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Neurotechnologies for the Nonpharmacological Treatment of Sleep Disorders

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Sleep is needed for maintenance of normal homeostasis and memory consolidation processes and the deep third stage of sleep plays a particularly important role. However, a significant proportion of the population suffers from poor sleep quality, insomnia, and problems with going to sleep. Pharmacological treatment of these problems is not always possible or appropriate, and in recent years we have seen increasing interest in nonpharmacological methods of influencing falling asleep and sleep. This review addresses various approaches to improving sleep quality and accelerating going to sleep: sensory actions of different modalities, approaches using transcranial stimulation, and normalization of daily sleep–waking rhythms. This article considers their main possible mechanisms of action. Nonpharmacological treatments most commonly produce increases in slow-wave activity in the third stage of sleep. The areas of application of different approaches are assessed: from exclusively research purposes to application in clinical practice and use in consumer devices.

Keywords: sleep impairments, nonpharmacological treatment, stimulation during sleep, sound stimulation, transcranial stimulation, slow waves.

Introduction. A number of studies have shown that 33–50% of the population suffer from insomnia (sleeplessness) and other sleep disorders in different periods of life. Complaints of insomnia (along with headache) are among the major causes of medical consultations. However, most complaints do not form part of chronic insomnia and are not confirmed by objective investigations, which frequently fail to detect significant impairments in either the duration or structure of patients' nocturnal sleep. In rarer cases, in fact, polysomnography identifies real impairments to the sleep–waking cycle. Chronic insomnia and lack of sleep increase the risk of developing other somatic and mental disorders, and induce impairments to cognitive functions [Poluektov, 2016], which are dangerous for occupational activities [Dorokhov, 2014]. The increase in the daylight period due to artificial illumination and fixed timetables for work and study force people with different stable preferences for sleep–waking regimes (chronotypes) to sleep in parts of the day which are nonoptimal for them, which generates problems with going to sleep and daytime sleepiness [Putilov, 2021].

The treatment of clinical forms of insomnia conventionally uses pharmacological therapy with hypnotic drugs. All the earlier generations of hypnotics – barbiturates, benzodiazepines, and Z-drugs – are agonists of different segments of the same GABA receptor complex. However, along with very powerful target effects, all these drugs have a whole series of well studied side effects, including memory impairments (on prolonged use) and produce metabolites with residual activity. In Russia, early-generation benzodiazepines, some of them addictive drugs, have thus far been readily available to all. These are being replaced by safer drugs: state-of-the-art benzodiazepines and latest-generation Z-drugs, though these too have side effects and can have adverse influences on sleep quality, the power of slow-wave brain activity during sleep, and people's status while awake. Furthermore, there is the risk of interaction with other drugs [Arbon et al., 2015; Schroeck et al., 2016]. When there is no clinically severe sleep impairment, use of hypnotics is not required and the psychotherapy approach is sufficiently effective. Differentiated versions of cognitive behavioral ther-

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apy constitute the leading nonpharmacological approach to treating insomnia, though this requires significant financial and time investment and not all patients follow advice stringently enough, which leads to recurrence of sleep problems [Poluektov, 2016; Herrero Babiloni et al., 2021].

Many people complain of sleep problems not reaching the clinical level but degrading quality of life. The development of nonpharmacological and low-invasive methods for improving sleep and increasing sleep quality may help many groups of people for whom pharmacological treatment is contraindicated due to risks or is inappropriate, and may constitute a valuable addition to the behavioral therapy of sleep disorders.

Current concepts [Borbély et al., 2016] indicate that sleep is regulated by two interacting mechanisms: homeostatic and circadian. The former of these is the evolutionarily younger and is responsible for the fine tuning of body rhythms to changing environmental conditions. It is apparent in the regulation of the sleep–waking cycle as increased tiring and sleepiness during waking and decreases in these during sleep. The latter is evolutionarily more ancient and supports synchronization of endogenous biorhythms and daily changes in the external environment: illumination and electromagnetic processes of heliogeophysical origin. One of the most notable manifestations is oscillations in the level of sleepiness: decreased in daytime and increases at night. According to this model, the state of the body at any time of day is determined by the algebraic sum of the circadian and homeostatic components. Sleep starts when this sum (or difference) reaches some threshold and ends when it decreases to zero.

Sleep in humans consists of four stages: three stages of slow-wave sleep, or non-rapid eye movement sleep (NREM), and rapid eye movement (REM), or paradoxical, sleep. In REM sleep, the EEG picture is similar to that in active waking: a marked β rhythm (12–30 Hz) and the presence of the θ rhythm (4–10 Hz). So-called sleep spindles appear in the second and third stages of sleep, these being periods of marked σ activity (12–15 Hz) lasting 0.5–2 sec. The third and deepest stage of slow-wave sleep is characterized by slow-wave activity (SA) in the δ range (0.8–4 Hz) in the EEG [Achermann and Borbely, 1997; Koval'zon, 2011]. This period is also often called slow-wave or δ sleep, because of the predominance of this rhythm. The interpretation of δ waves is that they reflect highly synchronized cortical activity: the lower point of the wave corresponds to the propagation of hyperpolarization and the upper to synchronized depolarization and increased excitability of neural networks [Timofeev and Chauvette, 2019]. SA during sleep increases in proportion to preceding waking because of the accumulation of homeostatic sleep pressure. Topographically, SA is most marked in the frontal areas of the brain [Borbély et al., 2016].

SA recorded during the slow-wave sleep phase is linked with metabolic processes, for example, glucose metabolism [Van Cauter et al., 2008; Copinschi et al., 2014]. Data from many studies provide evidence that this corresponds to the consolidation of various types of memory [Walker and van Der Helm, 2009; Marshall et al., 2020]. Slow-wave sleep and the processes of interactions between subcortical and cortical structures apparent on the EEG as sleep spindles play a particularly important role for memory function, so many researchers focus on these as treatment targets. Reviews have been published on potential actions on sleep with the aim of improving and preserving cognitive functions both in general terms [Diekelmann, 2014; Malkani and Zee, 2020] and in aging [Grimaldi et al., 2020]. Stimulation may potentially improve the quality of the homeostatically most important phase, i.e., the slow-wave stage of nocturnal sleep, both via increases in SA and spindle power and by increasing the duration of slow-wave sleep.

The commonest approach to influencing the mechanisms of homeostatic regulation of sleep consists of presenting stimuli of different modalities at a frequency of about 1 Hz, i.e., close to the frequency of δ waves, which make up the main rhythm in slow-wave sleep. Independently of stimulus modality, two groups of nonpharmacological methods of influencing sleep are distinguished, as reviewed in detail by Henao et al. [2020]. The first, nonadaptive, group of influences is methodologically simpler and does not involves changes in the stimulus depending on the state of the brain during sleep. The second is the adaptive group of treatments, using feedback and changes in stimulation parameters determined by EEG indicators of sleep: slow waves, sleep spindles, and changes in sleep depth. These treatments can increase or impair ongoing brain activity.

Using the auditory system as an example, we will consider in more detail the possible physiological mechanisms of actions on sleep and ways of implementing the two main approaches to nonpharmacological influences on sleep.

Sound Stimulation on Going to Sleep and during Sleep. Audio stimulation has long been in wide use in sleep research. Sound signals are often used to assess levels of activation and arousal as a function of sleep depth and to inhibit the onset of deep sleep in studies of evoked brain activity during sleep. However, sounds can serve not only to arouse the sleeping brain: sound stimuli of near-threshold intensity are used at different stages of sleep to accelerate going to sleep and increase sleep depth. Apart from direct influences on sleep, there is interest in subsequent improvements in wellbeing and cognitive functions during waking [Bellesi et al., 2014]; Henao et al., 2020]. Audio stimulation is an attractive and simple method to apply and is minimally invasive. In contrast to transcranial electrical and magnetic stimulation, it raises fewer questions with respect to long-term effects and can be regarded as more ecological. Although the long-term efficacy of stimuli of particular types remains subject to discussion in terms of improving sleep, devices using research results obtained in the last 10 years in this field are already available on the consumer market. These include the Philips SmartSleep Deep Sleep headband and Dreem headband (sound stimulation) and the Welltiss Mind (low-frequency electromagnetic pulse stimulation) devices, which are wearable on the head.

Possible Mechanisms of Action of Sound Stimulation. The experimental studies discussed above suggest that specific sound stimuli may influence the rate of going to sleep and the properties of bioelectrical activity in deep sleep. The neural pathways and mechanisms of auditory system reactivity during sleep reman incompletely understood, though the current theory is based on the existence of two anatomical and functionally distinct pathways of conduction from the cochlear nuclei to the cerebral cortex. The lemniscal pathway passes through cells in the nucleus of the medial geniculate body (MGB) of the thalamus and projects predominantly to the primary auditory cortex. The nonlemniscal pathway passes through brainstem structures to cells in the MGB matrix and then gives rise to extensive projections to the associative cortex. The lemniscal pathway sends highly precise auditory information for processing in the cortex. Multimodal integration, delayed responses to sound stimulation, and rapid adaptation to unchanging stimuli are more typical of the nonlemniscal pathway, and its function consists of more general tracking of changes in the environment. The pathways and nuclei of the nonlemniscal pathway show significant overlap with brain arousal system, allowing the brain to respond to sound stimuli during sleep [Hu, 2003].

Activation of the nonlemniscal auditory pathways, not eliciting waking, can induce synchronized activation of cortical neurons. The thalamocortical system is in a bistable state during deep sleep, such that synchronized neuron depolarization is followed by hyperpolarization, which at the EEG level is manifest as high-amplitude synchronized slow-wave activity. This mechanism proposes the existence of a “window” of acceptable sound stimulus intensities, below which stimulation is ineffective and above which it impairs sleep. Such stimuli will act on the bottom-up reticular activation system but is sufficiently strong to activate the nuclei of the locus ceruleus, inducing waking [Bellesi et al., 2014]. Because of the specific features of rapid adaptation of nonlemniscal pathways to unchanging stimuli, it is desirable to vary the frequency characteristics of sound presentation. Stimulus presentation time relative to the phase of oscillations is extremely important: in the state of hyperpolarization, the thalamocortical system is unable to respond to stimuli; stimulation is most effective at the beginning of the depolarization phase after passage of the negative peak of the EEG slow wave [Schabus et al., 2012]. Overall, such oscillatory phenomena as SA and sleep spindles significantly modulate sound signal processing during slow-wave sleep [Dang-Vu et al., 2011; Lustenberger et al., 2018]. The physiological processes described above in the auditory system constitute the main adaptive actions of audio stimulation using feedback and changes in stimulation parameters determined by EEG sleep indicators.

Nonadaptive approaches using audio stimulation make use of the entrainment phenomenon – synchronization of EEG rhythms with an external stimulus. For example, rhythmic sound stimulation in the EEG frequency range induces increases in EEG power in the corresponding ranges, which is manifest as an auditory steady state response (ASSR). The thalamocortical system is probably involved in generating ASSR [Lustenberger et al., 2018]. The specific features and mechanisms of involvement of brain rhythms at different frequencies and responses evoked by rhythmic stimulation, and the actions on sleep of stimuli synchronized with δ-wave phase have been discussed in detail in a review by Henao et al. [2020].

Nonadaptive Sound Stimulation Methods. The 2010s saw the beginning of active research into the possibility of increasing SA during sleep using rhythmic sound stimuli. Ngo et al. [2013a] compared bursts of pink noise presented chaotically or at a frequency of 0.8 Hz. Stimulation started before going to sleep at night and continued for about 90 min thereafter. Rhythmic stimulation had a dual effect: on the one hand, going to sleep was significantly slowed as compared with the control condition without sound or on chaotic presentation, while on the other, SA power was increased and sleep spindle activity was suppressed after onset of the second stage of sleep. SA was modulated and synchronized with rhythmic stimuli, though the number of slow waves did not change significantly. Stimulation at the beginning of the night had no effect on overall sleep architecture or the number of episodes of activation [Ngo et al., 2013a]. This study established a pattern, confirmed in other studies, of selective sensitivity to stimulation depending on sleep stage.

More effective entrainment of SA can be obtained using selective presentation of stimuli only during deep sleep. Furthermore, it allows problems with going to sleep and waking from shallow sleep to be avoided. Golrou et al. [2018] presented stimuli only with automatic detection of sleep depth, with chaotic variation in the loudness of presentation to avoid acclimation. This action did not lead to any significant change in total SA power or alterations in the NREM/REM sleep ratio but increased the total duration of the third stage of sleep at the expense of the less deep stages and decreased the number of wakings as compared with control nocturnal sleep without stimulation; it also improved subjective assessment of sleep quality.

Studies comparing different types of sounds in terms of their ability to influence sleep properties are of particular interest, as they emphasize the diversity of responses within a single protocol. A study published in 2020 compared the effects of sounds and noises “strengthening” and “impairing” nocturnal sleep. “Improving” stimuli were bursts of pink noise at a frequency of 0.8 Hz with different variants based on addition of baseline pure tones or loudness pulsations. “Impairing” stimuli (pager signals, engine noises), as expected, decreased sleep quality, decreased the proportion of deep sleep and SA, and reduced reaction speed in waking. "Improving" stimuli increased the proportion of deep sleep as compared with controls but produced no significant changes in EEG δ activity throughout the night. Sounds of any type induced local increases in δ activity after presentation as compared with controls, so integral assessment of effects throughout the whole night is important [Schade et al., 2020].

Studies of rhythmic audio stimulation mostly focus on influences on slow-wave sleep and δ activity, though attempts have been made to act on other sleep phases, such as REM sleep. Research in humans has shown that brief and loud (90 dB) beeps presented once every 20 sec during REM sleep throughout the night led to increases in the proportion of REM sleep in the experimental and next nights, and also increased sleep efficiency. The same stimulation 10 min after the end of the REM sleep period, of the same duration as this period, decreased sleep efficiency because of increases in the frequency and duration of wakings [Salin-Pascual et al., 1991]. Sound stimulation in REM sleep not only influenced this directly, but also improved memorization of the Morse code [Guerrien et al., 1989].

Rhythmic audio stimulation can also influence the characteristics of sleep spindles. Pulses of white noise amplitude-modulated at a frequency of 14 Hz (the frequency of sleep spindles) or 40 Hz (the frequency inducing marked ASSR) were presented during daytime sleep. ASSR reactions were also marked during sleep, though less strongly than in waking, and stimuli increased EEG signal power in the sleep spindle range during and after presentation of tones, especially for the frequency 14 Hz [Lustenberger et al., 2018].

There are many years of experience in facilitating going to sleep using music (for review see [De Niet et al., 2009]), and various audiovisual stimulation devices have been released for this purpose [Tang et al., 2016]. However, there have been very few experimental laboratory studies seeking to develop methods to accelerate going to sleep using sounds. This is probably because while the electrophysiological picture of δ sleep is quite conserved and differs only slightly in different individuals, the EEG on going to sleep is very individual [Santamaria and Chiappa, 1987].

Apart from sounds delivered synchronously to both ears, relaxation and psychotherapy programs often use so-called binaural beat (BB). BB is a subjective sensation observed on hearing two sound signals with slightly different frequencies through stereo headphones, one sound to each ear. If one ear hears a tone with a frequency of 440 Hz and the other a tone with a frequency of 434 Hz, the subject experiences the sensation of auditory beat at the difference frequency of 6 Hz. The neurophysiological mechanisms of action of binaural beat on sleep remains poorly studied, though it can induce an ASSR, just like rhythmic sound stimuli, and can produce specific changes in the functional connectivity of the EEG [Orozco Perez et al., 2020]. Data have been obtained showing that this has positive influences on sleep quality and work capacity after waking in professional sportsmen using BB at 20–8 Hz for eight weeks [Abeln et al., 2014]. A series of studies by Shumov et al. showed that BB on the background of pink noise does in fact accelerate the process of going to sleep as compared with monaural beats of sound loudness or unmodulated pink noise [Shumov et al., 2017, 2021; Shumov et al., 2020]. In addition, BB strengthens activation of the parasympathetic compartment of the autonomic nervous system, which is apparent as changes in measures of heart rhythm variability [Bakaeva et al., 2021]. The action of BB at a frequency of 3 Hz in the second stage of nocturnal sleep accelerated onset of the third stage and increased its duration and activity in the δ EEG range [Jirakittayakorn and Wongsawat, 2018]. Hearing only BB was subjectively uncomfortable, which can have negative impact on going to sleep or the desire to use this method. BB at 6 Hz combined with so-called "ASMR triggers" such as the sound of rain or a waterfall is calming and can aid going to sleep. Studies of this type of stimulation demonstrated an effective increase in EEG θ activity typical of the first stage of sleep and improved subjective evaluation of psychological stability [Lee et al., 2019]. The term ASMR – autonomous sensory meridian response – is an established informal name for the pleasant sensation of goosebumps on the skin of the head and back which some people experience in response to specific stimuli of different modalities, often auditory [Barratt and Davis, 2015].

A number of studies have addressed the possibility of some semantic processing of sound signals even during sleep. Studies have shown that the brain responds to speech even in the state of sleep and identifies the presence of subjectively important stimuli in the surroundings [Kouider et al., 2014; Blume et al., 2018]. For example, a study in 2020 used the idea of activating cognitive concepts associated with sleep and relaxation to improve sleep quality. Presentation of words associated with relaxation during slow-wave sleep, as compared with neutral words, lengthened the period of deep sleep, increased SA immediately after presentation of the words, and improved subjective assessment sleep quality [Beck et al., 2021].

Adaptive Sound Stimulation Methods. Studies have shown that sounds can be used to lengthen deep sleep, though there is always the problem of the balance between increased slow-wave activity and activation of the whole of the cerebral cortex and consequent waking. The brain is most sensitive to external stimuli at particular phases of slow waves. Systems tracking ongoing brain electrical activity and adjusting stimulation to it are optimal.

In the last decade, many groups have started to develop adaptive systems with dynamic control of stimulation based on EEG signals. These programs constantly monitor to ensure that sleep depth is sufficient (low power in the α and β EEG frequency ranges), with delivery of stimuli on appearance of δ waves, taking account of the required phase of the δ wave. Algorithms using signals in closed "stimulation system–brain" circuits were adapted from radio engineering (automatic frequency control, AFC) and their operating principle consists of detecting oscillations at a particular frequency in the signal, tracking further changes in these, and adjusting the moment of stimulation to the wave phase. In the case of audio stimulation during sleep, the algorithm detects the positive peak of the δ wave and the stimulus is presented in its ascending phase, when the "window" for arousability to somatosensory cortex is open [Santostasi et al., 2016]. This action induces not only strengthening of the δ wave immediately following the stimulus but also recruits the faster rhythms of the θ range and sleep spines [Henao et al., 2020]. There are also other approaches claiming greater precision and flexibility, modeling the whole of the ongoing oscillatory activity of the EEG using a set of sine functions [Talamini and Juan, 2020].

Ngo et al. actively addressed studies of the influence of adaptive sound stimulation using AFC and the EEG (closed-loop stimulation) on sleep and cognitive functions. In their first studies (2013), which provided grounds for further stimulation paradigms, they demonstrated increases in SA, synchronization of sleep spindles and slow waves, and improvements in declarative memory using sound stimulation in slow-wave nocturnal sleep using pairs of clicks of pink noise where the first click was synchronized with the rising front of the δ wave and the second was delivered 1.075 sec later, coinciding with the next wave. Pairs of stimuli delivered out of phase with oscillations, conversely, impaired synchronized SA [Ngo et al., 2013b]. It is interesting that a further increase in the number of stimuli running sequentially in the train gave no advantage: this regime also induced the appearance of trains of several sequentially running δ waves and improved word memorization, though there were no significant differences compared with pairs of clicks. This suggested that the possible action of EEG-synchronized sound stimuli is limited by endogenous factors, probably refractoriness in the thalamocortical system, such that the occurrence of excessive "build-up" of SA becomes unlikely [Ngo et al., 2015].

The same research groups showed that sensitivity to sound stimulation with AFC changes with age. In the older age group (mean 56 years), stimulation also increased synchronized SA and slow-wave-associated sleep spindles, though the effect was less marked and had a different time dynamic. No positive influence on declarative memory was seen in this group [Schneider et al., 2020]. Adaptive sound stimulation during nocturnal sleep also increased SA in children, imHproving consolidation of declarative memory in healthy children and improving motor learning and working memory in children with attention deficit hyperactivity disorder [Prehn-Kristensen et al., 2020].

Single but not paired stimuli presented at the rising front of the δ wave also enhanced SA and sleep spindles in deep sleep and had selective positive influences on memorization of pairs of words, but not images, "face-name" pairs, or motor tasks [Leminen et al., 2017].

Another group of investigators [Ong et al., 2016] demonstrated widening of the influence of this type of stimulation on EEG parameters. Stimuli with trains of five tones during daytime sleep increased the amplitude of slow-wave activity, the θ rhythm, and fast sleep spindles (14–16 Hz), and also improved results in a declarative memory test. Stimulation at the rising front of the δ wave [Krugliakova et al., 2020] globally increased the δ, θ, and σ rhythms. In addition, linkage between the δ and σ rhythms changed locally, which may be associated with reorganization of neuronal plasticity processes.

One group developing an approach using an algorithm with automatic tuning showed that a system with software could be created to deliver paired stimuli with AFC in automatically detected slow-wave sleep [Santostasi et al., 2016]. This showed improvements in SA and sleep spindle activity, as well as declarative memory, including in elderly subjects [Papalambros et al., 2017]. In the case of elderly subjects with moderate amnestic cognitive impairments, improvements in memorization were not seen in all cases and were associated with increases in SA [Papalambros et al., 2019].

When using adaptive stimulation, it is extremely important for stimulus delivery to be in the rising phase of slow waves – if not, adverse changes can occur. Sound stimuli delivered in the decay front of a δ wave not only decreased SA, but also led to degradation of motor learning, again emphasizing the tight connection between sleep and memorization processes [Fattinger et al., 2017].

Both SA and sleep spindles are closely connected with memory consolidation processes, so they are also targets for stimulation. Presentation of pink noise after detection of sleep spindles induced activation in the θ and β ranges and directly suppressed spindle activity. Further studies demonstrated improvements in motor learning using similar stimulation during daytime sleep, though only in subjects not displaying sleep spindles with delays with respect to the stimulus [Choi et al., 2018, 2019], while no marked influence on declarative memory was seen [Ngo et al., 2019]. Stimulation was also delivered in REM sleep, where 1-sec presentation of noise modulated at 5 Hz, linked to the appearance of the θ rhythm, led first to amplification and then to suppression of the θ rhythm and amplification of the β rhythm [Harrington et al., 2020].

Slow-wave sleep has important physiological functions and stimulation can potentially influence processes outside the central nervous system. This is indicated by the ability of adaptive sound stimulation to increase hormonal changes characteristic of slow-wave sleep – decreases in the cortisol level and increases in aldosterone – and also to decrease blood B- and T-lymphocyte levels [Besedovsky et al., 2017]. Increases in SA, decreases in drops in cortisol levels from evening to morning, contraction of the duration of sympathetic activation, and strengthening of parasympathetic activity during stimulation were seen in work reported by another group [Grimaldi et al., 2019]. Actions at the hormonal level are not always confirmed: another group demonstrated the effects of nocturnal stimulation on the cortisol, chromographin A, and α-amylase levels as compared with controls [Arnal et al., 2017]. Slow-wave sleep is closely associated with the regulation of glucose metabolism, though adaptive stimulation in the first half of the night in healthy men had no effect on the blood glucose level on waking, measures in the glucose loading test, food consumption, or energy expenditure [Santiago et al., 2019].

On the basis of the principle of sound stimulation during deep sleep, stimulation devices operating with adaptive algorithms have already appeared on the consumer market. One of these is the Dreem (France). This device can record the EEG, respiratory rate, and heartbeat, and automatically identify the stage of sleep with accuracy comparable to that of clinical polysomnographic systems [Arnal et al., 2020]. The Dreem system uses frontal and occipital dry electrodes to detect the third stage of sleep and deliver pairs of sound stimuli in the rising phase of two sequential δ waves, which leads to increases in SA. The effect lasts at least 10 nights of continuous use [Debellemaniere et al., 2018]. Another device – the Philips SmartSleep Deep Sleep Headband – also employs single-use electrodes to deliver hybrid sound stimuli in deep sleep as trains of five stimuli with 1-sec intervals, the first of which is coupled with the rising front of a δ wave. This device also increased SA and sleep spindle activity [Garcia-Molina et al., 2018, 2019].

Other Sensory SA Treatments. Temperature Treatment. Another approach to correcting sleep disorders in humans consists of temperature treatment or targeted changes in environmental temperature. This approach is based on extensive experimental data and the concepts that the evening rise in sleepiness and the onset of sleep are accompanied by decreases in core body temperature and an increase in limb temperature due to increased cutaneous blood flow and increased heat loss from the skin surface. Notable deviations in environmental temperature from the comfort level led to decreased sleep quality [Rogers et al., 2007; Troynikov et al., 2018].

Consistent with these concepts, studies have shown that warming of the skin can serve as the input signal for cerebral sleep regulatory systems and induce onset of sleep and increase slow-wave sleep [Raymann et al., 2005, 2008]. It has also been shown that an increase in the proportion of deep sleep can be achieved by gradually decreasing body temperature using smooth changes in environmental temperature [Togo et al., 2007]. Maintenance of a comfortable microclimate in the bedroom is itself a factor with positive influences on sleep depth [Troynikov et al., 2018].

Vestibular Stimulation. Rocking is one of the first actions on falling asleep and sleep experienced by humans in life. This method objectively promotes reductions in arousal not only in humans. Animal studies have shown that even in *Drosophila*, rocking or vibration induces sleep and decreases activity; an important role is played by the process of habituation [Öztürk-Çolak et al., 2020]. In mice, rocking improved going to sleep and increased the quantity of slow-wave sleep, this effect being mediated by the reaction of the vestibular system to acceleration [Kompotis et al., 2019]. Despite these studies, the exact mechanisms of the relaxing effect of rocking remain unclear although, perhaps, the mechanism consists of synchronization of the thalamocortical networks with vestibular signals, as in the case of other sensory treatments [Bayer et al., 2011; Perrault et al., 2019].

Vestibular stimulation has a long history of use as a therapeutic method in a whole series of psychiatric, neurological, and other disorders, as reviewed by Grabherr et al. [2015]. Despite the wide use of rocking as a home method, there is relatively little scientific research into its actions on falling asleep and sleep. For example, rocking on going to sleep and during movements was comfortable for children with sleep-related rhythmic movement disorder, though single exposures had no effect on their sleep [van Sluijs et al., 2020a].

The positive influences of rocking on sleep in adult subjects have been demonstrated in several experiments. During daytime sleep, rocking at 0.25 Hz accelerated falling asleep and increased the proportion of the second stage of sleep, increasing the number of sleep spindles and SA in the second half of sleep [Bayer et al., 2011]. Acceleration of falling asleep with rocking at 0.24–0.3 Hz in daytime sleep was also demonstrated in another study, though sleep structure did not change [van Sluijs et al., 2020b]. Rocking for two nights led to a reduction in the time taken to go to sleep and a decrease in the proportion of the second stage of sleep without affecting daytime sleepiness [Woodward et al., 1990]. This effect was not always seen: in another study, rocking of subjects without sleep problems before nocturnal sleep or in the first two years had no effect on overall sleep structure, though during rocking there were increases in the proportion of the second stage and sleep spindles, and subjects preferred nights with rocking [Omlin et al., 2018]. It may be that rocking during the whole night is more effective, as it accelerated the onset of deep sleep, increased sleep depth, increased SA, and had positive influence on memorization [Perrault et al., 2019]. On the other hand, nocturnal rocking in elderly subjects on a subjectively comfortable axis did not improve sleep or memorization, doing no more than reducing EEG δ activity. This difference in effects may be linked both with an age-related decrease in vestibular sensitivity (stimulation was subthreshold) and the specific features of bed movements in different studies [van Sluijs et al., 2020c].

Different types of rocking may have different levels of effectiveness: a study using rocking in six different axes of bed movement showed that the subjectively preferred axis for relaxation was the vertical axis, though the authors noted the absence of any change in the EEG or ECG on rocking and extensive individual variation in preferences [Crivelli et al., 2016]. Another group of researchers simulated maternal rocking movements and demonstrated the importance of the linear (along the body) component of movement and also determined the optimum parameters of such rocking for going to sleep, including frequency (0.234 Hz). Rocking improved daytime falling asleep and was significantly better than aromatherapy and other types of rocking [Ashida et al., 2015; Shibagaki et al., 2017].

Rocking is not they only way of acting on the vestibular system in humans; direct stimulation of the vestibular nerve can also be used. For example, single transcranial electrical stimulation of the vestibular apparatus can promote falling asleep when going to sleep is shifted to earlier times (a model of insomnia) in people with low daytime sleepiness [Krystal et al., 2010]. This stimulation gave a positive effect when applied before sleep for 14 days in another study, where improvements were obtained on the Insomnia Severity Index and subjective assessment of sleep quality [Kumar Goothy and McKeown, 2021].

Overall, rocking is a safe, ecological, and quite effective method for relaxation and improving going to sleep, though subjective comfort and real actions on sleep may not be associated with each other and may also require selection of parameters and duration of action taking account of individual characteristics.

Phototherapy. Phototherapy (bright light therapy) is a popular approach to influencing the circadian system and is a physiotherapeutic method for correcting and treating emotional and somatoautonomic disorders and sleep impairments in seasonal affective disorder and systemic desynchronoses of other types. A theoretical model describing the influence of light on the state of biological rhythms includes the concept of resetting the phase synchronization of a biorhythm using an external action.

Phototherapy uses fluorescence or LED lamps simulating the spectrum of natural daylight illumination. The systemic circadian effects of phototherapy include regulation of basal temperature and melatonin concentration and an increase in the spectral power of slow-wave sleep. Phototherapy is currently prescribed in both the morning and evening hours, as well as at both times of day [Pudikov and Dorokhov, 2018]. Its effectiveness is due to the importance of illumination as a signal for adjustment of the biological clock controlling the circadian rhythm [Putilov, 2021]. Presenting patients with bright light at a strictly defined time of day can be used to treat certain sleep impairments [van Maanen et al., 2016] and to correct sleep impairments due to a change in time zone [Roach and Sargent, 2019]. In elderly people, phototherapy can not only eliminate sleep disorders, but can also decrease unfavorable behavioral and cognitive symptoms due to dementia and depression [Gammack, 2008].

Electric light in combination with current lifestyles with long periods of time spent indoors has led to profound changes in the way people interact with light. The action of light at night suppresses production of the sleep-inducing hormone melatonin and induces impairments to circadian rhythms, which is linked with a whole series of adverse consequences for health, including sleep disruption. Melatonin production is most strongly suppressed by blue light [West et al., 2011].

One way of solving this problem consists of selecting bulbs for domestic lighting with spectral characteristics with a minimum of short-wave blue light. Light from low-energy and LED bulbs contains much more arousing blue light than incandescent bulbs. However, there are also state-of-the-art LED bulbs with no or minimal amounts of blue light in their spectra [Cain et al., 2020]. Another recommendation consists of not watching televisions, computers or smartphones before sleep, as screen light contains large amounts of blue light [Brunborg et al., 2011]. Filtration of short-wavelength light entering the eye before nocturnal sleep can be achieved using glasses with orange or amber lenses (Blue Blocker Glasses) [Ostrin et al., 2017; Schechter et al., 2020].

Electrocutaneous Stimulation. Indurskii's group [Indurskii et al., 2013; Gulyaev et al., 2017] showed that rhythmic electrocutaneous stimulation of the palms at near-threshold intensity at a frequency of the order of 1 Hz during the slow-wave stage of sleep improved nocturnal sleep quality. The slow-wave stage of sleep was identified using the phasic component of the cutaneous galvanic response (CGR) recorded from the subject's palm. This technology is currently realized as autonomous wearable device Sonya (Neurokom, Russia), which is attached to the palm overnight and allows rhythmic electrocutaneous stimulation to be applied at a frequency of 1 Hz during the slow-wave stage of sleep as identified from the CGR. Clinical trials of this device showed it to have positive influences on sleep quality. Analysis of somatosensory event-related potentials to electrocutaneous stimulation using this technology demonstrated plastic rearrangements during sleep stage 3 [Dorokhov et al., 2017], which could be interpreted as the possible involvement of habituation processes in improving sleep quality using electrocutaneous rhythmic stimulation.

Audiovisual Stimulation. Sensory stimuli of different modalities can quite easily be combined into a single methodology, and the most practical and extensively studied is combined audiovisual stimulation (AVS) combining rhythmic light flashes with sound stimuli. Historical attempts to develop this technique and early devices were addressed in a review by Tang et al. [2016]. There are now both adaptive AVS methods based on EEG signals and nonadaptive approaches to rhythmic stimulation which are simpler to use and are employed in consumer devices. AVS has been studied as a method of decreasing the level of emotional stress, for optimization of cognitive functions, and treating insomnia. AVS can aid relaxation and the onset of sleep, including in elderly patients, possibly because of the effects of involving EEG rhythms [Tang et al., 2015, 2016]. After onset of sleep, the effectiveness of light stimulation drops:

comparison of adaptive stimulation with pulses of red light and sound stimuli increased SA in response to sound but not light. Combined stimulation had no advantage over sound stimulation [Danilenko et al., 2020].

Transcranial Electrical and Magnetic Stimulation. Use of electric currents to act on sleep has a history of more than a century. The concept of electrosleep was proposed as early as the 1910s [Robinovitch, 1914]. Electrosleep generally uses pulsed direct currents and the duration of action was up to 120 min. This method and its development have been described in more detail in a review of methods for transcranial electrical stimulation [Guleyopoglu et al., 2013]. Technological developments have led electrical stimulation to join transcranial magnetic stimulation and these two methods are now subject of detailed attention.

Rhythmic transcranial magnetic stimulation (rTMS) and transcranial electrical stimulation with direct or alternating currents are noninvasive means of acting on the excitability of areas of the brain based on the use of powerful magnetic field pulses or weak electric currents through brain tissue respectively. Depending on stimulation parameters, these methods provide both increases and decreases in neuron activity. rTMS at low frequencies (<1 Hz) can suppress neuron operation, while high frequencies (>5 Hz) lead to additional activation [Lefaucheur et al., 2014]. Anodic transcranial direct current stimulation (tDCS) usually leads to increases in neuronal electrical activity while cathodic stimulation decreases activity [Lefaucheur et al., 2017]. These methods can have direct actions on different areas of the cortex and indirect actions on subcortical structures, giving them potential as methods for treating a variety of neurological and neuropsychiatric disorders. Insomnia is also regarded as a target for modulating the level of cortical arousal using these methods. They may also be of interest for other diseases associated with impaired sleep quality or depth. Despite the effectiveness of these methods in modulating brain activity, relatively few studies of their actions on sleep have been reported as compared with other clinical directions, and there is still little standardization of optimum treatment protocols [Romanella et al., 2020; Herrero Babiloni et al., 2021].

Transcranial Electrical Stimulation. Studies of the influences of electrical stimulation on sleep generally use low-power direct currents (transcranial direct current stimulation, tDCS). Treatment using currents changing at low frequencies (a few Hz) is also referred to as tDCS, or is termed slow oscillating tDCS (sotDCS) or transcranial oscillating DCS (toDCS). Studies of the effects of tDCS on going to sleep and sleep in humans have been run both in healthy subjects (for reviews see [Annarumma et al., 2018; Gorgoni et al., 2020]) and in people in a variety of neurological and neuropsychological disorders (for review see [Herrero Babiloni et al., 2021]). Similar effects have been demonstrated in many of these groups: tDCS with particular parameters can influence sleepiness and going to sleep, while sotDCS used during sleep increased SA.

SA during sleep and the process of memory consolidation are closely linked with each other, so it is not surprising that anodic tDCS of the frontal areas during sleep influences not only brain electrical activity, but also memorization. Aging is accompanied by impairments to the memory consolidation systems and tDCS is a potential approach to improving its functioning. A review addressing this theme noted that despite limitations, this approach is promising as a nonpharmacological and noninvasive action on sleep and memory in elderly people, including those suffering from neurodegenerative diseases [Salfi et al., 2020]. tDCS is quite simple as a method for use outside clinics and has potential for wider use, though the question of selecting the optimum time and power level remains open.

Transcranial Magnetic Stimulation. Transcranial magnetic stimulation (TMS) is widely used in studies seeking to alter the state of excitability of particular areas of the cortex. A magnetic field focused on a small area of the brain stimulates or suppresses a group of neurons and can also act on the subcortical areas connected to them and even spinal structures. TMS can be delivered as single or paired pulses or as rhythmic pulsation.

As compared with other approaches, relatively few studies of the influences of TMS on sleep have been reported. Application of this method during sleep can increase SA and have delayed effects, such as increasing SA after stimulation during waking. The potential for its use in healthy people and people with various neuropsychological disorders has been addressed in several reviews [Cellini and Mednick, 2019; Romanella et al., 2020; Herrero Babiloni, 2021].

There is a number of limitations to the use of TMS. Stimulation can induce headache and feelings of fatigue, and in rare cases can provoke epileptic seizures. However, the main hindrance is the complexity of the method. Stimulation can only be applied by a trained specialist and requires great precision of action and immobility of the head, while the magnetic coil emits loud sounds during operation [Malkani and Zee, 2020]. TMS is therefore mostly a research method with limited clinical application.

Contactless Superweak Electromagnetic Stimulation. On the basis of evolutionary considerations, there are grounds for suggesting that weak natural electromagnetic fields (EMF) at extremely low frequencies (ELF) would be able to influence the mechanisms of the circadian regulation of sleep. Some authors have put forward the hypothesis that rhythmic processes occurring in living organisms from the origin of life on earth are determined by the main daily rhythm connected with the electromagnetic components of heliogeophysical factors [Presman, 1968; Bliss and Heppner, 1976; Breus, 2003].

Along with illumination, periodic variations in weak natural ELF EMF have also been shown to be able to operate as carriers of biological rhythms over a wide range of frequencies [Kudryashov and Rubin, 2014]. The main advantage of natural ELF EMF as a synchronizing factor, as compared with illumination, is their ability to penetrate. Data have been obtained indicating that the influence of ELF EMF on circadian rhythms, like changes in daily illumination, are mediated by the pineal and are involved in regulating melatonin [Kudryashov and Rubin, 2014].

The main source of natural ELF EMF consists of processes in near-earth space: 1) in the cavity formed by the earth's surface and ionosphere (Schumann resonances at frequencies of 8, 14, 20, and 26 Hz) and 2) interactions between the earth's magnetosphere and the solar wind (geomagnetic variations in the range 0.001–4 Hz).

The frequencies of Schumann resonances (8, 14, 20, and 26 Hz) fall within the range of oscillations of the brain's own biocurrents – the α rhythm (8–13 Hz) and the β rhythm (13–30 Hz) – and may therefore be biologically significant. This suggestion has recently been confirmed by several research groups [Pobachenko et al., 2006; Saroka et al., 2016], who have demonstrated quantitative correlations between variations in global geomagnetic fields in the range of the Schumann resonances with local frequency changes in brain EEG rhythms.

Particular attention should be paid to daily variation of the geomagnetic field in the form of Alfvén waves, which oscillate in the frequency range 0.5–3 Hz depending on the state of the ionosphere. Amplification of Alfvén resonance occurs at nighttime, while the amplitude of spectral increases drops to the noise level during the daytime. It has been suggested [Khabarova, 2002] that the similarity in the frequencies of the sleep δ rhythm (0.5–4 Hz) and Alfvén waves (0.5–3 Hz) may be evolutionarily driven and that the intensity of the Alfvén resonance increases after the sun sets at night. Thus, we note an interesting fact: the frequency peak of Alfvén resonance disappears from the spectrum of the ionospheric electromagnetic noise not only in the daytime, but also during peaks of solar activity [Gorelkin, 1999].

The biological effects of ELF EMF can be seen at very low intensities. In electromagnetic biology, the term "weak" usually applies to ELF EMF whose magnitude is comparable with the levels of geomagnetic variations [Zenchenko and Breus, 2021], which are significantly lower than the acceptable limiting levels established in Russia (100 μT for living and office spaces). The mean tension of the earth's constant magnetic field is around 50 μT and the amplitude of its slow variations can reach 1 μT.

Until recently, the existence of magnetic sensitivity in humans was controversial. In 2019, Wang et al. reported results which can be regarded as the first experimental evidence of the existence of magnetoreception in humans.

Evidence for the need for natural ELF EMF as an important ecological factor is provided by degradation of well-being and cognitive activity in people in screened structures providing hypomagnetic conditions with a deficiency of natural electromagnetic fields [Bingi, 2011].

Thus, daily variation in the range of geomagnetic perturbations and Schumann resonances, along with daily changes in illumination, are additional synchronizing factors and can determine circadian rhythms, as they are both associated with the presence of the sun during the day and its absence at night.

These data provided the basis for studies of the normalizing influence of artificial weak ELF EMF in the range of frequencies of Schumann resonances and geomagnetic perturbations on the circadian mechanisms regulating the sleep–waking cycle [Ohayon et al., 2019].

Pelka et al. [2001] carried out a four-week clinical trial using pulsed magnetic field therapy in a group with insomnia. Sleep latency (the time taken to fall asleep) was measured, along with the frequency of nighttime wakings, sleepiness after rising, daytime sleepiness, difficulty with concentration, and daytime headaches. Values for all criteria were much improved in patients receiving active treatment. ELF EMF has been shown to have positive effects on daytime sleep quality and architecture using fields with intensity <0.2 μT and frequencies of 1, 2, and 8 Hz [Dorokhov et al., 2019, 2020]. A consumer device working on this principle has been developed – a sleep cube installed on the headboard.

Alternative Medicine and Sleep. Alternative medicine is generally defined as a set of methods for healing, prevention, diagnosis, and treatment based on the experience of many generations of people. When alternative medicine methods are used alongside standard methods, this practice is termed complementary medicine. The term "complementary and alternative medicine" is widely used for the combination of complementary and alternative practices of nonconventional medicine. The end of the 20th century was marked by an increase in interest in eastern healing and self-treatment methods directed to mobilizing the body's natural resources. The wide use of folk medicine methods can be explained by their relative simplicity and their ability to supplement or in some cases even replace medication-based and physiotherapeutic treatment methods. This approach has long been subject to criticism because of the difficulty of obtaining objective evidence of the efficacy of the methods. However, recent years have seen the appearance of serious research and reviews assessing the efficacy of alternative medicine. We will consider data on the possible use of these approaches for improving sleep quality using the three most widely employed methods as examples: deep breathing, aromatherapy, and reflex therapy (acupressure).

Slow Deep Breathing. Breathing is one of the basic functions of the body; a person can only live a few minutes without breathing. Breathing is one of a small number of autonomic functions which can be controlled voluntarily. The voluntary control of deep breathing is a major component of ancient eastern methods for improving the body and soul [Bertisch et al., 2012]. However, the discovery of the mechanisms linking control of slow breathing with its psychophysiological effects nonetheless remain at the discussion stage. A review by Zaccaro et al. [2018] suggested two possible physiological mechanisms: one is associated with voluntary control of the autonomic nervous system (ANS) with increased parasympathetic activity and the other is associated with the role of mechanoreceptors in the vault of the nasal cavity and the translation of slow breathing into modulation of the activity of the olfactory bulb, which in turn regulates the activity of cortical structures in the brain.

Sleep is needed to mediate the body's complex homeostatic functions, which are to a large extent regulated by the ANS. Transfer from waking to sleep is linked with slowing of respiratory rate and an increase in regularity as parasympathetic tone increases. Most people with ANS disorders suffer from sleep disruption; short durations of sleep and insomnia are associated with statistically significantly lower levels of parasympathetic activity and higher levels of sympathetic activity in different states: in daytime breathing, on the transition from sleep to waking, and during nocturnal sleep. Using the practice of slow deep breathing, this increase in arousability can be decreased by the moment of going to sleep. Slow-wave sleep promotes increases in parasympathetic tone and produces drops in elevated autonomic tone [Jerath et al., 2019].

Although deep breathing is the most commonly used relaxation technique in insomnia, some studies have empirically addressed the link between slow breathing and insomnia [Bertisch et al., 2012]. Breathing rates of 0.1 Hz produce the largest increases in heart rate variability (HRV), which is due to the fact that breathing at a rate of 6 per min is associated with maximal vagus nerve stimulation as a result of the action of respiratory arrhythmia of the heart; in the literature this is termed resonant breathing [Rzeczinski et al., 2002; Steffen et al., 2017]. HRV is widely used to assess the functional state of the ANS, the so-called sympathovagus balance, and the body as a whole. HRV is believed to be a marker of health and adaptation, and increases in HRV improve health, mood, and adaptation to stress. Tsai et al. [2015] suggested that autonomic dysfunction could be part of the pathology of insomnia and showed that slow breathing at a rate of 0.1 Hz increases vagus nerve tone and, thus, activity in the parasympathetic system, leading to improvements in sleep quality: latency of sleep onset decreases and the continuity of nocturnal sleep improves. Polysomnographic evidence for the effectiveness of the action of deep slow breathing at a rate of 0.1 Hz on sleep quality was also reported by Kuula et al. [2020]. Several apps have been produced for home use of deep breathing and one, Breathing App, was used in this study.

A negative but clear example of the connection between breathing and sleep is provided by a sleep-related breathing disorder – sleep apnea, which is generally due to relaxation of the respiratory tract muscles and periodic collapse of the walls of the pharynx and is apparent as cessation of breathing during sleep on the background of snoring. These cessations last from 10 sec to 2–3 min and in severe cases occur hundreds of times a night, such that overall the person may not be breathing for 3–4 h. Such severe oxygen starvation is very dangerous, as all organs, including vitally important ones, suffer from oxygen deficiency. Sleep is totally disrupted, homeostatic processes cannot flow normally, and the person experiences severe daytime sleepiness. Apnea provokes and exacerbates the course of many diseases [Vein et al., 2002]. Sleep apnea is treated using continuous positive airways pressure (CPAP), which prevents collapse of the respiratory pathways during sleep, leading to episodes of breathlessness. This normalizes sleep and the person's well-being [McArdle et al., 1999; Nicolini et al., 2014].

Aromatherapy. Aromatherapy has been used to normalize sleep since the times of Avicenna, was popular in the ancient East, and is widely used today. Aromatherapy is a variety of alternative medicine, a treatment method using natural essential oils introduced into the body via the respiratory tract, skin, and/or mucous membranes. The actions of essential oils on people are defined in two ways – reflex and humoral: 1) the influences of aromatherapy molecules are linked primarily with their actions on receptors in the olfactory areas of the nose, perceived as odors and instantaneously transmitting information to the central nervous system, i.e., the olfactory center of the brain, which is an ancient part of the brain; 2) the second mechanism of the influence of essential oils is humoral, which in aromatherapy and inhalation is directly associated with the influences of essential oil molecules on the respiratory tract mucosa, while in massage with essential oils, the capillary-rich structure of the skin promotes easy penetration of aromatherapy substances. There are two main means of using essential oils: via the respiratory system (aroma lamps and inhalation) and via the skin (aroma baths, compresses, aroma massage). Essential oils have direct and various actions on the central nervous system. Some oils are calming and relaxing, while others are toning and arousing. More complete information on the physiological effects of various essential oils and the mechanisms and methodologies for the therapeutic application of aromatherapy can be found in reviews [Burenina, 2009; Shutova, 2013].

Aromatherapists visit clinics, operate private practices, and even medical insurance providers have started to include aromatherapy treatments in the list of services covered. The simplicity and availability of aromatherapy allows it to be used to improve going to sleep and sleep quality. The efficacy of aromatherapy in sleep disorders has been demonstrated in many randomized trials which have been analyzed in reviews. Lillehei and Halcon [2014] presented a review addressing quantitative studies of the effects of inhaled essential oils on sleep published between 1990 and 2012. This review concluded that inhalation of essential oil vapors could be a safe alternative to pharmaceutical interventions in mild and moderate sleep disorders. The most recent review [Cheong et al., 2012] also concluded that use of aromatherapy could be a highly effective means of solving sleep problems, including the quantitative and qualitative effects of sleep. A number of studies have shown that the influences of aromatherapy on factors such as stress, depression, anxiety, and fatigue were even more significant than that on sleep. This review also concluded that inhalation of one aromatic was more effective than inhalation of mixed aromatics consisting of multiple essential oils. Among single inhalation methods, inhalation of lavender had greater effects than other essential oils. We note that the effects of inhaling lavender aromatic were stronger in people experiencing more significant impairments to sleep as compared with those complaining of general sleep difficulty. It has also been shown that the effects increased significantly with increases in the number of aromatherapy sessions.

Acupressure – Point Massage. Acupressure is an alternative medicine method similar to acupuncture and is based on experience of the ancient Chinese method of therapeutic needling. In acupressure sessions, introduction of needles at biologically active points is replaced by application of physical pressure with the hand, elbow, or various devices. The number of points recommended by different authors ranges from five to eight. In learning to use the acupressure method independently, locating these biologically active points is initially difficult, though most people can find points quite accurately on practical use of the method. The main advantage of point massage is that it can be used in any situation and at any time. A number of reviews [Yeung et al., 2012; Waits et al., 2018; Wu et al., 2018] have presented results providing evidence that point massage is a safe and effective method for achieving higher-quality sleep.

Sleep Hygiene. Apart from specific physiological actions on sleep, there are also recommendations for sleep hygiene. Sleep hygiene is a behavioral and ecological practice developed at the end of the 1970s as a method helping with mild and moderate insomnia. Sleep hygiene advice includes establishing a regular sleep schedule, cautious use of daytime sleep, avoiding physical or mental effort before sleeping, limiting stressful stimuli, limiting light exposure before sleep, avoiding using the bed for anything other than sleep and sex, and avoiding consumption of alcohol, nicotine, caffeine, and other stimulants for several hours before sleep, along with recommendations for creating a calm, comfortable, and dark context for sleeping. Diagnostic assessments of the effectiveness of these sleep hygiene recommendations are based on clinical interviews, self-assessment questionnaires, and use of sleep diaries for 1–2 weeks. There are online sleep diary forms with automatic generation of recommendations for improving sleep. In the last decade, sleep hygiene has entered use as monotherapy for insomnia, though it has clear potential in public health and for promoting and developing healthy sleeping habits [Irish et al., 2015].

Conclusions (potentials and opportunities for nonpharmacological stimulation of sleep). Different types and modalities of stimulation during sleep, with correct selection of parameters, increases slow-wave activity and in some cases sleep spindles. Improvements in the consolidation of declarative memory constitute a likely positive effect in the area of cognitive functioning, though it is not seen with a significant proportion of approaches or even treatment regimes. It is interesting that stimulation generally has no marked influence on sleep architecture overall; the distribution of sleep stages generally remains unaltered. It is possible that increases in SA lead to relaxation of sleep pressure, which is usually reflected as a high proportion of slow-wave sleep.

Adaptive approaches, in which signals are modified on the basis of ongoing brain electrical activity, have gained popularity in recent years. These allow actions to be focused on the most sensitive periods of activity. The commonest adaptive methods use sound stimulation, though theoretically they can also be used in many other approaches, where they have the potential to increase the efficacy of stimulation.

Among the sensory methods for targeted enhancement of slow-wave sleep activity with the greatest potential is adaptive sound stimulation. Vestibular, audiovisual, olfactory, and temperature stimuli are quite ecological and noninvasive, and can be regarded as techniques improving going to sleep and improving sleep quality. It is potentially possible to create combinations of such actions to produce new, comfortable conditions for sleep. In turn, light therapy and correction of the spectrum and intensity of illumination at different times of day provide an effective method for correcting sleep impairments and countering difficulties in changing work shifts associated with the circadian system.

As regards transcranial stimulation methods, electrical stimulation methods are more suitable for nighttime use than TMS and may also produce less physical discomfort and arousal. TMS largely remains a research method with limited clinical application. Transcranial stimulation during sleep has demonstrated positive effects, most commonly using slow oscillating anodic tDCS, though not in all studies.

Consumer devices delivering one or another type of stimulation to improve going to sleep and sleep itself are now available. These are not medical devices and are intended for healthy people wishing to stabilize and improve their sleep. The question of whether these stimulation methods will be as effective in populations with decreased levels of SA (as compared with healthy young people) remains under discussion. Use of nonpharmacological stimulation to treat sleep impairments is of the greatest interest, though it remains at the stage of individual clinical trials. Application of some of the methods of eastern medicine to improve sleep quality can be recommended on the basis of recent studies. Establishment of healthy sleep habits and use of sleep hygiene rules are effective preventative methods against the occurrence of sleep impairments.

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