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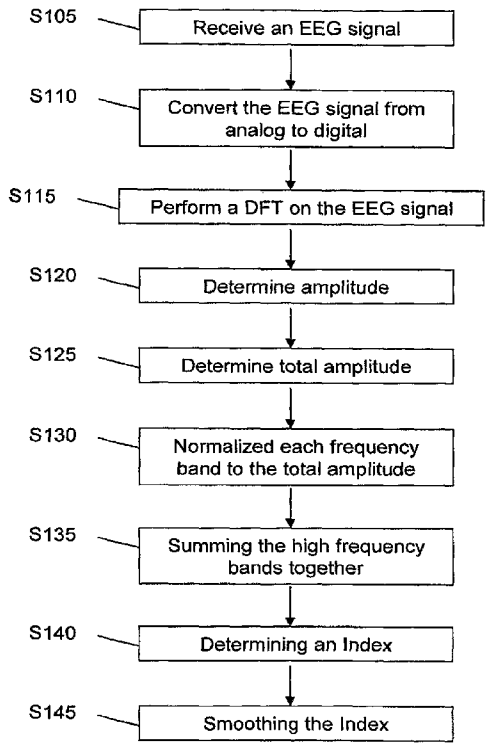


(57) Abstract: The invention includes a method and system for providing an Index representing the alertness state of an individual based at least in part on EEG signals obtained from the individual. In at least one exemplary embodiment, the EEG signals are divided into frequency bands and a total amplitude of the power is determined. Based on the proportion of the high frequency band compared to the proportion of the low frequency band, an Index is determined that is indicative of an individual's ability to perform a cognitive task.

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# Alertness/Drowsiness and Cognitive Capacity Index

## I. Field of the Invention

The invention relates to using EEG information to calculate an index score that is indicative of the ability of an individual to perform a cognitive task.

## II. Background of the Invention

Brain electrical activity (EEG) is studied conventionally in the 0-30 Hz frequency range from which wake, sleep depth levels, and rapid eye movement (REM) are classified using polysomnography (PSG). PSG sleep scoring is based on the concurrent recording, or at least recording in such a way as allows the latter synchronization (typically with time-stamping or time-linking) of the data, of electroencephalogram (EEG), electrooculogram (EOG), and electromyogram (EMG). These signals are typically then visually inspected on an epoch-by-epoch basis (each epoch traditionally is 30 seconds in length for PSG) to determine an individual's stage of sleep or wakefulness. Polysomnographic sleep scoring distinguishes between wake, non-rapid eye movement sleep (NREM) and rapid eye movement sleep (REM), with NREM sleep being further distinguished into four stages (stages 1, 2, 3, and 4) on the basis of characteristic EEG markers. PSG is not a practical method for determining sleep and wakefulness in applied settings (e.g., while driving, working, or on the battlefield), because PSG requires that individuals be attached to sensors or electrodes that connect with a recording device, and currently the only accepted method for PSG scoring is by visual inspection of the recorded EEG, EOG, and EMG results.

Most commercial EEG systems are designed to record up to about 256 Hz, because that is the upper limit for extracting useful information in PSG scoring. As a result, there has been no need to examine EEG data for the frequencies above 256 Hz.

There is a general emphasis in making polysomnographic determinations of whether a person is either sleep or awake with little attention directed to the in between states of drowsiness or alertness. Existing alertness systems are looking for physical manifestations indicating that a person is alert or not alert. Methods and apparatuses related to alertness detection fall into five basic categories: a method/apparatus for unobtrusively monitoring current alertness level; a method/apparatus for unobtrusively monitoring current alertness level and providing a warning/alarm to the user of decreased alertness and/or to increase user's alertness level; a method/apparatus for monitoring current alertness level based on the user's responses to some secondary task possibly with an alarm device to warn the user of decreased alertness and/or to increase user's alertness level; methods to increase alertness; and a method/apparatus for predicting past, current, or future alertness.

These methods and apparatuses that unobtrusively monitor the current alertness level are based on an "embedded measures" approach. That is, such methods infer alertness/drowsiness from the current level of some factor (e.g., eye position or closure) assumed to correlate with alertness/drowsiness. Issued patents of this type include U.S. Patent

No. 5,689,241 to J. Clarke, Sr., et al. disclosing an apparatus to detect eye closure and ambient temperature around the nose and mouth; U.S. Patent No. 5,682,144 to K. Mannik disclosing an apparatus to detect eye closure; and U.S. Patent No. 5,570,698 to C. Liang et al. disclosing an apparatus to monitor eye localization and motion to detect sleepiness. An obvious disadvantage of these types of methods and apparatuses is that the measures are likely detecting sleep onset itself rather than small decreases in alertness.

In some patents, methods for embedded monitoring of alertness/drowsiness are combined with additional methods for signaling the user of decreased alertness and/or increasing alertness. Issued patents of this type include U.S. Patent No. 5,691,693 to P. Kithil describing a device that senses a vehicle operator's head position and motion to compare current data to profiles of "normal" head motion and "impaired" head motion. Warning devices are activated when head motion deviates from the "normal" in some predetermined way. U.S. Patent No. 5,585,785 to R. Gwin et al. describes an apparatus and a method for measuring total handgrip pressure on a steering wheel such that an alarm is sounded when the grip pressure falls below a predetermined "lower limit" indicating drowsiness. U.S. Patent No. 5,568,127 to H. Bang describes a device for detecting drowsiness as indicated by the user's chin contacting an alarm device, which then produces a tactile and auditory warning. U.S. Patent No. 5,566,067 to J. Hobson et al. describes a method and an apparatus to detect eyelid movements. A change in detected eyelid movements from a predetermined threshold causes an output signal/alarm (preferably auditory). As with the first category of methods and apparatuses, a disadvantage here is that the measures are likely detecting sleep onset itself rather than small decreases in alertness.

Other alertness/drowsiness monitoring devices have been developed based on a "primary/secondary task" approach. For example, U.S. Patent No. 5,595,488 to E. Gozlan et al. describes an apparatus and a method for presenting auditory, visual, or tactile stimuli to an individual to which the individual must respond (secondary task) while performing the primary task of interest (e.g., driving). Responses on the secondary task are compared to baseline "alert" levels for responding. U.S. Patent No. 5,259,390 to A. MacLean describes a device in which the user responds to a relatively innocuous vibrating stimulus. The speed to respond to the stimulus is used as a measure of the alertness level. A disadvantage here is that the apparatus requires responses to a secondary task to infer alertness, thereby altering and possibly interfering with the primary task.

Other methods exist solely for increasing alertness and depend upon the user to self-evaluate alertness level and activate the device when the user feels drowsy. An example of the latter is U.S. Patent No. 5,647,633 and related patents to M. Fukuoka in which a method/apparatus is described for causing the user's seat to vibrate when the user detects drowsiness. Obvious disadvantages of such devices are that the user must be able to

accurately self-assess his/her current level of alertness, and that the user must be able to correctly act upon this assessment.

Methods also exist to predict alertness level based on user inputs known empirically to modify alertness. U.S. Patent No. 5,433,223 to M. Moore-Ede et al. describes a method for predicting the likely alertness level of an individual at a specific point in time (past, current or future) based upon a mathematical computation of a variety of factors (referred to as "real-world" factors) that bear some relationship to alterations in alertness. The individual's Baseline Alertness Curve (BAC) is first determined based on five inputs and represents the optimal alertness curve displayed in a stable environment. Next, the BAC is modified by alertness modifying stimuli to arrive at a Modified Baseline Alertness Curve. Thus, the method is a means for predicting an individual's alertness level, not cognitive performance.

## III. Summary of the Invention

The invention includes a method and system for providing an Index representing the alertness state of an individual based at least in part on EEG signals obtained from the individual. In at least one exemplary embodiment, the EEG signals are divided into frequency bands and a total amplitude (square root of the power) is determined. Based on the proportion of the high frequency band compared to the proportion of the low frequency band, an Index is determined that is indicative of an individual's ability to perform a cognitive task.

The invention in at least one exemplary embodiment includes a system including means for transforming a EEG signal to the frequency domain with a Discrete Fourier Transform, means for obtaining the amplitude of each frequency component, means for summing all of the amplitudes of each frequency component to obtain a total amplitude, means for summing all of the amplitudes of frequencies in the range of 201-500 Hz to obtain a high frequency amplitude, means for summing all of the amplitudes of frequencies in the range of 1 to at least 15 Hz to obtain a low frequency amplitude, and means for calculating an Index based on the total amplitude, the high frequency amplitude, and the low frequency amplitude.

The invention in at least one exemplary embodiment includes a computer program product for providing an Index, the program product having a computer readable medium; first program instruction means for transforming a digital EEG signal to the frequency domain with a Discrete Fourier Transform, second program instruction means for obtaining the amplitude of each frequency component, third program instruction means for summing all of the amplitudes of each frequency component to obtain a total amplitude, fourth program instruction means for summing all of the amplitudes of frequencies in the range of 201-500 Hz to obtain a high frequency amplitude, fifth program instruction means for summing all of the amplitudes of frequencies in the range of 1 to at least 15 Hz to obtain a low frequency amplitude, and sixth program instruction means for calculating an Index based on the total amplitude, the high frequency amplitude, and the low frequency amplitude.

The invention in at least one exemplary embodiment includes a system including at least two electrodes, and alertness means for providing a representation as to the alertness level of an individual based on EEG signals provided by the at least two electrodes when connected to the individual.

The invention in at least one exemplary embodiment includes a method for determining an index representative of the level of alertness/drowsiness of an individual including receiving an EEG signal, transforming the EEG signal into the frequency domain, summing all of the amplitudes for each frequency band, determining a total amplitude for all frequency bands, determining the ratio of each frequency band to the total amplitude for at least the lowest and highest frequency band, determining the index of the highest frequency band ratio to the lowest frequency band ratio, and providing the index.

## IV. Brief Description of the Drawings

FIG. 1 illustrates an exemplary method according to the invention.

FIG. 2 illustrates raw EEG data.

FIG. 3 illustrates the EEG data from FIG. 2 broken into frequency bands and normalized.

FIGs. 4-13 illustrate graphs depicting the index value and its changes in particular between sleep deprived and non-sleep deprived states. The index value is a continuous quantity, but for ease of illustration is expressed in intervals of 0.25 along the Y-axis of these graphs.

FIG. 14 illustrates an exemplary system according to the invention.

FIG. 15 illustrates an exemplary system according to the invention.

## V. Detailed Description of the Drawings

The invention includes a method for determining an index that is indicative of whether the person that is being monitored is likely able to perform a cognitive processing task. The method described in the exemplary embodiment receives EEG signals for processing and determination of an index. The index is applicable to different individuals at least in part to individuals generating the same patterned brain waves in the different states of awake, drowsy, asleep, or active cognition.

An exemplary system for use with the method obtains EEG signals recorded from scalp electrodes located at the C3 and C4 positions. The electrodes, for example, may be affixed to the individual or located in a head covering such as a hat or helmet. The recording system at a minimum must be able to acquire the EEG signals at a sampling rate of at least 1000 Hz, i.e., 1000 samples per second. There are a variety of commercial polygraph systems available that can provide this minimal sampling period, for example, Grass/Telefactor Gamma® Systems. Depending upon the implementation, the electrodes are directly connected to the stationary polygraph system or to a portable personal data assistant (PDA) specifically equipped with electronic capability for acquiring and processing the EEG signals. In at least one other exemplary embodiment, the electrodes are in wireless communication with at least one other

aspect of the system. The EEG signals may be processed in real-time taking into account a moving sampling window or stored for later analysis. In at least one exemplary embodiment, the results of the analyzed EEG signals are transmitted to a central monitoring station for use by a supervisor or a commander. In at least one exemplary embodiment, the raw (or digitally converted) EEG signals are transmitted to a central monitoring station for analysis by a supervisor or a commander.

An exemplary method is illustrated in FIG. 1. The method receives an EEG signal as an input, S105. FIG. 2 illustrates a sleep deprived EEG signals from C3 and C4. The EEG signal is converted from an analog signal to a digital signal, S110. If the EEG signal is digital as outputted by the electrodes, then step S110 can be omitted. Based on this disclosure, these two steps could be performed separate from the rest of the method including by different equipment or system.

The digitized sample is a representation of the EEG signal in the time domain. The method transforms the digitized sample to the frequency domain by discrete Fourier Transform (DFT) on a second-by-second basis, S115, although different epoch lengths can be utilized depending upon the desired resolution of data desired. Furthermore, the epoch length is not restricted and user may select any length suitable for his/her use. However, the DFT result applies to the entire epoch then, i.e., 30 seconds as in polysomnography, and no specific incident of alertness/drowsiness/sleepiness can be pin-pointed within that epoch. Second-by-second is the smallest discrete increment allowing a resolution capable of showing instantaneous changes – what some sleep researchers call "microsleep", a moment when there is a lapse in cognitive capability possibly allowing a catastrophic event to occur. The output of the DFT is 500 frequency components from 1 Hz to 500 Hz representative of power ($\mu V^2$). The amplitude ($\mu V$) of each frequency component is obtained by taking the square root of power, S120, which provides a linear and therefore additive property. The Total Amplitude (TA) per second is obtained by summing all of the amplitudes of frequencies in the range of 1 to 500 Hz, S125. In at least one exemplary embodiment, the frequencies are separated into seven frequency bands as follows:

1. 1-15 Hz
2. 16-50 Hz
3. 51-100 Hz
4. 101–200 Hz
5. 201–300 Hz
6. 301–400 Hz
7. 401–500 Hz

Alternatively, the first two frequency bands may be 1-20 Hz and 21-50 Hz, respectively. The difference between these range sets is that 1-20 Hz provides a more certain determination of drowsiness, while 1-15 Hz has a natural bias towards sleepiness. Each of these frequency

bands at their lowest level provides about 5% of the Total Amplitude (TA). The 0 Hz frequency is omitted because it would bias the power spectrum towards the lower frequency band. Typically, if the lower frequency band is more than 50% of the Total Amplitude (TA), then the individual is asleep. Alternatively, the bands 5-7 could be combined into one band of 201-500 Hz, and if this occurs then the summation step S135 is omitted.

The sums of each frequency band's amplitudes are calculated and normalized with respect to the Total Amplitude (TA), S130. FIG. 3 illustrates the normalized amplitudes for the EEG signals illustrated in FIG. 2 using a ten second moving average to smooth the data, which the use of a moving average is discussed in a later exemplary embodiment. This provides the relative contribution of each frequency band to total energy in each second and allows for intra-individual as well as inter-individual comparisons regardless of the absolute amplitude values which may vary within as well as across individuals depending on the scalp-electrode contact and individual impedance. The frequency bands in the range of 201-500 Hz are summed together to form a single frequency band, S135. One of ordinary skill in the art will appreciate that other frequencies can be included in this single frequency band. The higher frequency band (201-500 Hz) is indicative of brain activity during active cognitive processing in individuals.

The index value is determined based on the ratio of the proportion of high frequency band (201-500 Hz) to proportion of low frequency band (either 1-15 Hz or 1-20 Hz) contribution to the Total Amplitude (TA), S140. FIG. 4 illustrates the Index for the normalized EEG readings from FIG. 3. The ratio can use the raw Total Amplitude (TA) or the normalized Total Amplitude (TA). In embodiments where the raw Total Amplitude (TA) is used from S125, then the normalization step S130 may be omitted. The index value as determined reflects the intrinsic nature of the constantly oscillating state of energy in the brain, i.e., not a steady state but rather one having potentially large relative value changes from one second to the next.

In at least one exemplary embodiment, the method further includes smoothing the string of index values forming the data with a moving average, S145. An exemplary moving average is 10 point, i.e., 10 second window. The moving average parameter can be any reasonable value depending upon the resolution desired including values falling within the range of 2 to 60 seconds. Exemplary values include 5 seconds, 20 seconds, and 30 seconds. The moving average will provide greater stability for the index value as well as providing more easily viewed data. The moving average alternatively may instead by used in connection with each frequency band as illustrated, for example, in FIG. 3.

In general, an Index greater than or equal to 1.25 (to as high as 3.5) signifies awake, alert and capable of cognitive processing. An Index around 1.0 can be indicative of an alert state or a drowsy state depending upon the individual. An Index below 0.8 (or 0.9) is evident of a drowsy state and the asleep state is defined as the Index less than or equal to 0.25.

FIGs. 5 and 6 illustrate different Index calculations where the frequency range being compared to the lowest frequency range is different. The sensitivity for discriminating between

different states is highest for the high frequencies of the 201-500 Hz range when compared to the 1-15 Hz range. FIG. 6 further illustrates the different states labeled between awake, drowsy, and asleep.

FIGs. 4 and 7-13 illustrate graphs depicting the index value and its changes in particular between sleep deprived and non-sleep deprived states. Although the Index is a continuous quantity, the Y-axis of these figures includes hash marks at intervals of 0.25. The Y-axis is not at the same scale for each of the illustrated graphs in order to better show each range difference at an appropriate resolution.

FIGs. 7 and 8 illustrate the Index during a sleep latency test in which the individual attempts to sleep within either a 20 minute or 15 minute period. FIG. 7 illustrates a sleep latency test of a non-sleep deprived individual who for the most part maintains the Index above 0.75, which is indicative of an awake state with slight drowsiness, except for two brief intervals when the Index declines slightly below this level. FIG. 8 illustrates a sleep latency test of a sleep deprived individual who exhibits a progressively declining Index as the subject proceeds from the awake state to the asleep state.

FIGs. 9 and 10 illustrate the Index for two individuals during the Performance Assessment Battery (PAB) task, which involves multiple types of cognitive processing, i.e., arithmetic, choice reaction time, memory, spatial orientation. FIG. 9 illustrates a PAB of a rested individual who except for a small period of slight alertness decline remains awake during the entire test session while maintaining a high level of throughput (i.e., the product of speed and accuracy) during the test session. The majority of the Index values are well above 1.0, and some extend to almost 2.0. FIG. 10 illustrates a PAB of a sleep deprived individual that shows a vastly different picture of the Index during PAB testing than that shown in FIG. 9. In FIG. 10, the individual is struggling to maintain alert wakefulness by repeated attempts of arousal from on-going drowsiness. Each arousal effort is not sustained for very long.

FIGs. 4 and 11 illustrate the Index during performance of the Psychomotor Vigilance Test (PVT), a task which requires sustained visual attention and vigilance. FIG. 11 illustrates a PVT of a rested individual who consistently has an Index greater than 1.0, which indicates the individual is awake and alert during the entire test session. On the other hand, FIG. 4 illustrates a PVT of a sleep deprived individual whose Index reflects the inability to maintain wakefulness during the test, in fact, the individual fell asleep for at least three continuous minutes at about four minutes into the test.

FIGs. 12 and 13 illustrate the Index during the Choice Visual Perception Test, which was the longest lasting test administered during the study from which this data was taken. The Choice Visual Perception Test requires both sustained peripheral visual attention and a manual response indicating left or right location to presence of single or double LED light stimuli of 250 milliseconds duration. The device used in this test was the patented Lateral Visual Field Tester (LVFT) invented by COL Michael Russo (U.S. Pat. No. 6,849,050).

FIG. 12 illustrates the test of a rested individual who maintained Index values (in excess of 0.75 and most of the time in excess of 1.0) reflecting the subject's rested state of being awake and alert during the entire test session as reflected by the high accuracy score and no lapses in responses. FIG. 13 illustrates a sleep deprived test session where the Index remained mostly at the level of drowsiness or had a progression towards drowsiness ending in an interval of at least four minutes in which the subject was asleep during the test session. The accuracy score and response lapses in 132 out of 150 stimuli clearly reflect that the individual was in an advanced state of drowsiness/sleep during the entire test session.

Another exemplary embodiment provides assessment information regarding the state of the individual. A method for providing this information uses regression analysis of the 10 point moving average to obtain the slope value. Depending upon the point value, the regression analysis would use the same number of points. The slope provides a measure of the current status of the individual with reference to the immediate past 10 seconds in this example. If the value of the slope is positive, then alertness is trending upwards. If the value of the slope is negative, then alertness is trending downwards. If the value of the slope is zero, there is no change from the previous 10 seconds in this example. If the value of the slope is near zero and positive, there is a potential state change from drowsiness towards alertness. If the value of the slope is near zero and negative, there is a potential state change from alertness towards drowsiness.

Another exemplary embodiment adds a filtering step between S110 and S115 of FIG. 1 to filter out the line frequency and its harmonics (60, 120, 180, 240, 300, 360, 420, 480 Hz). An exemplary way to accomplish a filter is with a narrow band FIR filter to eliminate the raw EEG data for these frequencies. In a further exemplary embodiment, the average of the 1000 EEG values in each second is obtained and subtracted from each of the 1000 EEG values as the average is the DC or zero frequency. The decision to use a filter can be based on a visual inspection of an EEG waveform.

In the instrument used in the study, 60 Hz noise was a prominent artifact. In instruments not affected by line frequency interference, filtering or not filtering would be an option. Filtering out these few frequencies does not affect the overall relationship in the Index, in particular because the amplitude in the higher frequency bands is a magnitude of order lower than the low frequency bands, so large numbers are not deleted. The highest magnitude is the 60 Hz artifact, but the Index is not impacted by this frequency.

Another exemplary embodiment eliminates a sample in which the Total Amplitude (TA) of the entire spectrum, for example, 1 to 500 Hz although other ranges could be utilized, exceeds the mean TA + 3 sd. In some embodiments, the threshold is met if the current Total Amplitude exceeds the mean TA + 2 sd. An exemplary way to obtain the mean Total Amplitude (TA) is for each subject, an initial 60 second sample baseline EEG is recorded under normal conditions where the individual is well rested (i.e., not sleep deprived), awake and sitting quietly.

The average and sd of the sixty Total Amplitudes are calculated. This provides assurance that true high amplitudes are not rejected. This is done to take into account that each subject differs in absolute values for the EEG measurements, due to differences in individual impedances, electrode adherence, etc. This will eliminate EEG readings that are considered to be artifactual, and as such the relative magnitudes can be adjusted.

Another exemplary embodiment adds providing a notification regarding the Index value. The notification can be to the individual being monitored, to a supervisor, to a monitoring system or other data collection system. In at least one exemplary embodiment the system provides a notification once the Index crosses a certain threshold and/or the slope of the Index is indicating the individual is approaching drowsiness or sleep. The threshold depending upon the implementation can be at 1.0, 0.8, 0.5 or at some level above these to provide the individual a chance to stop the task being performed or to take other action to reduce the risk of an incident or other problem.

An exemplary system for performing the above described method is illustrated in FIG. 14. The system includes at least two electrodes 1410 in communication with a processor 1420. The processor includes alertness means for providing a representation as to the alertness level of an individual based on EEG signals provided by said at least two electrodes when connected to the individual. The communication between these components can be accomplished wirelessly if the electrodes include or are connected to transmitters for communicating with the processor or these components can be wired together as such the dash line 1430 represents these possibilities as a means for communicating EEG signals from said at least two electrodes to the alertness means. In at least one exemplary embodiment illustrated in FIG. 15, the system further includes a communications module 1440 for sending notifications. The communications module 1440 can include a transmitter or other output for sending a signal to alert the individual, their supervisor, or another system.

In a study that included thirteen subjects who underwent a four day study which included a period of forty hours of continued wakefulness. The subjects wore EEG electrodes at two central locations, C3 and C4, for the test sessions for seven different cognitive tasks and two overnight sleep sessions. The cognitive tests ranged from five minutes to twenty-six minutes and included stimulus presentations that were directly synchronized with two tasks, the CVPT and the PAB. EEG records were collected and analyzed for each subject. The analysis of these EEG records in conjunction with the cognitive test data confirms the validity of the index.

This study included thirteen military and civilian individuals having a mean age of 30.5 ± 6.0 yrs. The number of hours of sleep deprivation was 40. The physiological signals monitored included: EEG, EOG, EMG, EKG, Wrist and tri-axial Actigraphy, and pulse. The signal sampling rate was 1000 Hz for the EEG and EKG monitoring. Each participant was resident in the laboratory for 4 days. The schedule was as follows:

Day 1: Electrodes were attached to the subjects. The subjects were trained on the test tasks and allowed eight hours in bed.

Days 2 & 3: Scheduled hourly testing of tasks using at least one of SLT, CVPT, PAB, and PVT over the next forty hours.

Day 4: The subjects were allowed recovery sleep of ten hours beginning at 0000 and awoken at 1000 to resume hourly testing till 1800. The subjects were then debriefed, electrodes removed, and departed the laboratory at 1900.

The study produced 326 EEG files for each subject and a total of 4,238 files, of which about 150 were not usable. Each subject received the following number of tests: 19 CVPT, 12 MSLT, 20 PAB, 60 PDA based PVT, 20 computer based PVT, 30 PVT, and 2 sleep.

The study results were that the sleep state suppresses all high frequency EEG activity; EEG signals in high frequency range are manifestations of active thought processes; sleep deprivation increases low frequency amplitude and decreases high frequency amplitude; a decline in alertness, or conversely, increase in drowsiness results in equivalent loss of cognitive function capacity to respond to external stimuli resulting in apparent "lapse". Without cognitive function capacity, there can be no cognitive performance. High frequency EEG provides an objective assessment for quantifying cognitive function capacity, can indicate when intervention measures may be introduced to alleviate a drowsy/sleepy state, and can be an aid in cognitive performance modeling.

The invention can take the form of an entirely hardware embodiment, an entirely software embodiment or an embodiment containing both hardware and software elements. In at least one exemplary embodiment, the invention is implemented in software, which includes but is not limited to firmware, resident software, microcode, etc.

Furthermore, the invention can take the form of a computer program product accessible from a computer-usable or computer-readable medium providing program code for use by or in connection with a computer or any instruction execution system. For the purposes of this description, a computer-usable or computer readable medium can be any apparatus that can contain, store, communicate, propagate, or transport the program for use by or in connection with the instruction execution system, apparatus, or device.

The medium can be an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system (or apparatus or device) or a propagation medium such as carrier signal. Examples of a computer-readable medium include a semiconductor or solid state memory, magnetic tape, a removable computer diskette, a random access memory (RAM), a read-only memory (ROM), a rigid magnetic disk, and an optical disk. Current examples of optical disks include compact disk – read only memory (CD-ROM), compact disk – read/write (CD-R/W) and DVD.

A data processing system suitable for storing and/or executing program code will include at least one processor coupled directly or indirectly to memory elements through a system bus.

The memory elements can include local memory employed during actual execution of the program code, bulk storage, and cache memories which provide temporary storage of at least some program code in order to reduce the number of times code must be retrieved from bulk storage during execution.

Computer program code for carrying out operations of the present invention may be written in a variety of computer programming languages. The program code may be executed entirely on at least one computing device, as a stand-alone software package, or it may be executed partly on one computing device and partly on a remote computer. In the latter scenario, the remote computer may be connected directly to the one computing device via a LAN or a WAN (for example, Intranet), or the connection may be made indirectly through an external computer (for example, through the Internet, a secure network, a sneaker net, or some combination of these).

It will be understood that each block of the flowchart illustrations and block diagrams and combinations of those blocks can be implemented by computer program instructions including software and/or means. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions specified in the flowcharts or block diagrams.

The exemplary and alternative embodiments described above may be combined in a variety of ways with each other. Furthermore, the steps and number of the various steps illustrated in the figures may be adjusted from that shown.

It should be noted that the present invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, the embodiments set forth herein are provided so that the disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. The accompanying drawings illustrate exemplary embodiments of the invention.

Although the present invention has been described in terms of particular preferred and alternative embodiments, it is not limited to those embodiments. Alternative embodiments, examples, and modifications which would still be encompassed by the invention may be made by those skilled in the art, particularly in light of the foregoing teachings.

Those skilled in the art will appreciate that various adaptations and modifications of the preferred and alternative embodiments described above can be configured without departing from the scope and spirit of the invention. Therefore, it is to be understood that, within the scope of the appended claims, the invention may be practiced other than as specifically described herein.

## VI. Industrial Applicability

The invention can be utilized in a variety of settings to provide information as to whether an individual is becoming drowsy or has fallen asleep to avoid problems developing as a result. For example, an air traffic controller monitoring radar would receive notification along with a supervisor if the air traffic controller was becoming drowsy or fell asleep. Another example of an industry that would benefit from this invention is the trucking industry, because the driver may not be aware of their condition and this would provide a notification that they have become drowsy.

The invention can also be utilized as a research tool, for example, to see the impact of sleep schedules and/or pharmaceutical products and/or drugs on individuals. In these circumstances the invention may be coupled with cognitive tests to be performed by the individual.

**IN THE CLAIMS:**

We claim:

1. A method comprising:

transforming a EEG signal to the frequency domain with a Discrete Fourier Transform,

obtaining the amplitude of each frequency component,

summing all of the amplitudes of each frequency component to obtain a total amplitude,

summing all of the amplitudes of frequencies in the range of 201-500 Hz to obtain a high frequency amplitude,

summing all of the amplitudes of frequencies in the range of 1 to at least 15 Hz to obtain a low frequency amplitude, and

calculating an Index based on the total amplitude, the high frequency amplitude, and the low frequency amplitude.

2. The method according to claim 1, further comprising smoothing the Index.

3. The method according to claim 2, wherein smoothing the Index using a 10 point moving average.

4. The method according to claims 2, further comprising obtaining a slope value of the Index.

5. The method according to claim 4, wherein the slope value of the Index is obtained for a 10 point moving average.

6. The method according to claim 5, providing an indication as to increasing or decreasing alertness level based on the slope.

7. The method according to claim 4, providing an indication as to increasing or decreasing alertness level based on the slope.

8. The method according to claims 1, further comprising obtaining a slope value of the Index.

9. The method according to claim 8, wherein the slope value of the Index is obtained for a 10 point moving average.

10. The method according to claim 9, providing an indication as to increasing or decreasing alertness level based on the slope.

11. The method according to claim 1, wherein the low frequency amplitude is obtained for frequencies in the range of 1-20 Hz.

12. The method according to claims 11, further comprising smoothing the Index.

13. The method according to claim 12, wherein smoothing the Index using a 10 point moving average.

14. The method according to claim 11, further comprising obtaining a slope value of the Index.

15. The method according to claim 14, wherein the slope value of the Index is obtained for a 10 point moving average.

16. The method according to claim 11, providing an indication as to increasing or decreasing alertness level based on the slope.

17. The method according to claim 1, further comprising:

obtaining an EEG signal, and

converting the EEG signal from analog to digital.

18. The method according to claims 17, further comprising smoothing the Index.

19. The method according to claim 18, wherein smoothing the Index using a 10 point moving average.

20. The method according to claim 17, further comprising obtaining a slope value of the Index.

21. The method according to claim 20, wherein the slope value of the Index is obtained for a 10 point moving average.

22. The method according to claim 17, providing an indication as to increasing or decreasing alertness level based on the slope.

23. The method according to any one of claims 1-22, wherein obtaining the amplitude of each frequency component includes grouping the frequencies into frequency bands.

24. The method according to claim 23, wherein the frequency bands include 1-15 Hz, 16-50 Hz, 51-100 Hz, 101-200 Hz, 201-300 Hz, 301-400 Hz, and 401-500 Hz.

25. The method according to claim 23, wherein the frequency bands include 1-20 Hz, 21-50 Hz, 51-100 Hz, 101-200 Hz, 201-300 Hz, 301-400 Hz, and 401-500 Hz.

26. The method according to claim 23, wherein the frequency bands include 1-15 Hz, 16-50 Hz, 51-100 Hz, 101-200 Hz, and 201-500 Hz.

27. The method according to claim 23, further comprising smoothing the amplitude of each frequency band.

28. The method according to claim 23, wherein smoothing the amplitude of each frequency band using a 10 point moving average.

29. The method according to claim 23, further comprising providing a notification when the Index is less than a threshold.

30. The method according to claim 29, wherein the notification is provided to the individual wearing the EEG source.

31. The method according to claim 29, wherein the notification is provided to someone other than the individual wearing the EEG source.

32. The method according to claim 29, wherein the threshold is equal to 1.

33. The method according to claim 29, wherein the threshold is equal to 0.8.

34. The method according to claim 1, further comprising providing a notification when the Index is less than a threshold.

35. The method according to claim 34, wherein the notification is provided to the individual wearing the EEG source.

36. The method according to claim 34 or 35, wherein the notification is provided to someone other than the individual wearing the EEG source.

37. The method according to claim 34 or 35, wherein the threshold is equal to 1.

38. The method according to claim 34 or 35, wherein the threshold is equal to 0.8.

39. The method according to any of the above claims, further comprising providing an indication of their alertness level based on the Index to a source of the EEG signal.

40. A computer readable medium having instructions for performing the method of any one of claims 1-39.

41. A system comprising

at least two electrodes, and

alertness means for providing a representation as to the alertness level of an individual based on EEG signals provided by said at least two electrodes when connected to the individual.

42. The system according to claim 41, further comprising means for communicating EEG signals from said at least two electrodes to said alertness means.

43. The system according to claim 41 or 42, further comprising a communication module connected to said alertness means.

44. A computer program product for providing an Index, the program product comprising:

a computer readable medium;

first program instruction means for transforming a digital EEG signal to the frequency domain with a Discrete Fourier Transform,

second program instruction means for obtaining the amplitude of each frequency component,

third program instruction means for summing all of the amplitudes of each frequency component to obtain a total amplitude,

fourth program instruction means for summing all of the amplitudes of frequencies in the range of 201-500 Hz to obtain a high frequency amplitude,

fifth program instruction means for summing all of the amplitudes of frequencies in the range of 1 to at least 15 Hz to obtain a low frequency amplitude, and

sixth program instruction means for calculating an Index based on the total amplitude, the high frequency amplitude, and the low frequency amplitude.

45. A system comprising:

means for transforming a EEG signal to the frequency domain with a Discrete Fourier Transform,

means for obtaining the amplitude of each frequency component,

means for summing all of the amplitudes of each frequency component to obtain a total amplitude,

means for summing all of the amplitudes of frequencies in the range of 201-500 Hz to obtain a high frequency amplitude,

means for summing all of the amplitudes of frequencies in the range of 1 to at least 15 Hz to obtain a low frequency amplitude, and

means for calculating an Index based on the total amplitude, the high frequency amplitude, and the low frequency amplitude.

46. A method for determining an index representative of the level of alertness/drowsiness of an individual comprising:

receiving an EEG signal,

transforming the EEG signal into the frequency domain,

summing all of the amplitudes for each frequency band,

determining a total amplitude for all frequency bands,

determining the ratio of each frequency band to the total amplitude for at least the lowest and highest frequency band,

determining the index of the highest frequency band ratio to the lowest frequency band ratio, and

providing the index.

47. The method according to claim 46, further comprising eliminating any sample whose total amplitude exceeds a mean total amplitude plus 2 sd,

where mean total amplitude is calculated from an initial sampling period for the EEG.

48. The method according to claim 46 or 47, further comprising filtering out the power line frequency and its harmonics.

49. The method according to any one of claims 46-48, wherein the highest frequency band is 201-500 Hz.

50. The method according to any one of claims 46-48, wherein the lowest frequency band is 1-15 Hz.

51. The method according to any one of claims 46-48, wherein the lowest frequency band is 1-20 Hz.

52. An alertness/drowsiness indicator system being substantially as herein described with reference to the accompanying figures.

53. An alertness/drowsiness indicator method being substantially as herein described with reference to the accompanying figures.

54. An alertness/drowsiness index determination system being substantially as herein described with reference to the accompanying figures.

55. An alertness/drowsiness index determination method being substantially as herein described with reference to the accompanying figures.

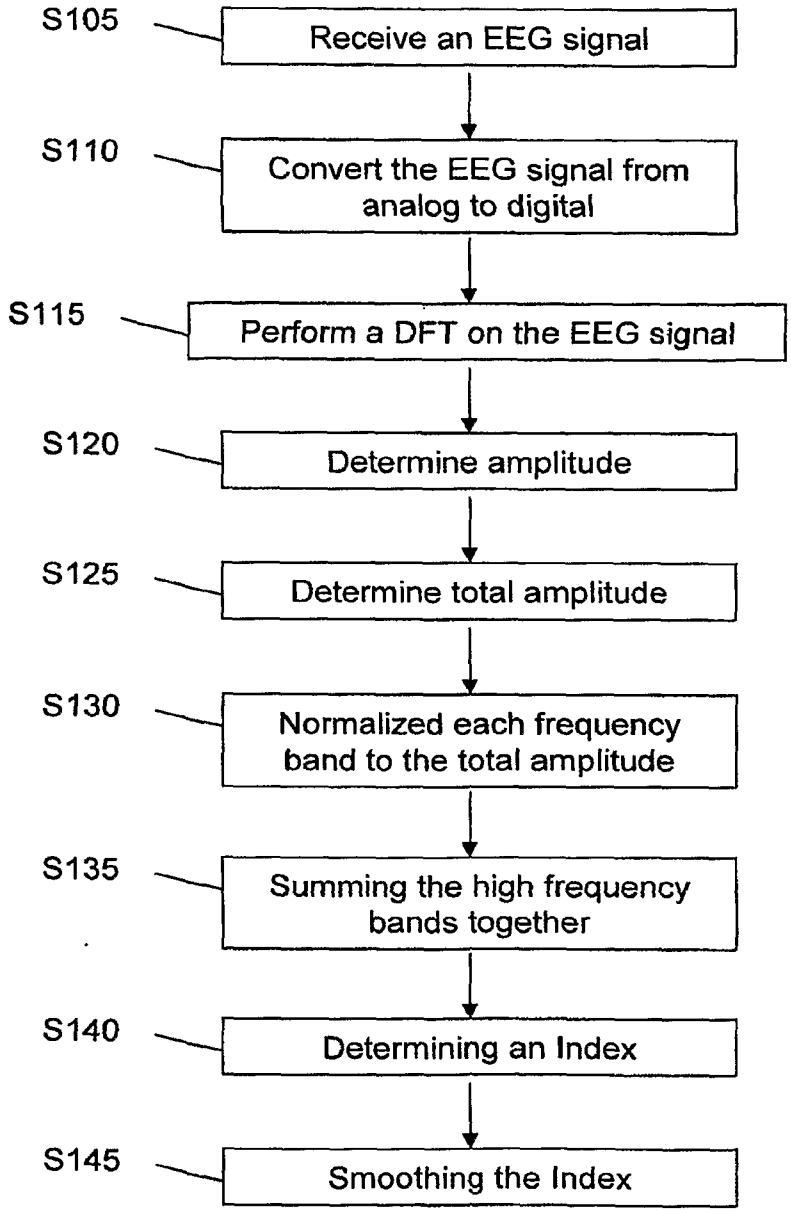
S105
Receive an EEG signal
S110
Convert the EEG signal from analog to digital
S115
Perform a DFT on the EEG signal
S120
Determine amplitude
S125
Determine total amplitude
S130
Normalized each frequency band to the total amplitude
S135
Summing the high frequency bands together
S140
Determining an Index
S145
Smoothing the Index

FIG. 1

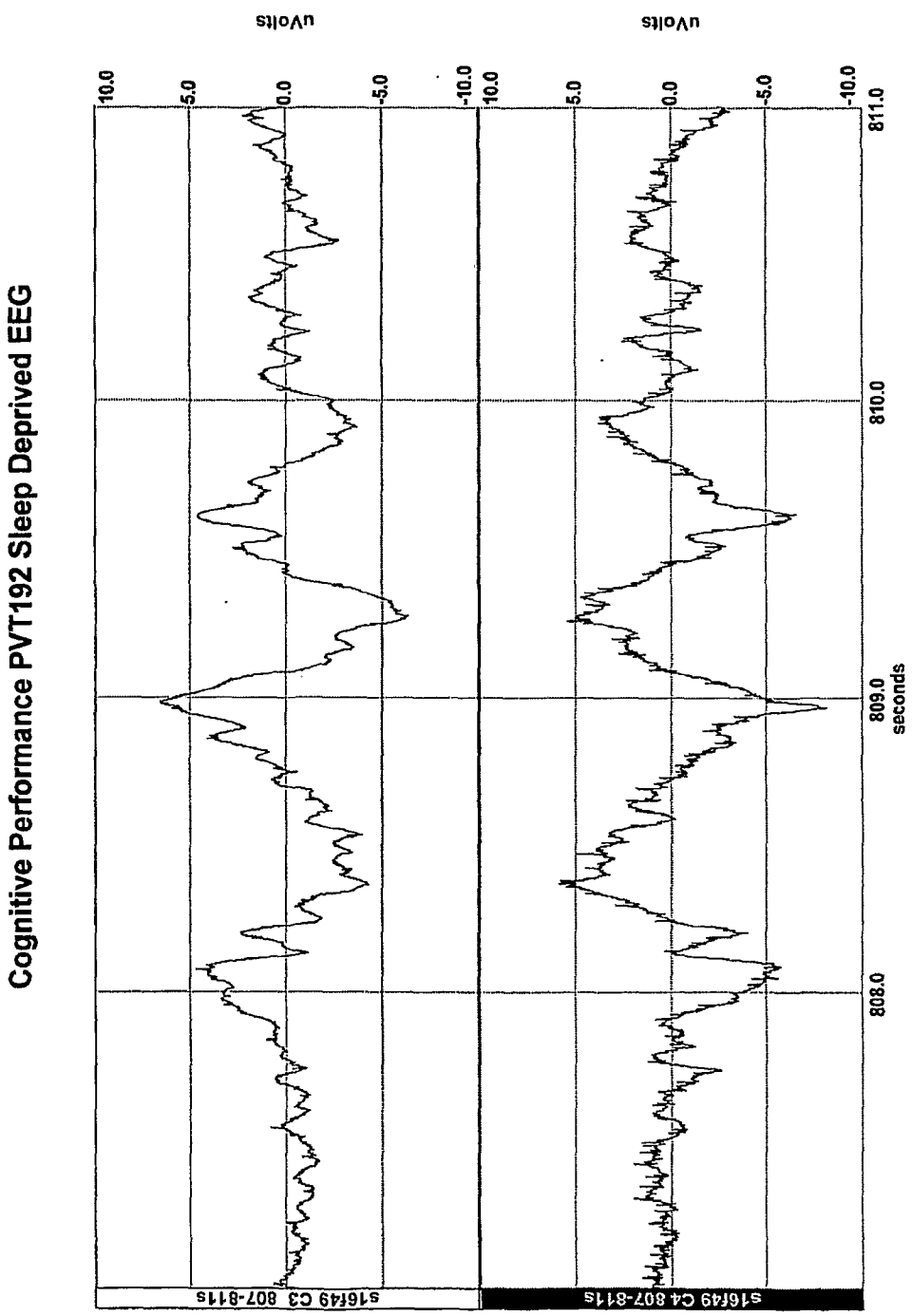
Cognitive Performance PVT192 Sleep Deprived EEG
uVolts
10.0
5.0
0.0
-5.0
-10.0
s16fa49 C3 807-811s
s16fa49 C4 807-811s
808.0
809.0
810.0
811.0
seconds

FIG. 2

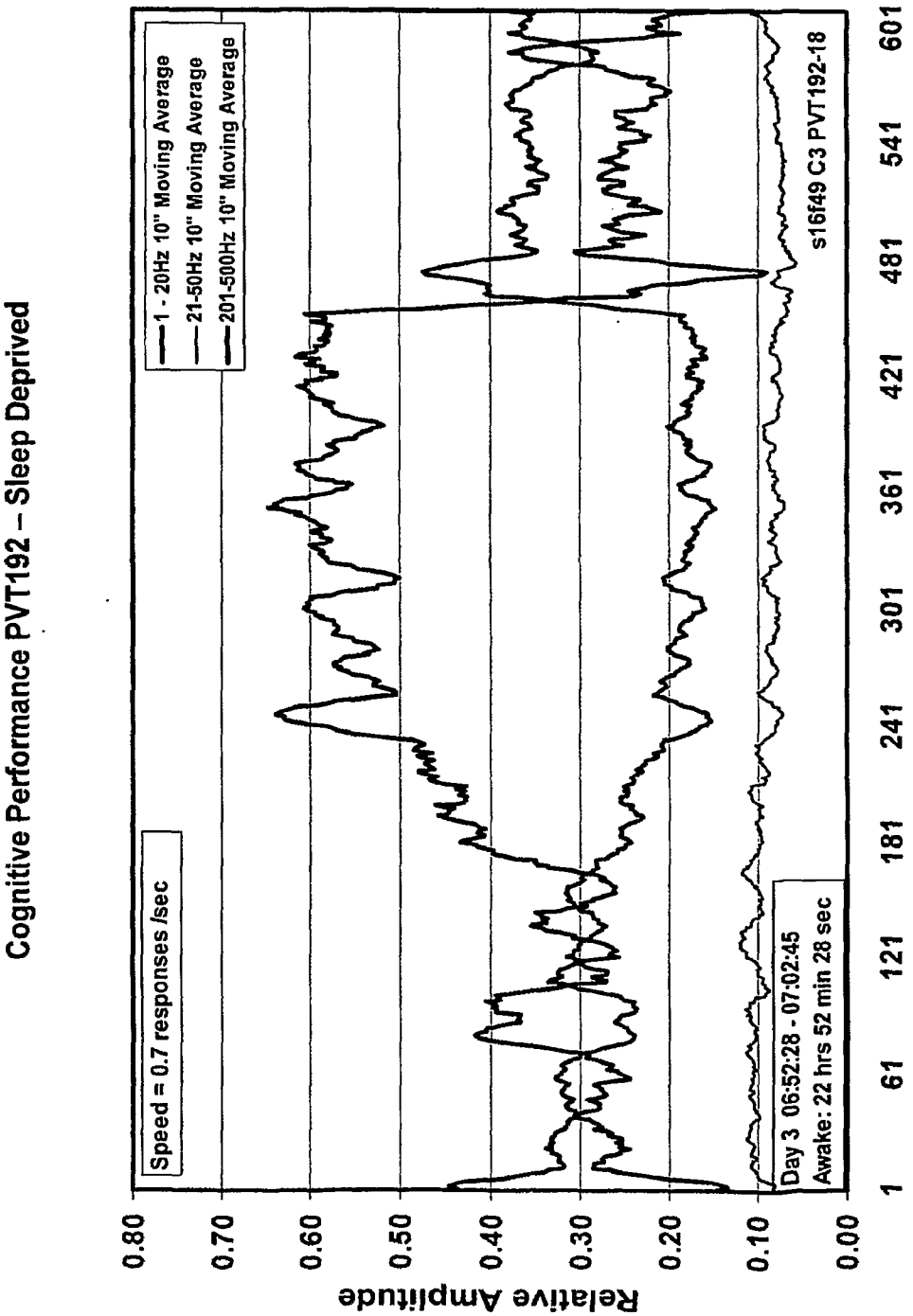
Cognitive Performance PVT192 – Sleep Deprived
Speed = 0.7 responses /sec
1 - 20Hz 10" Moving Average
21-50Hz 10" Moving Average
201-500Hz 10" Moving Average
Day 3 06:52:28 - 07:02:45
Awake: 22 hrs 52 min 28 sec
s16f49 C3 PVT192-18
Relative Amplitude
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1
61
121
181
241
301
361
421
481
541
601
Elapsed Time (sec)

FIG. 3

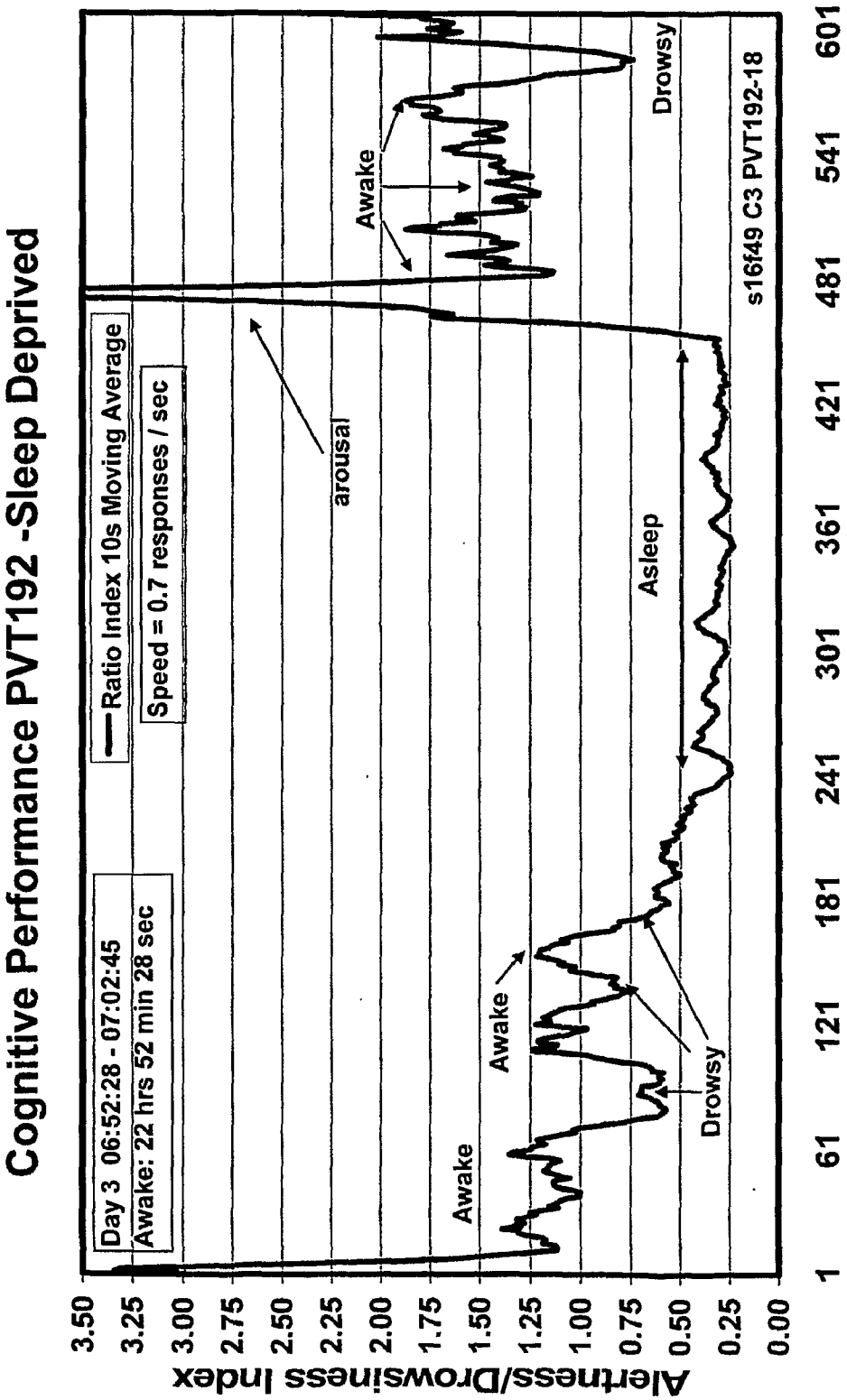
Cognitive Performance PVT192 -Sleep Deprived
Day 3 06:52:28 - 07:02:45
Awake: 22 hrs 52 min 28 sec
Ratio Index 10s Moving Average
Speed = 0.7 responses / sec
arousal
Awake
Awake
Asleep
Drowsy
Drowsy
s16f49 C3 PVT192-18
Alertness/Drowsiness Index
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
61
121
181
241
301
361
421
481
541
601
Elapsed Time (sec)

FIG. 4

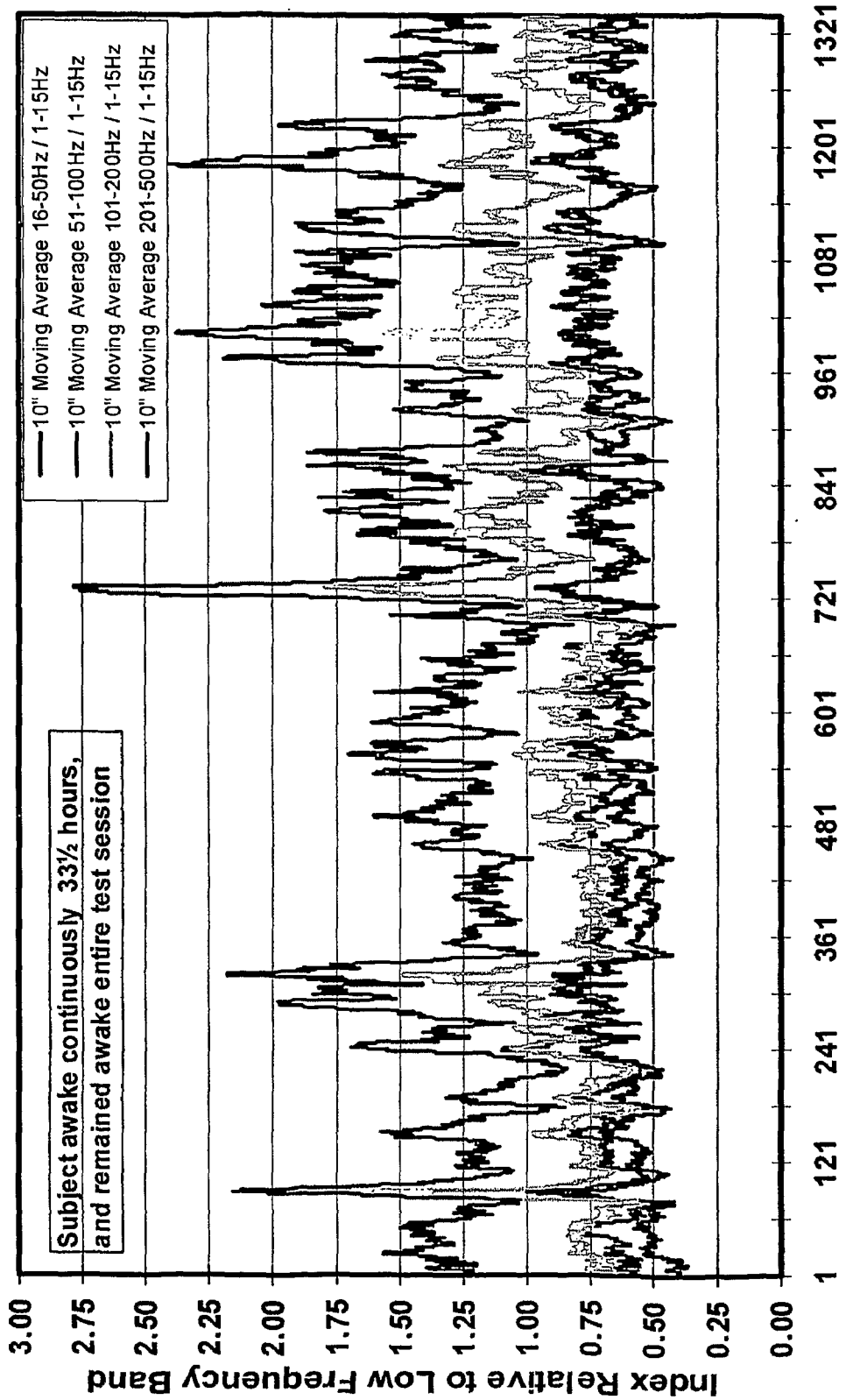
s11 CVPT14 Index
Subject awake continuously 33½ hours, and remained awake entire test session
10" Moving Average 16-50Hz / 1-15Hz
10" Moving Average 51-100Hz / 1-15Hz
10" Moving Average 101-200Hz / 1-15Hz
10" Moving Average 201-500Hz / 1-15Hz
Index Relative to Low Frequency Band
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
121
241
361
481
601
721
841
961
1081
1201
1321
Elapsed Time (sec)

FIG. 5

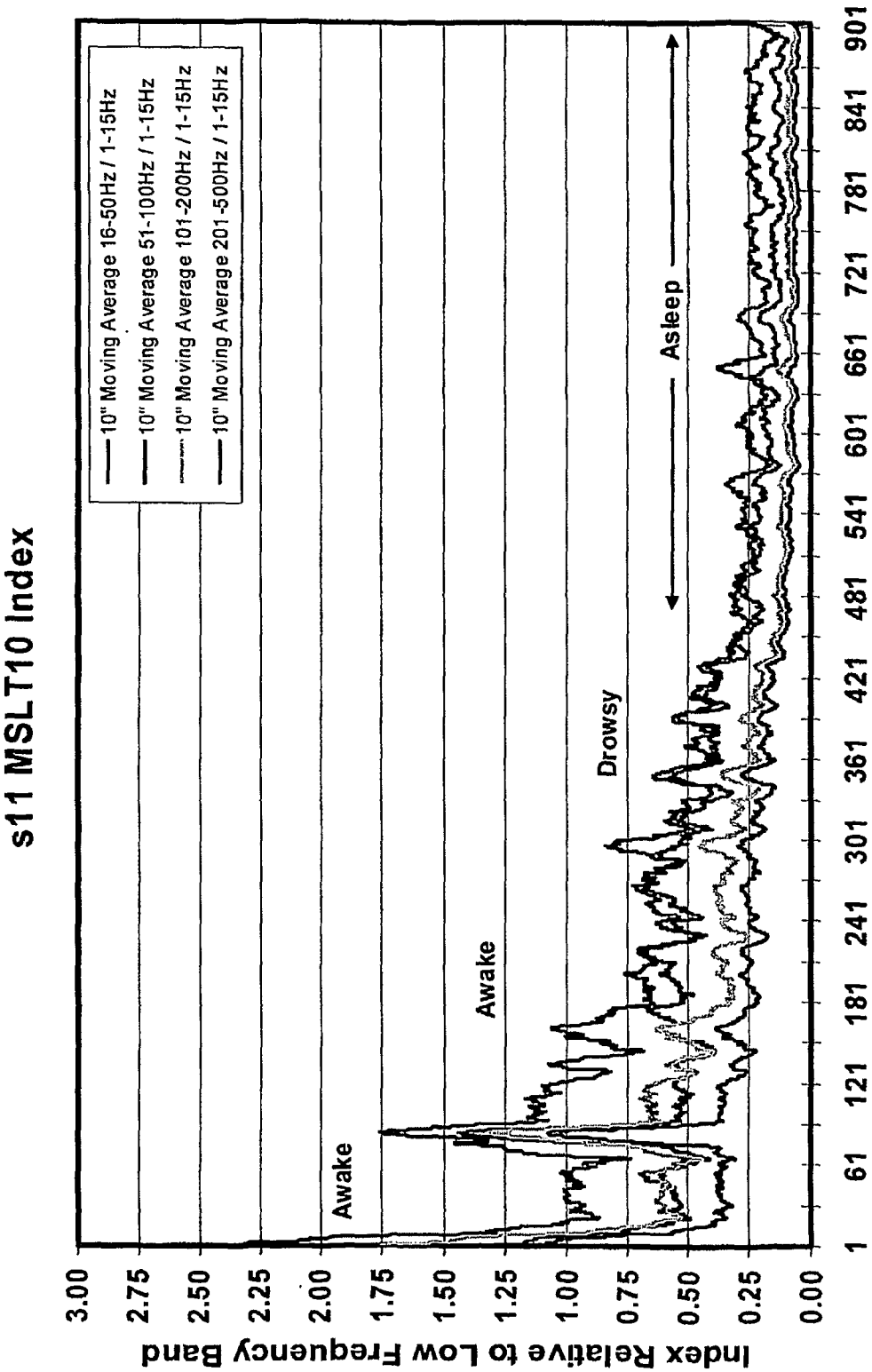
s11 MSLT10 Index
10" Moving Average 16-50Hz / 1-15Hz
10" Moving Average 51-100Hz / 1-15Hz
10" Moving Average 101-200Hz / 1-15Hz
10" Moving Average 201-500Hz / 1-15Hz
Awake
Awake
Drowsy
Asleep
Index Relative to Low Frequency Band
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
61
121
181
241
301
361
421
481
541
601
661
721
781
841
901
Elapsed Time (sec)

FIG. 6

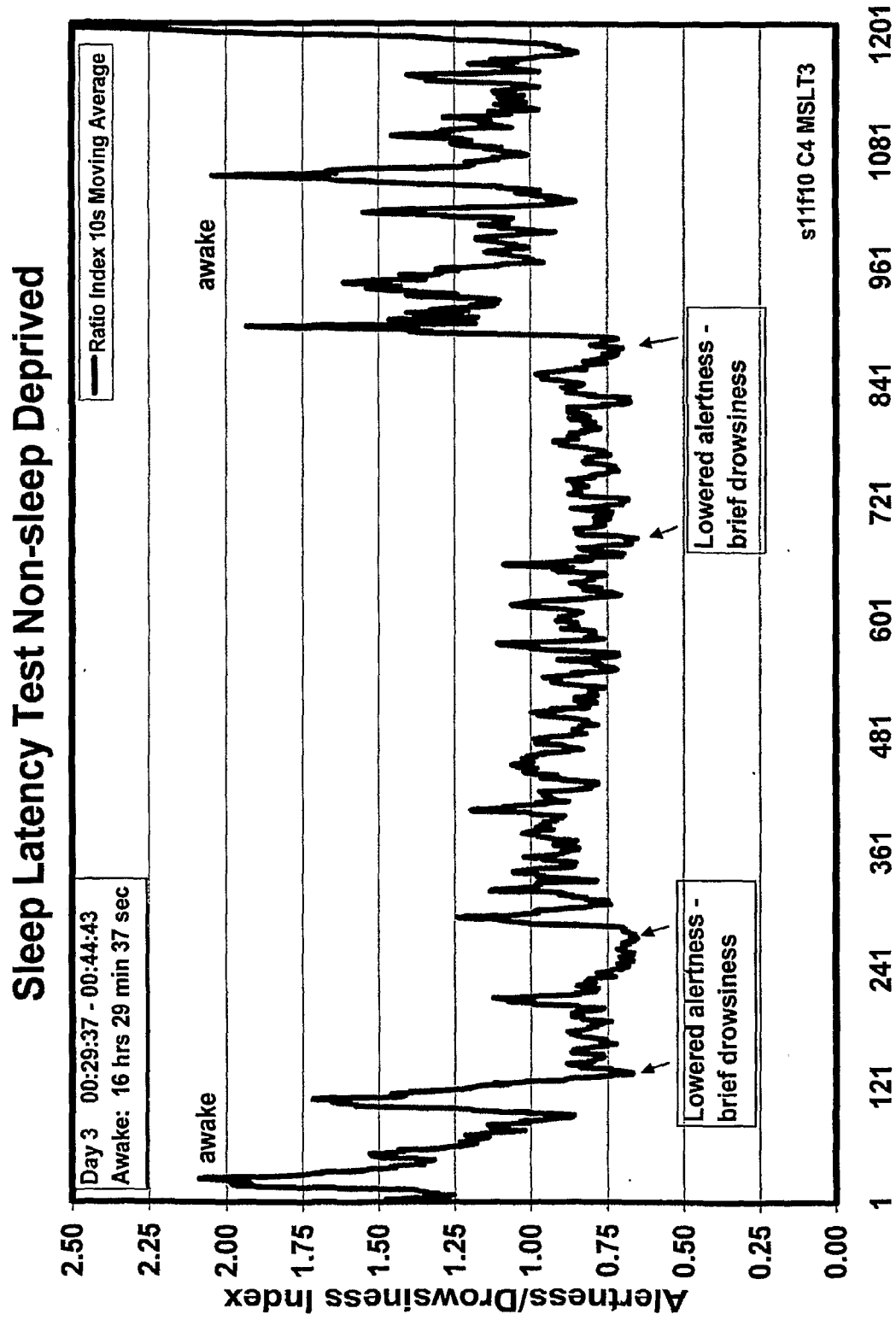
Sleep Latency Test Non-sleep Deprived
Ratio Index 10s Moving Average
Day 3 00:29:37 - 00:44:43
Awake: 16 hrs 29 min 37 sec
awake
awake
Lowered alertness - brief drowsiness
Lowered alertness - brief drowsiness
s11f10 C4 MSLT3
Alertness/Drowsiness Index
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
121
241
361
481
601
721
841
961
1081
1201
Elapsed Time (sec)

FIG. 7

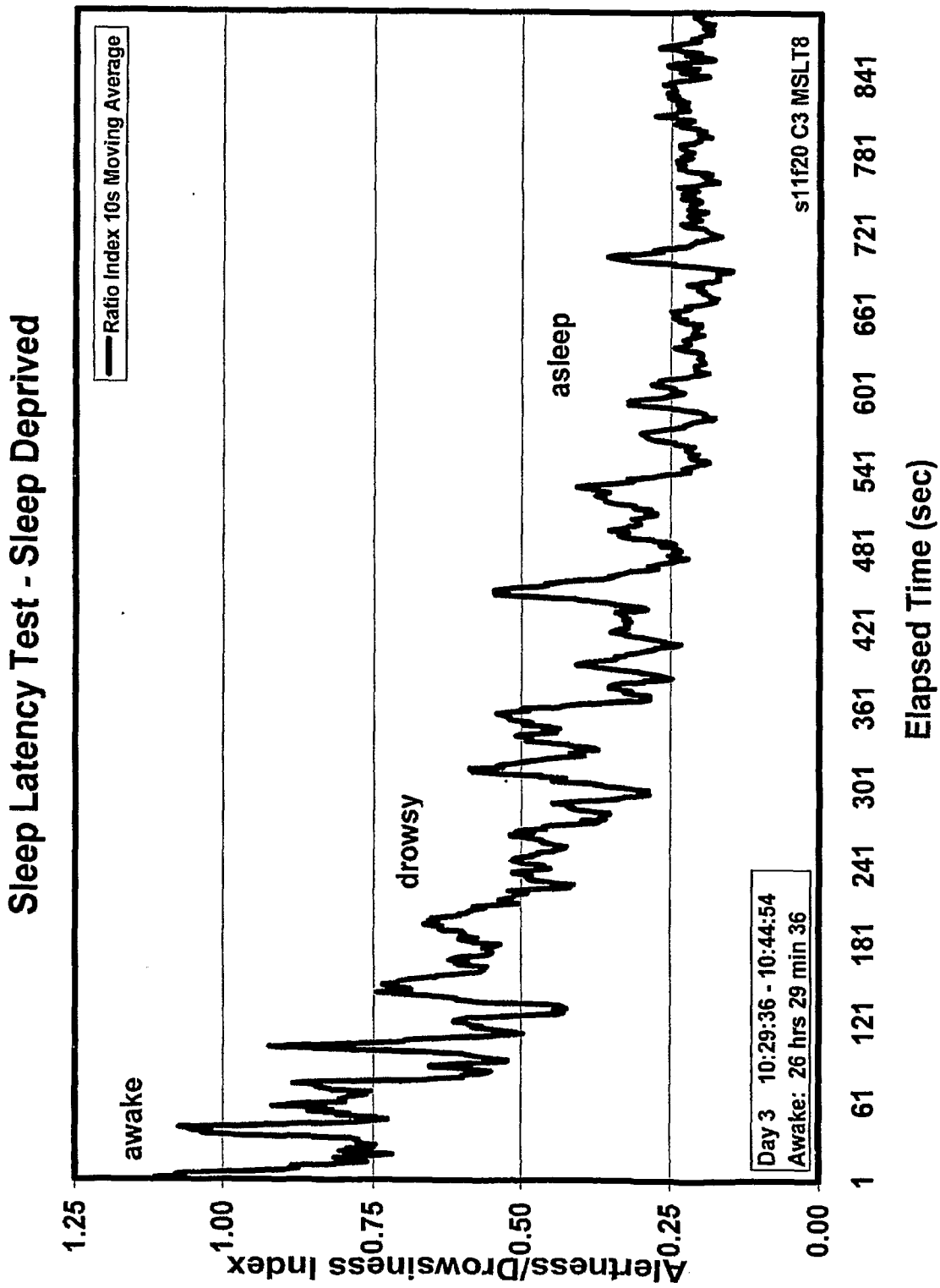
Sleep Latency Test - Sleep Deprived
Ratio Index 10s Moving Average
awake
drowsy
asleep
Day 3 10:29:36 - 10:44:54
Awake: 26 hrs 29 min 36
s11f20 C3 MSLT8
Alertness/Drowsiness Index
1.25
1.00
0.75
0.50
0.25
0.00
1
61
121
181
241
301
361
421
481
541
601
661
721
781
841
Elapsed Time (sec)

FIG. 8

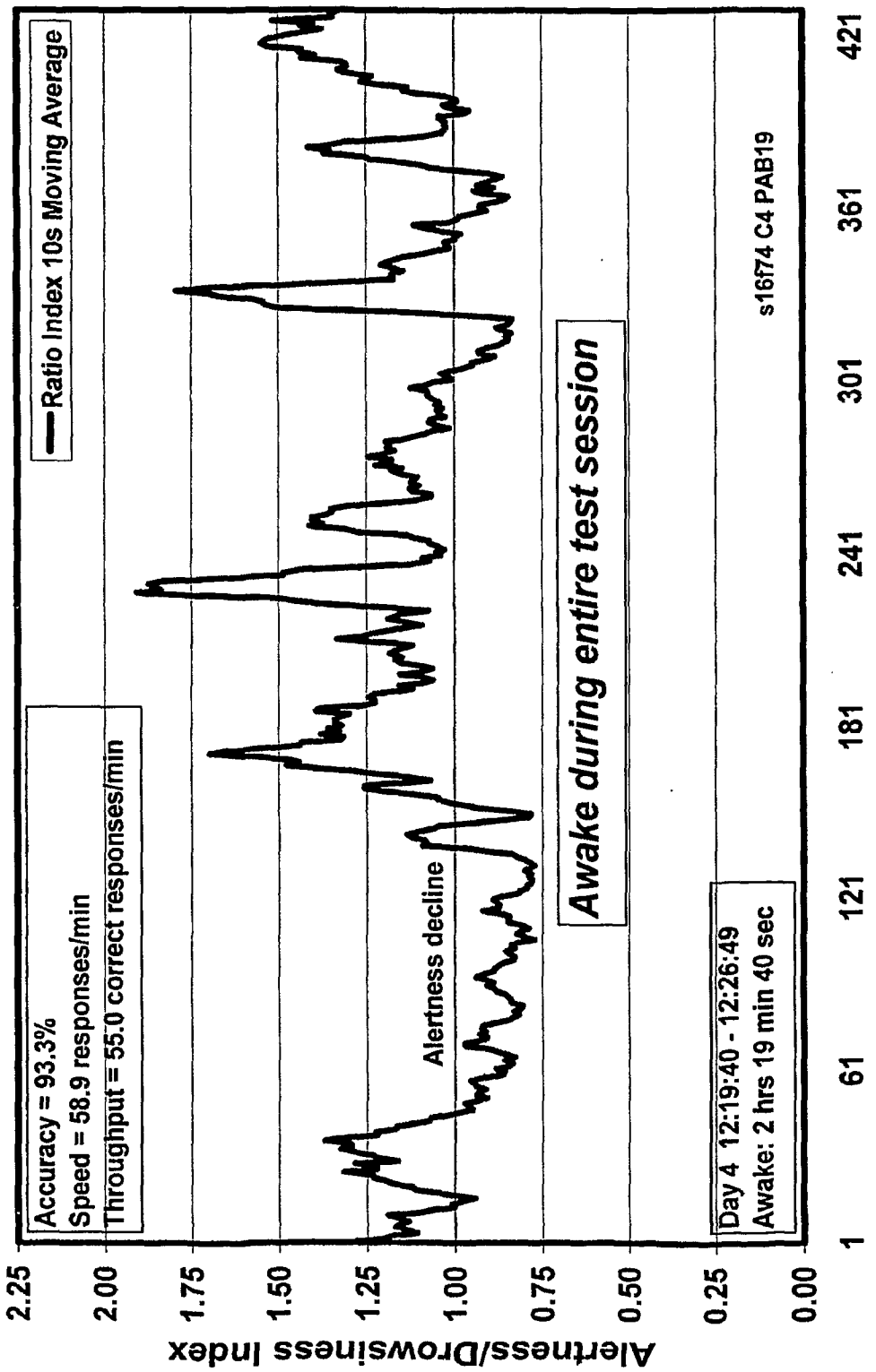
Cognitive Performance PAB - Rested
Ratio Index 10s Moving Average
Accuracy = 93.3%
Speed = 58.9 responses/min
Throughput = 55.0 correct responses/min
Alertness decline
Awake during entire test session
Day 4 12:19:40 - 12:26:49
Awake: 2 hrs 19 min 40 sec
s16f74 C4 PAB19
Alertness/Drowsiness Index
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
61
121
181
241
301
361
421
Elapsed Time (sec)

FIG. 9

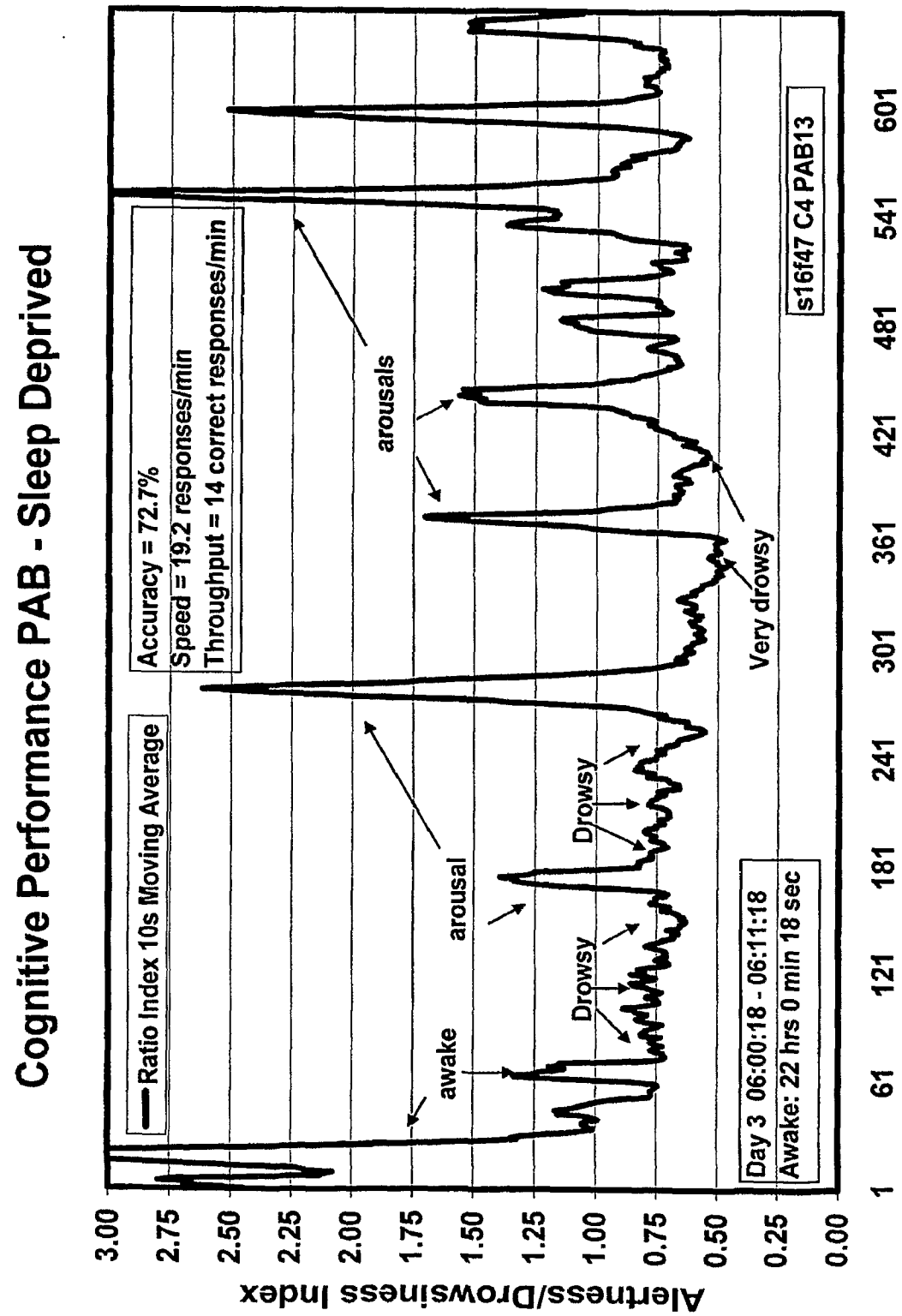
Cognitive Performance PAB - Sleep Deprived
Ratio Index 10s Moving Average
Accuracy = 72.7%
Speed = 19.2 responses/min
Throughput = 14 correct responses/min
arousals
awake
arousal
Drowsy
Drowsy
Very drowsy
Day 3 06:00:18 - 06:11:18
Awake: 22 hrs 0 min 18 sec
s16f47 C4 PAB13
Alertness/Drowsiness Index
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
61
121
181
241
301
361
421
481
541
601
Elapsed Time (sec)

FIG. 10

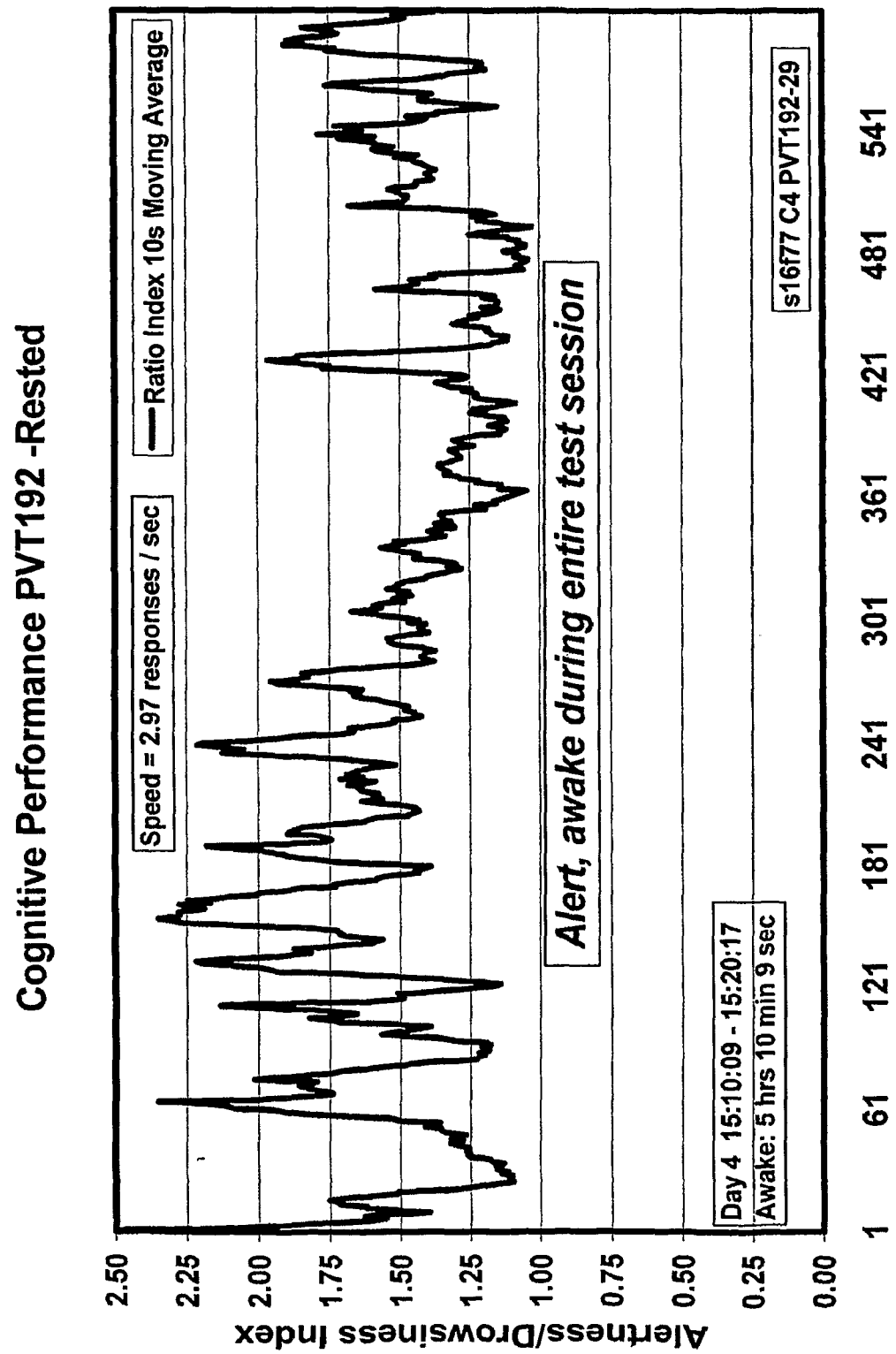
Cognitive Performance PVT192 -Rested
Speed = 2.97 responses / sec
Ratio Index 10s Moving Average
Alert, awake during entire test session
Day 4 15:10:09 - 15:20:17
Awake: 5 hrs 10 min 9 sec
s16f77 C4 PVT192-29
Alertness/Drowsiness Index
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
61
121
181
241
301
361
421
481
541
Elapsed Time (sec)

FIG. 11

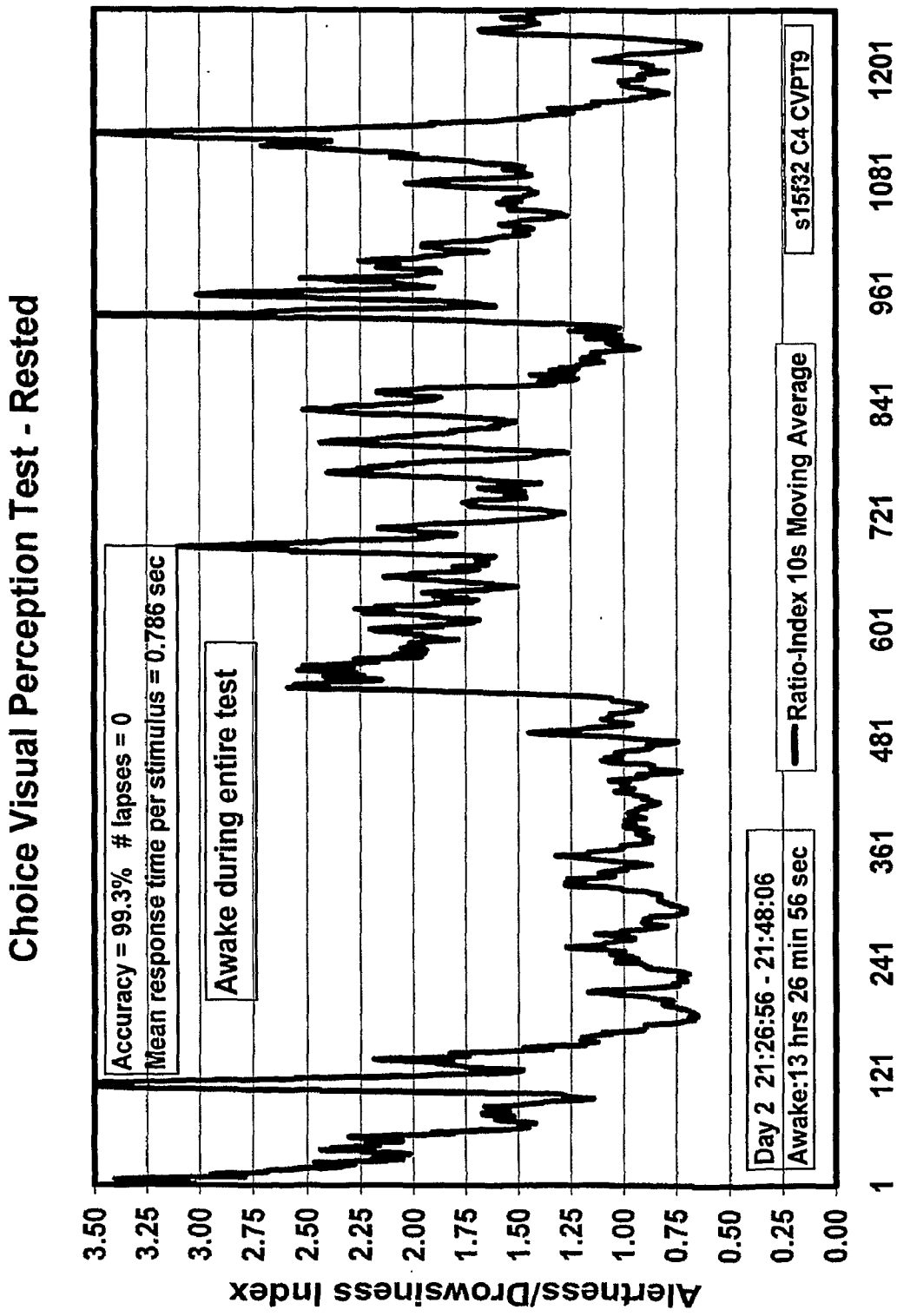
Choice Visual Perception Test - Rested
Accuracy = 99.3% # lapses = 0
Mean response time per stimulus = 0.786 sec
Awake during entire test
Day 2 21:26:56 - 21:48:06
Awake:13 hrs 26 min 56 sec
Ratio-Index 10s Moving Average
s15f32 C4 CVPT9
Alertness/Drowsiness Index
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
121
241
361
481
601
721
841
961
1081
1201
Elapsed Time (sec)

FIG. 12

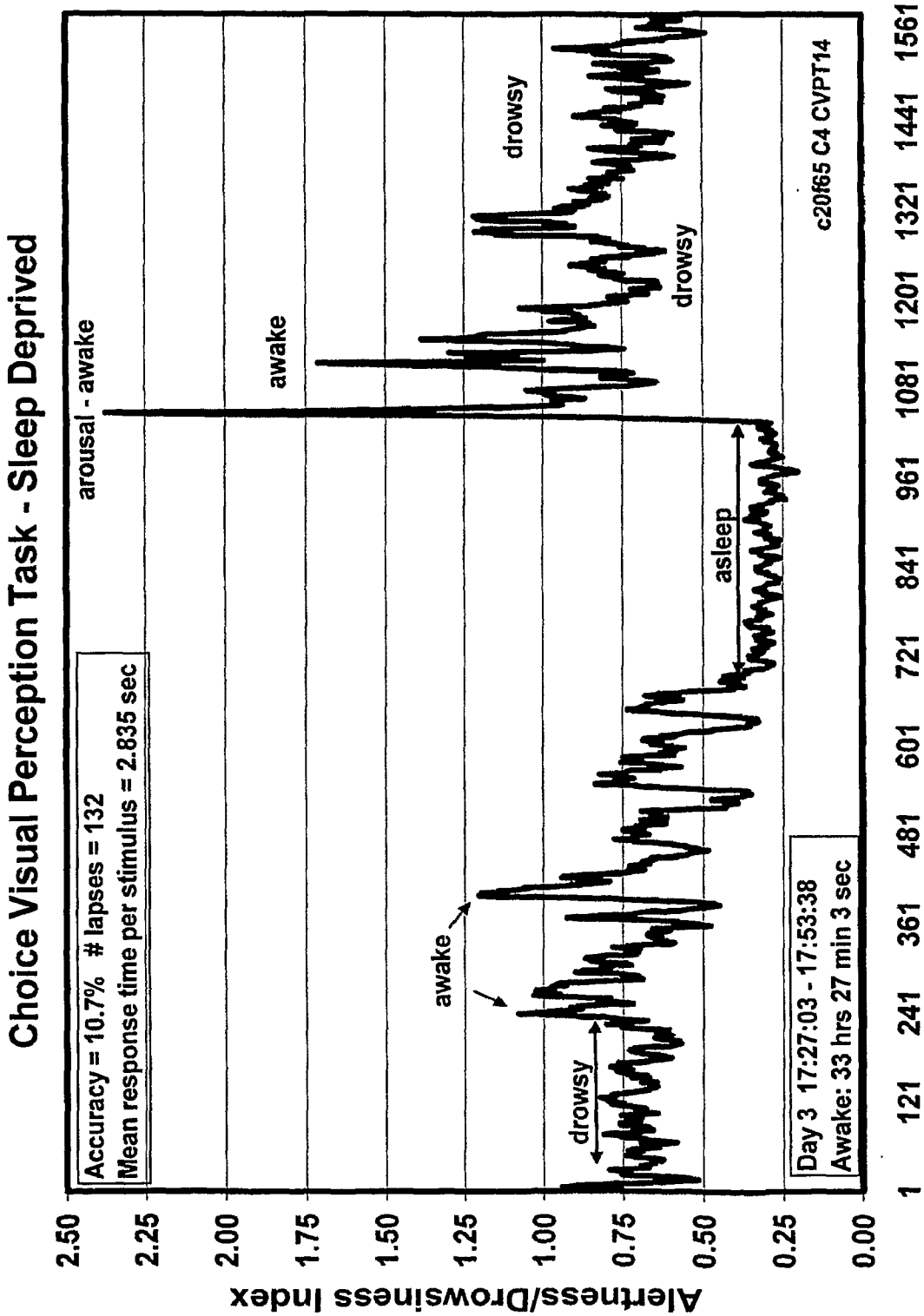
Choice Visual Perception Task - Sleep Deprived
Accuracy = 10.7% # lapses = 132
Mean response time per stimulus = 2.835 sec
arousal - awake
awake
drowsy
drowsy
asleep
awake
drowsy
Day 3 17:27:03 - 17:53:38
Awake: 33 hrs 27 min 3 sec
c20f65 C4 CVPT14
Alertness/Drowsiness Index
2.50
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
1
121
241
361
481
601
721
841
961
1081
1201
1321
1441
1561
Elapsed Time (sec)

FIG. 13

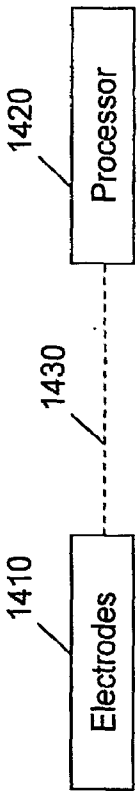
1420
Processor
1430
1410
Electrodes

FIG. 14

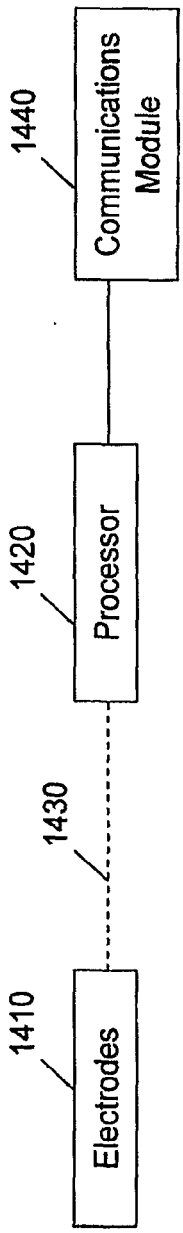
1440
Communications Module
1420
Processor
1430
1410
Electrodes

FIG. 15