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Analysis of the process of falling asleep – literature review

Analiza procesu zasypiania – przegląd piśmiennictwa

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ABSTRACT: Involuntary falling asleep at the wheel is the cause of many road accidents and is an important social problem. For this reason, it seems important to explore the physiological processes associated with human falling asleep. Particularly interesting are those physiological parameters, which changes accompany the transition from the state of full consciousness to sleep. Monitoring them could be used eg. in determining the level of driver drowsiness and therefore assesment of the risk of falling asleep at the wheel. In this article we present a summary of knowledge on changes in selected physiological parameters that occur on the border of allertness/ sleep and deep sleep.

Significant changes are particularly evident in the incidence of brain waves in the EEG. In addition, decrease in the activity of the autonomic nervous system leads to a decrease in heart rate and blood pressure. Also respiratory rate decreases and tidal volume increases. Spectral analysis of heart rate variability (HRV) shows decrease in the amplitude of the power spectral density function in the low frequency range. Also transition of eye movement from saccade to slow wave occurs during sleep which correlates with EEG changes. In addition, eyelids vibration disappear. Electromiography (EMG) shows gradual muscle tension fall. Warming in distal parts of limbs is also observed when falling asleep.

All these parameters tend to be useful for evaluating the fatigue of the driver. In this article, we also try to determine which of them are suitable for drivers drowsiness monitoring.

KEYWORDS: process of falling asleep, polysomnography

STRESZCZENIE: Bezwiedne zasypianie za kierownicą jest powodem wielu wypadków drogowych i stanowi ważny problem społeczny. Z tego powodu istotne wydaje się poznawanie procesów fizjologicznych towarzyszących zasypianiu człowieka. Szczególnie interesujące są te parametry fizjologiczne, których zmiany towarzyszą przechodzeniu ze stanu pełnej świadomości do zasypiania. Ich monitorowanie mogłoby posłużyć, np. w określeniu poziomu senności kierowcy, a co za tym idzie – ryzyka zaśnięcia za kierownicą. W niniejszym artykule przedstawiamy podsumowanie wiedzy na temat zmian wybranych parametrów fizjologicznych, które zachodzą na pograniczu czuwania i snu, a także w czasie samego snu.

Istotne zmiany są szczególnie widoczne w obrazie fal mózgowych w badaniu EEG. Ponadto zmniejsza się aktywność układu autonomicznego, co prowadzi do spadku tętna i ciśnienia tętniczego. Dochodzi również do zwolnienia rytmu oddechowego oraz pogłębienia oddechu. Analiza widmowa zmienności rytmu serca (HRV) wskazuje na spadek amplitudy funkcji gęstości widmowej mocy w zakresie składowych wolnych. Interesującym parametrem wydaje się monitorowanie narządu wzroku. Ruchy gałek ocznych w czasie zasypiania przechodzą ze skokowych na wolnofalowe, a przejście to dobrze koreluje ze zmianami w obrazie EEG. Ponadto stopniowo zanikają drgania powiek. Mierzone elektromiograficznie (EMG) napięcie mięśni spada. Opisanym zwiastunem zapadania w sen jest ocieplenie dystalnych części kończyn. Wszystkie te parametry wydają się być użyteczne w ocenie zmęczenia kierowcy. W artykule próbujemy również określić, które z nich są na tyle stabilne i łatwo mierzalne, aby mogły być zastosowane w celu efektywnego pomiaru senności kierowcy.

SŁOWA KLUCZOWE: proces zasypiania, polisomnografia

Traffic accidents are a significant social problem Driving mistakes, particularly those made by professional drivers, are often due to excessive, uncontrolled drowsiness leading to disturbed alertness and attention as well as to involuntary falling asleep. The fatigue may be intensified by long-lasting static postures as well as by the monotony of audible and visible external stimuli. Despite numerous attempts to identify the phenomena that accompany the transition from full alertness to falling asleep, no unambiguous criteria of the moment of falling asleep were established to date. Studies in driving simulators demonstrated poor correlation between subjective assessment of drowsiness and objective incidence of microsleep episodes. It is therefore reasonable to undertake research programs aimed at identification of measurable physiological parameters that differentiate the alertness from falling asleep. Literature reports highlight the role of non-invasive methods for the monitoring of physiological parameters of drivers and the behavior of driven vehicles. The monitoring of traction and driving wheel movements on one hand and the frequency of blinking, percentage of eyelid closure, heart rhythm fluctuations, changes in muscle tones and bioelectrical activity of the brain (EEG) on the other hand may be indicative of the driver's fatigue levels [12].

Literature contains a number of studies of the electrophysiological aspects of the process of falling asleep based on EEG waveforms (α, β, γ, δ, θ waves). Analyses revealed variability in the wavelengths of the bioelectrical activity of the brain in the transition periods between alertness and N1 as well as between N1 andN2 [20]. The comparison of amplitudes and frequencies of theta, delta, sigma, and alpha waves may be used to characterized drowsiness on clinical practice as well as facilitate the modeling of EEG records during sleep; however, the susceptibility of EEG records being disturbed by external interference is a significant methodological limitation of real-life monitoring possibilities. Therefore, changes in EEG waveforms must not be the only criterion for the assessment of drivers' fatigue [7].

Sleep is a reversible state of perceptive disconnection and absence of reactions to environmental stimuli. It is associated with behavioral changes, recumbent position, reduced muscle tine and eyelid closure [16]. It is considered to be a state of natural unconsciousness characterized by changes not only in the activity of the central nervous system, but also in the function of many other systems, including the cardiovascular, respiratory, and muscular systems as well as hormonal secretion [18]

Physiological changes occurring immediately before falling asleep include the central nervous system (CNS) as well as other organs, leading to changes that may be measured by means of functional markers. In recent decades, numerous research teams attempted to develop a universal description of functions and processes that accompany the process of falling asleep, i.e. the transition from alertness to physiological sleep. Among other findings, a decrease in the activity of cerebral cortex was observed during the transition within the CNS, which is referred to as gradual depression of awareness [6,9]. The main role in the process of falling asleep is played by the hypothalamus. Increased activity is observed within the anterior part of hypothalamus, particularly within the preoptic area, with simultaneous reduction in the activity of the ventrolateral region of the posterior part of the organ. There are two types of sleep: rapid eye movement (REM) sleep and non-rapid eye movement (NREM) sleep, i.e. the deep sleep phase. NREM sleep is divided into three stages [1].

ANALYSIS OF THE BIOELECTRICAL ACTIVITY OF BRAIN.

Clinical identification of transition from alertness into sleep is based on the analysis of changes in the structures and durations of individual wave types in EEG records [24]. According to some researchers, sleep is present only after stage 2 features become evident, since stage 1 is often associated with alternating features of alertness and sleep [28].

Changes occurring in EEF waves during the onset of sleep are difficult to standardize due to the inter-individual variability and spatiotemporal character of the process of falling asleep, i.e. translocation of changes from the frontal towards the occipital region [21].

EEG waves are conventionally described in groups characterized by different frequency ranges. Alpha (α) waves have the frequency range of 8 to 13 Hz. The amplitude of alpha waves is about 30-100 μV. They are well visible upon the absence of visual stimuli (upon eyelid closure) and suppressed during visual perception. The α waves are also associated with the state of relaxation and reduced level of cognitive activities. The morphology of these waves is stable throughout the individual's life and is not age-dependent. The α waves are recorded with the highest strength in the occipital region. During the onset of sleep, the α waves follow a crescendo-decrescendo pattern. The occurrence of α waves is considered to be a sensitive indicator of the onset of sleep. Literature reports highlight the correlation between the presence of α waves and the reduced alertness in drivers [10].

In 98% of subjects, the beta (β) waves have the frequency range of 13 to about 30 Hz (usually 18-25 Hz) and amplitude of less than 20 μV. They reflect the cortical involvement in cognitive activities. Low-amplitude β waves are observed upon focusing attention. They may also be evoked by pathological conditions or benzodiazepines. The β waves are predominant within the frontal lobes, with maximum amplitudes being achieved in the central fissure region. They increase in intensity during the stage of drowsiness and during the first stage of sleep.

The theta (θ) waves are characterized by frequency range of 4 to 8 Hz. The activity of θ waves may be observed in hypnotic states such as trance, hypnosis, and light sleep. They occur during the first and the second stage of NREM sleep. A different type of theta waves, referred to as frontal midline theta (FM θ) is associated with cognitive activity, particularly attention as well as with memory processes.. It is observed predominantly within the medial frontal part of the brain.

The delta (δ) waves are characterized by frequency range of up to 4 Hz. They are observed predominantly during the third stage of NREM sleep.

The gamma (γ) waves are characterized by frequencies of above 30 Hzand up to 80-100 Hz; the gamma rhythm accompanies the motor functions and activities.

Upon transition from sleeplessness (alertness) through stage 1 (nap) and 2 (light sleep) to stage 3 (deep sleep), the activity of α waves is reduced and the signal strength shifts towards the low-frequency components. Stage 2 is characterized by ϑ activity and sleep spindles (K complexes). Sleep spindles are spindle-shaped waves of increasing and dwindling amplitude and frequency of 12-14 Hz lasting no less than 0.5s. The third stage of sleep is characterized by the presence of low-frequency δ waves. After the deep sleep stage, the record may enter the REM stage. The cycle is repeated several times during the sleep, albeit with changes in the durations of its individual stages [29]. Predominance of NREM sleep was observed in the first two cycles while predominance of REM sleep was observed in the two last and longest cycles [11].

Gradual suppression of cortical activity leads to an increase in the threshold for the perception of external stimuli. Disconnection of the cortex from the rich source of information provided by the visual route, consisting in the closure of eyelids, is of the key importance here. The measurements of cerebral blood flows demonstrated slight reduction in metabolic activity of the brain during sleep. Cerebral blood flows reflect the changing activities of individual CNS regions during the onset of sleep and the sleep itself [17]

Cerebral activity varies depending on the phase of sleep. Reversed activity of brain hemispheres was observed, with right hemisphere being more active in left-handed individuals upon alertness and less stimulated during full stage 2 NREM sleep [4]. The glucose metabolism and oxygen consumption are reduced by 25-44% during the deep sleep (NREM) as compared to the alert state whereas during the REM sleep, the glucose metabolism and oxygen consumption are at the same level or even at a higher level than in the alert state. During NREM, the activity of thalamic nuclei, brain stem, ganglia, hypothalamus, parietal and cingulate cortex and precuneus is reduced while REM phase is associated with activity within the brain stem, particularly midbrain tegmentum, thalamus, amygdala, hippocampus, and anterior cingulate cortex. High activity of the limbic system during the REM phase confirms the hypothesis regarding the relationship between REM and memory processes [5].

Changes that accompany the onset of sleep and later the deepening of sleep may also be observed in the function of other organs.

ANALYSIS OF CHANGES IN THE CARDIOVASCULAR SYSTEM

Upon the onset of sleep, numerous changes are observed in cardiovascular parameters due to the reduced activity of autonomic nervous system. The heart rate drops on average by 6.68 bpm, leading to bradycardia at the level of 55-60 bpm [2].

Significant heart rate drops are observed upon transitions between each of the 4 states that precede stable sleep, i.e. alertness, 1NREM, 2NREM with excitations and stable 2NREM. The heart rate and the blood pressure during stable stage 2 NREM are significantly lower than in the alert state or the 1 NREM stage. The transition from the alert state to NREM is characterized by an increase in the incidence of respiratory sinus arrhythmia [3], although the research results are ambiguous. It is suggested that the incidence of respiratory sinus arrhythmia is related to the diurnal rhythm involving the falling asleep in the evening [2]. The spectral analysis of heart rate variability (HRV) reveals a drop in the amplitude of power spectral density function at the low frequency (LF) range of 0.1 Hz upon the onset of sleep followed by a slow increase upon arousal. Opposite changes are observed while dreaming: during the REM stage, the respiratory rhythm becomes accelerated, and so does the heart rate. The blood pressure also increases significantly [22,27].

The slight drop in blood pressure upon falling asleep is in close correlation wit the dilation of peripheral vessels, reduction in vascular resistance and drop in the systolic function of the heart due to the reduced activity of the sympathetic nervous system. The cardiac output drops slightly in a gradual fashion; the highest drop is observed in NREM stage (down by ca 10% of the baseline value) [13].

ANALYSIS OF THE RESPIRATORY SYSTEM

A slowing-down in the respiratory rhythm and the deepening of respiration is observed during the transition between the alert state and sleep. Pulmonary ventilation is reduced; the partial pressure of CO_2 in the blood is increased while the partial pressure of O_2 is slightly reduced. Stage 1 NREM sleep is usually preceded by hypercapnia by several seconds. The reduced activity of arterial chemoreceptors is responsible for the 50% drop in systemic response to hypercapnia as compared to the alert state [23]. Variable respiratory rate is observed due to the behavioral control of respiration, usually present in the alert state, being turned off at this stage. This leads to a reduced tone of upper respiratory tract muscles, increased resistance in upper airways and increased activity of intercostal muscles. Upon falling asleep, 40-80% of healthy individuals present with periodic breathing consisting in regular changes in the amplitude of respiratory movements; this is more common in adults than in children. In this state, minute ventilation is decreased and fluctuations are observed in the partial pressures of CO_2 and O_2 as well as slight fluctuations of oxygen saturation (SaO_2). Phases of sleep apnea of central origin, less commonly of obstructive origin, are also observed in the transition period [26].

ANALYSIS OF THE ORGAN OF VISION

With regard to the organ of vision, observations and measurements revealed chaotic, jumpy eyeball movements (saccades) and gradually decreasing eyelid flicker superseded by slow eye movement [8]. The slow eye movements are observed upon transition from the state of alertness into the 1st phase of NREM sleep. The appearance of slow eye movements is correlated with the changes in EEG records – a decrease in the strength of alpha waves (characteristic for relaxation) is observed with simultaneous increase in the strength of delta and theta waves (characteristic for deep sleep) [11]. The appearance of SEM is also correlated with the subjective impression of strong fatigue while the speed of the appearance of SEM after eyelid closure is positively correlated with the sleep onset latency period [19]. The monitoring of SEM could provide a parameter identifying the state of strong fatigue and the approaching onset of sleep. Attempts are made at recording the SEMs in order to detect the risk of driver's falling asleep. As the sleep deepens, the eyeball movements decrease gradually [25].

ANALYSIS OF THE MUSCULAR SYSTEM

Upon falling asleep, the tension of skeletal muscles as measured by electromyographic (EMG) methods gradually decreases to reach its minimum during the REM stage. The decrease in the tension is measured in the genioglossus muscle, tensor veli palatini muscle and diaphragm observed upon falling asleep is in the range of 1.6-4.3%. The drop is independent of respiratory activity and is associated with the transition from alertness to sleep [15]. Changes are also observed in the skin as its resistance and temperature are reduced (Hori, 1982; Van Den Heuvel et al., 1998). A difference between the proximal and distal body parts can be observed. Increased temperature of distal parts of the limbs as a consequence of vessel dilation is considered to be a warning sign of the onset of sleep [14].

SUMMARY

Fatigue and drowsiness of drivers creates a significant danger for traffic safety, particularly on freeways and expressways. The development of a system for early warning about the possibility of losing alertness and falling asleep would contribute to the reduction in the number of traffic accidents caused by involuntary falling asleep. The warning signals should be delivered after detection of reduced alertness or increased drowsiness; however, no clear criteria for operation of such an early warning system could be established to date due to inter-individual differences in states preceding the loss of consciousness in subjects. It appears that the development of an adaptational system based on analysis of multiple signals from physiological processes monitored in real time. The potential best candidates for the measurements of the level of drowsiness include, besides the difficult-to-record EEG signals, the variations in heart rhythm, eyeball movements, position of eyelids relative to the eyeballs, the tone of selected muscle groups and multiple-point temperature measurements.

References

1. Adrien J., Billiard M.: Neurobiology of the sleep-wake cycle, Sleep Physiology, Investigations and Medicine. Springer Science+Business Media, LLC. New York 2003.
2. Burgess H.J., Kleiman J., Trinder J.: Cardiac activity during sleep onset. Psychophysiology. 1999; 36: 298–300.
3. Burgess, H. J., Trinder, J., Kim, Y.: Cardiac parasympathetic nervous system activity does not increase in anticipation of sleep. Journal of Sleep Research. 1996; 5: 83–89.
4. Casagrande M., Bertini M.: Laterality of the sleep onset process: Which hemisphere goes to sleep first? Biological Psychology. 2008; 77: 76–80.

5. Dauvilliers Y., Billiard M.: The major physiological functions during sleep, Sleep Physiology, Investigations and Medicine. Springer Science+Business Media, LLC. New York 2003.
6. Davis H., Davis P.A., Loomis A.L., Harvey E.N., Hobart G.: Changes in human brain potentials during the onset of sleep. Science. 1937; 86: 448–450.
7. De Gennaro L., Bertini M.: The boundary between wakefulness and sleep: quantitative electroencephalographic changes during the sleep onset period. Neuroscience. 2001; 107: 1–11.
8. De Gennaro L., Ferrara M., Fabio F., Bertini M.: Slow eye movements and EEG power spectra during wake-sleep transition. Clin. Neurophysiol, 2000; 111: 2107–2115.
9. Dement W.C., Kleitman N.: The relation of eye movements during sleep to dream activity: an objective method for the study of dreaming. Journal of Experimental Psychology. 1957; 53: 339–346.
10. Gast H, Schindler K, Rummel C, Herrmann U.S., Roth C, Hess C.W., Mathis J.: EEG correlation and power during maintenance of wakefulness est after sleep-deprivation. Clin. Neurophysio. 2011; 122: 2025–2031.
11. Gilleminault C., Kreutzer M.L., Billiard M.: Normal Sleep, Sleep Physiology, Investigations and Medicine, Springer Science+Business Media, LLC., New York 2003.
12. Herrmann U.S., Hess C.W., Guggisberg A.G., Roth C., Gugger M., Mathis J.: Sleepiness is not always perceived before falling asleep in healthy, sleep-deprived subjects. Sleep Med. 2010; 11 (8): 747–751.
13. Huikuri H.V., Niemelä M.J., Ojala S., Rantala A., Ikäheimo M.J., Airaksinen K.E.: Circadian rhythms of frequency domain measures of heart rate variability in healthy subjects and patients with coronary artery disease. Effects of arousal and upright posture. Circulation. 1994; 90: 121–126.
14. Krauchi K., Cajochen C., Werth E., Wirz-Justice A.: Functional link between distal vasodilation and sleep-onset latency? Am. J. Physiol. Regulatory Integrative Comp. Physiol., 2000; 278: 741–748.
15. Lo Y.L., Jordan A.S., Malhotra A., Wellman A.: Influence of wakefulness on pharyngeal airway muscle activity. Thorax. 2007; 62: 799–805.
16. [16] Kryger M.H., Roth T., Dement W.C., Carskadon M.A.: Monitoring and staging human sleep. Principles and practice of sleep medicine. St. Louis: Elsevier Saunders, 2011; 16–26.
17. Maquet P.: Sleep function(s) and cerebral metabolism. Behav. Brain Res. 1995; 69: 75–83.
18. Martin E. A.: Oxford Concise Medical Dictionary. Oxford University Press, Oxford 2015.
19. Marzano C., Fratello F., Moroni F., Pellicciari M.C., Curcio G., Ferrara M.: Slow eye movements and subjective estimates of sleepiness predict EEG power changes during sleep deprivation. Sleep. 2007; 30: 610–616.
20. Morikawa T., Hayashi M., Hori T.: Auto power and coherence analysis of delta-theta band EEG during the waking-sleeping transition period. Electroencephalogr. Clin. Neurophysiol., 1997; 103: 633–641.
21. Ogilvie R.B.: The process of falling asleep. Sleep Medicine Reviews. 2001; 5: 247–270.
22. Orr W., Lin B., Adamson P., Vanoli E.: Autonomic control of heart rate variability during sleep. Sleep Research. 1993; 22: 26.
23. Phillipson E.A.: Control of breathing during sleep. Am. Rev. Respir. Dis. 1978; 118: 909–939.
24. Rechtschaffen A., Kales A. (Eds.): A Manual of Standardized Terminology: Techniques and Scoring System for Sleep Stages of Human subjects. B.I.S. Brain Research Institute, Los Angeles, CA. 1968.
25. Shin D., Sakai H., Uchiyama Y.: Slow eye movement detection can prevent sleep-related accidents effectively in a simulated driving task. J. Sleep Res. 2011; 20: 416–424.
26. Traczyk W., Trzebski A.: Fizjologia człowieka z elementami fizjologii stosowanej i klinicznej, Wydawnictwo Lekarskie PZWL, Warszawa 2015.
27. Vaughn B.V., Quint S.R., Messenheimer J.A., Robertson K.R.: Heart period variability in sleep. Electroencephalography and Clinical Neurophysiology. 1995; 94: 155–162.
28. Wright K.P., Badia P., Wauquier A.: Topographical and temporal patterns of brain activity during the transition from wakefulness to sleep. Sleep. 1995; 18: 880–889.
29. Zieliński J., Pływaczewski R., Bednarek M.: Zaburzenia oddychania w czasie snu. Wydawnictwo Lekarskie PZWL, Warszawa 2006.

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