract; figures 1, 4, 8, 10 paragraphs [0010] - [0012], [0032] - [0048], [0064] - [0068] -----	1-5, 11-15
X	GB 2 233 764 A (MATSUSHITA ELECTRIC WORKS LTD [JP]) 16 January 1991 (1991-01-16) abstract; figures 1, 6-7 page 6, line 10 - page 7, line 22 page 11, line 22 - page 18, line 12 -----	1-5, 11-15
X	US 2011/230790 A1 (KOZLOV VALERIY [UA]) 22 September 2011 (2011-09-22) abstract; figures 1, 3, 5, 1011-12, 13A paragraphs [0013] - [0021], [0028] - [0030], [0061] - [0075], [0100] - [0111] -----	1-5, 11-15
A	EP 2 460 464 A1 (KONINKL PHILIPS ELECTRONICS NV [NL]) 6 June 2012 (2012-06-06) the whole document -----	1-5, 11-15

1

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 2008234785	A1	25-09-2008	JP 2008229248 A		02-10-2008
			US 2008234785 A1		25-09-2008
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			WO 2012138761 A1		11-10-2012
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			WO 2005084538 A1		15-09-2005
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EP 2460464	A1	06-06-2012	CN 103228203 A		31-07-2013
			EP 2460464 A1		06-06-2012
			EP 2645924 A1		09-10-2013
			US 2013338446 A1		19-12-2013
			WO 2012073183 A1		07-06-2012

INTERNATIONAL SEARCH REPORT

Box No. II   Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [X] Claims Nos.:   6-10
   because they relate to subject matter not required to be searched by this Authority, namely:

   Rule 39.1(iv) PCT - Method for treatment of the human or animal body by therapy.

2. [ ] Claims Nos.:
   because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III   Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [ ] As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest   [ ] The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

[ ] The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

[ ] No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (April 2005)