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Geoclimatology and sleep in Africa: a mini-review

**Authors:** Alain Buguet<sup>1</sup>, Rahamatou Gati Ouonkoye<sup>2</sup>, Pascal Bogui<sup>3</sup>, Raymond Cespuglio<sup>4,5</sup>

**Authors' addresses**

<sup>1</sup>Malaria Research Unit, UMR 5246 CNRS, Claude-Bernard Lyon-1 University, 69622

Villeurbanne, France. E-mail: buguet.alain@orange.fr

<sup>2</sup>Département des Sciences Fondamentales et Mixtes, Faculté des Sciences de la Santé,

Université Abdou Moumouni, Niamey, Niger. E-mail: samanagay@yahoo.fr

<sup>3</sup>Laboratoire de physiologie et explorations fonctionnelles, UFR Sciences Médicales, Université

Félix Houphouët Boigny, Abidjan, Côte d'Ivoire. E-mail: pasbogui@yahoo.fr

<sup>4</sup>Centre de recherche en neurosciences de Lyon (CRNL), Centre hospitalier Le Vinatier,

Bâtiment 462, Neurocampus, 95 boulevard Pinel, 69500 Bron, France. E-mail:

cespuglio@univ-lyon1.fr

<sup>5</sup>Sechenov 1<sup>st</sup> Moscow State Medical University, Laboratory of Psychiatric Neurobiology,

Moscow, Russia.

**Corresponding author postal address:**

Professor Alain Buguet

21 rue de Champfranc

38630 Les Avenières Veyrins-Thuellin

France

E-mail address: buguet.alain@orange.fr

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**Abstract**

Sleeping habits and morningness-eveningness questionnaires (chronotype), and polysomnography (internal sleep organization) were proposed to healthy volunteers living under natural climates from different locations in West Africa (Niger, Côte d'Ivoire) and Central Africa (Angola, Congo). Under the Sahelian dry climate, 138 Niger medical students (130 had afternoon naps) completed 1,792 sleep questionnaires during 7-day sessions in the cool-dry and hot-dry seasons. As everywhere else on Earth, daily sleep lasted 7 to 8 hours. In Abidjan (hot-humid climate), 78 medical students reported shorter sleep time, because of course schedules. Also in Abidjan, 23 African sportsmen and Expatriate soldiers slept at night and in afternoon naps. They reported similar sleep amounts than Niger students. In Congo villages, during a 5-year human African trypanosomiasis (HAT) research campaign, 45 healthy volunteers expressed morning chronotypes. The 71 HAT patients shifted from the indifferent chronotype towards morningness type. Chronotyping such patients may help evaluating treatment efficacy on brain function alterations. French soldiers executing missions in Africa were typed for morningness-eveningness. Regarding malaria prophylaxis and mosquito control, morning chronotype was more compliant than evening type. Polysomnography demonstrated internal sleep organization differences in different geoclimatic zones. The Sahelian climate promoted N3 slow-wave sleep in Africans and Expatriates during both the cool-dry and hot-dry seasons, with higher amounts in the hot-dry season. Increasing heat load by physical exercise further augmented N3. Rapid-eye-movement R sleep was high compared with values from temperate and hot-humid climates. Supramaximal exercise triggered a surprising R stage increase in the hot-dry season. In Côte d'Ivoire, Caucasian and African volunteers fragmented their sleep, although internal sleep organization approached that of temperate climates. Sleep patterns were also similar in Angola high hills and on Congo River shores. Therefore, Africans and Caucasians living in Niger hot-dry Sahelian climate exhibited major differences with those exposed to hot-humid or temperate climates.

**Keywords :** sleep; questionnaires; polysomnography; hot climates; Africa

## 1. Introduction

A number of literature reports have examined the effects of short-term exposure to heat on sleep in humans. These were mostly focused on thermal exchanges during sleep, sleep structure itself being regarded as second to the establishment of relationships between thermoregulatory variables and sleep stages [1]. Short-term exposures to heat led to sleep fragmentations and decreases in slow-wave sleep (N3 sleep or state N3) and/or REM sleep (rapid-eye-movement, R sleep or state R) [2,3]. Long-term exposures to hot environments, which were meant to mimic warm climates, are rare in the literature. The authors even considered that being submitted to heat continuously during 5 nychthemera (days and nights) represents a chronic situation [3]. However, in such experimental conditions, sleep was disturbed, although individuals reacted differently. For several years, sleep studies in heat exposure were undertaken in laboratories, especially in the Environmental Physiology and Psychology Laboratory at Strasbourg. Libert et al. [4] reported on 6 volunteers who spent three consecutive periods of 5 nychthemera in the bioclimatic facility at dry temperatures of 20°C (baseline), 35°C (heat exposure), and again 20°C (recovery). The nocturnal R-NREM (non-REM) sleep cycle was shortened in the heat, due to shorter R sleep episodes more frequently interrupted by awakenings. Episodes of R sleep were shortened during the first two nights. Interestingly, no changes did occur in stage N3. More recent investigators also focused their approach on the relationship of sleep with thermoregulatory processes [5]. However, laboratory conditions do not perfectly match field climatic exposure, which allows to adapt progressively to seasonal climatic variations.

Due to the opportunities provided by either professional postings or scientific missions, sleep patterns were analyzed in humans living in sub-Saharan African climates. The investigations were conducted over a period of 33 years in both laboratory and village field conditions. Answers to sleep questionnaires were used to delineate sleeping habits and polysomnographic recordings were undertaken to specifically focus on sleep patterns in different locations in West Africa and Central Africa. The purpose of this review is to describe the eventual differences impacted on human sleep by the diverse geographical locations and climatic conditions in which the investigations were conducted.

## **2. Material and Methods used**

### **2.1. Study locations and subjects**

The investigations were performed in different locations and climatic conditions: hot and dry climate in the Niger Sahel, during the dry season (October-May); warm and humid equatorial climate in Côte d'Ivoire at Abidjan and in the area of Sinfra in the sleeping sickness croissant; warm and humid equatorial climates in the Republic of Congo along the Congo River and its tributaries; tropical climate at hill altitude in Angola. Table 1 gives the geographic localization of the different sites at which the investigations were conducted.

Volunteers to participate in the investigations were either healthy medical students from the Universities of Niamey and Abidjan, or French military Expatriates in Niger and Côte d'Ivoire, sportsmen in Niger and Côte d'Ivoire. Also, during diagnosis and treatment campaigns on African sleeping sickness, human African trypanosomiasis, control healthy volunteers from the same towns and villages as the patients were asked for their contribution in Côte d'Ivoire (Daloa and Sinfra), Angola (Viana-Luanda and Samba Cajù) and the Republic of Congo (Brazzaville and Mpouya). The latter group of subjects was composed of young and middle-age people matching the ages of the sleeping sickness patients.

### **2.2. Ethical considerations**

Each subject gave his written informed consent in agreement with the World Medical Association Declaration of Helsinki II (adopted in 1964, amended several times and finally in 2013), the French Loi Huriet-Sérusclat (1988) and with the recommendations of the World Health Organization Research Ethics Review Committee. The Marseille II Ethics Committee and/or the Lyon Léon Bérard Ethics Committee were also consulted as some countries hosting the investigations had not yet developed their own Ethics Committee. In that case, the Health authorities of the country were asked to approve the research protocol.

### **2.3. Studies on sleeping habits and quality**

Chronotypology of the volunteers was obtained through the Horne and Österg [6] morningness and eveningness questionnaire in its reduced form proposed by Adan and Almirall [7] to determine the subject's chronotype: morning, evening and indifferent types (Appendix 1). Morning people wake up early and are more alert during the first part of the day [8]. Evening individuals tend to go to bed later and are more alert during the latter part of the day. Indifferent chronotype is in between the two previously defined characters. The reduced questionnaire [7] is easier to use in field conditions. It comprises five questions based on the original 19 questionnaire [6] and has been validated in young adults [9]. The chronotypes were used to either select the subjects or verify their impact on disease prophylaxis or time course.

Qualitative and quantitative aspects of sleeping habits were obtained from a questionnaire developed by our team to be applied in field conditions [10]. The questionnaire (Appendix. 2) was completed upon awakening, after nocturnal or diurnal sleep. Five questions required quantitative answers to obtain time in bed, sleep latency, sleep period time, i.e., from first asleep to last awake, number of awakenings and number of dreams. The use of analog scales unevenly disposed in the questionnaire form allowed to avoid copying from one scale to the other. It also permitted to obtain a note corresponding to perceived symptoms such as restorative sleep quality, easiness to go to sleep, need to sleep or fatigue upon awakening, work drive, physical shape, moral, mood and the agreeable/disagreeable perception of dreams.

#### **2.4. Polysomnographic studies**

Polysomnography was performed using paper recordings on electroencephalographs (EEG) until we disposed of portable recorders. These were also of two types due to progressive improvements of available products. The elements of comparison for the sleep patterns and values of internal sleep organization across the investigations across Africa were taken from studies conducted in baseline conditions by our group in Europe [11] and in Canada [12].

In Niamey, polysomnography was taken on an ECEM T3 EEG machine at paper speed of 15 mm/s determining 20-s scoring epochs. Subjects were equipped in the evening to allow time for adaptation. The allotted time to sleep equaled 8 hours per night, the subjects sleeping in a bedroom adjacent to the EEG laboratory, cables transmitting biological signals through a hole in the wall between the two rooms. The rooms were air conditioned and ambient temperature was

set at  $24-25 \pm 1^\circ\text{C}$ . The environment of the laboratory facility was very quiet at night, being away from any road traffic and city noise. In order to eliminate a possible first night effect [13], three consecutive nights were recorded in each of the two sessions (one in the cool part of the dry season, cool-dry; the other in its hot part, hot-dry). Two channels were assigned to the EEG, electrodes being fixed to the scalp with collodion that was easily removed in the morning. Facial electrodes were fixed with hypoallergenic surgical tape, two electrodes at the outer canthi of the eyes on a diagonal line to record horizontal and vertical eye movements (electro-oculogram, EOG) and two electrodes at the tip of the chin (electromyogram, EMG) in a bipolar montage. Respiration was explored by measuring the nasal and buccal air flow temperature variations with thermistors and by recording chest movements with a strain gauge to determine the eventual occurrence of sleep apneic episodes. Heart rate was recorded using a bipolar montage. One electrode was taped to the forehead to ground the patient.

Ambulatory monitoring of 24-hour polysomnography was initiated in 1989 with Oxford 9000-II<sup>®</sup> 8 channel analogue cassette tape recorders (Oxford Instruments, Abingdon-on-Thames, UK). These recorders were used in Côte d'Ivoire and Angola. Similarly to the above description, subjects were equipped, the procedure taking place in the morning to allow them to become accustomed to recording conditions. The recordings were played back on paper afterwards, using an Oxford 9200 reading unit. Sleep scoring was performed on 20-s epochs.

In 2004, we acquired digital portable recorders (Temec Vitaport 3<sup>®</sup>, Temec Instruments, Kerkrade, The Netherlands), a modular system that allows optimal configuration of signal acquisition parameters and signal conditioning. These recorders were used at Mpouya. Subjects were again equipped in the morning. Scalp electrodes were connected to the recorder. Four facial electrodes were fixed with surgical tape. The recorder was placed in a waist bag, subjects being freely moving but requested to avoid running and heavy work (Fig. 1). They were instructed to retire to bed whenever feeling sleepy. Digital signals were stored on PCMCIA 512 Kb memory cards. Polysomnographic recordings were analyzed using the PRANA<sup>®</sup> software (PhiTools, Strasbourg, France).

Before 2007, the scoring technique followed Rechtschaffen and Kales recommendations [14]. After 2007, in order to follow more recent recommendations issued by the American Academy of Sleep Medicine, the technique complied with Iber et al. scoring recommendations [15]. In order to harmonize data presentation, the recent terminology will also be used throughout

this review: wakefulness becomes stage W; stage 1 becomes N1 (from non-REM sleep, NREM, stage 1); stage 2 becomes N2; slow-wave sleep (stages 3 and 4) becomes N3; REM sleep (or paradoxical sleep) becomes stage R [15,16]. Calculations included recording time, sleep period time (SPT); from falling asleep to last awakening), W occurring during SPT, total sleep time (TST=SPT minus awakenings), sleep latency (from the beginning of the recording to stage N1). Latency to stage R (from sleep onset to the beginning of R) was measured during each sleep episode. Two sleep episodes were considered to be different when separated by at least 10 min of continuous W. Accordingly, two W episodes differed when interrupted by more than 10 min of sleep. Two R phases differed when separated by more than 15 min. Each sleep stage was analyzed by measuring total duration, number of phases, mean phases duration and proportion vs. TST. The mean duration of the R-NREM sleep cycle was calculated.

### **3. A Review of Results and Discussion**

#### **3.1. Sleeping habits in African dry and humid climates**

In Niamey, investigations were conducted during the cool-dry season of the Sahelian climate (e.g., January, mean ambient temperature  $T_{db} = 31.1 \pm 0.8^{\circ}\text{C}$ ) and the hot-dry season (e.g., May,  $40.6 \pm 0.3^{\circ}\text{C}$ ), with very only slight differences in daylight duration (January, 11 h 25 min; May, 12 h 45 min) [17,18]. The students completed the sleep questionnaire (Annexe 2) upon awakening from night or nap sleep during 7 days, three weeks before academic review in January and May. The analysis was carried out on a total of 1,792 questionnaires. The majority of the 138 subjects napped, being inclined to do so because the academic courses started only à 16:00 h due to the afternoon heat. Only 8 of them did not nap. Among the subjects, 53 completed the 7-day sessions in January and May. In the average, the students having to work in their courses in the evening, night bedding down occurred at 00:06 h  $\pm$  1.2 min and rising time at 07:08 h  $\pm$  1.8 min in both sessions. After lunch, they went to bed at 13:52 h in January and 13:02 h in May. They woke up at 15:30 h  $\pm$  3.0 min in January and 15:08 h  $\pm$  4.8 min in May. In the subjects who usually had a nap, night sleep duration was approximately 380 minutes, being similar in January and May whether they had a nap or not. Nap sleep lasted 70 to 80 min, giving a 24-h average sleep of 450 to 460 min. Sleep latency was 49% longer during afternoon naps than at night, although it stayed below 20 min in January but decreased below 13 min in May. The 8 subjects

who never napped had a similar night sleep duration in January, but increased their nocturnal sleep to 440 min. They were therefore more sensitive to climatic heat variations than the subjects who usually napped. In the students who usually napped, the scores for sleep quality, physical rest and mood dropped to 66% of night sleep values after waking up from naps. However, naps seemed to be more refreshing in May as scores represented 76.6% of morning values vs. 56.6% in January. Subjective sleep quality scored around 7/10 except for the May data for the group that never napped (5/10). In May also, this group scored the lowest values for physical rest and mood. Sleep fragmentation was low, as the number of awakening recalls was small at night (1.1) and during the naps (0.5). At night, the subjects woke up because of general physiological discomfort (31.1% of the cases), need to urinate (23.5%), noise (17.4 %) and feeling cold especially in January (15.4%). Vivid dreams were reported as being the cause for waking up in 9.3% of the cases, nightmares occurring in 0.6%. According to the reasons invoked for awaking in the night, the subjects were sensitive to their environment, especially in the hot-dry season. Therefore, in Niamey as everywhere else on Earth, the students slept between 7 and 8 hours daily [19]. However, the majority of students napped in the afternoon, longer than under other latitudes. Sleep quality, working drive, physical shape and mood deteriorated after the naps compared to waking up in the morning. These subjects did not exhibit any climate-related difference in night-time or daytime sleep. Contrarily, those students who did not nap increased night sleep duration in the hot-dry season.

A similar investigation was performed in 78 Abidjan University students [20]. Alike their colleagues from Niamey, they completed the questionnaire during seven days, during which ambient temperatures varied from 29.5 to 35°C with relative humidity ranging from 75.5 to 89.5%. However, because seasonal climatic variations are buffered in such an equatorial climate, the investigation was conducted only once. The subjects did not nap in the afternoon, certainly because of the courses starting again at 14:00 h. The students bedded down at 00:34 h  $\pm$  2.4 min. They stayed in bed for an average 357.4  $\pm$  4.4 min, increasing in week-end days. They slept approximately 30 min less than Niger students. Sleep latency lasted 12.8  $\pm$  0.9 min. They rarely woke up during sleep. The subjective values were similar to those recorded in Niamey: easiness to fall asleep (6.8/10), sleep quality (6.1), working drive (6.4), physical shape (5.7), morale (6.3) and mood (6.4). Therefore, because of constraint from work hours, the Côte d'Ivoire students had a shortened time allotted to sleep, and subsequently a 41-min shortening of night sleep.

In Abidjan also, at the infirmary-hospital of the French base at Port-Bouët, 11 Ivorian volunteers (the 12<sup>th</sup> subject disclosed the investigation after one day) were matched with 12 French Caucasian troopers living in Côte d'Ivoire since at least four months [21]. All volunteers were used to sustained sport activities. They were thoroughly screened medically, and to discard both Horne and Östberg questionnaire extreme chronotypes [6] and sleep disorders (with Gaillard's sleep questionnaire) [22]. The subjects slept on beds in the hospital-infirmary without air conditioning during three consecutive nychthemera for adaptation to sleeping conditions and avoid the first night effect [13]. Sleeping was permitted between 22:30 h and 05:30 h at night and between 13:30 h and 15:00 h after lunch. Alike the Niger students who napped, the Abidjan volunteers slept a little more than 7 hours and 30 min per day, without any difference in the two groups (Ivorian, 455.4 min; French, 454.4 min). The sleep quality and subjective feelings were collected at the end of each sleep epoch. The two groups of subjects slept similarly, whether at night or during nap sleep. However, after awakening from night and nap sleep, and contrary to the Ivorian volunteers, the French troopers reported lower subjective values regarding vigilance, work drive, physical shape, and mood, although sleep quality did not differ in the two groups. Therefore after morning rise and after the afternoon nap, the African subjects felt less sleepy, more inclined to work, more refreshed and in a better mood than their French counterparts. Therefore, the lack of sleep observed in the Abidjan medical students [20] is most likely due to the professional environment, especially regarding the working hours and work pressure, rather than climatic factors.

### **3.2. Morningness-eveningness chronotypes and their potential interference with health**

The morningness-eveningness questionnaire [6,7] was mainly used to select volunteers. The extreme chronotypes (definitely morning type and definitely evening type) were discarded. This was the case in most polysomnographic investigations, as well as in the latter investigation in Abidjan [21].

#### **3.2.1. Chronotypes of sleeping sickness patients**

In the Republic of Congo, we conducted a five-year investigation in the Couloir focus of African sleeping sickness on the Congo River right shores. The focus extends from the northern outskirts of Brazzaville to Makotimpoko at approximately 300 km. We recorded polysomnography in 76 patients and 45 control matched volunteers who also completed the abridged version of the morningness-eveningness questionnaire [23].

The majority of healthy controls bedded down at 20:50 h  $\pm$  9 min and arose at 05:49 h  $\pm$  6 min. In the conditions of the investigation, i.e., volunteers having to moderate their physical activity because of carrying the polysomnographic equipment, the healthy controls usually napped too, for an average of 66  $\pm$  6 min. The subjects belonged to the Moderately morning type (20 individuals, 44.4%) or Definitely a morning type (14, 31.2%). The Neither type-indifferent chronotype was found in 11 subjects (24.4%). In the average, the chronotype score equaled 19.8  $\pm$  0.45, corresponding to a Moderate morning type. Interestingly, no tendencies towards evening types were observed. This morningness preeminence is not surprising as there was no electrical light in the villages, except for the rare festive evenings during which the large generator was turned on. Furthermore, villagers must provide daily food supply to their family. They are used to rise early in the morning to work at cultivated fields or at fishing in the river.

Out of the 71 Couloir focus patients who completed the questionnaire correctly before treatment, the morning type tendency was also found in the patients: 23 Moderately morning type (32.4%), 28 Definitely morning type (39.4%), and 20 Neither type, indifferent (28.2%). The patients as a group did not differ from the healthy controls. Initially, the investigation protocol was meant to be applied only once. However, we hypothesized that patients, especially those at stage 2 (sleeping sickness meningoencephalitis), may have changed their chronotype after treatment. It was thus decided to pursue the patients' chronotyping during the post-treatment semi-annual follow-up procedure to verify this assumption. Therefore, the number of patients participating in this analysis varied throughout follow-up sessions, because sleeping sickness screening was performed every six months in the villages scattered along the Congo River. Newly recruited patients would then join the team. Furthermore, some patients did not complete the questionnaire; others were released after being declared as cured; others disappeared and three died.

Table 2 shows that, compared to pre-treatment values, patients at stage 2 (altered cerebrospinal fluid, CSF, with  $\geq$  5 cells/ $\mu$ L; clinical manifestations especially regarding

neurological and psychiatric signs and/or symptoms) changed their chronotype towards increasing their morningness scores on the 18<sup>th</sup> month post-treatment follow-up session compared to data obtained before treatment, and at the 6<sup>th</sup> and 12<sup>th</sup> months follow-up sessions. Such changes were also observed in patients at stage 1 (the hemolympathic stage with no neurological or psychiatric sign, no CSF abnormality, with  $\leq 5$  cellular elements per  $\mu\text{L}$ ). They increased their morningness chronotype score at the 12<sup>th</sup>, 18<sup>th</sup> and 24<sup>th</sup> months semi-annual follow-up sessions. Therefore, in a given population, chronotype may vary according with the health status of the individuals. Chronotyping patients is a perfectly non-invasive technique that may represent a good and quick way to appreciate the improvement of their neuropsychological status.

### **3.2.2. Chronotypes and compliance with anti-malaria prophylactic measures**

The chronotyping procedure applied to the subjects proved to be valuable in dealing with compliance regarding malaria chemoprophylaxis [24] and vector (mosquito)-control measures [25]. The latter was examined in 2,093 and the former in 2,205 French soldiers, respectively. They belonged to 100-150-men companies (19 and 20 units, respectively) serving in 5 African countries in West Africa (Côte d'Ivoire, Senegal), Central Africa (Chad, Gabon, Central African Republic) and Djibouti (for the vector-control study [25]). Each unit was missioned to its African location during 4 months. The study was conducted over a period of 44 months ending in September 2007. The research team belonged to the century-old Pharo Institute of Tropical Medicine in Marseille. Mosquito-control measures included using insect repellents, sleeping under an insecticide-impregnated bed net, and wearing long clothes at night when unprotected by the bed net. Morning type personnel, confirmed by chronotype and bed time hours, were more likely to show correct compliance. Evening types were less compliant with chemoprophylaxis and vector protection. Eveningness represents therefore a risk factor considering the control of malaria. Interestingly, morningness is related to better life style than eveningness. The evening type has been associated with personality traits and dimensions, evening people having been described to seek novelty, to express impulsivity, with independent behavior, lack of persistence, and to be inclined to extraversion and take risks [26].

### **3.3. Internal sleep organization in healthy volunteers over three African climates**

The sleep quality questionnaires dealt with sleeping habits and the perceived feelings upon awakening in dry and humid climates. They explored the sleep shell, but did not penetrate the internal sleep organization. The morningness-eveningness questionnaires showed that chronotype may impact on behavior, e.g., in controlling malaria burden and control. They also evidenced the effect of disease severity on chronotype, thus giving one more argument to its multifactorial organization and variability according to genetic and environmental factors [27]. As of today technical means, polysomnography remains the only tool to visit the inside of sleep. We performed such recordings in healthy volunteers in the hot-dry Sahelian climate, in the humid equatorial climates of Côte d'Ivoire and Congo, and a low-hill altitude in the Angolan province of Kuenza Norte.

### **3.3.1. Polysomnographic sleep patterns under Sahelian climate influences**

Between 1981 and 1992, 8-hour (from 22:00 h to 06:00 h) nocturnal polysomnographic recordings were obtained from 17 Niger students (aged 21-26 years, [28] and 6 French Expatriates (aged 32-39 years, [29]) to compare cool-dry season values and hot-dry season data in sedentary medical students. A total of 138 night recordings were obtained (students, 102; Expatriates, 36). The last two nights were considered for further comparisons, because of the occurrence of a first night effect in the students and the Expatriates (Fig. 2) [13]. In the African volunteers, stage R was shorter on the first night, due to a lower number of R phases and longer intervals between them. In the Expatriates, stages W and N2 were increased in the first night recording, along with lower N3 values. We must also stress that, although sleep recordings were performed in the air conditioned bedroom, all subjects were submitted to the outside temperatures during several hours in the daytime. Following Jouvet's definitions [30], the observed changes may be regarded as diachronic in nature, i.e., distant in time from the climatic strain (contrary to synchronic, e.g., during sleep time).

Table 3 indicates that in the Niamey students, sleep was fragmented by numerous awakenings. Although sleep latency was in the limit of normal range, sleep fragmentation accounted for the reduction of TST. Most strikingly, we found that the amount of stage N3 was elevated compared to the figures encountered in temperate conditions [28,31]. In the hot-dry

season of the Sahel climate, N3 also increased compared to the cool-dry season, reaching very high values. However, the amounts of stage R (around 27% of TST) were elevated and did not vary from one season to the other.

These features were also found in the Expatriates [29]. As we wanted to also analyze the climatic transition between the cool-dry (February) and hot-dry parts of the dry season (May), these volunteers were also recorded in March, during which ambient temperature increases. Similarly to the students, sleep fragmentation by W was high during the three sessions. A decrease in stage N2 occurred from February to March and May, accompanied by a progressive increase in N3 in the hot-dry season culminating in May.

The changes in N3 were attributed to the seasonal increase in thermal load. In another group of 8 Niger-born students and French Expatriates, we also showed the absence of differences in the circadian rhythm of body temperatures variation between the cool-dry and the hot-dry seasons [32]. The elevated R amounts in the Sahel climate and the absence of seasonal changes may indicate an effect of the climatic dryness component. Few studies have been performed regarding the relationship between water reabsorption by the kidney and sleep, and the role of arginine vasopressin is controversial [33]. In healthy pre-pubertal boys, intranasal arginine vasotocin has been shown to increase the amount of R, decrease R latency, and induced R periods at sleep onset (SOREMPs) [34]. A similar effect was observed in two narcoleptic patients [35]. However, Born et al. [36] showed that infusion of physiological doses of arginine vasopressin in young adult men during night sleep reduced R sleep dose-dependently. Arginine vasopressin may therefore be involved in R sleep elevated amounts in Niger, whether it be during the cool-dry (October-February) or the hot-dry months (March-May) of the dry season (October-May). If this were the case, it would mean that, in a dry environment, stage R may depend on water preservation.

We thought that climatic-induced changes in sleep patterns could be influenced by an elevation in endogenous heat production provided by physical exercise under Sahelian climatic conditions. Sedentary subjects followed a progressive 6-week training on an ergometer at room temperature of 23-24 °C during the cool-dry (control) and the hot-dry seasons [37]. Physical fitness improved during each training session. The sessions were separated by a 10-week interval, resuming sedentary routine activity lowering fitness levels to pre-training controls. Compared to baseline routine values, N3 increased after exercise in the cool-dry season. This increase was enhanced during the hot-dry season. Therefore, the conjunction of exercise and external climatic

heat load had led to a diachronic increase in SWS. Once again, stage R was not influenced by exercise nor by the season.

The potential effect of dehydration and rehydration during cycling was also tested in African athletes placed in sedentary conditions and after supramaximal exercise (130% of maximal aerobic power) [38]. Similarly to previous sedentary conditions, N3 was high in both baseline sedentary conditions and augmented in the hot-dry season (Table 3). This effect was also observed after exercise when rehydration was performed during the exercise. When non-hydrated during exercise in the cool-dry season, the subjects increased N3 vs. baseline values. But, stage N3 decreased in the hot-dry season compared to values obtained when the subjects were rehydrated while cycling. It is known that the exercise-induced body temperature increase is tempered by rehydration while exercising in the heat [39]. Regarding stage R, baseline values were high in both seasons. Exercising in the cool-dry season induced a decrease in R sleep in both hydration conditions in comparison with baseline data. This reaction may have been induced by stress hormones [11,31] and/or vasopressin as this hormone is known to reduce stage R [36]. Conversely, in the hot-dry season, R sleep increased after exercise when compared with baseline values, whether or not the subjects were rehydrated. An increase in R sleep is uncommon in the literature. It may be related to the interaction of exercise and heat acclimatization, as the latter is known to lower vasopressin secretion [40]. A decrease in vasopressin secretion may thus account for the increase in stage R following exercise in the hot-dry season. As for the enhanced N3 sleep in the so-called cool-dry season of the dry Sahelian climate, and *a fortiori* in the hot-dry season, it may be related to the energy-saving and the thermoregulatory devotion of this sleep stage to lower body temperature [41]. Decreasing body temperature (cooling the brain) in cats, Jouvet and his group demonstrated that a cooler body triggers paradoxical sleep, a state of high energy consumption [42,43]. We also base our understanding on Jouvet's diachronic/synchronic balance involved in N3 sleep and R sleep changes under the Sahelian climate during the dry season [30].

### **3.3.2. Polysomnographic sleep patterns in the humid equatorial climate**

The equatorial climate of Côte d'Ivoire and Congo differs from hot-dry Niger climate by the level of dry bulb temperatures. But the main difference resides in that relative humidity is much higher in the former two countries.

In Côte d'Ivoire, the polysomnographic recordings were conducted in the 23 healthy volunteers of the Port-Bouët group (Abidjan: 12 Caucasians and 11 Africans), and in 44 control volunteers in the villages that were visited for sleeping sickness screening (Sinfra: villagers; Table 3) [44].

The Port-Bouët group was allocated 90 min to nap after lunch. Both groups had a more fragmented sleep than the 1-5% of TST observed commonly in temperate climates in sedentary subjects. The number of stage changes during the night was also elevated. Sleep was fragmented in all groups, as shown by the elevated number of stage changes. Consequently, W was high, especially in the African subjects. The differences between the two groups of subjects concerned mainly the sleep stability indices at night, i.e., higher number of stage changes, shorter TST, longer W and longer N1 in the Africans. However, latency to N3 was shorter in the African subjects both at night and during naps, indicating a higher "pressure" for N3 (Table 3).

The sleep of the latter Ivorian group living in the city of Abidjan was compared to that of the villagers of the area of Sinfra, using 24-hour analogue cassette Oxford Medilog II ambulatory monitoring [44]. The two groups only differed in a slight increase in W and N1, and a decrease in N3 in the villagers, although the values stayed in the range of observations in temperate countries. Another five volunteers were recorded at Abidjan in the Yopougon University Hospital with an indwelling venous catheter to collect blood every 10 min [45]. They served as controls for endocrine and immunological analyses in patients with sleeping sickness who had been recorded in Brazzaville (Congo) [46]. The sleep-wake cycle was not disturbed, although their sleep was highly fragmented, leading to a drop in TST. Stage R was also decreased, although the R phases occurred at roughly 90 min intervals. These reactions to the strain of wearing a venous catheter were close to those found in similar experimental settings in a temperate climate [47].

In Angola, 17 control volunteers were recorded for one 24-hour polysomnographic recording to be compared with sleeping sickness patients. Digital ambulatory monitoring was performed. Their sleep patterns were similar to those of healthy subjects in a temperate climate. They did not show any circadian disturbance. Stage R was also normal and they did not have any SOREMPs, contrary to meningoencephalitic stage 2 sleeping sickness patients (Fig. 3). This was not surprising as the high hills of Kuenza Norte benefited from a temperate climate during the investigation.

In Congo, 47 villagers volunteered for 24-hour ambulatory polysomnography. Similarly to subjects in Angola (Fig. 3), their nocturnal sleep was undisturbed. They had no circadian alteration of their sleep-wake cycle and did not show any SOREMPs.

#### 4. In Conclusion

Sleeping habits of Africa-born healthy subjects were studied with questionnaires. Alike people living under temperate and/or cold climates, African people sleep between 7 and 8 hours a day. However, most of them were inclined to be morning type individuals, especially for those who lived in remote bush villages. They claimed that their sleep was generally satisfactory and refreshing. For example, their drive to participate in work and/or daytime activities, as well as other subjective well-being feelings, scored higher in African than in Caucasian people. The majority of individuals living under hot-dry Sahelian conditions take naps in the afternoon. This was not the case in Côte d'Ivoire nor in other places with humid climatic conditions, except when the experimental protocol devoted time to the possibility of sleeping in the afternoon. In that case, no differences were seen between Caucasian and African volunteers, except that subjective well-being feelings scored lower upon rising from nap sleep than after night sleep, indicating a certain sleep inertia after napping sleep in both groups.

Polysomnography showed that the internal sleep organization differed between people living in the Sahel during the dry season and people living under more equatorial latitudes. Table 3 is a summary of the observed changes. In the Sahel, sleep tended towards elevated amounts of N3 and R sleep. Stage N3 is known to be a thermoregulatory sleep that aims at decreasing body temperature, and *a fortiori* brain temperature, to allow the occurrence of stage R [42]. In stage N3, sweating and vasodilation promote thermolysis to oppose hyperthermia [1]. Furthermore, N3 is also a state of energy conservation as demonstrated in a patient with anhidrotic ectodermal dysplasia, with the congenital absence of sweat glands [48]. In this patient, weight loss during sleep was only half of that of healthy individuals, as the sweating-deprived patient lost weight through insensible physical skin evaporation. However, although thermolytic processes did not vary, on two occasions, he experienced a 0.3°C loss in rectal temperature concomitantly with two N3 phases, indicating a large decrease in metabolic heat production. Therefore, it is not surprising that individuals living under climatic heat load will enhance stage N3. Contrarily, stage R is a

state of poor thermoregulation, i.e., almost a poikilothermic state [49]. Sweating slows down, thus decreasing body thermal loss [1], and skin and central temperatures increase in the heat. We discussed above the possibility that stage R may be impacted by a combined action of stress, heat acclimatization and water balance regulation [38]. Supramaximal exercise is likely to promote stress hormones that are deleterious to R sleep [11], such as vasopressin [36]. However, vasopressin being inhibited during heat acclimatization [40], its brake-like action on stage R would be relieved.

The investigations in humid tropic-equatorial climates demonstrated slight differences between night recordings and nocturnal sleep in 24-hour recordings. Compared to 24-hour polysomnography, the subjects being equipped prior to night sleep had a slightly more restless sleep, with more stage shifts, W after sleep onset, stages N1 and N2 and lower quantities of N3 and R sleep. In the 24-hour set-ups, the subjects were equipped with ambulatory monitoring in the morning and took their daily sleep at night. Their sleep patterns were even less restless in Angola and Congo, where they had observed numerous patients walking with their electrodes and equipment in the streets of the village. Interestingly, in such village configurations, the internal organization of sleep was within the range of observations made by our group in temperate conditions [11,12].

Table 3 illustrates the comparisons between the diverse climatic conditions. The dry Sahelian climate was the theater of the largest changes in intra sleep organization. The data exposed in this review were obtained throughout natural heat acclimatization processes. They differed from acute heat-exposure experiments in non-acclimatized volunteers in air-conditioned facilities [1-5]. Our sleep recordings under different latitudes across the western half of Africa revealed geoclimatology-dependent differences between diverse human groups. The general picture of how humans sleep in hot African climates remains to be complete, as sleep patterns of healthy people were not recorded in the Eastern Plateau and mountainous lands. This almost 40 year-long scientific adventure is therefore untermiated as there is still data mining to be performed. However, the general lines have been drawn.

### **Disclosure of interest**

The authors declare that they have no competing interest.

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## Figures captions

**Figure 1** – Ambulatory 24-hour polysomnography monitoring using Oxford Medilog 9000 in a healthy control subject at Sinfra in Côte d'Ivoire. The electrodes are fixed on the scalp (EEG), at the outer canthi of the eyes in a diagonal line (EOG), at the tip of the chin (EMG) and on the chest (ECG).

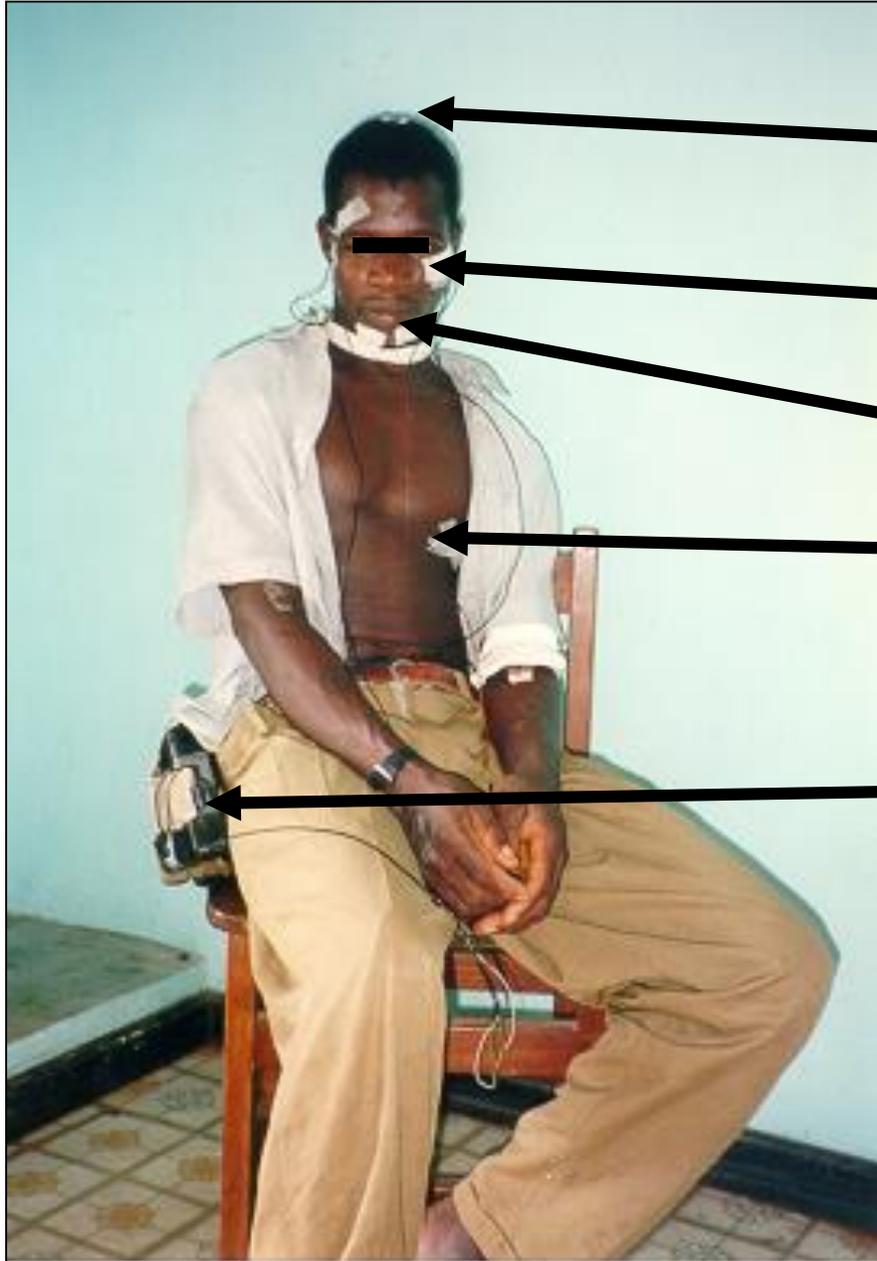
**Figure 2** – Hypnograms showing the nocturnal distribution of polysomnographic sleep-wake stages. The data were obtained using an ECEM T3 electroencephalograph during a 3-night recording session in the hot part of the hot-dry Sahelian climate in Niamey (Niger) in one healthy student [37] and one healthy Expatriate [29]. W: wakefulness; R: Rapid-eye-movement sleep; N1, N2, N3, non-rapid-eye-movement sleep (NREM), with N3 comprising stages 3 and 4 of Rechtschaffen and Kales classification [14]. Both subjects experienced a first night effect due to experimental conditions (more fragmented sleep). Note that N3 sleep was elevated and occurred throughout the night, during almost all R-NREM sleep cycles; stage R amount was also elevated, although it was frequently interrupted. Darkened areas correspond to numerous stage changes, which are evidenced especially in the Expatriate volunteer. The hypnogram has been drawn following Michel Jouvét's conception, with the R stage being fully individualized.

**Figure 3** – Hypnograms showing the 24-hour distribution of ambulatory polysomnographic sleep-wake stages. The bottom hypnograms were obtained from two healthy volunteers living in a village of the Sinfra district in Côte d'Ivoire. The data were collected using a portable Oxford Medilog II recorder. The upper hypnogram was obtained from a healthy volunteer from Samba Cajù, in the Kuenza Norte province of Angola. The subject was equipped with a Temec Vitaport 3 ambulatory digital recorder. W: wakefulness; R: Rapid-eye-movement sleep; N1, N2, N3, non-rapid-eye-movement sleep (NREM), with N3 comprising stages 3 and 4 of Rechtschaffen and Kales classification [14]. The subjects did not nap. Note that the subjects' night sleep was undisturbed. They had been equipped in the morning to allow several hours before nocturnal sleep time. Note also that N3 sleep occurred mainly in the first half of the night, especially during the first two R-NREM sleep cycles. Darkened areas correspond to numerous stage changes. The hypnogram has been drawn following Michel Jouvét's conception, with the R stage being fully individualized.

## Appendix Captions

**Appendix 1** The reduced form of the Horne and Östberg's Morningness-Eveningness Questionnaire [6] proposed by Adan and Almirall [7]. The questionnaire comprises five questions. In the first three questions, respectively, the subjects are asked to indicate the time of the day at which they feel at their best, their preferred time to get up, and to go to bed. In question 4, the subject reports on the degree of perceived fatigue during the first half hour after waking. In answering question 5, the subjects must give their morningness or eveningness preferences.

**Appendix 2** - The sleeping quality questionnaire [10]. The questionnaire contains 15 items. Quantitative aspects of the sleep-wake cycle are explored: time in bed, i.e., time between bedding down and morning arising; sleep latency, from lights out to first asleep; sleep period time, i.e., from first asleep to last awake; number of awakenings and reason for waking up; number of dreams. Qualitative characteristics of the sleep episode include: perceived sleep quality; easiness to go to sleep; need to sleep or fatigue upon awakening; working drive; physical shape; morale; mood; dream agreement. To quantify qualitative items, the subject ticks on the 5-cm long visual analogue scale, between – (minus) to the left and + (plus) to the right, at the place where he thinks the intensity of the given symptom is best represented. The distance between the tick and the left extremity of the line is considered to be representative of the value of the dependent variable measured on a 0-10 scale. The subject can also give the reasons for waking up, his dream reports and the bedding garments and conditions.



Electroencephalogram (EEG)

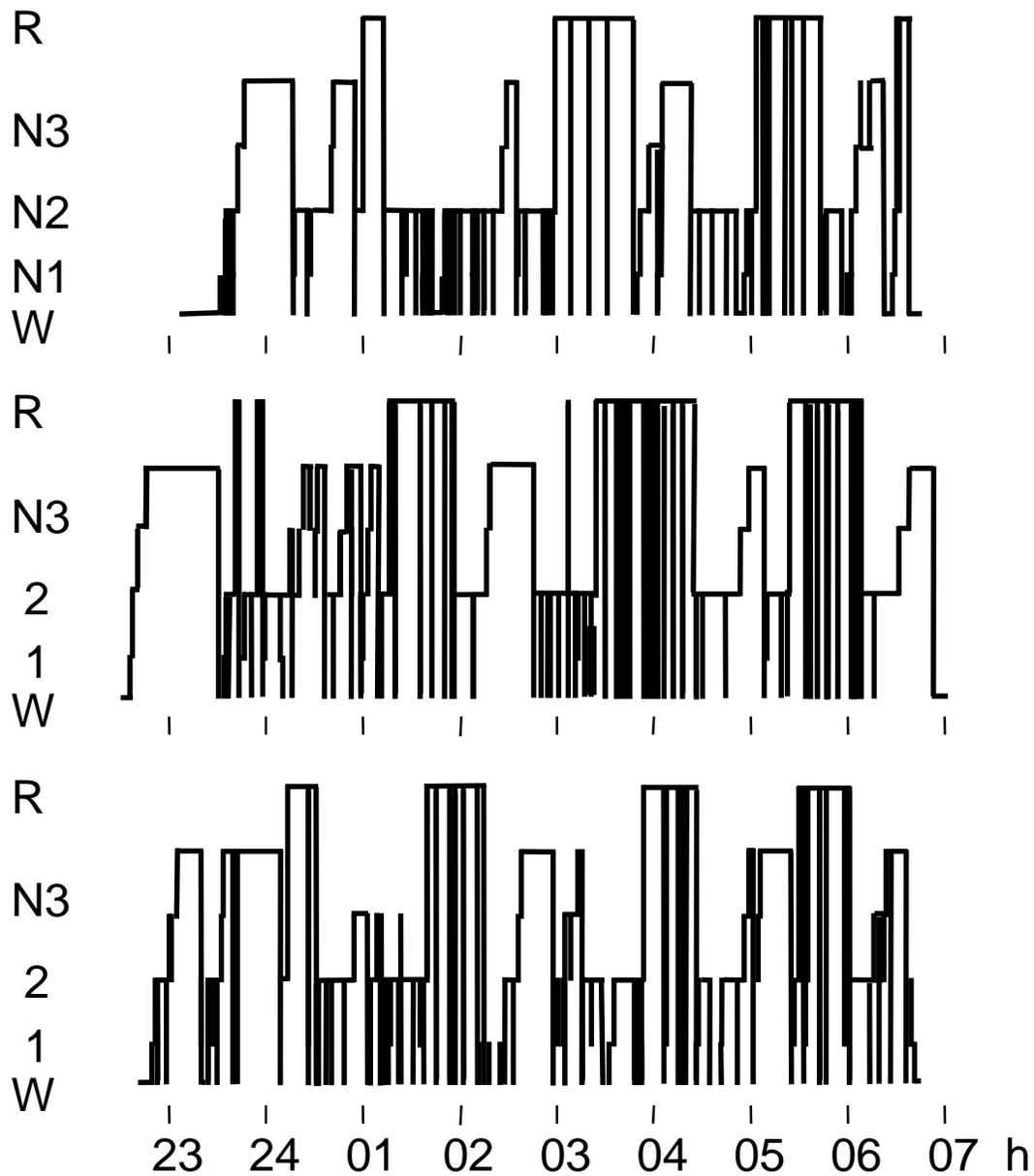
Electro-oculogram (EOG)

Electromyogram (EMG)

Electrocardiogram (ECG)

Portable recorder

# Niger student

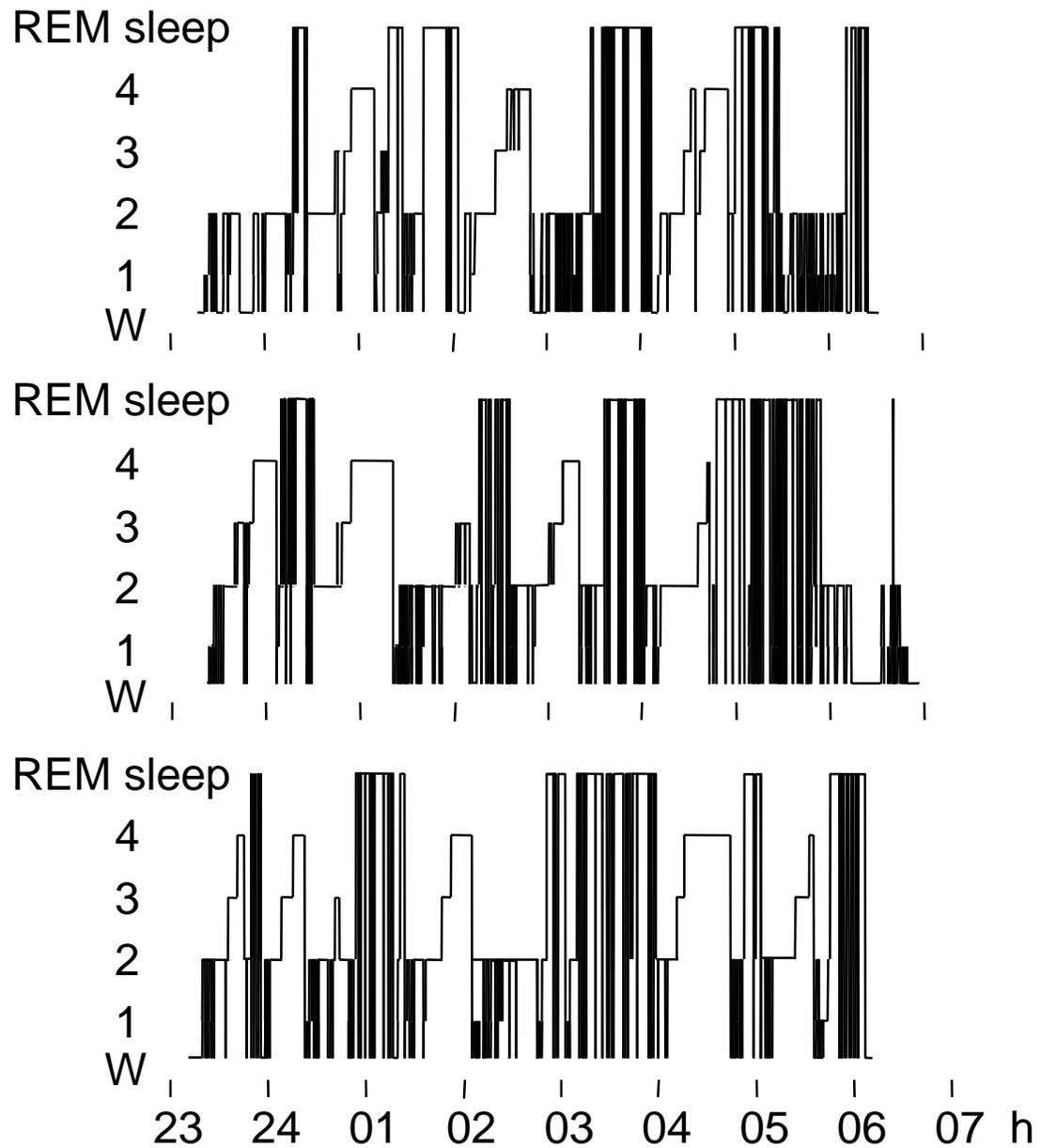


Night 1

Night 2

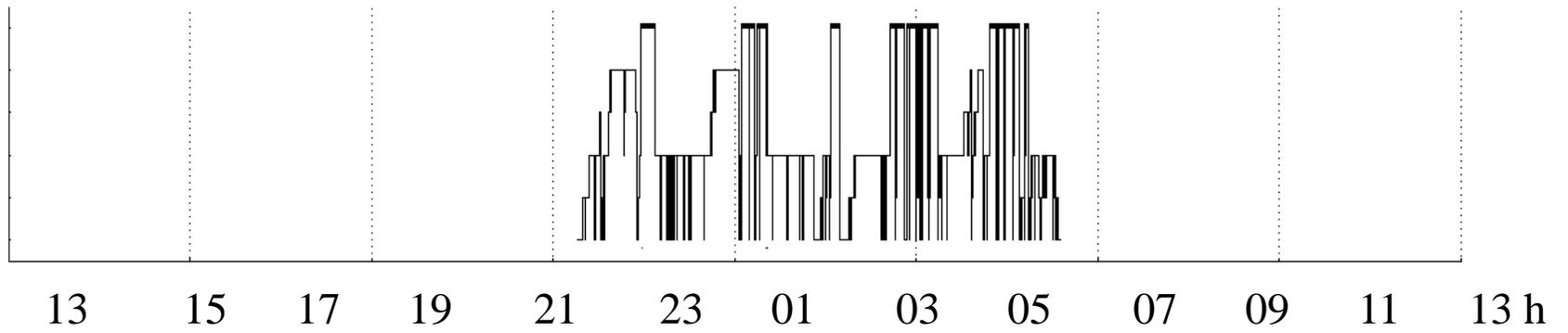
Night 3

# Expatriate



Two healthy volunteers  
from Sinfra district,  
Côte d'Ivoire

R  
N3  
N2  
N1  
W



Healthy volunteer  
from Angola

R  
N3  
N2  
N1  
W



**Table 1 – Geographic and climatic characteristics of the investigation locations (latitude, longitude, altitude, type of climate).**

Location	Latitude (decimal degree)*	Longitude (decimal degree)*	Altitude (m)	Dry bulb temperature <sup>§</sup> (°C)	Relative humidity (%)
Niamey (Niger)	13.503347	2.080762	188	32/17-41/28	16-39
Abidjan (Côte d’Ivoire)	5.26429	-3.925439	6	30/24	60-80
Daloa (Côte d’Ivoire)	6.79281	-6.47319	269	31/22-32/23	60-80
Sinfra (Côte d’Ivoire)	6.61675	-5.908950	259	31/22-32/23	60-80
Luanda Sul (Angola)	-8.90228	13.420499	130	31/25-32/26	70-80
Samba-Caju (Angola)	-8.912947	13.478693	1200	30/24	65-85
Brazzaville (Congo)	-4.266789	15.268077	296	31/22-31/22	75/90-70/85
Mpouya (Congo)	-2.61497	16.212899	280	31/22-30-19	unknown

\*Latitude and longitude are expressed in degree, minute, seconds. <sup>§</sup>Ambient temperatures (dry bulb) correspond to maximum/minimum during one investigation - two investigations.

Table 2 – Chronotype score obtained with the morningness-eveningness questionnaire obtained in the Couloir focus from African sleeping sickness patients at stage 1 and stage 2 throughout the post-treatment follow-up semestrial sessions (mean score  $\pm$  SEM)

Stage	Before treatment	Follow-up at 6 months	Follow-up at 12 months	Follow-up at 18 months	Follow-up at 24 months
Stage 1 patients	19.96 $\pm$ 0.42 n = 46	20.00 $\pm$ 0.64 n = 23	20.96 $\pm$ 0.62* <sup>\$</sup> n = 22	21.95 $\pm$ 0.59* n = 19	21.60 $\pm$ 0.47* n = 25
Stage 2	19.84 $\pm$ 0.66 n = 25	19.00 $\pm$ 0.75 n = 9	19.86 $\pm$ 1.08 n = 7	22.50 $\pm$ 0.57* <sup>\$\$</sup> n = 8	22.27 $\pm$ 0.33 <sup>£</sup> n = 11

Questionnaire score correspondence to chronotype: >22, Definitely a Morning type; 18-21, Moderately morning type; 12-17, Neither type, indifferent. Significant differences: 1) with pre-treatment scores: \*P<0.05 and <sup>£</sup>P<0.10; 2) with Follow-up at 6 months scores: <sup>\$</sup>P<0.05; and 3) with Follow-up at 12 months: <sup>§</sup>P<0.05. The statistical analysis used the Wilcoxon signed Rank test to compare sessions (pre-treatment and post-treatment follow-up sessions at 6, 12, 18 and 24 months).

Table 3 – Sleep measures (mean ± SEM) of the baseline nights in healthy volunteers living in a temperate climate (12 Caucasians)

compared to data obtained in Niger (Africans and Caucasians) and Côte d’Ivoire (Abidjan, Africans and Caucasians; Sinfra, Africans)

Sleep measures	Temperate climate*	Niamey Africans**		Niamey Caucasians <sup>‡</sup>	Abidjan Africans <sup>§</sup>	Abidjan Caucasians <sup>§</sup>	Sinfra Africans
		Cold dry	Hot dry				
Sleep latency min	13.5±2.1	15.3±10.1	7.5±4.3	8.3±5.5	37.1±9.6	29.9±5.0	2.2±0.5
SPT, min	474.5±2.7	441.7±36.6	443.7±13.5	416.6±13.3	459±10.1	462.7±4.2	492.6±23.5
WASO (% SPT)	7.0±1.8	6.5±0.6	8.4±2.7	14.4±1.7	15.9±1.9	41.7±2.1	18.8±2.4
W, n	32.2±3.7	48.5±7.8	46.3±4.6	86.3±7.7	92.2±4.9	80.3±2.5	87.9±12.2
State changes, n	162.5±12.5	152.4±20.9	141.9±9.4	254.0±16.8	236.2±7.5	214.7±6.2	276.6±15.7
TST, min	441.2±4.9	418.8±	402.0±13.1	357.8±16.2	386.1±11.6	420.9±5.7	391.6±14.6
Sleep efficiency %	92.9±0.8	93.4±0.6	89.7±3.3	85.9±4.6	84.1±1.8	84.0±1.4	81.2±2.4
N1 (% TST)	3.9±0.4	3.7±0.7	3.7±1.1	7.8±1.0	7.5±0.6	6.4±0.8	10.0±0.9
N2 (% TST)	51.8±1.5	36.0±3.5	28.2±3.9	39.2±1.3	47.9±1.8	51.1±3.4	50.1±1.7
N3 (% TST)	21.1±1.7	32.8±3.4	39.9±2.9	26.0±1.0	24.7±2.0	22.5±1.8	18.5±1.8
N3 n	4.6±0.4	5.5±0.7	5.6±0.7	15.2±0.9	31.4±3.7	5.9±07	23.4±2.1
R (% TST)	23.2±0.7	27.7±2.6	28.2±2.3	27.0±1.8	19.8±1.2	20.1±1.1	21.4±1.9
R n	4.7±0.3	5.1±0.7	4.8±0.5	4.7±0.2	4.9±0.2	4.9±02	4.8±0.2
R latency min	81.5±7.0	72.5±25.8	78.9±15.5	66.6±4.9	74.7±8.4	77.2±	67.6±9.2
R-NREM min	91.2±2.1	89.6±1.2	90.1±1.7	89.7±3.5	78.1±3.5	81.5±5.4	93.9±3.1

\*Reference [12]; \*\*Reference [37]; <sup>‡</sup>Reference [29]; <sup>§</sup>Reference [44]; SPT, sleep period time; TST, total sleep time; R-NREM, R-non-

REM sleep cycle