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Sleep on manned space flights: Zero gravity reduces sleep duration

Alain Gonfalone [1]

European Space Agency, France

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ABSTRACT

The success of a manned space mission depends on the well-being of the crew. Sleep in space has been the concern of researchers from the earliest days of manned space flight. In the new frontier of space exploration one of the great problems to be solved relates to sleep. Although many reports indicate that sleep in space differs only in minor ways from terrestrial sleep, such as being somewhat less comfortable, a consistent finding has been that sleep duration in space is shorter than that on the ground. This review considers the accumulating evidence that the main reason for the shorter duration of sleep in space is the absence of gravity. This evidence shows that, similar to the effect of many other environmental variables like light, sound and cold, gravity has a measurable impact on sleep structure. As opposed to ground, in zero gravity conditions the innate, permanent, and almost unconscious effort to maintain posture and equilibrium is reduced while simultaneously the vigilance against gravity or "the fear of falling" diminishes. These phenomena may potentially explain research findings that REM sleep latency and duration are shorter in space. This assumption also implies that sleep on ground is due in part to the effort to compensate for the presence of gravity and its effects on the posture and motion of the human body: an ignored and unsuspected contribution to sleep.

1. Introduction

1.1. Sleep

The history of manned space flight now spans more than fifty years. The duration of manned missions has increased since the early years from as little as a few hours to many months in the current era. Many studies of the sleep of astronauts, whatever their sex, ethnic origin, language, religion or creed, now unambiguously support the conclusion that sleep duration in space is shorter than the duration of sleep on Earth. An immediate and obvious conclusion, supported by evidence from similar studies carried out on the ground, is that space missions of lengthy durations are associated with sleep deprivation [1,2].

As early as the first Skylab mission [3] the study and promotion of normal sleep was a central concern of mission planners since the success of a manned space mission depended critically on the mental alertness and wellbeing of the crew. Since then, many other investigations have sought to determine the reasons for sleep disturbance in Space. Despite many opportunities to study the sleep activity of other species, and in particular that of mammals, these research efforts have focused almost exclusively on sleep in humans. This is in contrast to parallel studies that have been carried out on Earth where what has been learned from the study of mammals, such as cats and rodents, has proven quite fruitful for providing insights into the nature of sleep in humans [4].

1.2. Gravity

Opposed to the phenomena of sleep, which is one component of life sciences, the effect of gravity, which belongs to the world of physics is one important environmental variable of our world. Even if the existence of gravity cannot be explained its effects are evident, measurable, predictable, and follow strict, rigorous mathematical rules. Gravitational acceleration has been constant throughout the 4 billion years of biological evolution on Earth. Gravity interacts with other environmental factors to produce today's Earth; for example, gravity is responsible for giving weight to living and inert objects on Earth, so gravity is necessary for rain to fall, for water to drain, for air and water to separate [5] but also for the weight of humans including astronauts. "If the laws of physics weren't just they couldn't be here at all. The sun couldn't be there, the laws of gravity . . . have to be just the way they are for us to be here" [6]. During Evolution life has evolved from the sea, terrestrial species had to adapt to the atmosphere and develop lungs, to adapt to changing temperature and develop a warm blood system, to adapt to gravity

E-mail address: alain.gonfalone@wanadoo.fr
[1] Former staff.

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and develop limbs to support their weight so as to be able to move and forage in wider areas [7]. All living creatures are accustomed to the effects of gravity and hardly notice them. In humans there are different sensors to detect the physical environment of the outside world: eyes for light, ears for sound, etc. . . Gravity is not detected by a single sensor but rather a distributed system, which is spread throughout the body and is extremely complex: the main sensor is in the ear, the semi-circular canals and the otoliths. This system, along with various brain centers, collectively makes up the vestibular system. The body's balance however is also achieved with the contribution of important information delivered by the eyes to the brain. There are also receptors in the muscles and tendons called proprioceptive receptors, discovered by Sherrington in 1906. A concise and abrupt statement concerning proprioception is quoted by J. Paillard [8]:

> *"Suddenly deprived of life, the body collapses, inert, brought down to the ground by the forces of gravity. The muscles are soft, and the moving parts of skeleton can be made in all possible positions*"

(translated from French). The presence of these receptors means that almost every joint in the body further contributes to the important physiological and life protective goal of maintaining position and orientation in physical space. Humans think about their weight often but carry it most of the time without noticing and unconsciously. The effects of gravity on many life functions vary considerably and is often difficult to study but can easily be detected in invertebrates such as bacteria and insects [9]. In human crews on space missions, it has been noted that the long term lack of gravity has generally debilitating effects: "The intensive exercises performed by crews are not able to counteract the loss of bone/muscle mass and strength because exercising in space without gravity does not produce the same level of mechanical loading possible on Earth." [10]. This paper is not based on either astronaut's interviews or neurophysiological measurements or neurobehavioral performance tests. It is based on an extensive and careful review of already published results, which confirm that the total sleep duration, REM sleep latency and REM sleep duration are shorter in space than on Earth. The assumption that the absence of gravity plays a role in sleep explains a large proportion of the results previously found.

2. Sleep on earth

2.1. Effects of gravity on REM sleep

Sleep is a natural, periodically recurring state of inactivity characterized by the loss of consciousness and reduced responsiveness to external stimuli [4]. On Earth humans probably don't think about it often, but gravity affects their every move and also their posture when at rest. During waking the brain is permanently concerned by the equilibrium of the body and maintains it through motion of body masses. In a recent paper, it is demonstrated that the commencement of REM sleep is associated with a reduced sensitivity to all environment parameters, such as light, sound, contact and the unexpected particular parameter: gravity [11]. A simple way to evaluate how gravity can affect sleep is to consider that humans, like many other mammals, are born with the fear of falling (FOF) [12] and as long as the brain has not overcome this fear, REM sleep cannot occur. One important and determinant experimental result was obtained by Jouvet who observed that a cat on a platform above water could sleep but was not able to dream, i.e. the state corresponding to the REM sleep stage [4]. It can be concluded that the cat controls its equilibrium while it sleeps and does not stop monitoring its position against the gravity vector. Maintaining a state of permanent alertness against a possible fall is reduced at night and especially before REM sleep episode. All terrestrial animals are seemingly bound to Earth's surface due to this all-pervasive invisible force. Terrestrial animals need to securely lie down or safely clamp themselves to achieve REM sleep. Whether the sensation of weightlessness results from a reduced attention of the brain, or is the result of a "paralysis" of all gravity and posture sensors, still remains to be clarified but will need very fine and skillful experiments. Many experiments have demonstrated that the FOF is innate in almost all species. FOF implies many efforts during the wake period to maintain the posture of the body and the different parts of the body in the upright position and it includes as well keeping balance.

Note: throughout the paper the expression "fear of falling" (FOF) is used, but this is a concise statement covering and encompassing all the complex efforts during the wake period to maintain the posture of the body and the different parts of the body in their natural position. It includes as well the maintenance of equilibrium. For this task all antigravity muscles attached to the skeleton, are under tension to preserve postural stability. An individual requires the complex integration of sensory information regarding the position of the body relative to the surroundings, and the ability to generate forces to control the body movement. Miniaturised accelerometers are the usual tools for measuring the amount of movement of the body [13]. If during the wake period all muscles are under tension, during REM sleep the atonia corresponds to a complete loss of tone in the muscles except for a few. Usually the head is maintained straight above the shoulders through a permanent tension of the neck muscles, which prevents the head from falling over the chest. Muscles in the back and in the legs participate to the posture. Elephants, horses and many others mammals have to lie down to experience REM sleep, while they can sleep standing by locking their legs. Throughout the animal world, other species adopt sleep postures that reduce the effort to stand up against gravity at night. Initially sleep was studied primarily in mammalian systems [9], sleep research using lower vertebrate and invertebrate species including zebra fish, cockroach, bees, drosophila, crayfish, mollusks, has significantly furthered the field and demonstrated the phylogenetic conservation of the physiological need for sleep [14,15]. All animals with legs, supporting their weight, seem to need a period of reduced activity. Animals in the ocean benefit from neutral buoyancy [16,11], and do not have the same sleep as animals on ground, and in particular they miss REM sleep, which terrestrial animals can achieve once they lie safely. The Archimedes force opposes the force of the weight. Astronauts usually train in Neutral Buoyancy Facilities which give them a feeling of weightlessness although the directions like up and down are conserved. In space the absence of gravity is different and exists in all directions.

2.2. Effect of sleep deprivation

If astronauts were subject to sleep deprivation (SD) the effects would be easy to detect. SD produces a change of the behavioural alertness of tested subjects [17]. In an experiment conducted among 16 healthy young adults who had their sleep restricted to an average 4.98 h per night for 7 consecutive nights the subjective sleepiness ratings, sub-scale scores for fatigue, confusion, tension, and total mood disturbance from the mood and ratings of mental exhaustion and stress were elevated across days of restricted sleep [18]. In another sleep restriction study, the reduction of sleep time to 6 h had no overt effect on mental functioning on the first day, but the influence rose significantly with the number of days of restricted sleep [19].

It is recognized today that trying to save on sleep duration is counterproductive [20]. For the future of space exploration one of the great problems to be solved relates to sleep [21].