Research Article

The Secret of Sleep

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ABSTRACT

Is there a relation between sleep and gravity? The topic has not received a lot of attention or interest, and a scrupulous, serious and systematic literature survey shows that most papiers only indirectly invoke the question. Considering the effects of gravity, mostly add clarity and explanation to the questions or observations.

During a particular phase of Sleep, the Rapid Eye Movement phase, the brain with attenuated sensations, has the illusion that gravity is reduced.

In the Animal world many observations of the sleep postures and the absence of REM sleep in certain species, like fishes, confirm the presence or absence of the effects of gravity. Also, a study of the sleep of the Fur Seal obviously can be interpreted then easily.

A further indication of the effect of gravity is given by the sleep of humans in Space, where gravity is compensated, and consequently a series of papers indicate that the duration of sleep is reduced. A particular experiment of water immersion in advance of space flights is concretely addressing the gravity and its effect on sleep, and this is the first and only paper giving a clear indication that gravity has an effect on sleep.

In conclusion the relation between sleep and gravity is confirmed by a number of observations. but as gravity is part of our environment and cannot be changed the possibility to exploit this finding for our health, is for the time being limited,

Keywords: Sleep; Anxeity

Introduction

This paper reviews literature studying the association between gravity and sleep. Sleep remains an important research area, as it is a complex phenomenon. In particular, variables from the external world influence sleep. A few such variables include light, sound, and temperature, which are easily recognized from daily experience. Although it has been proposed that sleep has a universal physiological function across species, there is no agreement as to what that function might be. Furthermore, sleep has been observed in almost all animal species. Its universal character is now established, such that at least one of its causes should also be universal.

There are only a few published studies addressing this subject. Not many scientists have thought about associating the two phenomena. If the role of gravity cannot be explained in detail, it is both surprising and convincing that by studying the effects of gravity, one can resolve many unanswered questions about sleep in humans and animals. Some of the questions in the papers that are referenced, point towards questions that could easily be answered with the simple and obvious inclusion of the influence of gravity.

One difficulty may arise from the fact that a number of sensors in humans detect gravity, as opposed to other senses that benefit from precise sensors like the eyes, ears, nose, tongue, and skin. Further difficulty arises because gravity cannot be seen and is permanent, elusive, intangible, untouchable, and yet omnipresent; only its effects can be appreciated.

Gravity, has existed on earth since its formation, and affects everything on the surface of the planet. Newton's law of universal gravitation states that every particle attracts every other particle in the universe with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers. Physics tells us that any upright body reaches equilibrium if the vertical line passing through the center of gravity also passes through the support polygon. For millennia, humans have learned to maintain a vertical posture almost "unconsciously," and subsequently activate muscles in the body, in the head, neck, torso, and limbs, to maintain this vertical line in the right position. We fall when this rule is not met.

Methods

This paper is not concerned with medical, biological, or neurophysiological measurements. It is based on an extensive review of published scientific results, that all confirm, after in-depth analysis, that sleep and gravity are related. A detailed research on the Internet using the search words "Sleep" and "Mammals," led us to the few relevant research papers, which were acquired and examined carefully. Many questions raised in these papers about sleep can be answered by the obvious inclusion of gravity. A number of quotations from the authors that raise important questions and observations have been reproduced.

The sense of balance takes into account the pull of gravity. This is a very real sense. Our brain perceives gravity through multiple senses. Coordination of movement and the sensory organization of postural control are affected by information from the inner ear and proprioceptors, cells and nerve endings in the muscles, tendons, and joints that normally tell the body where it is relative to its surroundings. [1] Even though gravity is a phenomenon that originates outside of our bodies, the only thing we learn from its detection is which way is "up" or "down," allowing us to maintain our bodies in an upright position as we stand or walk, even when our eyes are closed.

Paradoxical sleep

When Hans Berger [2] discovered that the brain emitted faint electrical waves during sleep, a new era of sleep discoveries began. During the night, changes in the frequency and intensity of the waves were recorded in a consistent manner, and hypnograms were obtained using Electroencephalography (EEG). In summary, successive and different stages were observed from N1 to N3 with a change in sleep intensity and consciousness. Finally, the important stage of paradoxical sleep concluded the series of phases of sleep with increased duration in later parts of the night. It also included the consistent occurrence of rapid eye movement (REM), such that the phase is often referred to as the REM phase. [3],[4] Today, there is a tendency to simplify the coding; phases N1 to N3 are referred to as non-REM (NREM) phases, as opposed to the REM phase. The different phases do not seem to be clearly associated with abrupt and noticeable changes in biological body functions.

A possible and new explanation of the jump from one phase to another may come from the definition of sleep provided by Prof. Jouvet, a neurophysiologist [5], "*Sleep is a periodic and necessary condition of decreased alertness in which we cease to make contact with the outside world,*" which means that all information coming from our senses are attenuated when we fall asleep. It is probable but not confirmed, that we first lose sensitivity to light, then hearing is reduced along with our sense of touch, but we are also insensitive to odors and tastes. The sense of balance is attenuated and the perception of gravity is reduced during REM sleep. REM sleep reduces central homeostasis, permitting fluctuations in respiration, thermoregulation, and circulation, which do not occur in any other stages of sleep. The body abruptly loses muscle tone, a state known as REM atonia and a fundamental change in behavior.

It is also the period when the brain dreams. [6] At the end of the 1950s, Michel Jouvet [5] observed through brain waves that a cat on a platform surrounded by water could sleep but would not enter the REM sleep phase, which can be easily recognized by the distinctive brain waves. Gonfalone [7] has proposed that if the effect of gravity is considered, the explanation is obvious, the cat fears falling in the water. Mammals, including humans, are born with the "fear of falling," which is associated with the sense of balance. When the body loses muscle tone, as in the state of atonia, it imposes a safe and stable posture for REM sleep. Because during the REM sleep phase, all skeletal muscles are atonic, a fall is unavoidable.

The fear of falling encompasses anxieties accompanying the sensation and possibly dangerous effects of falling. Studies on nonhuman subjects strongly support the theory that falling is an inborn fear. Gibson and Walk [8] performed experiments with young chickens, turtles, rats, lambs, kittens, and puppies. The results were similar to those of human infants, although each animal behaved slightly differently according to the characteristics of its species. Based on the results of the animals tested, the findings indicate that the fear of falling is instilled in animals at a very young age, if not innate. Newborns are then aware of the possible effect of gravity, a fall.

One question remains, if the cat had no REM sleep while fearing the effects of gravity, would other mammals behave the same way?

Animal sleep

In the animal world, sleep is extremely variable in duration and structure. The theory of evolution proposes that most terrestrial animals evolved from aquatic species that left the ocean to live on land. The aquatic and land environments are very different. One can imagine that the lungs were developed to respire oxygen and warm blood to deal with variations in temperature. The limbs were developed for locomotion and to support the animal's body weight against gravity. The biomechanical demands of aquatic and terrestrial locomotion are vastly dissimilar, and are reflected in the different energy costs for swimming and walking or running.

Despite these differences, human sleep behavior can provide some insights into the sleep patterns of other species. Most mammals carry their body weight on four limbs; equilibrium is more difficult to control on two legs, as the center of gravity must be above the support polygon and the behavior of the human species should show a greater dependence on gravity than that of four-legged animals.

Mammals

Sleep and sleep duration in mammals has been extensively studied, in particular by Campbell and Tobler [9], Zepelin and Rechtshaffen [10], and Allison and Cicchetti. [11]

Siegel first investigated how sleep was affected by body weight. [12] The author provided graphs for carnivores, herbivores, and omnivores and observed that sleep duration is an inverse function of body weight across all terrestrial mammals. Another paper by Madan and Jha, [13] questioned the probability of the loss of REM sleep in water and compiled total sleep time (TST) and percentage of REM sleep duration for 76 mammals, semi-aquatic mammals, and aquatic mammals but did not consider distribution in relation to bodyweight. Another study by Gonfalone [14] associated REM sleep duration with the gestation length of each species and concluded that the heaviest species, with longest gestations, sleep less, as was previously observed. It is possible that longer periods of brain development during gestation correspond to a reduced need for sleep.

Most mammal postures during sleep show that animals have their head and brain laying in a position where the chances to fall are minimal. [15]

Horses can sleep standing on their legs that lock, but only enter REM sleep if they lie on the ground. Elephants share a similar behavior [16,17]. Giraffes can sleep either in a standing or recumbent position [18,19].

These papers do not explicitly mention "gravity," but these observations strongly suggest the effects of gravity. It is noteworthy that when on land, sleep in fur seals, studied by Lyamin and Mukhametov [20,21], generally resembles that of most terrestrial mammals, i.e., the sleep cycle alternates between NREM and REM sleep and the bilateral EEG exhibits synchronization during NREM sleep and de-synchronization during REM sleep. However, when the fur seal is in water, the occurrence of REM sleep declines to the extent that there may not even be a single episode. It is not known how the brain switches from terrestrial bihemispheric to aquatic unihemispheric sleep in semi-aquatic mammals. In fact, it has been suggested that sleep in fur seals defies the principle of homeostatic regulation, since no rebound of lost REM is seen when it returns to land after staying several weeks in water. This unusual behavior can be explained in a different manner, as will be discussed below. Fish do not exhibit REM sleep in the water and it looks like the fur seal behaves like a fish when in water where gravity has no effect and like a normal mammal once on land where it is affected by gravity..

Birds

In summary, birds exhibit two types of sleep that are similar to mammalian REM and NREM sleep. Rattenborg, Roth, and Lesku [22], and Klein [23] have studied sleep in birds. From their results, some observations can be associated with gravity. Asymmetric or unihemispheric NREM sleep occurs with one eye open, enabling birds to visually monitor their environment for orientation and predators. Frigate birds primarily engage in this form of sleep in flight, perhaps to avoid collisions with other birds. If the sleep of these birds is greatly reduced, it is possible for the birds to be sustained by the air when gliding, which does not require effort to remain airborne as the air provides a net upward force on the wing.

Some other birds sleep in safe and stable positions; however, most of them can fly and thanks to their wings do not fear falling. Flamingos can sleep standing on one leg; REM sleep-related reductions in skeletal muscle tone appear largely restricted to muscles involved in maintaining head posture.

Ostriches [24] and penguins are two families of birds that do not fly. These exhibit sleep postures similar to those of mammals; in particular, ostriches put their heads in the ground for safety. Their REM sleep is easily detected as they lower their heads. For penguin chicks, their posture is variable and they can sleep laying down, sitting, or even standing.

Although most research has focused on NREM sleep, there are also aspects specific to avian REM sleep. REM sleep-related reductions in skeletal muscle tone appear largely restricted to muscles involved in maintaining head posture. Other aspects of sleep manifest as a mixture of features of NREM and REM sleep.

Fishes

Fish in water are indeed subject to gravity as every other being on Earth. However, aquatic creatures are buoyed by fat and air, allowing water to support their body so that they do not sink. The effect of gravity is then negligible, as they do not have to support their mass (Archimedes effect). Perhaps because it not so easy to equip fish with EEG apparatus, REM sleep has not been yet detected in fish, although sleep is present in most examined species.

Questions about the absence of REM sleep in fish can be answered if one takes into account the role of gravity. Jha and Madan published a paper titled, "*Sleep alterations in mammals: Did aquatic conditions inhibit rapid eye movement sleep*?". [25] Another paper considering possible explicative theories was published by Bahammam titled, "*Why REM Sleep is Reduced in Aquatic and Semi-aquatic Mammals? A Discussion of the Possible Theories*". [26]

The absence of gravity is suggested to explain the lack of REM sleep.

The situation is different in aquatic and semi-aquatic mammals. Nature has given these animals the ability to sleep in one brain hemisphere at a time. The other hemisphere is awake, allowing the animal to continue moving, see through one eye, and access air during the night. Whales have been observed sleeping underwater, in circles, suspended motionless, revealing a position in which whales in the wild display atonia and some form of REM sleep.

It was said above that thermoregulation ceases during REM sleep, an observation made originally by Glotzbach and Heller [27]. Loss of thermoregulation would make REM sleep in aquatic animals especially dangerous as heat loss would be 90 times faster in water.

Sleep in reptiles and amphibians remains unclear; however, very meticulous experiments by Libourel have shown similarities to mammals. [28] The universal character of sleep is confirmed by observations of sleep in jellyfish [29] and drosophila [30], which are both affected by gravity.

Sleep in space

Early simulations of microgravity

As soon as human space flight was envisaged, methods of simulating microgravity were developed. Many associated biomedical problems could be reproduced and compared with real flight effects.

There are several ways to "switch off" weight without leaving the Earth's gravity field. They all share the feature that the object is in "free fall", for example in a drop tower, on a parabolic flight, or in a sounding rocket, but they are not adapted for sleep studies.

Other methods that can be used for longer periods, like water immersion and head down tilt, permit assessment of the effects of reduced gravity, in particular the effect of simulated weightlessness primarily on the blood and lymphatic system. These simulations also work with examining the effects on the musculoskeletal system and are faster with dry immersion.

In advance of manned space flight, there was a serious concern over the possible effects of prolonged weightlessness on human physiology. [31]

In the years 1960s, the US Air Force performed an experiment that practically solved the question of sleep in reduced (not 0) gravity and surprisingly the paper by Graveline [32] has not had the publicity that it deserves and has not been widely available.

Researchers built a tank where a subject was immersed for a week. "In hypo-dynamic state, during immersion, there is no need to counteract G-forces. Therefore, the magnitude of the neuromuscular 'debt' will be greatly reduced, and the duration of the recovery period required will be reduced.

The subject of these experiments was immersed in this way for 7 days. It was expected that the subject would sleep for a period of 4-8 hrs, however, the amount of sleep each day was considerably less than 4 hrs and there was very little sleep after 3 hrs. The subject was alert during entire experiment and there was no evidence that 'sleep deficit was accumulating.' After the experiment was concluded, the subject returned to his normal sleep pattern, which was approximately 7–8 hrs each day."

In their conclusion, the authors state, "…the biological function of sleep is to provide a period with minimal requirements for counteracting gravity so that recovery from the neuromuscular 'debt' accumulating in the active man can take place."

This research in advance of human space flight truly provides the first hints of the interaction between sleep and gravity and was not appreciated by contemporary scientists. This was the first study to discover an influence of gravity on sleep. This prediction of the scientists turned out to be correct, as described in the following paragraph, i.e., the sleep duration of astronauts is shorter than the sleep duration on ground, and this is due to the absence of gravity.

Sleep duration in space vehicles

Manned space flights began more than 50 years ago. The duration of these flights has evolved from a few hours to many months. Although many studies, in particular those by Pavy le Traon, have reported that sleep in space only differs minimally from sleep on Earth [33], a general conclusion is that sleep duration in space is shorter. It was often concluded that astronauts were suffering from sleep deprivation, which could be harmful for the safety of the mission. Indeed, sleep in space is not as comfortable as sleep on Earth and this has been reviewed in detail; however, the role of gravity is minor in this discomfort. In early space history, during the Skylab flights, it was noted that sleep duration was shorter in space than on Earth. As quoted by Frost [34], "*This decrease in sleep time, however, was due not to an unusual amount of time spent in the awake state but instead to a reduction in the total rest period time itself. The subject thus slept quite well on most nights while he was in bed; however, he did not spend as much time in bed as he did during studies either before or after the mission.*"

At this early stage, in 1973, scientists did not suggest the absence of gravity as a potential cause of the reduction in sleep duration. Since then, many other investigations of sleep and sleep duration have been performed [35] and come to the same conclusion, including studies by Flin-Evans [36], Gundel Polyakov [37], Stickgold and Hobson [38], and Weitering [39] who said, "*Ten years of data show that astronauts normally do not get enough sleep, even though most take sleep medications during space missions. Recognizing that sleeping pills do not solve the problem helps researchers target further research on the effects of medication.*"

Space station crews usually sleep in sleeping bags located in small crew cabins. Each crew cabin is just big enough for one person. Generally, astronauts are scheduled for 8 hrs of sleep at the end of each mission day, but they sleep for only 6 hrs.

Hobson and Stickgold analyzed the sleep of four cosmonauts and one astronaut using a special cap and concluded, "*Preliminary analyses showed that REM sleep was severely diminished during flight for all five subjects. Both REM time and REM % (of total sleep time) were significantly diminished. On average, REM time was greatly reduced in flight compared to pre-flight…. In contrast, post-flight rates were essentially the same as pre-flight*". [38]

The absence of gravity may be the reason for the short duration of sleep.

During space sleep, the brain successively reduces the sensations to light, sound, and touch, as when on the ground, but the time to reduce vigilance against gravity and the fear of falling is shorter than on ground as the risk of a fall is reduced and may be instinctively detected by the brain. As a result, the REM sleep latency is shorter than on the ground. A second reason may be found in the reduced efforts of the muscular system to maintain posture and carry body weight.

On the ground a positional equilibrium is sought by instantly juggling the vagaries of our own shifting center of gravity as we stand. In contrast in zero-g conditions, any posture is in equilibrium without any muscle force, which demands a profound change in the brain/body control strategy.

"*Measurement of motion of the trunk with Actiheart monitor shows a decrease by nearly a factor of 10 in the average value of activity during flight relative to the corresponding pre-flight value*" was reported by Bin Wue. [40]

The fear of falling has to be understood as all the efforts the postural muscles provide on ground to maintain posture and balance. The sleeping position of astronauts is reminiscent of the position of the fetus within the body of the mother, where gravity is reduced in the amniotic fluid, with their hands at the level of the shoulders, as reported by Birnholtz [41]. If REM sleep latency is reduced and REM duration is reduced, the total sleep duration is shorter than on ground.

However, back on Earth astronauts show a rebound of REM sleep. Dijk wrote, "*A more speculative explanation is that this massive increase in REM sleep represents a response to the re-adaptation to one-G. REM sleep has been implicated in learning processes related to sensory-motor tasks in particular. Could it be that 'relearning' to walk on Earth is closely related to this REM sleep increase?*" [42]

Known risk factors for the health and safety of astronauts and ground control workers supporting spaceflight include disturbances in circadian regulation and sleep. [43] Disruption of sleep and circadian rhythms has been documented in space-flight missions as short as 10 days. Such problems may cause space program personnel to experience impaired alertness, loss of concentration, and diminished performance. Ambient light of the proper intensity, spectrum, and distribution can be a powerful countermeasure for both circadian misalignment and sleepiness.

Astronauts themselves are not always in agreement with the possible "sleep debt." A newspaper journalist, Barker, described an astronaut's opinion on this phenomenon, "*But what did the chronically sleep deprived say when asked how they felt? It's not affecting me. Even 14 days into the study, they said sleepiness was not affecting them.*" [44]
In a study of ISS crew-members' journals, sleep was among the top 10 topic categories and most of the entries were negative [35].

Environmental factors, such as light, noise, and uncomfortable temperatures, contributed to sleep loss in early spaceflight missions and continued to be a factor in shuttle and ISS missions. Operationally demanding schedules were also found to be significantly associated with difficulty in sleeping during shuttle missions. [45] Additionally, 90-min light/dark cycles as the spacecraft orbits the Earth, insufficiently interior light levels, and frequent shifts in sleep/wake schedules put crew-members at risk of circadian misalignment during missions [46,47].

During space stays, the most frequently used medication is for sleep problems according to Wotring. [48] It has been recognized that medication does not solve the issue of sleep duration, but it does reduce the effects of stress or other uncomfortable causes, but obviously cannot compensate for the absence of gravity. Countermeasures are numerous, e.g., changing the wavelength of light [49,50] and synchronizing ground nights and days with the crew on board, as reported by Barger [51] Monk and Mallis [52,53].

Sleep has been one of the concerns of the physiology of man in space; however, the most serious and major effects of the absence of gravity concerns the muscles and bones.

The usual stress that is applied on the ground due to gravity is lacking and its absence produces atrophy of muscles and loss of strength in the bones. Bone re-calcification and muscle re-building are slow processes and have been studied by Leblanc [54], Sibonga [55], and Vico [56], while normal sleep can recover within a few days after landing to reach pre-mission values [49]. It is understandable and reasonable that the serious change in the muscles and bones has received more attention than sleep.

Discussion

A survey of the scientific literature regarding the possible influence of gravity during sleep was described. Gravity exists but has no visual image. If one imagines that a gravity vector exists under any mass, it is easy to understand some of the curious circumstances of sleep. As mentioned in the introduction, the research is only based on observations that could spur further scientific inquiries. A great number of studies implicitly confirm the action of gravity. However, there are many questions that can be raised regarding this hypothesis.

If during REM sleep, the muscular system is atonic, as if there was a need for rest, then why do athletes not have longer REM sleep duration and therefore longer sleep duration? In contrast, a number of studies have shown that athletes obtain slightly less than the minimum recommendation of 7 h of sleep per night. Exercise is a complex activity that can be beneficial to general well-being but may also stress the body [57].

One phenomenon that has not been investigated concerns the work to maintain cohesion between all organs and parts of the body. The fascia, dense connective tissue sheets, may play an important role as force transmitters in human posture and movement regulation [58].

As gravity cannot be changed, except for space flights, the possible health implications on Earth seem to be, at least for the time being, reduced. However, the assumptions allow us to better see some of the singularities of sleep.

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