English translation of the first study reporting cyclical periods of increased respiration and eye and body motility during sleep in infants in 1926, with commentary

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Translator's note on the historical significance of the original work: This is an English translation of the first report in the worldwide literature on respiration and motility cycles during sleep in infants in the 1920's, as part of a series of studies on sensorimotor movements in infant sleep and child development [Denisova, M. P. and Figurin, N. L. (1926). Periodic phenomena in the sleep of children. *Novoe v refleksologii i fiziologii nervnoi sistemy, 2*, 338-345].

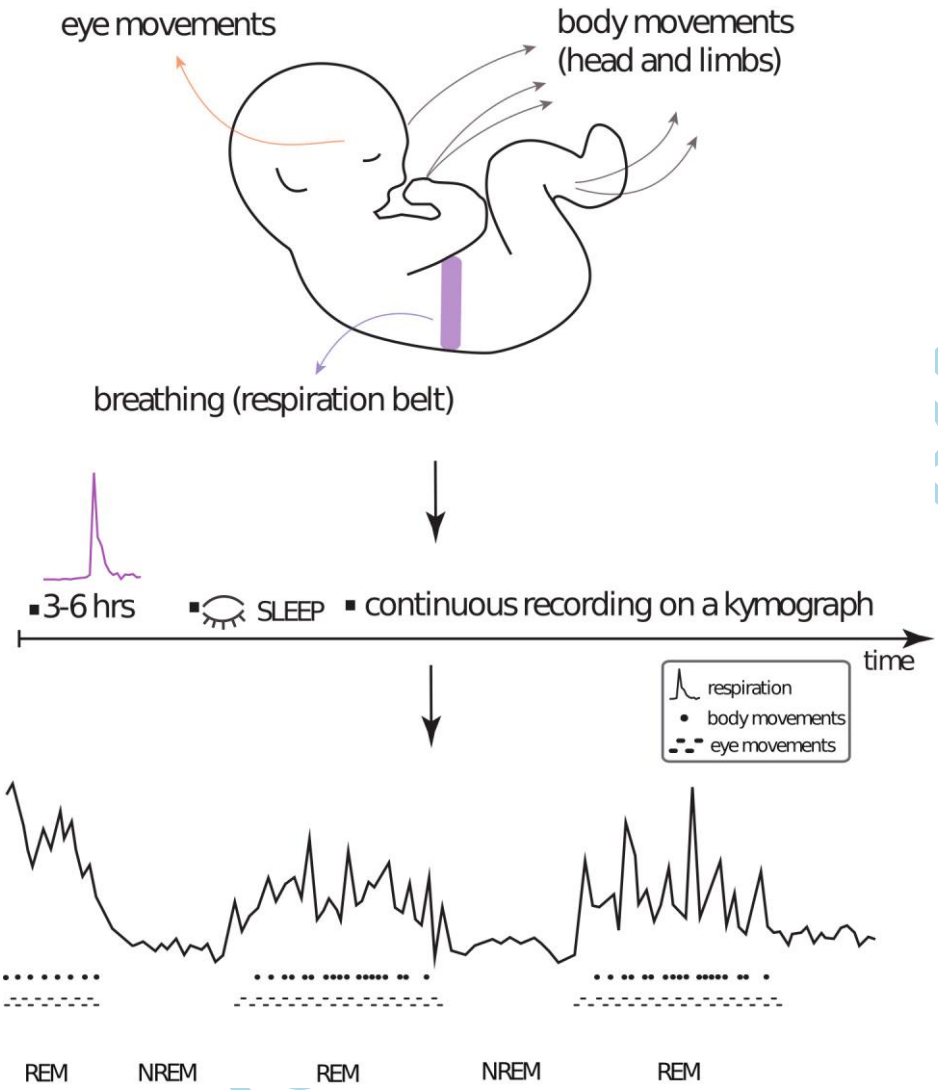
The author (KD) translated this text after extensive research into the history of infant sleep vis-à-vis sensorimotor brain development. The author discovered that this study investigates, using quantitative techniques, hypotheses related to infant sleep states. This study is the first to report data on what is currently termed active sleep or rapid eye movements (REM) sleep, thus preceding all published studies related to REM by other labs by about 30 years. Heretofore, these ideas were thought to be developed much later, in the 1950's. Thus, the comprehensive commentary accompanying this translation considers several noteworthy comparisons between Denisova and Figurin's (1926) study and later reports by Aserinsky and Kleitman (1955; 1953). In addition, biographical details of the original researchers and the Institute at which they worked are also presented for interested readers. Importantly, this significant study on infant sleep cycles has never been translated for Western audiences. Great care was applied to establish and map the meaning of original words used to terminology that would be readily recognizable by sleep researchers today, while also striving to retain the original nuances that conveyed the spirit and efforts of the authors, including unique turns of speech describing the research methods and procedures, approaches, and novel observations on infant sleep. For clarity, long sentences have been split into two separate sentences. There are several instances where Latin was used in the original text; these were retained. Occasions necessitating translator's clarifications for terms or words used are indicated as such by square brackets.

Abstract

This is the first English translation of the work *Periodic phenomena in the sleep in children*, published in 1926 in the Journal *Novoe v refleksologii i fiziologii nervnoi sistemy* (Vol. 2, pp. 338-345) by Maria Denisova and Nicholai Figurin; it is the first study to report data on what is currently termed Rapid Eye Movement (REM) sleep. The authors acquired continuous quantitative respiration data, as well as eye and body movements during sleep in children for up to 6 hours, and discovered several novel features of sleep cycles in healthy infants from birth to about 1 year of age.First, the study reports cyclical periods of increased respiration and eye and body movements, with rapid ocular movements visible under relaxed eyelids (separation:0.5-1 mm). These observations suggest atonia of REM sleep.Second, the length of the complete cycle (alternating active and quiet sleep phases or states) is about 50 minutes, an estimate that is consistent with later work.Third, the study identifies infant-specific ordering of sleep states, with the active phase beginning after sleep onset, followed by the quiescence phase. Importantly, these published data on sleep cycles precede all published studies related to the state now termed REM sleep by about 30 years (i.e.publishing in *Science* and in the *Journal of Applied Physiology* in the 1950s by Eugene Aserinski and Nathaniel Kleitman). In the historical commentary accompanying this translation, the findings of those later works are carefully compared to the original data on respiration and ocular and body motility cycles during sleep in infants, first reported and published by Denisova and Figurin(1926).

Keywords: sleep in infants, rapid eye movements, stages of sleep in infants, movements in infants

Graphical abstract



1. Data on respiration and eye and body motility cycles during sleep in infants in the translated 1926 study by Denisova and Figurin

As part of an extensive sensorimotor and cognitive brain research programme on child development, Denisova and Figurin (1926) reported, initially at a conference in 1925 and then via a publication in 1926, groundbreaking data on respiration and motility cycles during sleep in infants [Denisova, M. P. and Figurin, N. L. (1926). Периодические явления во сне у детей (Periodic phenomena in the sleep of children). *Novoe v refleksologii i fiziologii nervnoi sistemy (Beiträge zur reflexologie und physiologie des nervensystems; News in reflexology and physiology of the nervous system), 2*, 338-345].

To put these 1926 data in context, the current paper is organized as follows. The methods and main findings of Denisova and Figurin are summarized, followed by a commentary comparing work by Aserinsky and Kleitman (1955; 1953). Thereafter, historical context is provided, with biographical details of the researchers performing the 1926 study. The final section contains the English translation of the original study.

Denisova and Figurin's study quantitatively investigated breathing patterns during sleep in relation to eye and body movements during sleep, in healthy, typically developing infants from birth to about 1 year of age, in several sets of experiments. Participants were male (M) and female (F) infants ages 1, 2, 4, 5, and 8 months and 1 year; longitudinal data from one child (Zoya; F) were also acquired (at 1 and 4 months). All measures were acquired from infants in the 24-hour boarding nursery affiliated with Infant Division of the Institute (i.e. the usual "home" environment of the children) and from several older children from private families.

Quantitative recordings of breathing/respiration were acquired using a pneumograph (a respiration belt), with data recorded by means of the kymograph, an instrument used for recording time series. Specifically, breathing data from the pneumograph were transmitted to the kymograph, and recorded as time series tracings on a slowly moving tape of the kymograph. Ocular and body movements were observed and recorded on kymograph's tape simultaneously with the breathing trace (see summary **Figure 1**). Data were collected continuously, for as long as possible, from 3 to 6 hours mostly during nighttime (after the 10 pm feeding) or during daytime (after 11 am). Other events of interest (exogenous or endogenous) detailed below were recorded on the kymograph's tape manually, as they occurred. For example, the authors examined stimulus-evoked responses in order to study the depth of sleep during distinct phases, using an acoustic stimulus consisting of 5 turns of a rattle-like noisemaker (which produced sound of constant intensity), as well as the role of turning over an infant while sleeping (change in position) on sleep cycles. Additional studies examined the impact of urination on sleep cycle patterns. In some infants, pulse measures were acquired through the fontanelle. Data were also presented from older children and adults.

--insert Figure 1 about here--

Figure 1. Respiration and eye and body motility cycles during sleep in infants first reported in 1926 by M. Denisova and N. Figurin. The top of the schematic overviews the methods and devices used in the study, while the bottom presents overall findings of distinct, alternating phases during sleep, currently termed active sleep (or rapid eye movement, REM) and quiet sleep (NREM). (This summary illustration is made by K. Denisova for this commentary.)

The main findings revealed for the first time the existence of periodic, cyclic fluctuations during infant sleep. The cycles (about 50 minutes in duration) consisted of periods of rapid breathing accompanied by heightened motility (increased rapidity of body, head, and eye movements), and of alternating periods of sparse, quiet breathing and few movements. The rapidity of ocular and body motility was found to be tightly associated with the sleep phase characterized by rapid breathing; fewer movements occurred in the sleep phase characterized by quiet breathing. Importantly, Denisova and Figurin reported that during the rapid breathing phase, eye movements were visible through relaxed opening between the eyelids (i.e. the palpebral fissure) with a variable gap between 0.5 to 1 mm, as well as beneath closed eyelids, moving from side-to-side and up-and-down. This set of facts suggests atonia and thereby represents the circumstances of the sleep state that is currently termed REM sleep. In contrast, during the quiet or sparse breathing phase, the eyes are immobile beneath tightly closed eyelids.

Importantly, the onset of sleep began with the rapid breathing and ocular and body movement phase, followed by the quiet sleep phase. These periodic fluctuations were robust starting around 2 months after birth. Within the age range studied, the data indicate prolonged quiet sleep state with increasing age, and reduced periods of rapid sleep state with increasing age.

Moreover, in investigating the roles of different stimuli on sleep cycles, the authors found that the effect of an exogenous stimulus (a 'noise-maker') depends on the depth of sleep. While the reaction was limited during sparse breathing state, this stimulus elicited a strong reaction (e.g. waking up, crying) during the period of increased breathing rapidity, suggesting that the depth of sleep also has fluctuations. There was no effect of turning over the infant (i.e. changing the infant's position) on the periodicity of sleep cycles of the child. The occurrence of urination did not alter sleep cycles. Further, the authors reported that more rapid pulse was observed during the rapid breathing sleep state.

Denisova and Figurin used specific words including "rapid", "frequent" and "quiet", "sparse" to describe the alternating sleep phases shown by their 1926 data. The full translation of the study and Figures are included in the last section herein; several excerpts are below:

"These curves make very clear this phenomenon of **periodic change**. That is, more or less constant and infrequent breathing suddenly changes for **rapid** and very inconsistent." (pp. 339-340 in the original)

". . . there is a certain **relationship** between the **changes of breathing** during sleep and **movements**" (p. 339 in the original)

". . . the **periodic change** in the rapidity of breathing is **not an isolated phenomenon**, rather it is accompanied by several others." (p. 341 in the original)

" . . . it becomes clear that there is an important **connection between these phenomena**." (p. 341 in the original)

"During the **periods** of **increased rapidity of breathing** . . . there is a **concentration of movements** . . . and definitely the **movements of eyelids** …" (p. 341 in the original)

"[eye] movements are apparent . . . in **relaxed** palpebral fissure [**eye opening**], so that between the eyelids sometimes appears variable gap, 0.5 to 1 mm" (p. 341 in the original)

"During periods of sparse [**quiet**] breathing, . . . **the eyes are immobile** under tightly closed eyelids" (p. 341 in the original)

The 1926 data on distinct sleep states, which are differentially quantified by increases (vs. decreases) in rapidity of respiration and eye and bodily motility, precede any other data known to relate these phenomena, in particular, data on the rapid eye movements that appear during the rapid sleep phase, currently termed active sleep or REM sleep.

2. Key comparisons of the translated 1926 study with the 1955 and 1953 papers of Aserinsky and Kleitman

As there are several noteworthy comparisons between Denisova and Figurin's (1926) study and later reports by Aserinsky and Kleitman (1955; 1953), these are presented in detail in the next few sections. Before proceeding, important methodological details of both studies are presented, as follows.

Methodological details: Aserinsky and *Kleitman (1955; infant study)*

Aserinsky and Kleitman (1955) studied sleep in infants from 1 to 7 months (from a total N=14, including 4 infants with complete motility cycles). Existing behavioral data from several other infants were also analyzed. For the main study, measures were acquired in the home of the family. The study acquired quantitative recordings of body movements using a spring, with data recorded on tape (the type of apparatus used was not specified). To measure movement, a mechanical leverage device that inscribed a mark on a slowly-moving tape was used. For a few observations, infants' body motility was recorded electronically by a clock, which registered the duration of each movement in seconds. No additional events were recorded quantitatively. Eye movements were tracked by close viewing (direct observation). The authors also measured inter-feeding intervals, as they were interested to know if time between feedings is a function of the motility cycle.

Methodological details: Aserinsky and Kleitman (1953; adult study)

Aserinsky and Kleitman's (1953) sleep study involved adult participants (N=20). Eye movements were recorded by electrooculograms (EOGs), with the potentials collected via a Grass Electroencephalograph with EOG channels. For comparison to the EOG data, a monopolar frontal electrocortical recording was also acquired (EEG). For several subjects, the presence of ocular movements was verified by direct observation, and under different illumination conditions. For two subjects, videography was acquired under varying illumination conditions. Videography served to validate findings from other recordings, in particular, regarding the synchronicity of eye movements. A set of experiments focused on investigating whether eye motility was associated with dreaming; 10 subjects were awakened during periods of eye activity and also after a period of quiescence. Eleven subjects had undergone a continuous overnight recording (mean duration: 7 hrs) in order to estimate the number of motility periods per night. Another set of experiments (N=14) included calculations of respiratory rate (calculated for a minimum of ½ minute during eye motility periods, as well as 15 minutes before and after).

2.1. Comparisons to Aserinsky and Kleitman's (1955) infant sleep study

Differentiation of sleep into *two* phases: active sleep and quiet sleep

Denisova and Figurin (1926) reported data on two alternating phases during sleep in infants. One phase is characterized by the rapidity of breathing, rapidity of eye movements (including eye movements that were visible under relaxed eyelids with the eye opening separated by 0.5 to 1 mm, suggesting atonia of REM sleep), and rapidity of body movements. The other phase is characterized by an almost complete absence of these phenomena. These observations parallel findings in Aserinsky and Kleitman (1955). Specifically, the close relationship between heightened motility (rapid ocular activity and body movement) during sleep was evident mainly in one of the phases; this phase alternated with the phase characterized by the relative absence of these movements (Aserinsky and Kleitman (1955). Note the similarity between plotted curves showing alternating cycles of sleep phases observed by Denisova and Figurin (1926) (curves 2-5 shown in Figures 3 and 4) relative to the curves of sleep phases reported and shown in Figure 1 in Aserinsky and Kleitman (1955).

Total cycle length: about 50 minutes (slightly less than 1 hour)

Denisova and Figurin (1926) observed a cycle length of about 50 min. Similarly, the mean length of the motility cycle measured by direct observation was reported at 54.2 min in Aserinsky and Kleitman (1955).

Unique ordering of sleep phases in infants: rapid eye movement phase is at the onset of infant sleep

Denisova and Figurin (1926) reported that the phase characterized by rapid movements and rapid breathing begins first, followed by the quiescence phase. Similarly, examination of Figure 1 in Aserinsky and Kleitman (1955) indicates that the active sleep phase (heightened ocular activity and body movements) begins after initial sleep onset, thereafter alternating with the phase lacking ocular movements and characterized by reduced body movements. Thus, both infant studies report similar,

infant-unique ordering of the two cycles after sleep onset (in contrast, in adults, the NREM phase begins soon after sleep onset).

2.2. Comparisons to Aserinsky and Kleitman (1953) adult sleep study

There are a few relevant comparisons between Denisova and Figurin's (1926) infant study and Aserinsky and Kleitman's (1953) study of adults.

Increased frequency of respiration in the active sleep phase

Denisova and Figurin (1926) detected greater breathing rate (in addition to increased eye movements) during periods of increased rapidity of eye movements, that is, during active or rapid eye movement sleep phase. (In Denisova and Figurin's study, respiration was measured quantitatively using a pneumograph.) These data are echoed in later findings by Aserinsky and Kleitman (1953) who observed higher respiration rate during eye motility, in contrast to respiration during quiescence, although the methodology for measuring respiration/breathing was not specified.

Pulse is more rapid during active sleep phase

Denisova and Figurin (1926) measured pulse through fontanelle in some infants. The authors reported higher pulse during periods of increased rapidity of eye movements during infant sleep. Similarly, Aserinsky and Kleitman (1953) mentioned some results of additional ongoing experiments that indicate that heart-rate is also "probably higher" in the presence of these eye movements.

Existence of multiple cycles/phases of high and low motility throughout the night

Denisova and Figurin (1926) observed multiple alternating periods of high and low motility during sleep throughout the night. Aserinsky and Kleitman (1953) reported the existence of several periods of eye motility in adult subjects during a continuous overnight recording (mean duration: 7 hours; duration in Denisova and Figurin's study ranged between 3-6 hours). The periods of eye motility alternate with periods of quiescence ("often as many as 3 cycles, and sometimes a 4th one, during the course of the night"), consistent with the observations reported in 1926 by Denisova and Figurin during infant sleep.

Hunger a driver of high motility periods?

Finally, Aserinsky and Kleitman (1953) noted their interest in the role of hunger related to high level of central nervous system's (CNS) irritability, as potentially driving periods of high motility during sleep, for future work. This factor (hunger) was already ruled out in the previous literature as a cause for movements associated with the active sleep phase, including literature published mainly in

German on this topic and discussed in Denisova and Figurin (1926) (note: infants in Denisova and Figurin's study (1926) were recorded after feeding).

2.3. Influence of 1926 data in next steps for sleep research

The significant contribution of the 1926 data is establishing the existence of two unique sleep states using quantitative methods, thus paving the way for future researchers to characterize each state (and detect additional states) with finer and increasingly more precise techniques including electrocortical recordings. Indeed, Denisova and Figurin's (1926) study is cited as reference #1 in Aserinsky and Kleitman (1955; infant study), suggesting that Aserinsky and Kleitman were familiar with this early work. The original discoveries of infant sleep cycles by Denisova and Figurin (1926) including the active sleep state characterized by rapid breathing and ocular and body movements (currently termed REM sleep), the estimated duration of the sleep cycle (subsuming both active and quiet phases), and the unique ordering of the sleep states in infant sleep, provided the seminal basis for investigating sleep.

3. Biographical details of the authors of the translated infant sleep study and the Institute in which they worked

Maria Petrovna Denisova (b. 1898) and Nicholai Lvovich Figurin (b. 1896) were researchers and later collaborators at the Institute for Brain Research in Leningrad, Soviet Union. Dr. Maria Denisova graduated from the Women's Medical Institute of Petrograd (Leningrad/St. Petersburg) in the early 1920's and by around 1922 was conducting research on early child development in the Infant Division of the Institute for Brain Research. At the time, Nicholai Figurin was an assistant to Dr. Denisova; Dr. Figurin was a medical doctor who was also on staff at the Institute. Both Denisova and Figurin worked in the Infant Division, headed by Nicholai Matveevich Shchelovanov. All three were trainees of Vladimir Mikhailovich Behterev.

The Institute was founded by V.M. Behterev himself in May 17, 1918, and commenced work on October 1, 1918. The mission of the Institute was to advance research on brain and psychological function and included several research divisions, many of which were applied to help address specific challenges in society. For example, results of empirical studies on early child development helped inform early child education and interventions. By 1924, there were several divisions including the Division of Brain Morphology, Division of Reflexology, Infant (pedological) Division (where Denisova developed an infant sleep and child development research program), Labor (work) Physiology Division, and Scientific-Industrial Division. As an aside, it is not surprising that sleep was the focus of one of the Divisions of the new Brain Institute, since already by 19th century, sleep research had a prominent place in St. Petersburg, advanced by M.M. Manaseina, a female sleep scientist, and thereafter in the 20th century by Behterev, Pavlov, and later Bikov.

The Institute was well funded and equipped with the latest technology. Discretionary funds supported staff travel, scientific visits to conferences, and active collaborations with scientists in other countries. Importantly, V.M. Behterev established a number of initiatives, including a regular meeting of the Scientific Society for Reflexology, Neurology, and Biophysics. More broadly, V.M. Behterev's and his trainees' research on human brain, psychological functioning, and the role of environmental factors on cognition (including his discovery of association reflex in human participants) can be contrasted to animal-based research by his main competitor, Nobel Laureate Ivan Petrovich Pavlov, who carried out reflexological experiments and surgeries in dogs and who discovered conditioned reflex.

On December 24, 1927, V.M. Behterev died at the 1st All-Union Conference of neuropathologists and psychiatrists in Moscow. At that time, he was the Head of the Psychoneurological Academy, which subsumed his Institute for Brain Research. After his death, the Institute was renamed in 1929 in his honor as the V.M. Behterev Institute for Brain Research. The new Head of the Institute in 1929 became Victor Petrovich Osipov. In the 1930's the Division where Denisova and Figurin worked continued to be headed by N.M. Shchelovanov, but was now called the Developmental Division of genetic reflexology and contained several laboratories; children from birth to 1 year were studied in the Clinic of pedology and neuropathology of infancy. Further, in 1931 the Division, Clinic, and its staff were transferred to Moscow and became part of the Institute for Scientific Research of Maternal and Infant Care. That Institute has foundational roots in the 18th century and is currently subsumed under the auspices of the Academy of Medical Sciences.

During the course of their career, Denisova and Figurin produced many research studies focusing on newborn and infant sleep, on newborn, infant, and toddler reflexes, on early cognition and perception (e.g. color and object perception), and on child education, publishing in Journals edited by Behterev, Blonsky and Vygotsky. Notably, as part of their series of studies into sensorimotor movements in infant sleep and child development, they reported at a conference and then published in 1926 original quantitative data on respiration and eye and body motility cycles during sleep in infants, becoming the first report in the worldwide literature to produce and publish data on sleep states and in particular on what is now termed rapid eye movements (REM) sleep state. Their several monographs include a compendium of their research in early child development, published in 1949. Fundamentally, their body of research established the importance of sensitive periods in a child's development and cognitive functioning, in particular, the role of sleep in development, starting from the first few months of life.

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