The invention relates to a device for determining the depth of sleep of a human being, comprising a transformation device for transforming an EEG signal into the frequency range and a processing device which uses at least two of three frequency ranges for determining a depth of sleep index $S_F$. 
Abstract
The invention relates to a device for determining the depth of sleep of a human being, comprising a transformation device for transforming an EEG signal into the frequency range and a processing device which uses at least two of three frequency ranges for determining a depth of sleep index SF.
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Translation of the PCT Application "DEVICE FOR DETERMINING DEPTH OF SLEEP"

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DESCRIPTION

DEVICE FOR DETERMINING DEPTH OF SLEEP

The present invention relates to a device for determining the depth of sleep, in particular during a narcosis on the occasion of a therapeutic / surgical operation.

The determination of depth of sleep with a physiological as well as a drug induced sleep, as a rule ensues in a visual way by experienced experts, who evaluate a patient's EEG, and assign values to separate time intervals of 20 to 30 seconds duration, said values reflecting the depth of sleep. The evaluation is based on works by Rechtschaffen & Kales from 1969, and is nowadays the only generally acknowledged standard for the assessment and the determination of depth of sleep of human beings on the basis of an EEG.

It is obvious that this procedure is not suitable for being carried out on a larger scale or during a therapeutic / surgical operation, for which purpose the patient is placed into a drug induced sleep (narcosis). For this reason, numerous experiments have been undertaken to determine depth of sleep on the basis of an EEG signal. In particular, EEG signals have therefore been transformed (Fast Fourier Transformation), and the representation of the EEG signal in the frequency range was subjected to an evaluation. Thereby, particularly considered were frequencies, which generally were designated as Δ-waves, and which were in a range between about 0 and 3.5 Hz. A connection between these very long-waved portions of the EEG signal and the state of consciousness "sleep" was established, and methods were developed, which were intended to allow a determination of the depth of sleep on the basis of these frequencies. The results were verified in that the automatically determined depth of sleep was compared with the depth
of sleep visually determined by experts pursuant to the acknowledged procedure of Rechtsaffen & Kales. The hitherto used methods, however, did not lead to any reliable results or to results, which could be used only in a very restricted manner so that, in the end, a reliable, fully automatic determination of the depth of sleep is not possible to date.

Apart from the above-described attempts to determine the state of consciousness "sleep" in a universally valid and in a manner lending itself for being automated, efforts were made to assess in particular drug induced sleep. Separate frequency ranges were thereby in part examined, even outside of the range of Δ-waves. This, as well, furnished only moderate success and was, moreover, restricted to the respective examined drug, so that the results could not be transferred to other drugs. Even the validation of the results of a visual assessment on the basis of Rechtsaffen & Kales showed deficiencies, so that one could scarcely speak of a reliable assessment of the human sleep.

The knowledge of human sleep is not only of interest for scientific or medical examinations and applications. The absence of a drug induced sleep during a therapeutic / surgical operation represents a stress for the patient, which is scarcely imaginable for a non-concerned person. This applies all the more when, apart from the absence of a drug induced sleep, the drug induced insensitivity to pain is not achieved and at the same time, the paralysis of the muscle activities, which is regularly provided with narcoses, is successfully induced. This signifies in the end for the patients that a therapeutic / surgical operation is carried out without the patient being asleep or insensitive to pain, yet also without the patient being able to draw the attention to his state. By means of a reliable recognition of sleep carried out in a fully automatic manner, and accompanying the therapeutic / surgical operation and the therewith connected narcosis, remedial measures can here be taken.

Yet, independent on the above described and usually rare case of failure of narcosis, there exists fundamental interest in a reliable method for a qualified and quantitative determination of the state of consciousness sleep, so that the object on which the present invention is based can be seen in providing a device by means of which the depth of sleep can be reliably and fully automatically assessed on the basis of the EEG signal.

This object is achieved by means of a device having the features of patent claim 1. Advantageous embodiments result from the subclaims.

The invention is based on the finding that at least two of the three characteristic ranges of the EEG signal represented in the frequency range must be referred to for determining a
sleep depth index $S_T$. It is decisive that the EEG signal is examined relative to these ranges, and that the sleep depth index $S_T$ is assessed considering two, preferably, however, all three ranges.

In the following, one embodiment of the inventive device will be described in more detail with reference to the Figures, in which:

**Fig. 1** schematically shows the configuration of one embodiment of the inventive device;

**Fig. 2** schematically shows the course of the EEG signal in the frequency range, as well as the ranges to be considered according to the present invention.

One embodiment of the inventive device is schematically represented in **Fig. 1**. The embodiment comprises an EEG measurement apparatus 1, only electrodes C3 and C4, as well as electrode C2, being shown in **Fig. 1**. A standard EEG apparatus usually comprises 15 to 25 electrodes, in addition to electrode C2. The output signals of the electrodes are transmitted to an amplifier device 2, which amplifies and processes the electrode signals, so that a (not shown) recorder may therewith be driven, which records the EEG. In said amplifier device 2, (not shown) interference filters are preferably provided, suppressing the portions transmitted in the electrode signals ranging between 0 and 4.5 Hz and 7 and 12.25 Hz. With the inventive device, an EEG signal, preferably the one of the electrodes C3 and/or C4, is derived from the EEG measurement apparatus 1 and transmitted to a transformation device 4 for the realization of a Fourier transformation (Fast Fourier Transformation, FFT). The connection between the EEG measurement apparatus 2 and the transformation device 4 may be established in various ways, preferably via an optical connection, e.g. a glass fibre, so that even with longer transmission distances, an interference of the transmitted EEG signal is reliably excluded.

The output signal of the transformation device 4 transmits the Fourier-transformed EEG signal to a processing device 5, which further processes the EEG signal EEG(f) now present in the frequency range. For this purpose, three frequency ranges of the transformed EEG signal are examined in more detail. The frequency ranges are shown in **Fig. 2**, frequency range a being between 4.75 and 6.75 Hz, frequency range b between 12.75 and 18.5 Hz, and frequency range c being between 18.75 and 35.0 Hz. For each of these frequency ranges, the processing device 5 determines a representative value A, B and C, and determines thereof the index characterizing the depth of sleep

$$S_T = \frac{A + B}{C}$$
The sleep depth index $S_F$ reliably reflects the patient's depth of sleep, such as could be proven in a validation study in comparison with the stages of sleep assessed by Rechtsaffen & Kales.

The values A, B and C representative of the three frequency ranges a, b and c, may be obtained in various ways. It is decisive that at least two of the frequency ranges a, b and c, preferably, however, all of the three, are completely or partially taken into account when assessing the representative values. One method for determining representative values consists of integrating the transformed EEG signal from the initial frequency up to the final frequency of the respective range or of a cut-out within said range.

In Figure 2, the hatched surfaces reflect the representative values A, B and C, which are assessed of the integration of the transformed EEG signal in the frequency ranges a, b and c. However, also a mean value of the transformed EEG signal is fundamentally suited, which is determined by the separate frequency ranges a, b and c. Another form of assessment is based on the power distribution $h(f)$ of the signal, preferably of the filtered signal, according to the following mode:

$$S = \frac{\int h(f) \cdot f \, df}{\int h(f) \cdot df}$$

Moreover, any mathematical method comprising a similar proposition may be referred to.

Such as it is shown in Fig. 1, the herein described embodiment of the inventive device comprises a monitor 6 for displaying the sleep depth index $S_F$. In addition to the representation on a monitor, the signal $S_F$ may also be used for other purposes such as, for example, for an alarm. The signal $S_F$ may also be transmitted to the (not shown) EEG recorder so that on EEG 3, the sleep depth index $S_F$ is represented as well.

It must be observed that the inventive device indicates an index which had not been determined in this form to date and which is designated as sleep depth index $S_F$. This index distinguishes itself from the hitherto assessed values and allows for the determination of physiological and drug induced sleep independent of the drug used.

The transformation device and the processing device are preferably combined in a personal computer capable of providing also the arithmetic capacity necessary for transforming the EEG signal into the frequency range and/or for processing the transformed EEG signal, i.e. the determination of the sleep depth index $S_F$. 
CLAIMS

New Claim 1

1. Device for determining the depth of sleep, comprising

   - a transformation device (4) supplied with an output signal (EEG(t)) of an
     EEG measurement apparatus (1), and which transforms the supplied EEG
     signal into a frequency range comprising frequency ranges a, b and c, and

   - a processing device (5) supplied with the EEG signal (EEG(f)) transformed
     into the frequency range by transformation device (4), and which assesses
     representative values A, B and C for frequency range a between 4.75 and
     6.75 Hz, frequency range b between 12.75 and 18.5 Hz, and frequency
     range c between 18.75 and 35.0 Hz, or for at least two of said frequency
     ranges, and determines a sleep depth index \( S_F \) therefrom.

2. Device according to claim 1,
   characterized in that processing device (5) determines the sleep depth
   index \( S_F \) as being the quotient of the sum of representative values A and B and
   representative value C

   \[
   S_F = \frac{A + B}{C}
   \]

3. Device according to claim 1 or 2,
   characterized in that the processing device (5) assesses the representative
   values A, B and C by integrating the EEG signal in the frequency range.

4. Device according to either one of claims 1 or 2,
   characterized in that the processing device (5) assesses said representative
   values A, B and C by taking the mean of the EEG signal in the frequency range.

5. Device according to either one of claims 1 or 2,
   characterized in that the processing device (5) assesses the representative
   values A, B and C on the basis of the power distribution \( h(f) \) of the signal, pursuant
   to the mode

   \[
   S = \frac{\int h(f) \cdot f \, df}{\int h(f) \, df}
   \]
6. Device according to any one of the preceding claims, characterized in that the transformation device (4) transforms the supplied EEG signal (EEG(t)) into the frequency range by means of a rapid Fourier transformation (FFT).

7. Device according to any one of the preceding claims, characterized by at least one interference suppressing means, which suppresses the portions ranging between 0 and 4.5 Hz and between 7 and 12.25 Hz of the electrode signals of the EEG measurement apparatus (1).
Fig. 2

![Diagram showing EEG frequency analysis with frequency bands A, B, and C at frequencies f1, f2, f3, f4, f5, and f6.](image)