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Houda Daaloul

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Normandie Université

THÈSE

Pour obtenir le diplôme de doctorat

Spécialité SCIENCES ET TECHNIQUES DES ACTIVITES PHYSIQUES ET SPORTIVES

Préparée au sein de l'Université de Caen Normandie

Impacts of a midday nap on cognitive and physical performances according to the nap environment and prior nocturnal sleep

**Présentée et soutenue par
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**Thèse soutenue le 22/06/2021
devant le jury composé de**

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INDEX AND

ABBREVIATIONS

s: second

ms millisecond

min: minutes

h: hour

PM: Post Meridiem

AM: Ante Meridiem

yr: year

cm: centimeter

m: meter

km: kilometer

kg: kilogram

Hz: Hertz

% Percent

°C: Celsius

i.e. That is

df: difference

ns: non-significant

SD: Standard Deviation

EEG: Electroencephalogram

PSG: Polysomnography

EOG: Electrooculogram

EMG: Electromyogram

REM: Rapid Eye Movement

NREM: Non-Rapid Eye Movements

TTB: Total Time in Bed

TST: Total Sleep Time

SOL: Sleep Onset Latency

SL: Sleep Latency

SE: Sleep Efficiency

WASO: Wake After Sleep Onset

SWA: Slow Wave Activity

SWS: Slow Wave Sleep

ARAS: Ascending Reticular Activation System

VLPO: Ventrolateral Preoptic Nucleus

ACh: Acetylcholine

PPT: Pedunclopontine Tegmental Nuclei

LDT: Laterodorsal Tegmental Nuclei

LC : Locus Coeruleus

NA : Noradrenergic neurons

5-HT: Serotonergic neurons

Hcrt: Hypocretin/Orexin

vPAG: ventral Periaqueductal Grey Matter

DA: Dopaminergic neurons

LHA: Lateral hypothalamic Area

HIS: Histaminergic neurons

TMN: Tubermammillary nucleus

LHA: Lateral Hypothalamic Area

ORX: Orexin

SCN: Suprachiasmatic Nucleus

CBT: Core Body Temperature

RHT: Retinohypothamic Tract

SPZ: Supraventricular Zone

DMH: Dorsomedial Nucleus of the Hypothalamus

vSPZ: ventral Supraventricular Zone

dSPZ: dorsal Supraventricular Zone

BRAC: Basic-rest-activity-cycle

PSD: Partial Sleep Deprivation

RN: Reference Night

MEQ: Morningness-Eveningness Questionnaire

PSQI: Pittsburg Sleep Index Quality

KSS: Karolinska Sleepiness Scale

VAS: Visual Analog Scale

AASM: American Academy of Sleep Medicine

RT: Reaction Time

ERPs: Event Related Potentials

SDLP: Standard Deviation of the Lateral Position

NILC: Number of Inappropriate Line Crossing

DMST: Delayed Match to Sample Test

MRT: Mental Rotation Test

RAST: Running-Based anaerobic Test

MAT: Modified Agility Test

LRT: Lower Body Reaction Time

ELEP: Explosive Leg Extensor Power

SJ: Squat Jump

CMT: Counter Movement Jump

KST: Karate-Specific Test

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GENERAL INTRODUCTION

There are several rhythmic phenomena in life and the circadian rhythms of sleep and wakefulness are among the most prominent cycles (Roehrs and Roth 2019). Wakefulness refers to the capacity of interacting effectively with the environment by generating appropriate behavioral and emotional responses. Sleep is a vital activity that every organism needs to recover from daily events and to function properly the next day (Goel 2011, Brown *et al.* 2012). Sleep loss produces drowsiness which is regarded as the main cause behind impaired performances, decreasing productivity, and increasing incidences and accidents throughout the day (Markov and Goldman 2006). Here it is important to mention that even after an adequate night of sleep, the level of cortical arousal fluctuates in a predictable manner throughout the 24-h cycle presenting periods of maximum drive for wakefulness and periods of maximum drive for drowsiness (Strogatz 1987, Lavie 1989). For instance, the prevalence of drowsiness has led to a clear need to treat this symptom by understanding the functioning of the physiological mechanisms involved in modulating the states of sleep and wakefulness (Schwartz and Roth 2008).

Although the physiological mechanisms of sleep and wakefulness are highly interrelated, the scientific advance in the last decade has largely contributed to revealing the distinct neural circuitries and the specific neurochemical systems involved in both states (Saper *et al.* 2010, Arrigoni and Fuller 2012). On the one hand, wakefulness is promoted by the ascending arousal pathway that involves complex interactions between distinct subcortical cell groups, mainly consisting of monoaminergic and cholinergic neurons. On the other hand, sleep is activated by neurons of the ventrolateral preoptic nucleus. Sleep and wakefulness are regulated by mutual interaction between the sleep-promoting system and the ascending arousal system that function like an electrical “on-off” switch to ensure behavioral state stability (Saper *et al.* 2005). The brain circuitries controlling the switch mechanism are governed by the influences of the homeostatic and circadian processes (Brown *et al.* 2012). The homeostatic process (process S) seeks to

maintain a constant wake duration by accumulating pressure for sleep that increases with the time spent awake and dissipates in the course of subsequent sleep (Walker 2017). The circadian process (process C) alternates between states promoting either sleep or wakefulness by responding to changes in the solar light-dark cycle. Besides, the circadian process drives 24-h endogenous rhythmicity in almost all neurobehavioral and physiological variables (Eban-Rothschild *et al.* 2018). For instance, the process C fluctuates non-linearly during the waking period, presenting bimodal distributions of periods of maximum wakefulness and periods of maximum drowsiness. The first major peak for wakefulness occurs late in the afternoon, and the second peak takes place in the morning. On the flip side, the first major peak for drowsiness occurs late in the evening, and the second peak takes place in the early afternoon hours (Fuller *et al.* 2006, Goel 2011).

The two-process model of sleep regulation was proposed by Borbély in order to conceptualize a reciprocal interaction between the homeostatic and the circadian regulatory processes. The two-process model shows that the interaction between the homeostatic and the circadian processes determines the timing and the structure of subsequent sleep (i.e. nocturnal sleep and daytime naps), and modulates the dynamic changes in arousal and performance during the day. In the classical model of sleep regulation, the interaction between the homeostatic and the circadian processes occurs at the moment when the process S reaches the upper or the lower threshold of C to promote the transition between states of sleep and wakefulness (Borbély 1982). Furthermore, the model posits that during the waking period, changes in arousal levels and many neurobehavioral outputs are determined by the distance between S and C. Accordingly, a short distance between the homeostatic and the circadian processes corresponds to high arousal and performance levels, and conversely, a large gap between the two processes indicated low levels of arousal. Importantly, in the classical model of sleep regulation, process S does not influence the functioning of process C. However, the contemporary model of sleep-wake regulation introduced by Borbély *et al.* (2016) posits the existence of a mutual and continuous interaction between the circadian and the homeostatic processes. The model entails that the amplitude of the

circadian process depends on the status of sleep pressure. In general, the circadian amplitude of many physiological and neurobehavioral functions decreases when the level of homeostatic sleep pressure is high and increases when the level of sleep pressure is low (Borbély *et al.* 2016).

Daytime drowsiness and related deficit in performances naturally occur in the early afternoon hours (Campbell 1992, Bes *et al.* 2009). This decrease in arousal and performance is further amplified when the amount of prior nighttime sleep is reduced (Schmidt *et al.* 2007, Goel *et al.* 2013, Goel 2017). Laboratory studies showed that a short midday nap is an effective strategy to counteract the drawbacks of the post-lunch phase and to promote evident improvement in cognitive and physical performances throughout the day (Milner and Cote 2009). Nevertheless, the impacts of a short midday nap on performance are modulated by several factors, including the previous amount of sleep and wakefulness, the environment of sleep during the nap, and performance measures (Milner and Cote 2009). Therefore, investigating the impacts of a short midday nap on cognitive and physical performances with regard to the factors mentioned above is at the core of this research project. In an attempt to provide a more detailed analysis, we propose to distinguish between two different types of nap based on the previous amount of sleep and wakefulness (i.e. the level of sleep pressure). We introduced the term energetic nap to designate a short midday nap taken after a normal night of sleep, and we used the term restorative nap to designate a midday nap scheduled following sleep loss.

In the first section of this report, we start by providing a brief introduction to the properties and the characteristics of the circadian rhythms of sleep and wakefulness. We present the most contemporary advances made in the last decade regarding the brain mechanisms and the distinct neural circuitries and neurochemical systems underlying the sleep-wake states. We also trace the mutual inhibitory interaction between sleep- and wake-promoting circuitry regulating the stability of the sleep-wake states. In addition, we review the role of the homeostatic and circadian processes in controlling sleep and wakefulness, with reference to the physiological basis of homeostatic sleep drive and the circadian suprachiasmatic nucleus. We used the two-process model of sleep regulation to describe the reciprocal interaction between the homeostatic and the

circadian processes and to discuss the influence of the interaction on several aspects of sleep and waking behaviors. Then, we display the diurnal variation in cognitive and physical performances, and we examine the main factors that can modulate the dynamic changes in performance during the day, such as interindividual variability, sleep loss, and task-performance sensitivity to the homeostatic sleep pressure. Then, we describe the endogenous proprieties of a midday nap, and we distinguish between two types of midday naps according to prior nocturnal sleep: energetic and restorative naps. The contemporary model of sleep regulation is used as a basis to discuss the putative impacts of energetic and restorative naps on the circadian rhythmicity of many neurobehavioral functions. Finally, we review the main factors that can modulate the impacts of napping on performance, including interindividual variability, and the environment of sleep during the nap. The second section includes three experimental studies. Finally, in third section we discuss the main findings of the three studies in the light of the current literature. We also present concluding remarks and future perspectives.

I. FIRST CHAPTER: BACKGROUND

I. 1. CIRCADIAN RHYTHMS OF SLEEP AND WAKEFULNESS

I. 1. 1. INTRODUCTION

Rhythmicity is a fundamental property that dominates all levels of movements in living organisms ranging from the simplest arrangement of cells to the most complex organization of the ecosystem (Halberg 1977). This rhythmicity is orchestrated by cosmic movements that exhibit multiple processes of oscillations that emerge as a function of time. For instance, the rotation of the earth around its axis represents one of the most manifested rhythmic patterns by which the regular rhythm of light and darkness is repeatedly generated (Bordage 2013). Chronobiology is a field of biology that examines rhythmic phenomena in living organisms in congruence with time, along with recent knowledge in different scientific disciplines.

By definition, a rhythm is a regular oscillatory process that recurs in time with a similar pattern (Rosi *et al.* 1981). Common terminology is used to describe different features of biological rhythms, including period, phase, mesor, and amplitude (*Figure 1*). **The period** of a rhythm consists of the duration of one complete cycle. The cycle can be determined by the occurrence of two systematic events, such as two consecutive peaks (i.e.; acrophase: highest amplitude value) or troughs (i.e. nadir: lowest amplitude value). According to the period, rhythms are classified into (1) *circadian rhythms*: when their period is about 24-h, (2) *ultradian rhythms*, when the period is shorter than 24-h, (3) *infradian rhythms*: when the period is longer than 24-hr. In infradian rhythms, there are several sub-periodicities, including (4) *Circaseptan rhythms*: with a period of approximately 7 days, (5) *circalunar rhythms*: with a period of about 30 days, and (6) *circannual rhythms*: with a period of about 360 days. **The phase** has a double meaning. First, it is used to describe a chosen fractional part of the cycle during a predetermined period such as: during the ascending, the maximal, or the descending phase. Second, the term phase is used to describe the positional relationship between identifiable phases of two or more cycles (Palmer 2012). **The medium level or mesor** is a reference line representing the average value of periodicity for many samples of one given variable. **The Amplitude** is the difference between the

medium level and the maximum deviation (i.e. acrophase or nadir) of one variable in a specific period.

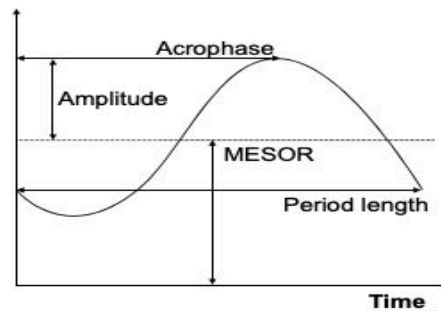


Figure 1. Schematic representation of different parameters of a rhythm: Period, Phase, Mesor, and Amplitude (Baganz 2006).

Scientific research on biological rhythms began during the 18th century when the astronomer Jean Jack d’Ortous De Marian provided insight into the relationship between internal physiology and the geographical cycle. De Marian noticed that the leaves of the mimosa plant opened toward the sun during the daytime and closed at night. When De Marian placed the plant in constant darkness, he noticed that the daily movements of the plant’s leaves continued to follow their usual oscillations (*Figure 2*). The response of the leaves to the environmental conditions proves that plants do have their endogenous rhythms that are self-sustained under constant environmental conditions. (Huang 2018).

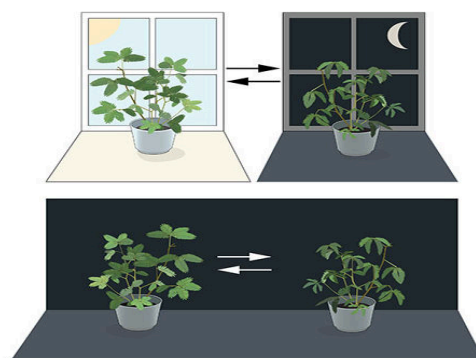


Figure 2. The leaves of the mimosa plant open toward the sun during the day and close at night (**upper part**). In constant darkness (**lower part**) the leaves continue to follow their daily rhythms. (Huang 2018).

Franz Halberg used the term *circadian* (Latin *circa*=about; *dies*= day) to refer to a subset of endogenous rhythms with a period of approximately 24-h. Since then, the term circadian has become popular and widely used (Refinetti 2013). There are several rhythmic phenomena in life that display circadian rhythms, and the sleep-wake rhythm is one of the most prominent cycles. In healthy humans, the circadian rhythms of sleep and wakefulness are synchronized with the 24-h dark-light cycle, involving approximately one-third of sleep during the dark phase and two-thirds of wakefulness during the light period (Roehrs and Roth 2019).

I. 1. 2. EXPLORATION PARADIGMS

Three basic studies' paradigms have been applied to examine circadian rhythms of human physiology and performance: constant routine, forced desynchrony, and time of day recording protocols.

The constant routine protocol is mainly used to unmask endogenous circadian rhythms. In this type of protocol, the measurements are conducted in isolated environments under constant conditions at regular intervals, for at least 24-h. This means that any external (e.g. temperature, light, and food) or internal (e.g. stress or motivation) factors that may influence physiological or behavioral parameters must be strictly controlled.

The forced desynchrony protocol, also called the free-running protocol, implies a forced adjustment of the sleep-wake cycle to a period that is different from normal conditions, and therefore, the endogenous circadian timing system starts to follow its own rhythm. The advantage of the free-running protocol is that it enables the effective separation of the influences of homeostatic sleep pressure from that of the circadian timing system. The influences of the homeostatic sleep pressure and the circadian system on wakefulness will be addressed in *section 1.2.5.5*.

The time of day recording protocol implies the measuring of physiological variables or performance outcomes at different times of the day in persons living in their normal environment.

The advantages and limitations of the three research paradigms mentioned above are well detailed in the reviews of Valdez *et al.* (2005), Schmidt *et al.* (2007), and Goel *et al.* (2013).

I. 1. 3. PROPRIETIES OF CIRCADIAN RHYTHMS

Free running environmental experiments have paved the way toward exploring the proprieties of circadian rhythms. The first time-free environmental experiment was in 1938 by Nathaniel Kleitman and his assistant Bruce Richardson, who were at the same time the subjects. They stayed together for 32 days in a cave in Kentucky, located in the South of the United States. The second contribution was run by Michel Siffre, a French researcher, and speleologist who also organized many other underground time-free environmental experiences. His first experience was conducted in 1962 at the age of 23 in which he spent two months in an underground glacier located in the French Alps. And, his last experience was in 2000, in which he stayed for 73 days in the caves of Clamouse in the South of France (Foer 2008).

One of the most pertinent observations from these experiences was that the circadian rhythm of sleep and wakefulness is endogenous: researchers have discovered that circadian rhythms continue to oscillate even in the absence of external time cues. This discovery provided evidence for the existence of an internal timekeeping mechanism; a biological clock in all human beings. The functioning of the biological clock will be detailed *in section 1.2.5.2*. Another propriety was identified through these experiments was that the internal timekeeping mechanism generates cycles with a periodicity slightly longer than 24-hr. The third propriety of circadian rhythms was that when deprived of exogenous environmental cues, the individual circadian rhythms of sleep and wakefulness shift in phase relative to the rhythm of the light-dark cycle. Finally, when returning to normal living conditions, the sleep-wake rhythm was readjusted to external time cues. The readjustment mechanism is called entrainment (Lavie, 1986, Vitaterna *et al.*, 2001, Kuhlman *et al.*, 2018).

In summary, the proprieties of the circadian sleep-wake cycle are the following: (1) the rhythm is endogenously generated, (2) persists in the absence of environmental influences, (3) retains nearly

the same periodicity in the absence of external environmental cues, (4) can be shifted or reset by entrainment (Lavie, 1986, Kuhlman et al., 2018).

I. 1. 4. CHARACTERISTICS AND MEASUREMENTS

I. 1. 4. 1. THE WAKEFULNESS STATE

Wakefulness is a construct associated with consciousness in which a healthy individual is capable of interacting effectively with his environment by generating appropriate behavioral, and emotional responses, and by retrieving continuously past experiences and encoding new ones (Deboer 2013, Daroff and Aminoff 2014, Heine *et al.* 2015). In this thesis, wakefulness is viewed as a multidimensional construct that includes physiological, behavioral, cognitive, emotional, and physical components.

The wakefulness state is characterized by high levels of excitability of brain structures and neurotransmitter systems of the ascending reticular activation system (Lavie 1989, Oken *et al.* 2006, Langner and Eickhoff 2013). The neural pathway and the physiological mechanisms of the ascending reticular activation system will be fully explained *in section I.2.2*. From an electrophysiological exploration, wakefulness is described by low-voltage and fast electroencephalogram (EEG) activity, a high muscle tone, and frequent voluntary eye movement and eye blink. This pattern of EEG is called desynchronized or activated EEG.

Wakefulness is mainly affected by determinants such as drowsiness, fatigue, or boredom. Although, drowsiness and fatigue are distinct phenomena, however, they have been used equally among scientists, and in everyday language (Bailes *et al.* 2006). Fatigue refers to the sense of tiredness, and it is characterized by a lack of energy to perform. Whereas, drowsiness refers to the sense of sleepiness and is characterized by low levels of arousal (Bailes *et al.* 2006, Rosenthal *et al.* 2008). The common interchange between these two phenomena is due to what they share in common, especially their ultimate impact in the reduction of the capacity to perform. Besides, most of the studies that have investigated alternation in the wakefulness state (i.e. drowsiness or fatigue) have commonly used tasks requiring a prolonged and demanding activity.

In what follows, we will attempt to clarify the basic characteristics of each phenomenon by highlighting the distinctive features of drowsiness (i.e. low arousal levels) and fatigue.

I. 1. 4. 1. 1. THE CONCEPT OF AROUSAL

Arousal is distinct from wakefulness, nevertheless, it is considered a basic precondition and a modulator of any given physiological or behavioral parameter for wakefulness (Lavie, 1989, Fischer et al., 2008). Arousal is determined according to the levels of cortical activation in a sleep-wake spectrum. For instance, different arousal levels indicate various states of brain function that structure behavioral responsiveness to internal and environmental signals. For instance, the arousal level must be heightened in the face of danger, maintained when performing cognitive tasks, and lowered at bedtime (Huang *et al.* 2015).

EEG recording is the best-used method in determining the levels of arousal during the waking period by recording the electrical activity of large groups of cortical neurons placed on the scalp (Brown *et al.* 2012). The different levels of arousal include hyperarousal, over-arousal, low-arousal. In the EEG, hyperarousal is characterized by low-amplitude gamma waves falling between 30 to 120 Hz. Over arousal is defined by beta waves falling between 15 to 30 Hz. Low level of arousal is characterized by alpha waves falling between 8 to 13 Hz, and by slow and rolling eye movements. The latter reflects the drowsy state (Brown *et al.* 2012, Ray and Cole 1985). The different levels of arousal are displayed in *Table 1.* and illustrated in *Figure 3.*

Table 1. Levels of arousal during the waking period, EEG marker: description and associated behavior.

<i>Levels of arousal</i>	<i>Wave</i>	<i>Frequency</i>	<i>Associated behavior</i>
Hyper-arousal	Gamma	30-120 Hz	Peak performances
Over-arousal	High-beta	15-30 Hz	Narrow focus, anxiety
	Mid-beta	15-18 Hz	Active, alert, focused
Low arousal	Low-beta	12-18 Hz	Relaxed wakefulness
	Alpha	8-13 Hz	Sleepiness, drowsiness

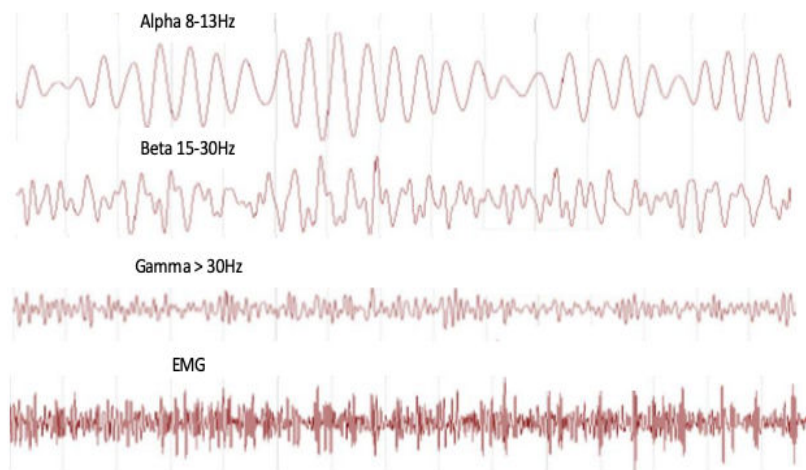


Figure 3. EEG frequency bands during the waking period at several levels of arousal.

In addition to EEG monitoring, subjective measurements are frequently used and easily applied to determine the levels of arousal during the day (Sander *et al.* 2015). However, different dimensions of arousal have been proposed in the literature, namely tense arousal and energetic arousal (Lavie 1989). Nevertheless, before scrutinizing the differences between each of them, it is important to highlight the issue related to the notion of energetic arousal in the literature. On the one hand, energetic arousal is described in a continuum ranging from feeling tiredness to energetic (Dickman 2002). On the other hand, it is described in a continuum ranging from feeling sleepy to awake (Schimack and Rainer 2002). The divergence in the description of energetic arousal is also caused by the issue related to the notions of “fatigue” and “sleepiness”. In this

thesis, the term energetic arousal will be used to describe arousal levels in a continuum ranging from feeling sleepy to feeling awake (*Figure 4.a*). Besides, we will maintain the basic definition of tense arousal which is described in a continuum ranging from calmness to anxiety (*Figure 4.b*) (Schimmack and Rainer, 2002, Dickman, 2002).

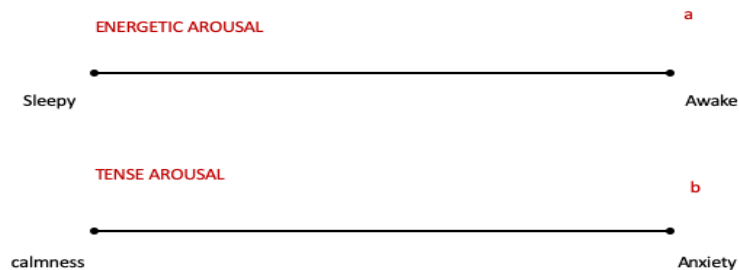


Figure 4. Illustration of subjective measurement of (a) energetic arousal and (b) tense arousal.

During the waking period, the ability to maintain high arousal levels is challenging especially that arousal fluctuates throughout the day (Cohen 2014). Changes in performance outcomes (i.e. improvement or decrement) represent a good marker for evaluating the level of arousal during the waking period (Sander *et al.* 2015). For instance, in the related literature performance tasks involving sustained attention are effective in monitoring arousal levels throughout the day (Wang *et al.*, 2019, Weiler *et al.*, 2000).

I. 1. 4. 1. 2. THE CONCEPT OF FATIGUE

Fatigue is generally defined as a decrease in the capacity to perform caused by a prolonged period of demanding cognitive or physical activities (Gawron *et al.* 2001, Marcora *et al.* 2009). Subjectively, it is characterized by feelings of “tiredness” and “lack of energy” associated with an increase in the perceived difficulty of the task at hand (Marcora *et al.* 2009). Behaviorally, fatigue is recognized by a transient decline in performance (Van Cutsem *et al.* 2017).

So far, two types of fatigue are presented in literature: central (mental), and peripheral (physical). Mental fatigue refers to the reduction in the capacity to perform a prolonged cognitive task that requires sustained attention or manipulation of information stored in memory. Physical fatigue is

defined as a reduction in the capacity to perform a physical activity in function of preceding effort (Gawron *et al.* 2001).

Mental fatigue, also known as central fatigue. The overload mental workload model was introduced to explain why it is difficult for human's mind to maintain a good performance level over time. The model implies that conducting a cognitive task over time is effortful and demanding. Therefore, the progressive decline in performance over time is the consequence of an over mental workload. In addition, the model entails that the information-processing resources are limited. In this model, resources are viewed as "reservoirs" of mental energy devoted to perform a particular task, and the "replenishment of the resources" is the main cause behind the gradual decline in performance over time (Helton and Warm 2008). The theoretical approach of the overload model has further been supported by several neuroimaging studies indicating that changes in the activation of brain areas, as identified by the cerebral blood flow, were accompanied by a parallel decline in the sustained attention performance over time (Hitchcock *et al.*, 2003, Mayleben, 1999, Heilman, 1995). Monitoring the cerebral blood flow velocity when performing a cognitive task is considered as a "*sensitive metabolic index of the utilization of information-processing resources*" (Hitchcock *et al.* 2003).

Moreover, mental fatigue can be subjectively measured by the Visual Analog Scale. In this scale, fatigue is described as a continuum with two extreme endpoints to express extreme feelings ranging from "very tired" to "in a good form" (*Figure 5*).

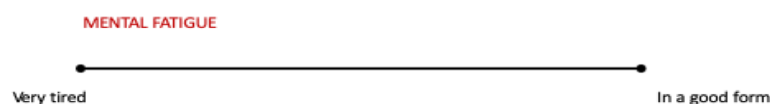


Figure 5. Illustration of the subjective measurement of mental fatigue.

Peripheral fatigue, also known as physical fatigue, is defined by an alteration in force production capacity of a neuromuscular junction and/or a muscle group, or both (Pageaux and Lepers, 2018). Here, it is important to highlight that central fatigue was proved to negatively affect performance on a subsequent physical task. Especially when the physical task requires a decision-making process, motor coordination, or in tasks that require whole-body endurance performance (Van Cutsem *et al.* 2017, Pageaux and Lepers 2018).

I. 1. 4. 2. THE SLEEP STATE

Sleep is a vital activity that every organism needs in order to recover from daily events as well as to function properly the next day. Conversely, a lack of sleep or poor sleep patterns can profoundly impair neurobehavioral waking functions (Goel 2011, Brown *et al.* 2012).

Sleep is a natural state characterized by a reduction in motor activity, a decreased sensitivity to stimuli, a stereotypic posture, and loss of consciousness. Sleep is distinguishable from other states of altered consciousness such as death or coma. It is an active, reversible, and highly organized process. Sleep is composed of two distinct sub-states that alternate cyclically during the night: non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep (Fuller *et al.* 2006, Arrigoni and Fuller 2012, Roehrs and Roth 2019). More particularly, NREM sleep includes three sleep stages (stage1, stage 2, and stage 3) that are different in-depth, and easily identified according to their activity in the EEG.

The REM-NREM cycle is repeated four to six times per night, averaging 90-min in each cycle. *Figure 6.* illustrates the histogram of the structure of sleep cycles in a healthy young adult across 8-hr of nocturnal sleep. The distribution of NREM-REM cycles during the sleep period shows a time depending change with the predominance of NREM sleep in the first 4-hrs of sleep, and the predominance of REM sleep in the last 4-hrs. The brain mechanisms controlling the sleep state will be detailed in *section I.2.3.*

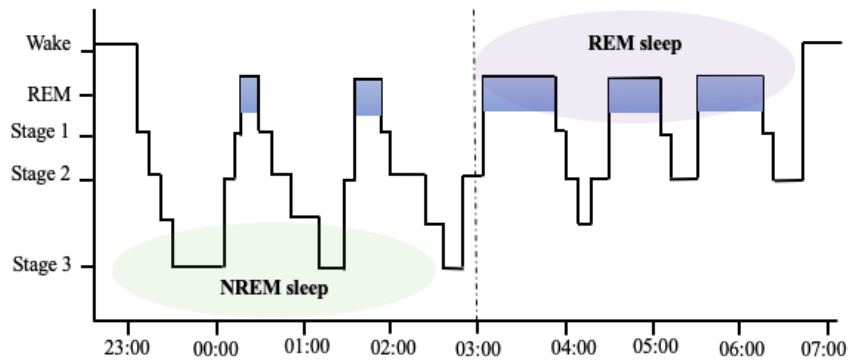


Figure 6. Sleep Histogram illustration showing the typical distribution of NREM-REM cycles across 8-hr of sleep. Adapted from Payne (2011).

The polysomnographic (PSG) recording is the most employed tool used in sleep research. The electrode application includes EEG electrodes attached to the scalp according to the system 10-20 system. Electrooculogram (EOG) electrodes are used to monitor eye movements, and chin electromyogram electrodes (EMG) are used to monitor muscle activity (Campbell 1992), (Figure 7).

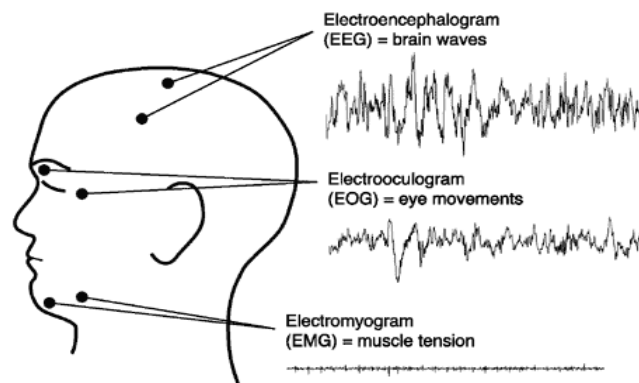


Figure 7. Basic electrode application for sleep recording.

For the analysis of sleep data, EEG frequencies are grouped into bands namely, delta (0.5 to 5 Hz), theta (4 to 8 Hz), alpha (8 to 12 Hz), spindles (7-15 Hz oscillations), and K complexes. Sleep is visually scored in sequential 30-second epochs according to the standards of the American Academy of Sleep Medicine (AASM) (Berry *et al.* 2012).

The transitional state from wakefulness to sleep is commonly referred to as Sleep Onset Latency (SOL). SOL represents the duration of time from turning the light off to full transition to NREM sleep. In the PSG, SOL is typified by alpha waves and eye movements associated with wakefulness that are intermingled with theta waves and slow eye movements associated with sleep. For the analysis, the presence of sleep characteristics should not predominate the 30-second epoch, otherwise, the transition to sleep is achieved (Varga *et al.* 2018). In healthy adults, when the timing of sleep is appropriate, sleep latency should not exceed 20-min (Zolovska and Shatkin 2013).

NREM sleep is characterized by high amplitude and low-frequency EEG, slow rolling eye movements, and a decreased muscle tone. NREM sleep is composed of three stages. Stage 1 NREM sleep is the lightest stage of sleep and represents only 5% of total sleep time. It is determined in the EEG by theta activity at frontal sites and alpha activity in posterior cortical areas. The 30-s epoch is scored as stage 1 when more than 50% of the alpha waves are replaced by low-amplitude mixed-frequency activity. Stage 2 NREM sleep is characterized by the complete loss of consciousness of the external environment. This stage of sleep occupies about 50% of the total sleep time during a typical night. In the EEG it is defined by the appearance of sleep spindles or K-complexes or both. Stage 3 NREM sleep is the deepest stage of sleep. It is defined in the EEG by the presence of delta waves. For note, sleep intensity is defined by an increase in total power, amplitude, and incidence of delta waves in the EEG (Fuller *et al.* 2006).

REM sleep is characterized by low-voltage fast EEG activity which is dominated by theta rhythms and coupled with a complete loss of muscle tone, and conjugate eye movements. (Gompf and Anaclet 2019). EEG brain wave patterns during sleep are illustrated in *Figure 8*.

RELAXED WAKEFULNESS

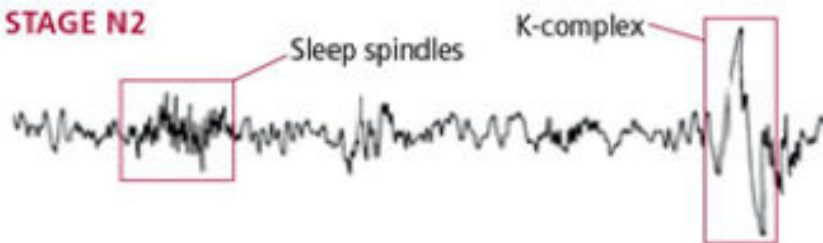
Alpha waves



STAGE N1

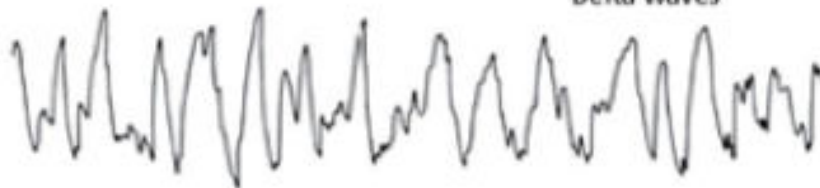


STAGE N2



STAGE N3 or DEEP SLEEP

Delta waves



REM or DREAMING SLEEP



Figure 8. EEG brain wave patterns during sleep.

I. 2. NEUROPHYSIOLOGY OF SLEEP-WAKE CYCLE

I. 2. 1. INTRODUCTION

The first hypothesis about neural circuitry supporting the sleep-wake system originated from the observations of Baron Constantin von Economo, in patients suffering from a viral infection in the brain, which is called encephalitis lethargica, also known as the “sleeping sickness”. The disease causes either states of prolonged sleepiness or states of insomnia. The post-mortem examination has yielded predictive insights about the brain circuitry promoting states of sleep and wakefulness. According to the von Economo hypothesis, the region of the anterior hypothalamus, near the optic chiasm, contains sleep-promoting circuitry, and the posterior hypothalamus contains wake-promoting circuitry (von Economo 1917, Saper *et al.* 2001). Later, Moruzzi and Magoun (1949) demonstrated that electrical stimulation of the reticular formation of the brain stem in anesthetized cats provokes changes in the activation of the cerebral cortex as measured by the EEG: from a high-voltage and slow activity to a low-voltage and high activity, a state similar to that observed during active wakefulness. Moreover, they demonstrated that nearly the same response is produced when stimulating the medial bulbar reticular formation, pontile tegmentum, midbrain tegmentum, and dorsal hypothalamus. Accordingly, Moruzzi and Magoun have conceptualized the physiological and neuroanatomic basis of the ascending reticular activation system (ARAS) (Moruzzi and Magoun 1949).

In recent years, the development of new technologies has enabled the identification, manipulation, and characterization of specific cell types in particular brain regions. These novel techniques have provided insights into brain mechanisms controlling sleep and wakefulness by the means of pharmacological manipulation, selective electric activation, inhibition, or lesion of specific cell types in the brain (Eban-Rothschild *et al.* 2018, Gompf and Anacleit 2020). Consequently, the hypothesis of ARAS was refined, as researchers have pointed out the major role of distinct neural populations, neurochemicals, and pathways involved in the switch mechanism regulating sleep and wakefulness (Saper *et al.* 2010, Arrigoni and Fuller 2012).

I. 2. 2. THE ASCENDING AROUSAL SYSTEM PROMOTING WAKEFULNESS

Wakefulness and associated arousal are promoted by complex interactions between distinct subcortical cell groups mainly consisting of monoaminergic and cholinergic neurons located in the brainstem, midbrain, hypothalamus, and basal forebrain. These cell groups are crucial for arousing the cerebral cortex and the thalamus (Saper *et al.* 2010). The ascending arousal system contains two major branches: the ascending dorsal pathway directed to the thalamus, and the ascending ventral pathway activating the posterior hypothalamus and that extends to the basal forebrain, which together, activate the cortex. Each pathway involves distinct cell populations and neurotransmitters.

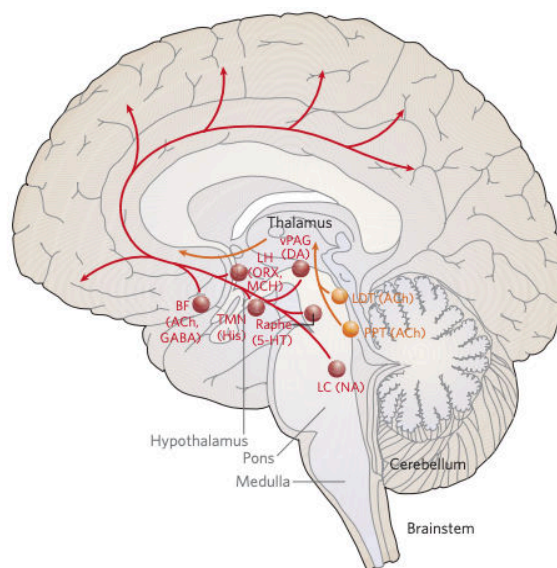


Figure 9. A schematic drawing showing the main components of the ascending arousal system. The ascending dorsal pathway is directed to the thalamus (**yellow pathway**). The ascending ventral pathway (**red pathway**), (Saper et al. 2005).

(1) The ascending dorsal branch directed to the thalamus is originating from two cholinergic structures producing acetylcholine (ACh), namely the pedunculopontine tegmental nuclei (PPT), and the laterodorsal tegmental nuclei (LDT). Cholinergic PPT and LDT neurons are responsible

for facilitating the transmission of sensory information to the cortex. These neurons fire rapidly during wakefulness and REM sleep and fall silent during NREM sleep (*Figure 9*).

(2) The ascending ventral branch projects into the lateral hypothalamus, and extends to the basal forebrain, which together, activate the cortex (Eban-Rothschild et al. 2018). The ascending ventral branch includes a number of the monoaminergic cell population, namely the locus coeruleus (LC) containing noradrenergic neurons (NA), the dorsal and median raphe nuclei containing serotonergic neurons (5-HT), the tuberomammillary nucleus (TMN) containing histaminergic neurons (HIS), and the ventral periaqueductal grey matter (vPAG) containing dopaminergic neurons (DA). The monoaminergic pathway obtains the contribution from peptidergic neurons of the lateral hypothalamic area (LHA) containing hypocretin/orexin (Hcrt) and melanin-concentrating hormone neurons (*Figure 9*). Neurons of the monoaminergic cell population fire fast during wakefulness, slow down during NREM, and are slightly active during REM sleep (Saper et al. 2005, Schwartz and Roth 2008, Arrigoni and Fuller 2012, Eban-Rothschild et al. 2018).

The activation of the cerebral cortex is enhanced by the lateral hypothalamic area (LHA) containing both orexin neurons, and melanin concentration hormone neurons, essential for sleep-wake regulation and stability: during the active period and goal-orientated behaviors, LHA neurons that contain orexin become highly activated, which reciprocally, increases the firing rates of neurons in the TMN, LC, and dorsal raphe. (Eban-Rothschild *et al.* 2018). LHA neurons that contain melanin concentration hormone neurons are activated during REM sleep and are thought to inhibit the firing rates of neurons in the TMN, LC, and dorsal raphe (for reviews, see Schwartz and Roth 2008, Arrigoni and Fuller 2012, Scammell *et al.* 2017, Eban-Rothschild *et al.* 2018).

Given the anatomy and function of these systems, it is not surprising that Von Economo found that lesions at the junction of the midbrain and forebrain produce profound and long-lasting impairment of arousal (Saper *et al.* 2005)

I. 2. 3. THE VENTROLATERAL PREOPTIC AREA PROMOTING SLEEP

Sleep is activated by neurons of the ventrolateral preoptic nucleus (VLPO), which are located in the anterior hypothalamus just above the optic chiasm. The VLPO nucleus contains neurons that form a compacted cluster part in the “core” of the nucleus, and also contains neurons that fill a more extended part (Saper *et al.* 2005). These neurons are active during sleep and release inhibitory neurotransmitters, namely GABA and galanin. Lesions of neurons in the cluster part of the nucleus reduce NREM sleep. Whereas, lesions of neurons in the extended part of the nucleus reduce REM sleep (Saper *et al.* 2005). Moreover, VLPO neurons project to many wake-promoting cell groups of the ascending arousal system, and therefore, influence indirectly the arousal system by inhibiting the wake-promoting circuitry (Saper *et al.* 2005, 2010, Gompf and Anaclet 2020). For instance, VLPO neurons have afferent projections to monoaminergic cell groups, including, histaminergic tuberomammillary nucleus (TMN), dopaminergic cell group of the ventral periaqueductal grey matter (vPAG), noradrenergic neurons of the locus coeruleus (LC), and serotonergic cells of the dorsal raphe nuclei (Raphe). Also, VLPO neurons project to cholinergic cell groups (in the pedunculopontine tegmental nuclei (PPT), and in the laterodorsal tegmental nuclei (LDT). Besides, it also innervates orexinergic neurons of the lateral hypothalamus (Saper *et al.* 2005), (*Figure 10*).

In accordance with the anatomy and functions of the VLPO cell population, it is no wonder that the damage of the anterior hypothalamus in Von Economo’s patients provokes persistent insomnia (Saper *et al.* 2005).

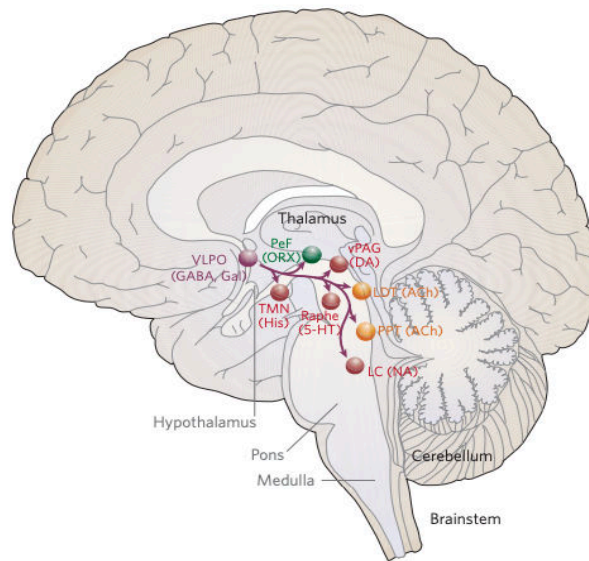


Figure 10. A schematic drawing showing key projections of the ventrolateral preoptic nucleus (VLPO). VLPO neurons have afferent projections to monoaminergic cell groups (**red circles**), VLPO neurons project to cholinergic cell groups (**yellow circles**), VLPO innervates orexinergic neurons (**green circle**) of the lateral hypothalamus, (Saper et al. 2005).

Reciprocally, during wakefulness, monoaminergic neurotransmitters of the ascending system inhibit GABAergic VLPO neurons (Gallopín *et al.* 2000). Therefore, VLPO is inhibited by the arousal system that it inhibits during sleep. This reciprocal interaction between the sleep-promoting system and the ascending arousal system gives rise to the “Flip-flop” switch model of sleep-wake regulation proposed by Saper (Saper *et al.* 2001, 2005, 2010), and this mechanism will be detailed in section I.2.4.

I. 2. 4. THE STATE TRANSITION

The “Flip-flop” switch model of sleep-wake regulation is derived from an electrical engineering circuit describing a system with two distinct states: a switch that can be either “ON” or “OFF”, resulting in an abrupt transition from one state to another and avoiding any intermediate state (Saper *et al.* 2001). According to this model, VLPO represents the “sleep-on” or the “wake-off” side, whereas ARAS represents the “sleep-off” or the “wake-on” side. Besides, Orexin neurons of the lateral hypothalamus (LHA) act as a “finger on the switch” (Arrigoni and Fuller 2012).

Overall, when VLPO is active, it inhibits wake-promoting neurons of the ARAS. By contrast, when regions that induce wakefulness are active, VLPO is inhibited. In this model, both mechanisms are reciprocally inhibited, and therefore, it is not possible to be simultaneously active. Moreover, the sleep-wake switch model entails that the transitional state is abrupt, and represents only a small part of each day compared to states of wakefulness or sleep (*Figure 11*), (Saper *et al.* 2001, 2005). Orexin neurons are not essential for sleep-wake generation, instead, they integrate information from different sites and determine whether to project to wake-promoting neurons of the ARAS, or to remind silent and therefore, to promote sleep (Saper *et al.* 2005, 2010, Arrigoni and Fuller 2012, Scammell *et al.* 2017).

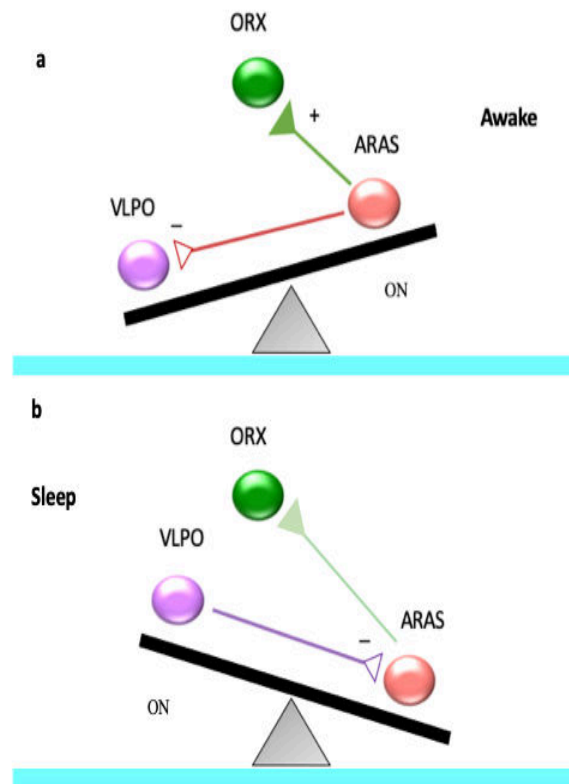


Figure 11. A Schematic representation of the wake-sleep switch model, modified from Saper *al.*, (2005). During wakefulness (**a**), orexin neurons (**green circle**) innervate the monoaminergic cell groups of the ascending arousal system (ARAS; **red circle**), In turn, ARAS inhibits the ventrolateral preoptic nucleus (VLPO; **purple circle**). During sleep (**b**), VLPO neurons (**purple circle**) inhibit the monoaminergic cell groups of the ARAS (**red circles**).

Although the sleep switch model provides important insights about the mechanisms and circuits underlying states of sleep and wakefulness, this model has its limits. First, intermediate states between sleep and wakefulness exist, and the prevalence of sleep inertia is one of the most frequent instances experienced by almost if not all individuals in our everyday life (Eban-Rothschild *et al.* 2018). Second, from a neural point of view, the mechanism responsible for state transitions is still equivocal: the switch remains in one state (i.e. wakefulness state, by the virtue of the excitatory action of orexinergic neurons on wake-promoting cell populations), the existence of a third mechanism activating VLPO neurons and causing the switch to sleep is still unclear (Brown *et al.* 2012). Nevertheless, homeostatic and circadian processes of sleep-wake regulation are considered to be key features to complement the observation of this model (Brown *et al.* 2012). The circadian and the homeostatic influences underlying sleep and wakefulness will be discussed in section I.2.5.

I. 2. 5. HOMOSTATIC AND CIRCADIAN REGULATION OF SLEEP AND WAKEFULNESS

The alternation between sleep and wakefulness is promoted by complex brain mechanisms under the control of the circadian and homeostatic processes. There is some evidence suggesting that the functioning of the two constituents' processes is not linear throughout the day (Schmidt *et al.* 2007). But rather, both processes interact either in synchrony or in opposition influencing the temporal profile of sleep and wakefulness, sleep characteristics, and the dynamic change in human performance throughout the day (Deboer 2018).

I. 2. 5. 1. THE SLEEP HOMEOSTAT

Homeostasis is the term that refers to maintaining an equilibrium or a balance in physiological and metabolic regulation (Wozniak 2000). The homeostatic process of sleep regulation is called the process S. Initially, it was proposed by Borbély (1982) in the two-process model of sleep regulation. The model entails that sleep pressure increases during wakefulness and dissipates in

the course of subsequent sleep (Figure 12). This observation paves the way toward suspecting the existence of a homeostatic substance in the brain, probably related to the metabolic activity that accumulates during waking and dissipates during sleep.

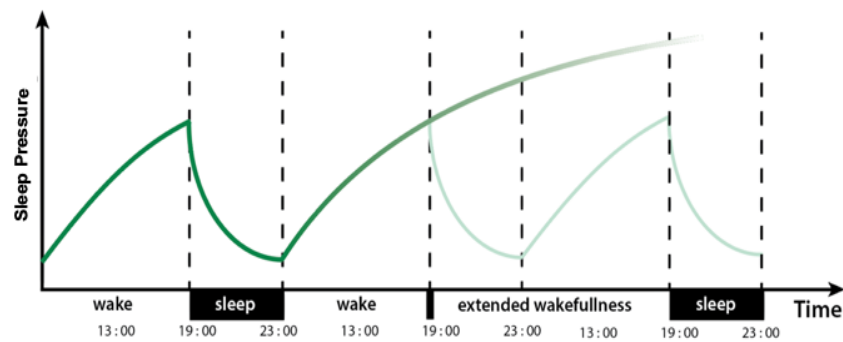


Figure 12. A schematic representation of the homeostatic sleep pressure, modified from Shi and Ueda (2018), and Walker (2017). Sleep pressure increases during wakefulness and dissipates in the course of subsequent sleep.

After the proposal of the Borbely's hypothesis, researchers have started to investigate the biochemical mechanism underlying the homeostatic sleep theory. A series of studies in sleep-deprived animals confirmed the existence of a "hypnogenic substance" in the cerebrospinal fluid. Interestingly, it was demonstrated that the injection of the cerebrospinal fluid of one sleep-deprived animal induced the need for sleep in another normal animal (Legendre and Piéron 1908, Ishimori 1909, Kornmüller *et al.* 1961).

Recent research has shed light into the nature of homeostatic sleep-promoting neurochemicals involved in this physiological process. Particularly, adenosine and other somnogenic factors have been identified, such as cytokines and nitric oxide substances (Brown *et al.* 2012, Morairty *et al.* 2013, Eban-Rothschild *et al.* 2018). At present, the best candidate for sleep-promoting neurochemical is adenosine. However, Carlos Blanco-Centurion and colleagues (Blanco-Centurion *et al.* 2006a) showed that the accumulation of adenosine in the basal forebrain is not a necessary factor for sleep drive. Nevertheless, the authors did not reject the hypothesis entailing that adenosine regulates sleep homeostasis. Instead, they have suggested testing the effects of adenosine concentration in other regions of the brain (Blanco-Centurion and Shiromani 2006b).

Overall, the homeostatic sleep regulation hypothesis entails that the concentration of sleep-promoting neurochemicals accumulates over time, generates pressure for sleep in function of time spent awake, and promotes the transition from awake to sleep: when the concentration level reaches an upper threshold, the homeostatic system actively promotes the transition from wake to sleep (*Figure 13*) by either exciting neurons of the VLPO or inhibiting the monoaminergic specific-cell groups (i.e. LC, TMN, and orexin-producing neurons), or both (Mingo 2009, Saper *et al.* 2010, Brown *et al.* 2012). The homeostatic sleep pressure dissipates after a certain duration of sleep, and the withdrawal of its output passively gates the transition to wakefulness (*Figure 13*) (Mistlberger 2005, Saper *et al.* 2010).

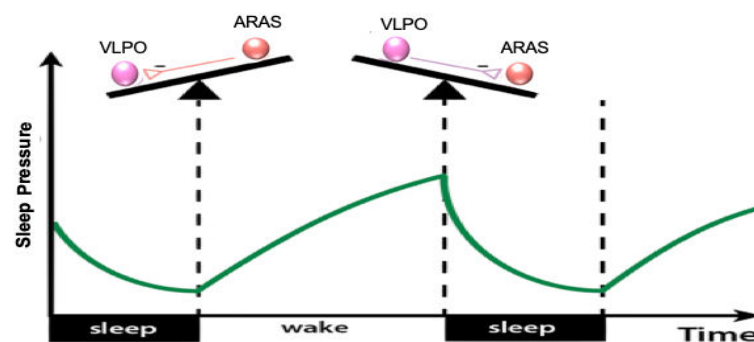


Figure 13. A schematic representation for the homeostatic regulation of the sleep-wake state transition. When sleep pressure increases above a certain threshold, the homeostatic system actively promotes the transition from wakefulness to sleep. When sleep pressure decreases at a certain level it passively gates the passage to wakefulness. Ventrolateral preoptic nucleus (VLPO, purple circle), Ascending arousal system (ARAS, red circle).

I. 2. 5. 2. THE CIRCADIAN CLOCK

The circadian timing system, which Borbely called the process C drives 24-hr endogenous rhythmicity in almost all neurobehavioral, physiological, and biochemical variables (Fuller *et al.* 2006, Goel 2011). The circadian clock, located in the suprachiasmatic nucleus (SCN) of the anterior hypothalamus regulates daily rhythms of core body temperature (CBT), and states of sleep and wakefulness by responding to the changes of the solar light-dark cycle (*Figure 14*), (Eban-Rothschild *et al.* 2018, Gompf and Anaclet 2020).

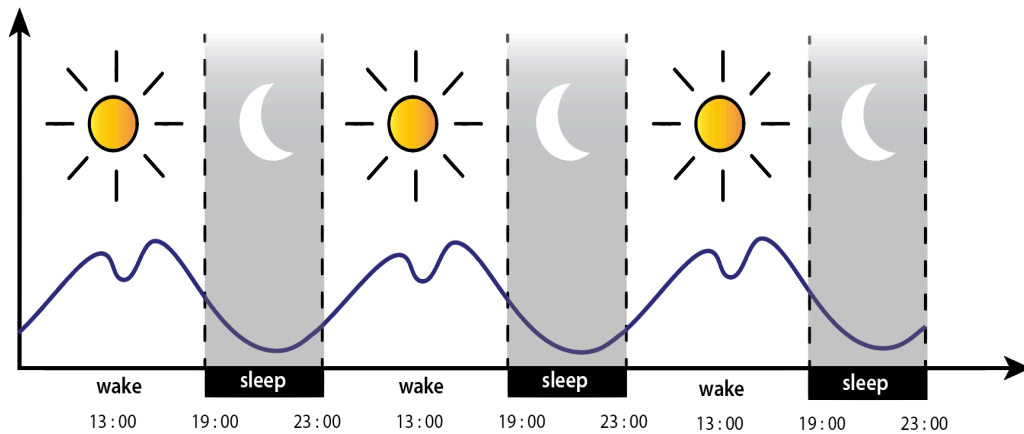


Figure 14. A schematic representation of the circadian rhythms of sleep and wakefulness are synchronized with rhythms of the solar day. The circadian system promotes wakefulness during the day and sleep at night.

Yet, even in the absence of environmental time cues, the SCN continues to run sleep-wake cycles with a period close to 24-hr. This finding indicates that the functioning of the SCN is autonomous and that environmental cues are utilized to entrain and synchronize the sleep-wake cycle to the 24-hr light-dark cycle (Mistlberger 2005). Lesion of the SCN in rodents abolishes circadian rhythmicity of the core body temperature (CBT) (Szymusiak 2018), and rhythmicity in range of behavioral variables including sleep and locomotor activity (Moore and Eichler 1972, Stephan and Zucker 1972). Together, these findings demonstrate the primary role of SCN in regulating the circadian timing system (Scammell *et al.* 2017). Besides, in addition to the SCN, other peripheral endogenous oscillators capable to function autonomously have been identified in several organs such as the heart, liver, kidney, lungs, skin, intestines, and the retina. The functioning of these peripheral clocks is synchronized with each other and aligns with the external daily light-dark cycle by virtue of the SCN (Touitou *et al.* 2017).

As outlined above, regular exposure to the daily light-dark cycle is regarded as the primary synchronizer to the outside world (Eban-Rothschild *et al.* 2018). The SCN receives direct light input from the retina via the retinohypothalamic tract (RHT), providing a mechanism by which differences in the intensity of light produce a suppression or, by contrast, stimulate the release of

melatonin from the pineal gland (Duffy and Czeisler 2009, Scammell *et al.* 2017). Interestingly, melatonin secretion is driven by the SCN, which in turn acts back on the SCN. In humans, the circadian peak of melatonin is released during the dark phase of the solar cycle. Conversely, exposure to the daylight results in lowering the secretion level of melatonin (Touitou *et al.* 2017). Although the critical role of SCN in governing the timing of sleep and wakefulness is evident, the link between SCN and the circuit controlling states of sleep and wakefulness has been a subject of many investigations and still is far from being clear (Fuller *et al.* 2006, Scammell *et al.* 2017). The SCN has minimal projections to sleep-promoting neurons of the VLPO and no projection to the ARAS. Instead, the circuit is mediated by multiple divergent pathways in the brain (Fuller *et al.* 2006). Most outputs from SCN use the supraventricular zone (SPZ) and the dorsomedial nucleus of the hypothalamus (DMH) as important neural pathways to regulate the circadian timing of sleep and wakefulness, along with the corresponding physiological and biochemical mechanisms.

The densest projection from the SCN travels in an arc dorsally and caudally and terminates in the SPZ. The ventral supraventricular zone (vSPZ) regulates behavioral circadian rhythms, and the dorsal supraventricular zone (dSPZ) regulates circadian rhythms of core body temperature. The SCN and vSPZ, in turn, project to the DMH. The DMH provides rhythmic output to the sleep-wake centers of the brain via its excitatory projection to the orexin-producing neurons in the LHA and to LC, TMN, LC, and dorsal raphe neurons. DMH is also thought to inhibit sleep-promoting neurons via its intense GABAergic projection to sleep-promoting regions, including the VLPO (Fuller *et al.* 2006, Saper 2013).

The functioning of the circadian clock is simplified in *Figure 15*. In summary, circadian rhythms of sleep and wakefulness are generated by the suprachiasmatic nucleus (SCN), and are synchronized with the solar day via a direct light input from the retina via the retinohypothalamic tract (RHT). SCN projections travel in an arc dorsally and caudally and terminate in the SPZ. The dorsal supraventricular zone (dSPZ) regulates circadian rhythms of the body temperature. The ventral supraventricular zone (vSPZ) regulates behavioral circadian rhythms. SPZ, in turn,

projects to the dorsomedial nucleus of the hypothalamus (DMH). The DMH provides rhythmic output to the sleep-wake centers of the brain its (a) via excitatory projection to the orexin-producing neurons (ORX) and to cell groups of the ascending arousal system (ARAS; red circle), and via (b) its inhibitory projection to the ventrolateral preoptic area (VLPO).

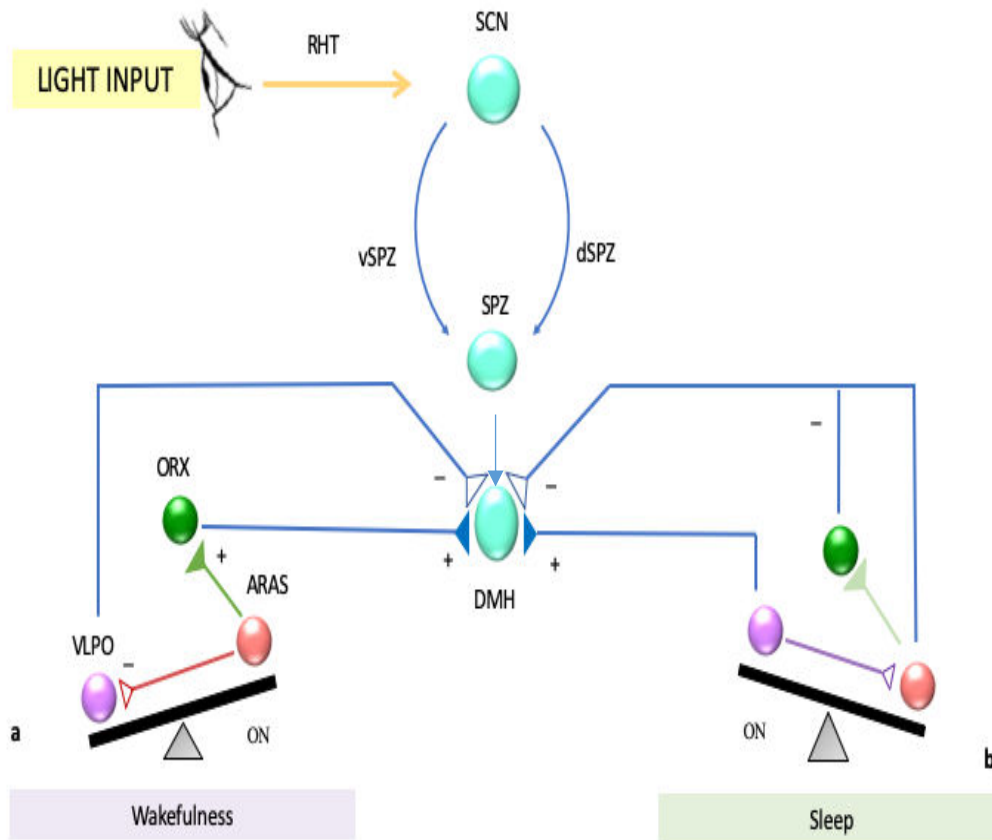


Figure 15. Schematic representation of the circadian regulation of the sleep-wake states. Modified from Saper et al. (2005, 2013).

Considering that sleep- and wake-promoting neurons are continuously interconnected, the hypothesis stating that SCN actively drives states of sleep and wakefulness by alternatively exciting or inhibiting either sleep- or wake-promoting regions, or both, has become generally accepted (Mistlberger 2005). The complex system connecting SCN to some elements of ARAS and VLPO via SPZ and DMH regulates the circadian timing of sleep and wakefulness, and other behaviors. The role of this complex system is now considered a factor that allows mammals to flexibly adapt their behavior to environmental cues (Fuller *et al.* 2006, Scammell *et al.* 2017).

I. 2. 5. 3. HOMEOSTATIC AND CIRCADIAN INFLUENCES ON STATE TRANSITION

The recent advances in sleep neurology gave rise to a compelling explanation of the general functioning of the switching mechanism based upon the mutual inhibitory interactions between sleep-promoting VLPO and wake-promoting cell groups of the ARAS, including both circadian and homeostatic influences, along with their multiple interconnections (Phillips *et al.* 2010).

Neurons controlling the switching mechanisms (i.e. wake-promoting monoenergetic systems and sleep-promoting VLPO) receive input from both homeostatic and circadian factors over time and transform these accumulating influences into a sharp transition in behavioral states. Once a state threshold is crossed, the mechanism controlling the consolidation of the other state begins. The circadian process alternates actively between promoting sleep and wakefulness at different phases of the solar cycle. The homeostatic process actively promotes sleep, and the withdrawal of its output passively drives the transition to wakefulness. The two constituents' processes are simultaneously interconnected, acting in synchrony, and in a predictable manner to determine the transition between states of sleep and wakefulness throughout the 24-hr cycle: when the circadian sleep-promoting system coincides with high levels of sleep pressure, sleep is triggered. Another way round, when the circadian wake-promoting system coincides with low levels of sleep pressure, the transition from sleep to wakefulness is triggered (*Figure 16*), (Mistlberger 2005, Schmidt *et al.* 2007).

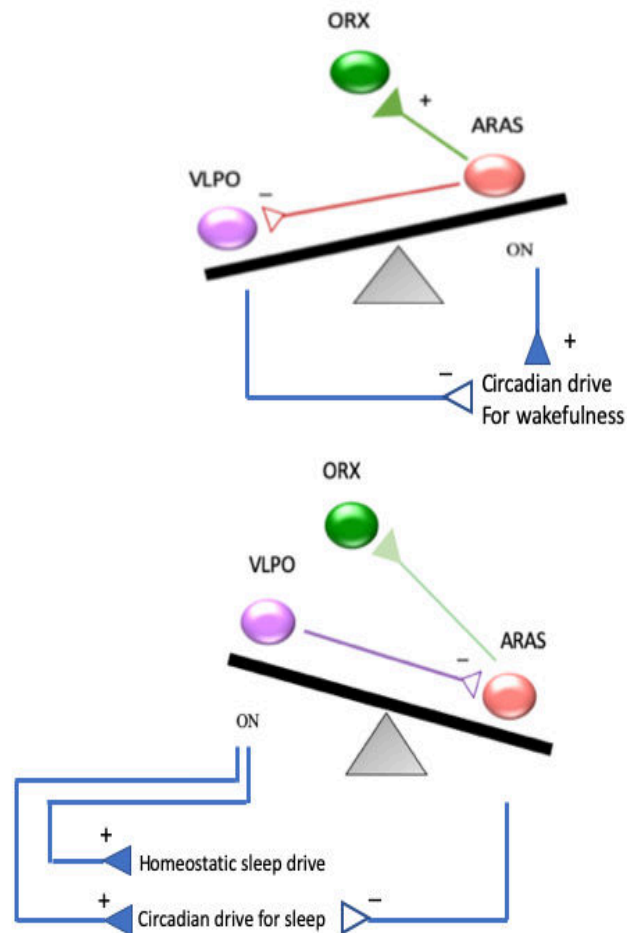


Figure 16. Homeostatic and circadian influences on state transitions. The circadian process actively alternates between promoting sleep and wakefulness at different phases of the solar cycle. The homeostatic process actively promotes sleep, and the withdrawal of its output passively drives the transition to wakefulness.

The switching mechanism is critical for ensuring stability and consolidation for sleep-wake behaviors. We should point out again that homeostatic and circadian influences accumulate slowly and over time, in the absence of a switching mechanism center, intermediate states or frequent fluctuations between sleep-wake states during the day may represent a life threat. Nevertheless, it is still unclear where the process takes place in the brain, and how information from different sleep-wake regulatory sites is processed to result in a consolidated sleep or a wakefulness state. Up to now, these questions remain central in the sleep neurobiology field of research (Mistlberger 2005, Eban-Rothschild *et al.* 2018).

Now that the overall mechanism is somehow disclosed, still, the major limitation of this recent model is that it describes a system with two distinct states, avoiding the possibility of the occurrence of any intermediate state. For instance, the presence of sleep inertia immediately after waking from sleep represents an intermediate state, and hence, is considered to highlight the limitations of this model. Recently, Saper *et al.* (2010) have attempted to explain this phenomenon by providing a convincing proposal. They stated that the overall mechanism controlling the sleep/wake switch acts like an electronic flip-flop switch, however, unlike the electronic mechanism that contains a single element on each side and acts almost instantly, the mechanism in the human brain takes place between a large population of neurons on each side, and therefore, the state transition may range from some seconds to some minutes.

I. 2. 5. 4. HOMEOSTATIC AND CIRCADIAN INFLUENCES ON SLEEP

I. 2. 5. 4. 1. THE TIMING OF SLEEP: SLEEP GATES AND WAKE MAINTENANCE ZONE

Sleep is promoted when both homeostatic and circadian processes interact with each other in a synergistical manner: the homeostatic process drives pressure for sleep that increases with the time spent awake. The circadian drive for sleep fluctuates non-linearly throughout the 24-h cycle, creating a bimodal distribution for drowsiness. The first major peak for drowsiness occurs at night, and the second peak takes place in the early afternoon hours (Lavie 1989, Mantua and Spencer 2017). These two phases of maximum drowsiness have been termed *sleep gates*. According to the two-process model of sleep regulation, the timing and the capacity to initiate sleep is determined when high levels of homeostatic sleep pressure coincides with phases of circadian sleep gates (Borbély 1982). The two phases of maximum drowsiness are separated by phases of the greatest drive for wakefulness, which have been labeled *forbidden zone for sleep* by Lavie (1989), or *wake maintenance zone* by Strogatz (1987) (Figure 17).

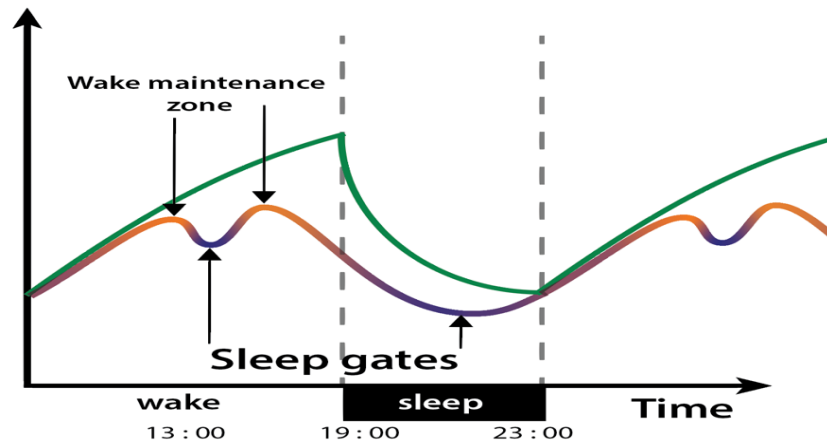


Figure 17. Sleep gates and forbidden zones

Laboratory studies confirmed that falling asleep is easier during the sleep gate zones than during wake maintenance zones (Lavie 1986). Furthermore, following prolonged wakefulness, the level of sleep pressure increases and consequently the capacity to initiate sleep during the circadian gates for sleep become more pronounced than in the baseline conditions (i.e. normal conditions).

I. 2. 5. 4. 2. THE STRUCTURE OF SLEEP: NREM-REM SLEEP CYCLES

Beyond determining the temporal profile of sleep during the day, the structure and depth of sleep are also driven by the interplay between the two constituent processes. In humans, NREM and REM sleep alternate cyclically in an ultradian rhythm during sleep. EEG Slow-Wave Activity (SWA) is the physiological marker of sleep homeostasis. Accordingly, the amount of SWA during sleep is determined by the duration of the antecedent waking period (Achermann *et al.* 2017), and it represents the intensity parameter of the sleep process (Gompf and Anacleto 2019). The proportion of SWA predominates the first part of sleep, but it decreases across NREM-REM cycles. It was demonstrated that the amount of SWA is enhanced when the prior waking period is prolonged. In contrast, SWA is reduced when the previous nocturnal sleep is extended, or when a daytime sleep is introduced (Achermann *et al.* 2017). On the other hand, the proportion of REM sleep increases over successive NREM-REM cycles and manifests no compensatory response when the prior waking period is prolonged (Borbély 1982). Accordingly, REM sleep represents the physiological determinant of the circadian oscillator system.

I. 2. 5. 5. HOMEOSTATIC AND CIRCADIAN INFLUENCES ON WAKEFULNESS

Wakefulness is promoted when both homeostatic and circadian processes interact with each other in opposition: the homeostatic process drives pressure for sleep that increases with the time spent awake. The circadian process modulates the waking behavior in a circadian manner as displayed in the dynamic changes in arousal, and many neurobehavioral outputs, including cognitive and physical performances (Goel *et al.* 2013).

The two-process model of sleep regulation posits that the difference between the homeostatic pressure for sleep and the circadian pressure for wakefulness and/or for sleep determines the level of arousal reached while awake (*Figure 18*), (Borbély 1982, Achermann and Borbély 1994). Accordingly, during the waking period, performance efficiency is assumed to depend on the distance between the two constituent processes: the smaller the gap is between the homeostatic and the circadian processes, the better the performance becomes, and vice versa. Recently, the two-process model has been readjusted (Borbély *et al.* 2016). In this updated version, the model stipulates that changes in arousal levels and many neurobehavioral outputs are determined by a continuous interaction between the homeostatic and circadian processes. For instance, the functioning of the circadian process depends on the status of homeostatic pressure, that is, the amplitude of process C decreases when the level of S is high and increases when the level of S is reduced (Borbély *et al.* 2016, Achermann *et al.* 2017). For example, under conditions of prolonged wakefulness, high levels of sleep pressure reduce the circadian amplitude of many neurobehavioral functions when compared to baseline levels (Borbély *et al.* 2016). A second example is that during phases of maximum drowsiness, the decrease in arousal levels and performance becomes more pronounced because of the increased pressure for sleep that occurs at that time. In the opposite direction, the input of the circadian process also might counterbalance the effects of high sleep pressure, especially during the phases of maximum wakefulness. The spontaneous increase in arousal and performances are evident under conditions of sleep loss. Nevertheless, the effects of sleep loss on many neurobehavioral variables are not without consequences. It has been pointed out that high levels of sleep pressure affect the dynamic

changes in arousal and performance by generating a stable but less optimal arousal state compared to basal levels (*Figure 18*), (Van Dongen and Dinges 2005, Schmidt *et al.* 2007, Goel *et al.* 2013, Goel 2017).

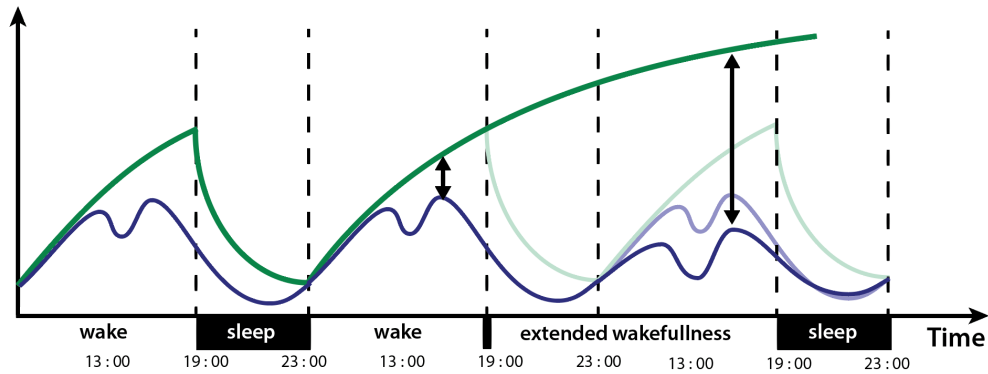


Figure 18. A Schematic simulation of the influence of the homeostatic (**green curve**) and circadian (**blue curve**) on the dynamic changes of arousal during the waking period following normal sleep-wake patterns and under extended wakefulness. The arrows indicate the difference in levels of sleep pressure throughout the waking period in normal condition (**left arrow**), and following extended wakefulness (**right arrow**).

I. 3. THE DIURNAL VARIATION IN PERFORMANCE

I. 3. 1. INTRODUCTION

The study of diurnal variations in human performance first began with experimental and educational psychology. The primary concern of these investigations was to determine the scheduling of the school hours for teaching an academic subject (LAVIE 1980, Carrier and Monk 2000). It is generally acknowledged that the study of rhythmic aspects of human performance started with Kleitman, who was the first to establish a link between sleep, rhythms in performance, and physiological parameters. In his model the basic-rest-activity-cycle (BRAC), he hypothesized that the cyclic recurrence of NREM-REM sleep (i.e period of about 100-min) continues to oscillate during the waking period in the form of phases of optimal performance and phases of less responsiveness (Kleitman 1987). Further, he suggested that the BRAC is a cyclic

phenomenon that also exists in all physiological parameters of the body under the influence of the core body temperature. Considerable efforts have been devoted to testing the validity of the BRAC hypothesis. Accordingly, several studies have confirmed the existence of BRAC cycles in human performance (Klein and Armitage 1979, Okawa *et al.* 1984, Schulz and Lavie 1985). Besides, many investigations confirmed the temporal relationship between diurnal variations in performance and CBT rhythms. However, others have reported the existence of cycles shorter than the BRAC (Davies and Tune 1969, Conte *et al.* 1995), and showed a delay in phase between CBT and the performance efficiency (Laird 1925, Rutenfranz and Hellbrügge 1957).

The differences in these observations have paved the way toward a new approach in studying diurnal rhythmicity in performance with more emphasis on the differences between rhythms rather than on similarities. This original approach was introduced by Folkard (1983) who evidenced through a number of systematic investigations the existence of different rhythms in performance (for more details, see Schmidt *et al.* 2007). Folkard, then, concluded that the diurnal fluctuation of a specific neurobehavioral output depends on the characteristics of the performed task (i.e cognitive domain, duration, and difficulty level), (Folkard 1983).

The field of circadian rhythms has helped to complement these observations by suggesting that the decrease in a particular task-performance throughout the day is assumed to be caused by its sensitivity to levels of sleep pressure that increase in function of the previous waking period. By contrast, the enhancement in a particular task-performance throughout the day is caused by the strong input of the circadian system into that specific neurobehavioral ability (for review, see Carrier and Monk 2000). Furthermore, interindividual variability in sleep-wake preferences and inter-individual vulnerability to sleep loss may influence the dynamic change of arousal and performance efficiency throughout the waking period.

I. 3. 2. THE INTER-INDIVIDUAL VARIABILITY

In healthy adults, there is a robust inter-individual variability in response to high levels of sleep pressure during the day, as evidenced by distinct neurophysiological techniques and neurobehavioral tasks sensitive to sleep pressure. Some individuals show a greater vulnerability to performance deficit from sleep loss than do other individuals (for review see, Tkachenko and Dinges 2018). Moreover, there is also an inter-individual difference in daily human behavior such as sleep habits and preference expressed over favorite periods of diurnal activities. This inter-individual variability in sleep-wake preference reflects the particular chronotype of an individual (Schmidt *et al.* 2007). The first questionnaire developed for assessing sleep-wake preference was the Morningness-Eveningness Questionnaire (MEQ) (Horne and Östberg 1976). The latter allows the distinction between individuals based on their score. In this context, laboratory studies have evidenced that extreme chronotypes display a circadian “phase-shifted” variation in their sleep habits. For instance, extreme morning types exhibit a marked preference for waking up early in the morning and for going early to sleep at night (i.e. advanced sleep period). However, extreme evening type shows a marked preference for waking up late and going to sleep late at night (i.e. delayed sleep period). Beyond influencing the sleep-wake habits, extreme chronotype also displays a distinct variation of peaks and trough in performance throughout the day that are also shifted in phase according to the chronotype (for review, see Schmidt *et al.* 2007).

I. 3. 3. THE DIURNAL VARIATION IN COGNITIVE PERFORMANCE

The ability to maintain a high level of performance efficiency in everyday activities is challenging especially that our ability to remain attentive fluctuate throughout the day. Attention is an important cognitive process that refers to the capacity to effectively interact with the environment (Valdez 2019). Nevertheless, attention is a multifaced cognitive processing concept that includes two dimensions, namely intensity, and selectivity.

Intensity reflects states of cortical activation that can be tonic or phasic depending on the task's demands (Cohen 2014). The tonic aspect of intensity refers to the general functioning of the arousal system throughout the day. The latter is intimately involved in sustaining attentional control, as well, it provides the necessary cognitive tone for performing complex cognitive abilities, such as working memory or executive control (DeGutis and Van Vleet 2010). The phasic component refers to a rapid increased change in arousal levels induced by a warning signal (Landry and Raz 2016). The latter is viewed as an important element in a wide range of human performances requiring fast and precise responses. The aspect of selectivity includes sustained attention, divided attention, and shifting attention. In this work, however, we will only consider sustained attention which refers to the ability of one's mind to be continuously focused on processing features or objects and to ignore all the other irrelevant stimuli while performing a particular cognitive task over time (Pattyn *et al.* 2008), (for review, see Langner and Eickhoff, 2013).

In time of day recording paradigm, cognitive performance is measured on several occasions throughout the day, and this may induce learning effects, fatigue, or boredom. Therefore, the appropriate selection of performance tasks is an important factor to consider when investigating the diurnal variation in a specific neurobehavioral function (Valdez 2019). The basic experimental paradigms frequently used to assess the diurnal changes in tonic and phasic components of attention are based on reaction time measures and continuous task monitoring paradigms.

Reaction time (RT) is assessed using a computer-based performance task that measure the elapsed time between a stimulus (i.e. auditory or visual) and the individual's response to it (Helton and Warm 2008). The time course of testing generally does not exceed 10-min, but the test can be introduced for several occasions per day. The decline of attentional control is expressed by an increase in RT, or by an increase in the number of errors over time, or both (Basner *et al.* 2018).

Continuous task monitoring paradigm is mainly used to measure tonic attention (Smith *et al.* 2002). The period of testing can range from 30-min to several hours. The decline in attention is generally documented through performance stability over time and by the increased number of

incidents or errors (Smith *et al.* 2002). Furthermore, the testing can be achieved either in real-life settings, such as on-road driving evaluation or, as a safer alternative, in a real-life simulated driving environment (Stern and Davis 2006). Other than safety issues, the driving simulator offers numerous advantages compared to on-road testing. First, it guarantees the measurements in controlled environments, and therefore, it enables the acquisition of reproducible study results. Unlike real-life driving settings, weather conditions, traffic densities and road layout are largely unpredictable, dynamic, and far from being controllable. Besides, the driving simulator programs offer the opportunity to analyze the entire driving behavior or to study a particular cognitive ability. For example, to evaluate sustained attentional ability, the driving scenario is assumed to be in a monotonous driving environment. By contrast, to assess higher cognitive functions, the driving scenario challenges the individual to monitor the vehicle in a more dynamic environment (Goode *et al.* 2013). Also, the use of a driving simulator provides the possibility to have data related to the vehicle's lateral position variability, and the number of inappropriate line-crossing over testing time. In this regard, one has to recognize that this data is difficult to obtain in a real-life sitting. Moreover, driving simulators have extensively been used to study situations that may negatively impact safety on the road, including drowsiness, drugs, or alcoholic beverage (Weiler *et al.* 2000, Wang *et al.* 2019). As well, they provide the opportunity for testing different strategies to counteract the decline in performance (Horne and Reyner 1996a, Lenné *et al.* 2004). Finally, driver simulators can easily be implemented in a small place in the laboratory, guaranteeing the cost and resource savings (for review, see Classen *et al.* 2011). Nevertheless, a significant limitation is related to the simulated driving discomfort that is experienced by certain individuals has to be mentioned. This discomfort is described as the "simulator sickness". Individuals who are susceptible to simulator sickness show signs of pallor, cold, sweat, nausea, the difficulty of focusing, and in some cases vomiting (for review, see De Winter *et al.* 2012).

I. 3. 3. 1. 1. OBSERVATIONS UNDER NORMAL DAY-NIGHT CONDITIONS

Research investigating the diurnal variation in cognitive performance under normal day-night conditions have identified the classical curve of attention (i.e. phasic and tonic components) during the day. The time course of performance reaches its lowest levels in the early morning, during the early afternoon hours, and at night. Better performance levels occur late in the morning and in the afternoon. The peak of cognitive performance is observed in the late afternoon hours (for review see, Schmidt *et al.* 2007, Valdez 2019). These changes in performance are correlated with electrophysiological measures of arousal and with rhythms of CBT. Besides, many studies have disclosed a temporal relationship between circadian rhythmicity of cognitive performance and self-reported feeling of arousal as evidenced by the Visual Analog Scale, Epworth Sleepiness Scale, or the Karolinska Sleepiness Scale (for review, see Oken *et al.* 2006, Goel *et al.* 2013).

I. 3. 3. 1. 2. OBSERVATIONS UNDER SLEEP LOSS CONDITIONS

Sleep loss is an extremely common problem that can be caused by sleep fragmentation, sleep deprivation, extended wakefulness, or circadian rhythm disruption. Compared to baseline performance levels, research investigating the diurnal fluctuation in attention following sleep loss showed that the decrease in performance becomes more pronounced in the early morning, during the early afternoon hours, and at night. Moreover, performance levels plateau late in the morning, during the afternoon, and evening hours. The impairment in cognitive performance is correlated with low levels of arousal as assessed by electrophysiological measures and by subjective questionnaires (for review, see Lowe *et al.* 2017).

I. 3. 4. THE DIURNAL VARIATION IN PHYSICAL PERFORMANCE

The examination of changes in physical performances under normal day-night conditions and under sleep loss conditions is a key measure that leads to the understanding on how sleep and circadian rhythms affect physical performance. Besides, is important in fields that strongly require high levels of performance. As a case in point, the study of performance in the field of sports science is considered as predominant factor to success. For instance, a small decrease in

performance might separate a winning team or an individual from another whose performance is marginally under the peak (Waterhouse *et al.* 2007).

Adequate sleep quality and quantity are considered key factors to ensure athletes' optimal outcomes and to promote adequate physiological and psychological recovery from daytime energy loss (Kölling *et al.* 2019). Nevertheless, sleep loss is a common issue among athletes, and for many reasons it is experienced by many of them (Gupta *et al.* 2017). One of the most persistent causes which negatively affect sleep is the overloaded schedule that includes high frequency and intensive training sessions. Likewise, sleep can be shortened due to early start time and late evening training sessions. Moreover, athletes who participate in national and international competitions face challenging demands that raise external and internal factors causing sleep loss. External factors are late evening competitions, circadian desynchrony (jet-lag), sleeping in unfamiliar environments, and pre-competition-imposed diet. On the other hand, internal factors are pre-competitive anxiety, and the strong pressure exerted the day prior to competition. These internal factors are further reinforced by some other psychological attributes in elite athletes such as perfectionism and the firm willingness to excel. In addition, some ritual habits may stand as factors causing sleep loss in athletes. For instance, during the month of Ramadan, Muslim athletes who refrain from food and drink from sunrise to sunset experience a whole disturbance in their daily habits that may also cause sleep loss in athletes. For review see (Gupta *et al.* 2017, Kölling *et al.* 2016, Kölling *et al.* 2019).

I. 3. 4. 1. OBSERVATIONS UNDER NORMAL DAY-NIGHT CONDITIONS

The majority of physical outcomes display diurnal variations in performance that increase progressively throughout the day with an acrophase observed in the afternoon and in the late afternoon hours, and with the poorest performance recorded late at night and early in the morning. For instance, anaerobic performance was found to be higher in the afternoon and evening than in the morning. A similar evening peak in performance was observed for muscular strength and explosive leg power. Besides, the aerobic performance was proved to be higher in the afternoon

and in the evening compared to the performance in the morning (for review, see Thun 2015). Together these rhythms are in phase with the circadian profile of CBT. Accordingly, high values of CBT correspond to the best-recorded performances. By contrast, low values of CBT correspond to the poorest performances.

I. 3. 4. 2. OBSERVATIONS UNDER SLEEP LOSS CONDITIONS

Researches have indicated that sleep loss does not affect the performance in tasks involving anaerobic and muscular strength performances. However, other studies have shown that sleep loss affects the diurnal fluctuation of physical outcomes in tasks requiring anaerobic performance. In fact, they have demonstrated a decrease in the amplitude of the evening peak in performance compared to the baseline curve of performance. Nevertheless, they showed that the acrophase is still observed in the afternoon, compared to morning performance (Souissi *et al.* 2003, 2008). However, endurance performance is proved to be highly affected by sleep loss. The negative impact of sleep loss on endurance performance is more pronounced in the evening hours than in the morning. In addition, sport-specific performance was proved to be sensitive to sleep loss. This effect was attributed to the complexity of components contributing to performance efficiency, such as cognitive and emotional factors. These components, however, were proved to be largely affected by sleep loss (Simpson *et al.* 2017)

I. 4. ENERGETIC AND RECUPERATIVE NAPS

I. 4. 1. INTRODUCTION

The human body tends to rest during the midday period, as well as at night (Lavie 1986). The concept of a midday nap has widely varied across cultures and over time. In many countries, napping is a commonplace culture (Webb and Dinges 1989). For example, in Spain, the “Siesta” (i.e. Spanish term, meaning nap) is considered one of the most traditional practices and ancient rituals in daily Spanish life. The name siesta is derived from the Latin term “*horasexta*” which

refers to the sixth hour of the day according to sundial time (Rossi and Russo 2017). The ‘siesta culture’ is also prevalent in other Mediterranean and Southern European countries. For instance, in Mexican and Latin American traditions, a short nap is a good option to consider since the effects of high temperature combined with a heavy midday meal commonly affect productivity. Interestingly, in Japan, workers have the constitutional right to nap in the workplace since it is considered a means to increase productivity (Flaskerud 2015). On the other hand, in “Non-Siesta cultures” and in some modern societies, sleep loss and physical marks of fatigue are seen as badges of honor testifying hard worker’s efforts. In these cultures, a midday nap is perceived as a practice of backwardness as well as a waste of time. Yet, Cola or coffee breaks are commonly favorable (Maas 2012).

The frequent recurrence of daytime naps in both siesta and non-siesta cultures has been a subject of considerable interest in multiple studies. Even though researchers have differently labeled the midday period; “sleep gate” (Lavie 1986), “nap zone” (Broughton and Dinges 1989), “post-lunch dip” (Monk *et al.* 1996), they have all been preoccupied with the understanding of this behavior and with unrevealing its nature. Accordingly, they have attempted to investigate whether the midday nap is a part of the endogenous biological rhythms, a compensatory response to sleep loss, or a behavioral response to exogenous factors such as heavy meal consumption and high ambient heat (Stampi 1992a). Here it is important to highlight that in order to prove that napping is a behavioral expression of the endogenous sleep-waking rhythms, it should meet the following criteria: (1) temporally repetitive, (2) maintaining a stable phase relationship with other components of circadian rhythms and (3) governed by rules of homeostatic and circadian processes of sleep-wake regulation (Campbell 1992).

I. 4. 2. ENDOGENOUS PROPERTIES OF THE NAP

I. 4. 2. 1. TEMPORAL PATTERNS OF NAPPING

Campbell (1984) investigated sleep-wake patterns during 60 hours of enforced bedrest protocol in which the experimental protocol was not restricted to a single sleep episode. Instead, the

spontaneous expression of sleep and wakefulness was authorized. The result outlined a strong tendency toward a polyphasic alternation of sleep and wakefulness throughout the experimental period with mainly two sleep episodes per 24-h. The first sleep episode corresponded to nocturnal sleep, and the second sleep episode corresponded to a daytime nap. Besides, Campbell (1984) examined the effects of meal consumption on the duration of wakefulness and the structure of sleep. The results showed that meal consumption did not affect the duration of wakefulness, nor the structure of daytime sleep. Furthermore, the natural inclination toward sleep in early afternoon hours was confirmed in the study of Zulley (1988) under 32 hours of constant bed rest protocol. Together, these results have asserted that under isolated time-free environments, napping manifests a stable pattern of recurrence throughout the 24h, confirming, therefore, the existence of a biological endogenous predisposition to sleep in the early afternoon hours, in well-rested individuals, whether or not food is consumed. For note, the first studies investigating the nature of napping under a free-time environment and constant routine protocols are reviewed in the book of Stampi (1992a) *Why We Nap: Evolution, Chronobiology, and Functions of Polyphasic and Ultrashort Sleep*, in the sixth chapter by Campbell (1992).

I. 4. 2. 2. PHASE RELATIONSHIP WITH OUTPUTS OF THE CIRCADIAN CLOCK

Zulley and Campbell (1985) studied the circadian course of CBT under a free-running environmental experiment in which the experimental protocol was not restricted to a single sleep episode. The results showed that major sleep episodes (subjectively, nocturnal sleep) occurred around the minimum phase of CBT, while other sleep episodes (subjective naps) occurred approximatively halfway between two successive temperature minima (*Figure 19*).

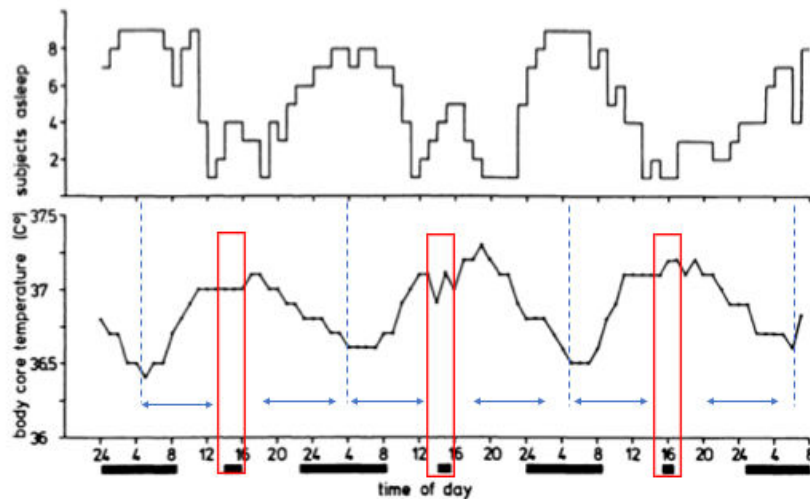


Figure 19. Relationship between sleep episodes and circadian rhythms of the core body temperature. Modified from (*Campbell and Zulley 1985*). Black bars represent the onset and duration of major sleep episodes and naps.

Together these results showed that the recurrence of a daytime nap is closely related to the circadian rhythm of CBT. Besides, these results assert convincingly that napping is a behavioral expression of the endogenous biological rhythms of sleep and wakefulness.

I. 4. 2. 3. HOMEOSTATIC AND CIRCADIAN INFLUENCES ON SLEEP DURING THE NAP

The timing and structure of sleep during the nap are determined by the same brain mechanisms and factors that regulate nocturnal sleep, which are based on circadian and homeostatic principles.

The interaction between the homeostatic and the circadian processes generates the appropriate timing and structure of sleep during the nap (Milner and Cote 2009). The temporal pattern of sleep is determined by the endogenous circadian process. By far, most of the scientific reports have asserted that there is a biological endogenous predisposition to napping in the early afternoon hours. As mentioned previously, sleep latency is the marker of the homeostatic and circadian processes on the sleep propensity parameter during the nap (Deboer 2018). For instance, sleep latency is shorter when the nap is scheduled during the sleep gate zone compared to a nap initiated during the wake maintenance zone. Furthermore, following sleep loss, the temporal pattern of the

sleep propensity parameter remains unchanged, however, the duration of sleep latency is reduced compared to baseline conditions (Lavie 1992).

As well, the structure of sleep during the nap is regulated by the homeostatic and circadian processes. As previously reported, SWA activity represents the physiological marker of the sleep homeostasis and intensity parameter of the sleep process (Gompf and Anaclet 2019). Accordingly, the amount of SWA during a nap depends on the history of prior wakefulness. For instance, the waking period preceding the nap in normal sleep-wake conditions is shorter than following sleep loss conditions (Dinges *et al.* 1987). Consequently, the amount of SWA is greater when a nap is scheduled following sleep loss than a nap taken in normal sleep-waking conditions (Deboer 2018). Given the influence of the circadian and the homeostatic processes, the structure of sleep during a midday nap in normal sleep-wake patterns is distinct from a nap scheduled under sleep loss conditions (Dinges *et al.* 1987, Mantua and Spencer 2017).

I. 4. 3. THE EFFECTS OF NAPPING ON WAKING PERFORMANCES

Given the fact that daytime drowsiness and related deficit on performances reach a peak in the early afternoon hours (Monk *et al.* 1996, Carrier and Monk 2000), a short nap scheduled at that time is considered as an effective strategy to overcome the drawbacks of post-lunch dip and to improve arousal and waking performances throughout the day. For instance, laboratory studies showed that a midday nap promotes evident improvements in performance across a variety of cognitive domains, such as memory and learning, psychomotor performance, and executive functions (for reviews, see Dinges 1992, Milner and Cote 2009, Ficca *et al.* 2010, Faraut *et al.* 2017, Mantua and Spencer 2017, Staton *et al.* 2020). It was also reported that napping produces equivalent and often better effects on arousal and performance compared to other countermeasures frequently used such as caffeine and other stimulant medications (Ficca *et al.* 2010). Here it is important to mention that the benefits of a short midday nap on performance are modulated by many factors, including the amount of previous sleep and wakefulness, interindividual variability, and sleep environment (Takahashi 2003, Milner and Cote 2009).

I. 4. 3. 1. PRIOR SLEEP AND WAKEFULNESS

As outlined above, the circadian variations of arousal and waking performance are affected by the influence of the previous amount of sleep and waking (i.e. homeostatic sleep pressure) (Deboer 2018). Therefore, in an attempt to provide a more detailed analysis of the impacts of a midday nap on performance, we endeavor to highlight some issues that have often been neglected in several studies but may be considered as fundamental in presenting an accurate account of napping in relation to performance. The first point we raised concerns the timing of the nap. In this work, we will mainly regard napping as a behavioral expression of the endogenous biological rhythms of sleep and wakefulness. Therefore, the term “midday nap” is meant to delineate a nap period that takes place in the early afternoon hours. The second point deals with the effects of a midday nap on performance as a function of the previous amount of wakefulness (i.e. homeostatic sleep pressure). The latter is proven to be a key factor modulating not only the structure of sleep during the nap but also on the dynamic change of performance during the day. Accordingly, we tried to distinguish between two different types of nap based on the previous amount of sleep and wakefulness. The first type is termed “energetic nap” and the second is “restorative nap”.

I. 4. 3. 1. 1. THE ENERGETIC NAP

We introduced the term energetic nap to designate a short daytime sleep period that occurs in the early afternoon and following normal sleep-wake patterns. The role of the energetic nap is to increase arousal and many neurobehavioral outputs beyond baseline levels.

Together, the contemporary model of sleep-wake regulation posits that the mutual interaction between homeostatic and circadian processes, regulate changes in arousal levels and corresponding performance throughout the day: the level of arousal attained at a specific time of day depends on the difference between the homeostatic pressure for sleep and the circadian pressure for sleep and/or wakefulness (Borbély *et al.* 2016). That is, a short distance between the two processes indicates high arousal levels. Furthermore, the model entails that the functioning of the circadian clock depends on the status of sleep homeostasis. Broadly, the circadian

amplitude of many neurobehavioral functions increased when sleep pressure is reduced, and the circadian amplitude is lowered when the level of sleep pressure is high. Moreover, these changes vary according to time of day (Borbély *et al.* 2016).

With regard to the contemporary model of sleep-wake regulation, the use of a midday nap would reduce the level of sleep homeostasis, and therefore, might increase the circadian amplitude of many neurobehavioral functions (*Figure 20*). Based on these observations, it could be said that the energetic nap enhances arousal levels and performance by increasing the afternoon and evening peaks in performance beyond baseline levels (*Figure 20*).

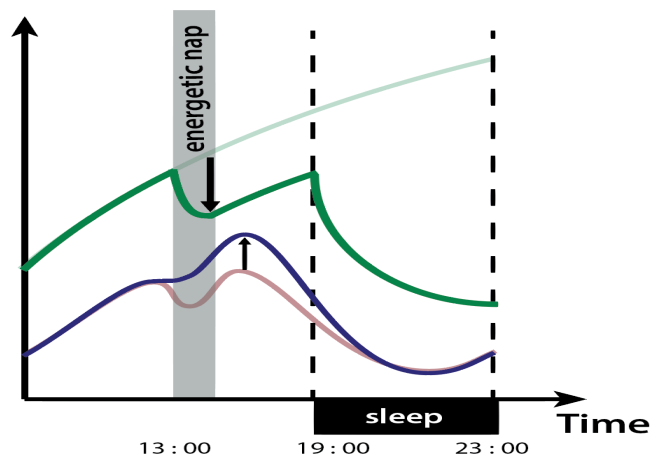


Figure 20. A schematic illustration of the changes in the homeostatic and the circadian processes under the influence of the energetic nap. The homeostatic sleep pressure decreases after the nap (**green curve**). Baseline circadian amplitude (**pink curve**) increased when the level of sleep pressure is low (**blue curve**).

The benefits of the energetic nap on cognitive performance have been asserted by studies that have applied modern neurophysiological techniques, such as event-related potentials (ERPs). ERPs are the ideal tool for assessing changes in arousal and attention following the nap. Brain potentials are recorded following the presentation of stimuli. The event-related P300 amplitude represents the amount of allocation attention, and the P300 latency represents the time spent on the evaluation of the stimulus (Milner *et al.* 2006). For example, Petit *et al.* (2018) tested the effects of a 20-min nap on arousal and cognitive performance. Their results showed that the

energetic nap increased the P300 amplitude and decreased P300 latency during the auditory oddball task. These results indicated that the amount of allocated attention was higher and the accuracy in the information processing speed was greater after the nap compared to the baseline condition (no-nap). Furthermore, Takahashi *et al.* (1998) showed that a 15-min midday nap improved subjective alertness, decreased P300 latency, and improved cognitive performance during an English transcription task.

On the other hand, other studies have reported that the energetic nap did not affect the performance on several aspects of physical outcomes, such as aerobic performances (Blanchfield *et al.* 2018), anaerobic performances (Petit *et al.* 2014, Tanabe *et al.* 2020), muscular strength, and jump velocity (Tanabe *et al.* 2020). Together, these results further suggest that the beneficial effects of an energetic nap on a particular task performance depends on its sensitivity to sleep pressure.

I. 4. 3. 1. 2. THE RESTORATIVE NAP

The second type is termed the ‘restorative nap’, also called the “replacement nap”. It is used to designate a midday nap that is taken following sleep loss. The role of the restorative nap is to restore or/and to attenuate the decrements in performance caused by high levels of sleep pressure (Broughton and Dinges 1989, Dinges 1989).

As previously mentioned, the circadian variations of arousal and waking performances are affected by the influence of the previous amount of wakefulness (Deboer 2018). Besides, according to the two-process model of sleep regulation, the homeostatic factor will seek to redress the balance between the accumulated levels of sleep pressure caused by extended wakefulness on subsequent sleep by either deepening the structure of sleep, or extending its duration, or both (Borbély 1982, Achermann *et al.* 2017). Given the influence of the homeostatic process on the structure and the duration of subsequent sleep, it is therefore expected that the structure of sleep of the restorative nap is distinct from the energetic nap. Furthermore, under conditions of prolonged wakefulness, high levels of sleep pressure would affect the functioning of the circadian clock by reducing the amplitude of the circadian curve of arousal and many neurobehavioral

functions. Based on these lines, one may conclude that the administration of a restorative nap will redress the imbalance induced by extended wakefulness, and consequently, will restore the afternoon and evening circadian amplitude to attain baseline levels (Figure 21).

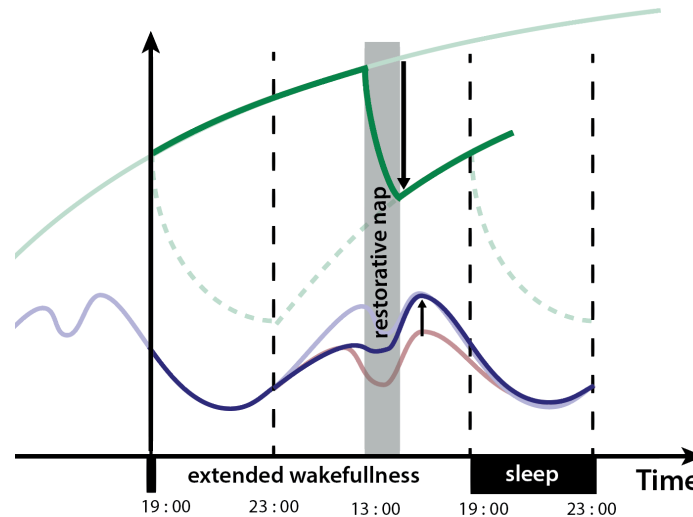


Figure 21. A schematic illustration of the effects of restorative nap on the dynamic changes of arousal following extended wakefulness (**blue curve**). The influence of the homeostatic sleep pressure on the circadian curve following extended wakefulness (**pink curve**) The effects of restorative nap on the homeostatic sleep pressure (**green curve**).

There is well-documented evidence for the restorative effects of a midday nap on arousal and cognitive performance following extended wakefulness (DMSc and DMSc 2000, Tietzel and Lack 2001, 2002, Brooks and Lack 2006, Waterhouse *et al.* 2007). In addition to cognitive recovery, laboratory studies have provided encouraging results concerning the benefits of a recuperative nap on different physical performances under conditions of sleep loss. For example, Blanchfield *et al.* (2018) found that the nap restored aerobic performance for runners who had a poor sleep-wake pattern. Furthermore, Waterhouse *et al.* (2007) showed that a short nap restored the performance during a repeated sprint task. Besides, (Hammouda *et al.* 2018) investigated the effects of different nap durations (i.e. 20-, 90-min) after a partial sleep deprivation on the running-based anaerobic sprint test (RAST). Their results showed that both naps' opportunities restored all indicators of RAST performance, with a better gain observed after the 90-min nap.

I. 4. 3. 2. THE INTERINDIVIDUAL VARIABILITY IN NAPPING BEHAVIOR

Considering the fact that napping is not a homogenous habit, the preferences toward napping differ widely among persons and so do the benefits gained from them (Evans *et al.* 1977, Faraut *et al.* 2017). For instance, for certain individuals, a midday nap is considered a part of their regular sleep-wake pattern and a daily habit that is not necessarily caused by sleep loss. In literature, this type of individuals is referred as “appetitive nappers”. For others, napping is mainly used in response to sleep loss (i.e restorative nappers or replacement nappers) or before an expected sleep loss (i.e. prophylactic nappers). However, for some people, napping is avoided because of the unpleasant mental and physical after effects that could result from it, such as impaired cognitive and sensory-motor performances after waking from the nap (Evans *et al.* 1977, Broughton and Dinges 1989, Dinges 1992). In this context, Johnston *et al.* (2001) investigated the difference in nocturnal sleep between habitual nappers and non-nappers, intending to prove that regular napping behavior is not necessarily caused by sleep loss. Accordingly, the results showed no differences in the nocturnal sleep quantity between groups. In addition, other scholars added evidence to the fact that napping is not necessarily provoked by sleep loss (Pilcher *et al.* 2001, Campbell *et al.* 2005, McDevitt *et al.* 2012).

Many studies are interested in investigating the distinct characteristics among individuals to prove that regular nappers are those who are “predisposed to be good daytime nappers” (Milner and Cote 2009), and who are more likely to benefit from napping than non-nappers (Evans *et al.* 1977, Taub 1979, Milner *et al.* 2006). For instance, Evans *et al.* (1977) attempted to classify habitual nappers and non-nappers according to the subjective experience resulting from the nap. Their results demonstrated that, contrarily to habitual nappers who were pleased with the nap, non-nappers reported that naps produced unpleasant after-effects. Additionally, it was pointed out that habitual nappers are more sensitive in response to sleep pressure during the day than non-nappers (Johnston *et al.* 2001, McDevitt *et al.* 2012). For exemple, McDevitt *et al.* (2012) investigated the relationship between the frequency of naps taken weekly and the level of subjective drowsiness

during the day. Their results showed that the more frequent the nap was taken, the higher the levels of trait and state of drowsiness throughout the day became.

Furthermore, there is evidence showing differences in the structure of sleep during the nap and its effects on performance between habitual nappers and non-nappers. Evans *et al.* (1977) demonstrated that sleep latency was shorter for napper compared to non-nappers. Moreover, habitual nappers' sleep during the nap was mainly composed of lighter sleep stages and least SWA, and more stage shifting during the nap. However, non-habitual nappers had a deeper and more consolidated sleep. Importantly, these results were further confirmed by many other studies (Milner *et al.* 2006, McDevitt *et al.* 2012).

I. 4. 3. 3. SLEEP ENVIRONMENT

Inspired by the concept of “power breakfast”, James Maas introduced the term “power nap” to encourage the use of naps in the workplace with the aim to counteract the negative impacts of sleep-related incidents and accidents and to improve performance and productivity at work (Maas 2012). Because drowsiness is considered a major contributing factor to the increasing number of road traffic accidents, one of the most often recommended countermeasures to prevent drowsiness at the wheel is napping (Horne and Reyner 1996a, Sagaspe *et al.* 2007). Nevertheless, before advocating for the use of the nap in the workplace or at the wheel, the problem related to the physical environment of sleep during the nap should be addressed. It is a major issue that has received little interest in literature.

In this context, it is well known that a noisy sleep environment affects the quality of sleep by causing frequent awakenings or shifts to lighter sleep stages (Kawada 2011, Halperin 2014). Besides, exposure to a high level of brightness reduces ones' capacity to initiate sleep (Blume *et al.* 2019). Furthermore, former researches have underlined the disturbing effects induced by a sitting sleep position on objective and subjective sleep quality compared with lying in a bed (Nicholson and Stone 1987, Aeschbach *et al.* 1994). Despite these relevant evidences on the

effects of the sleep environment on the quality of sleep, employees and drivers take their naps on their chairs and in non-suitable sleep environments filled with light and noise (Angardi 2020).

In the last twenty years, technological innovation has led to an evolution in design and production of ergonomic nap capsules often used in the workplace, hospitals, universities, airports, and public areas, to introduce napping to real-life settings. Let us cite the example of Metro Nap's Energy pods that launched the world's first chair specifically designed for napping in the workplace (Figure 22 A). Others pods are placed in public environments like the Pod Time capsule (Figure 22.B) implemented in the center of London's financial square mile. In France, Adilson Pod' Calm (Figure 22.C) reclining chair, and Sombox private nap rooms (Figure 22.D) are the recently presented products.



Figure 22. Different models of nap capsules

Each of these models prompts a unique experience by using (i) aromatic materials, including essential oils promoting sleep (ii) relaxing sounds and music to foster relaxation and to reduce stress, (iii) certain hues of colored light and evoking emotional and psychological well-being. The design and the degree of comfort and security provided in these small nap pods are considered contemporary markers of innovation and technology.

I. 2. PROJECT SUMMARY, OBJECTIVES, AND HYPOTHESES

Circadian rhythms of sleep and wakefulness are tightly interrelated behaviors regulated by complex systems of neural networks and neurotransmitters under the influences of the homeostatic and circadian processes (Saper *et al.* 2005). The homeostatic process (process S) builds up sleep pressure that progressively increases with the time spent awake and falls substantially during sleep (i.e. nocturnal sleep and daytime naps). The circadian process (process C) alternates between promoting pressure for sleep and/or wakefulness according to the time of day. During the waking period, the circadian pressure for wakefulness fluctuates non-linearly throughout the day, presenting periods of maximum pressure for wakefulness and periods of high pressure for sleep (Mistlberger 2005, Van Dongen and Dinges 2005). The interaction between the homeostatic and the circadian processes determines the timing and the structure of subsequent sleep (i.e. nocturnal sleep and daytime nap) and modulates the dynamic changes in arousal levels and performance during the day (Borbély *et al.* 2016).

Arousal is a physiological concept used to describe the activation states of the cerebral cortex underlying the sleep-wake dimension (Langner and Eickhoff, 2013). Furthermore, it is considered as a basic precondition and a principal modulator of any given physiological and behavioral parameter (Lavie 1989, Fischer *et al.* 2008). Importantly, changes in performance outcomes (i.e. improvement or decrement) represent a good marker for examining the level of arousal during the waking period (Sander *et al.* 2015). When the homeostatic and the circadian processes work in opposition during the day, the difference between the homeostatic pressure for sleep and the circadian pressure for sleep and/or wakefulness determines the level of arousal reached while awake (Achermann and Borbély 1994). Accordingly, a short distance between S and C indicates high arousal and performance levels. Conversely, a large gap between the two processes indicates low arousal and performance levels (Borbély 1982, Borbély *et al.* 2016). Importantly, in the classical two-process model, process S did not influence the functioning of process C. However, in the contemporary two-process model, the homeostatic and circadian processes are subjects to

more complex and continuous interactions (Borbély *et al.* 2016). In this updated version, Borbély posited that the functioning of the circadian process depends on the history of prior wakefulness and sleep, that is, the amplitude of process C decreases when the level of process S is high, but increases when the level of process S is reduced.

Given that the circadian pressure for arousal reaches its nadir in the afternoon (i.e. post-lunch phase), the use of a short midday nap was proved effective in counteracting the drawbacks of the post-lunch phase. As well, it promotes significant improvements in cognitive and physical performances throughout the day (Milner and Cote 2009, Mantua and Spencer 2017). Nevertheless, the potential benefits of a short midday nap on performances are modulated by several factors, including the previous amount of sleep and wakefulness, interindividual variability, performance measures (Milner and Cote 2009), and the environment of sleep during the nap (Zhao *et al.* 2010).

From a theoretical perspective, the core of this research project embeds the understanding of the reciprocal interaction between the homeostatic and the circadian processes under the influence of a short midday nap according to the history of prior wakefulness and sleep (i.e. normal sleep and partial sleep deprivation). In an attempt to provide a more precise groundwork, we differentiate between two different types of naps on the basis of previous amount of sleep and wakefulness (i.e. the intensity level of sleep pressure). We introduced the term energetic nap to designate a short midday nap taken after a normal night of nocturnal sleep, and we used the term restorative nap to designate a short midday nap taken under sleep loss.

Therefore, the objective of the present work is to investigate the impacts of energetic and restorative naps on the subjective levels of arousal and aspects of cognitive and physical performances in the afternoon in healthy habitual nappers. In order to meet our objective, three experimental studies were implemented:

The first study aimed to assess the impacts of a 25-min midday nap on subjective ratings of anxiety, arousal, and fatigue, sustained attention, and muscular power in the afternoon after a normal night of sleep in healthy habitual nappers. The first objective was to examine the structure

of the nap in different sleep environments and its impacts on cognitive and physical performances. Also, this work contributed to the scientific development and technological validation of a new sleep product consisting of nap rooms conceived to be set on highways. The second objective of this study was to compare cognitive and physical outcomes in the afternoon after the nap with the morning outcomes. The present study was financially supported by the startup SOMBOX and by the foundation VINCI Autoroutes. Finally, the results of this investigation will be considered for publication.

The second study aimed to assess the effects of a 30-min midday nap on subjective ratings of arousal and fatigue, and different aspects of cognitive and physical performances after a normal night of sleep. Then, we attempted to identify which aspect of the cognitive and/or physical performances is/are affected by sleep loss and that might be recovered following the nap. We also investigated the effects of fatigue induced by a high-intensity intermittent test on aspects of cognitive and physical performances. This study was published in the journal of *Medicine and Science in Sport and Exercise*.

The third study aimed to investigate the effects of a 30-min midday nap after a normal night of sleep on cognitive and physical performances. The first objective was to examine the impacts of the nap on cognitive performance using reaction time tests with distinct complexity levels. The second objective was to assess the effects of the nap on speed and directional ability in highly-trained athletes. The results of the third investigation will be submitted in May 2021.

With regards to the contemporary two-process model, we start with the hypothesis that when the normal amount of nocturnal sleep is preserved, the use of the energetic nap will reduce the level of process S, which consequently would improve the performance beyond baseline levels. We also speculate that when the normal amount of nocturnal sleep is reduced, the increased level of the process S will reduce arousal and performance levels below baseline values. In this case, we expect that the restorative nap will redress the imbalance between S and C, and consequently, will restore the decrease in performance to the baseline levels. Finally, we expect that the above-mentioned impacts of a short midday nap on cognitive and physical performances will be

modulated by the environment of sleep during the nap, and we also suppose that the effects of napping on performance will vary depending on the characteristics of the performed task.

II. SECOND CHAPTER: EXPERIMENTS

II. 1. STUDY I: EFFECTS OF A SHORT MIDDAY NAP ON SUBJECTIVE AROUSAL, FATIGUE, AND SUSTAINED ATTENTION IN DIFFERENT NAP ENVIRONMENTS.

II. 1. 1. INTRODUCTION

The attentional system modulates the brain activity to exert control over thoughts, feelings, and actions (Visintin *et al.* 2015). Tonic inputs of the cortical cholinergic activity of the ascending arousal system (ARAS) constitute the neural correlate of the attentional system (Sarter *et al.* 2001, Helfrich *et al.* 2018). The attentional system is involved in supporting the diverse aspects of performance including the perceptual, cognitive, and motor abilities that are essential for mastering everyday activities (Parasuraman 2000, Fortenbaugh *et al.* 2017). In particular, sustained attention refers to the ability to *maintain a goal-directed behavior in the face of multiple competing distractors over time* (Parasuraman 2000). The ability to sustain information processing activity over an extended period is critical in many operational settings such as production inspections, military surveillance, air traffic control, medical monitoring, and driving performance (Reinerman-Jones *et al.* 2011). In other respects, our ability to maintain sustained attention is not stable, instead, it fluctuates during the day (Lavie 1986, Dinges 1992). For instance, the emergence of drowsiness (i.e. low arousal levels) which typically occurs during the early afternoon causes attentional decline (Horne and Reyner 1996b, Garbarino *et al.* 2001). In certain circumstances, the attentional decline can negatively impact academic outcomes, work performance, and traffic safety (Fortenbaugh *et al.* 2017, Esterman and Rothlein 2019).

The use of a short midday nap is an effective strategy to counteract the effects of the post-lunch dip and to improve daytime arousal and performance throughout the day (Hayashi and Hori 1998, Hayashi, Watanabe, *et al.* 1999, Hayashi and Abe 2008, Zhao *et al.* 2010). Most of the studies that have investigated the effects of napping on different aspects of cognitive performances have

employed computerized reaction time performance tests. Particularly, in the present study, we sought to investigate the effects of a short midday nap on sustained attention based on tasks that simulate real-life situations such as a monotonous driving condition. The use of the driving simulator is appropriate because it requires the maintenance of attentional control over an extended period. Accordingly, in a monotonous driving task, the decline in attention is assessed by performance stability and by the increased number of incidents or errors over time (Smith *et al.* 2002). To date, the beneficial effects of napping on sustained attention using a driving simulator have previously been confirmed on shift workers (Centofanti *et al.* 2017), following sleep loss (Horne and Reyner 1996a, Reyner and Horne 1997, Watling *et al.* 2014), and during a prolonged nighttime driving (Phipps-Nelson *et al.* 2011). To the best of our knowledge, this study is the first that investigates the effects of a short midday nap on sustained attention in the afternoon using a monotonous driving task and following a normal night of sleep in healthy adults.

Nevertheless, before advocating napping in real-life settings, such as in the workplace or at the wheel, the problem of the environment of sleep during the nap has received little interest. The main issue related to the environment of sleep concerns the disturbing effect of napping in a sitting position on its impacts on the structure of sleep during the nap and subsequent performances. In this context, only one study compared the effects of a short midday nap on objective and subjective measures of arousal in different nap environments after a normal night of sleep (Zhao *et al.* 2010). The results of Zhao *et al.* (2010) showed no differences in the structure of sleep during the nap between a sitting forward-bending posture and a bed condition. Moreover, their results indicated that both naps were effective in improving subjective levels of arousal compared to the no-nap condition. However, in the objective measures of arousal assessed by the event-related potentials, the results showed a greater increase in the P300 amplitude after the nap in bed compared to the nap in a sitting position. Besides, P300 latency and reaction time after the nap in both conditions were not different from the no-nap condition. Although these findings are considerably important, it must be noted that in the study of Zhao *et al.* the morning activities were not controlled, since the testing started at 11:00 and took place after the morning classes. In

addition, the effects of the nap on performances were assessed 30-min after waking. Furthermore, no additional information about the duration of the reaction test was provided. Therefore, in the present work, we implemented the morning session to control the morning activities for all participants in the different experimental visits. In addition, we provided punctual and repetitive subjective testing sessions and continuous monitoring for sustained attention that started immediately after waking from the nap.

Given the importance of the environment of sleep during the nap. The startup SOMBOX has developed the first private nap rooms in France that are specifically designed to be implemented on highways to provide drivers and riders with the possibility to stop and to take a nap in suitable environmental conditions whenever they feel the need. The design and the degree of comfort and security provided in this small room are the markers of innovation and technology: the size of the nap room is about 2m². The design of the nap room was carefully refined by a team of experts to fit not only the purpose of the room but also the theme. Among the many integrated instruments and equipment, we find a lighting system that includes several intensities of lights and colors (i.e. white and red), accompanied by background music, and relaxing smells. The design of the box room is presented in *Annex C*. In order to evaluate the efficiency of the SOMBOX product, the structure of sleep during the nap and its effects on performance were compared to the bed and the reclining-chair conditions.

The focus of this study was to investigate the impacts of a 25-min midday nap on subjective ratings of anxiety, arousal, and fatigue, sustained attention, and muscular power during the afternoon after a normal night of sleep in healthy habitual nappers. The first objective was to examine the structure of the nap in different sleep environments and its impacts on cognitive and physical performances. Also, this work contributes to the scientific development and technological validation of the SOMBOX sleep product. The second objective was to compare the cognitive and physical outcomes in the afternoon after the nap, with the morning outcomes.

II. 1. 2. METHODS

II. 1. 2. 1. PARTICIPANTS

39 healthy adults (20 males and 19 females; age: 25 ± 4 years; height: 173.15 ± 8.5 cm; mass: 67.96 ± 12.4 kg) were recruited to participate in this study. They have had their driving licenses for at least 2 years, and the distance they drove averaged at least 5000 km per year. Before the inclusion all participants had a clinical appointment with a sleep specialist in the laboratory who granted that all participants fulfilled the following criteria: they have a social security coverage, exempt from any history of sleep disorder, had a normal sleep-wake habits, habitual nappers, and are not taking any drugs that would probably enhance or alter their level of arousal during the day. According to Pittsburgh Sleep Quality Index (PSQI) questionnaire (Fortenbaugh *et al.* 2017), all participants got a good sleep quality (score <5), (*Annex A. 1*). Moreover, they were selected as: morning-moderate type, evening-moderate type, or intermediate-type based on their scores in the Horne and Ostberg's Morningness-Eveningness questionnaire (Horne and Östberg 1976), (*Annex A. 2*). By contrast, extreme morning and evening chronotypes, alcoholic and caffeine consumers, shift workers, pregnant or breastfeeding women were excluded. Participants involved in this study signed an informed consent form. They were provided with detailed explanation of the study procedures, and they were paid 200 euros for their entire participation. As well, they were informed about their right to quit the study at any time they wished to, without being obliged to present any further explanation or excuse. Of course, even they opt for quitting the study they received 30 euros for every day they assist.

The protocol of this study was complied with the declaration of Helsinki for human experimentation, and was approved by the local Ethics. Ethical committee is registered under the following number: ID RCB n° 2018-A02253-52.

II. 1. 2. 2. PROCEDURES

The experimental design is detailed in *Figure 23*. Before the beginning of the experimental period, each participant attended one habituation session to be familiarized with the equipment and the experimental procedure. During the habituation session participants had electrodes attached on the scalp, and were required to experience a nap in the laboratory. During the experimental period, participants were asked to maintain a regular sleep-wake schedule. The day prior to the experimental session, subjects were instructed to ingest the telemetric e-Celsius capsule with water followed by a light dinner to aid the transit into the gastrointestinal tract (Byrne and Lim 2007). As well, they were required to sleep for at least 8 hours per night. To make sure that the protocol was respected, nocturnal sleep for nights prior to the experiment were monitored by actigraphic recording and sleep diaries. During the main experimental session, participants were required to wake up at 07:00 \pm 30, to get their usual breakfast at home, and to be in the laboratory at 9:00. First, they had electrode application, then at 10:00 they started the morning driving session. The driving task lasted for 104-min, and it consisted of a 52-min outgoing-trip, followed by a 52-min return-trip. A standardized lunch was served at 12:00. Thereafter, at 13:00 participants were assigned to have a 25-min nap opportunity, designed in a counterbalanced order in the following environmental conditions: bed, box, reclining-chair, and a control condition (i.e. no-nap). All naps were conducted in a suitable environment and in a quiet room. A subjective questionnaire of sleep during the nap was administrated immediately upon waking. For the no-nap condition, participants were not allowed to leave the laboratory, but they were free to choose activities like chatting or reading books. The post-nap driving session started at 13:30, alike the morning session it lasted for 104-min and was composed of the outgoing-trip, followed by the return-trip. Subjective measurements of anxiety, fatigue, alertness, and sleepiness were administrated for three occasions during the morning driving session in the following order: before the beginning of the outgoing-trip (TS 1), before the beginning of the return-trip (TS 2), and at the end of the return-trip (TS 3). Again, for the post-nap session subjective measurements were presented in the same order: before the beginning of the outgoing-trip (TS 4), before the

beginning of the return-trip (TS 5), and at the end of the return-trip (TS 6). Power of the lower limb was assessed at three different occasions: the first testing session occurred before the beginning of the morning driving task (TS 1). The second takes place at the end of the morning driving task (TS 3). And finally, at the end the post-nap driving session (TS 6). The whole experimental project was strictly controlled by two experimenters. Throughout the experimental period, participants were requested to maintain their habitual physical activities, and their habitual sleep-wake schedule. For the 24-h prior to testing, they were instructed to avoid any strenuous activities, excessive alcoholic or caffeine beverage.

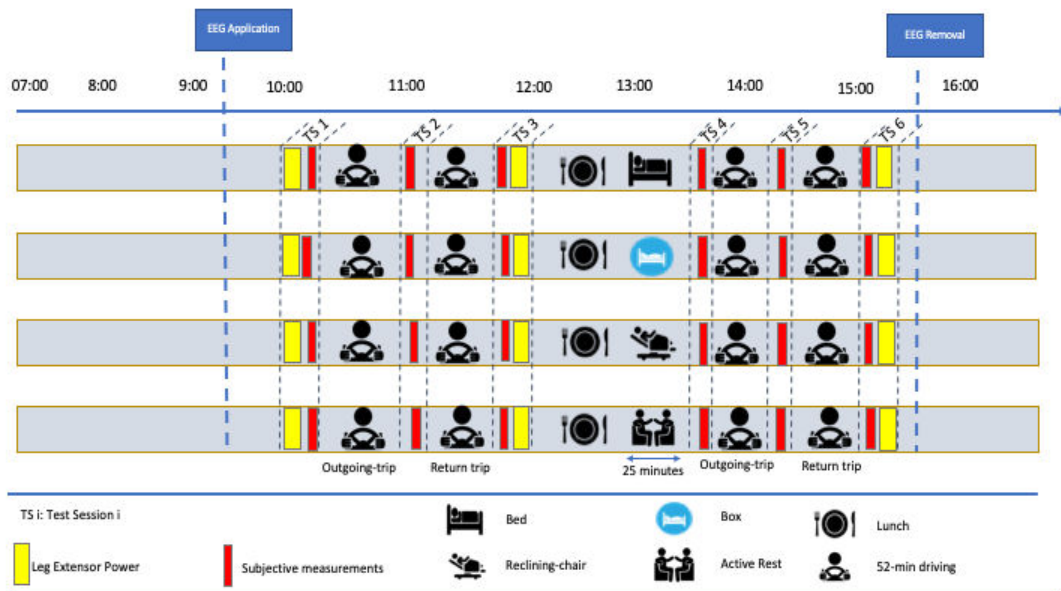


Figure 23. Experimental design

II. 1. 2. 3. MEASUREMENTS

II. 1. 2. 3. 1. ACTIGRAPHY AND SLEEP DIARY

Nocturnal sleep was monitored by a self-reported sleep diary in conjunction with actigraphy. The sleep diary provides reliable information about the quantity and the quality of nocturnal sleep (Kaplan *et al.* 2012). Participants were recommended to complete the sleep diary in the morning, and throughout the whole experimental period. Sleep diary is presented in *annex A.3*. Moreover, for objective sleep measurements, we used the Motion Watch actigraphy system (MW8;

Camntech ®), Subjects wore the MW8 device (*Figure. 24*) continuously on their non-dominant wrists. The device recorded data from a movement-sensitive sensor and provided information concerning sleep parameters. All watches were configured to collect data in 60-s epochs. The sleep variables examined for the night prior to the experimental sessions were edited manually within the information listed in the subjective sleep diaries, and scored using the software Motion Ware (version 1.0.25). Sleep variables analyzed in this study were the following: Bed Time, Fall Asleep Time, Wake Up Time, Total Time in Bed, and Assumed Sleep Time (the total period elapsed between “Fall Asleep Time” and “Wake Up” times).

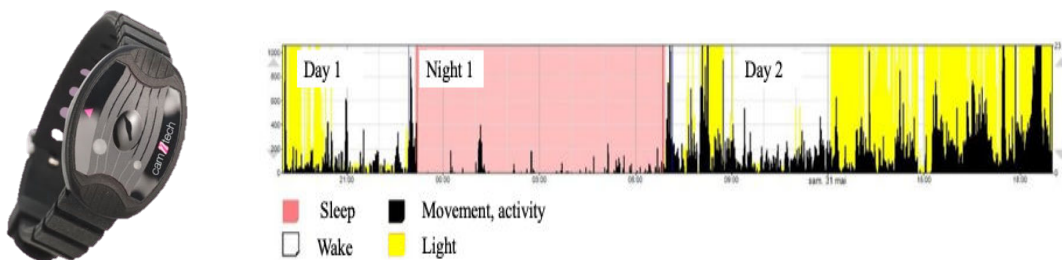


Figure 24. On the left: Motion Watch Actigraphy device. The device recorded data from a movement-sensitive sensor and provided information concerning sleep parameters. On the right: The actogram representing the activity-rest cycle.

II. 1. 2. 3. 2. EXPLOSIVE LEG EXTENSOR POWER (ELEP)

ELEP was measured in watts per kilogram (W/kg) using the Nottingham Power Rig machine (*Figure 25*). The instrument consists of an adjustable seat, and a large footplate connected through a lever and a chain to a flywheel (Bassey and short. 1990). Seat position was adjusted during the first visit, in a way that the knee angle at the start of the push was 90° for every participant. Subjects were seated with their pelvis supported at their back and with their arms folded. They were instructed to push the footplate as hard, and fast as possible. Leg extensor power of the right leg was recorded over 8 attempts, with at least 30s rest intervals between trials. For the analysis the best power output was recorded. Verbal encouragement was provided, but no feedback on performance was given.



Figure 25. The Nottingham Leg Power Rig machine to evaluate the Explosive Leg Extensor Power

II. 1. 2. 3. 3. CORE BODY TEMPERATURE (CBT)

Core body temperature was continuously monitored stored in 30-s intervals using the e-Celsius telemetric ingestible capsule (BodyCap[®], Caen, France), and a wireless data receiver system (e-viewer BodyCap[®], Caen, France), (*Figure 26*). The communication distance between the capsule and the receiver system can range from 1 to 3m. Nevertheless, the capsule has also its own memory, in case of a communication deficits between the capsule and the receiver, data can be re-synchronized with the receiver once the connection was established. The lifetime of the capsule inside the body ends naturally, and it depends on the transit time. Finally, the data collected can be displayed and stored on the laptop via a USB cable. The e-Celsius[®] pill is 17.6 mm long, 8.6 mm in diameter, and 1.2g in weight, with accuracy or 0.2 °C and a temperature range of 29-45°C.

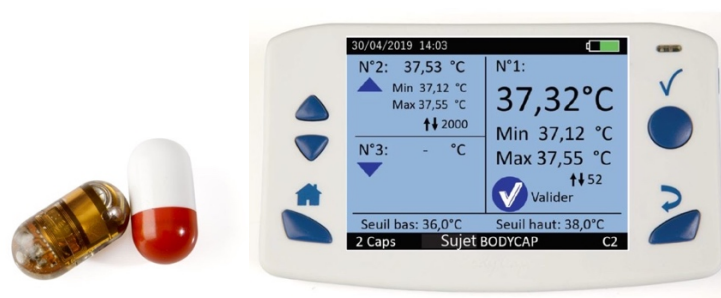


Figure 26. On the left: the BodyCap e-Celsius telemetric ingestible capsule. On the right: the wireless e-viewer BodyCap Data Receiver system.

II. 1. 2. 3. 4. SUBJECTIVE MEASUREMENTS

Subjective level of sleepiness was assessed via the Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg 1990), (*Annex A.4*). The KSS measures the subjective level of sleepiness at a particular time during the day. In this scale, subjects were instructed to indicate which level reflects the best their arousal state during the last 10-min. This scale is a 9-point scale (1= extremely alert, and 9= very sleepy, great efforts to keep awake, fighting sleep).

Subjective measures of anxiety, fatigue, and alertness were assessed using the Visual Analog Scale (VAS). The VAS consisted of 100-mm long horizontal line with two endpoints to express extreme feeling. The participants were instructed to cross on a straight line at the point that most expresses their level of agreement. The VAS we used had three lines to assess the levels of anxiety, fatigue, and alertness. The end points were designated as “very calm” and “very anxious”, “very tired” and “in a good physical form”, and “very sleepy” and “very alert” respectively (*Figure 27*).

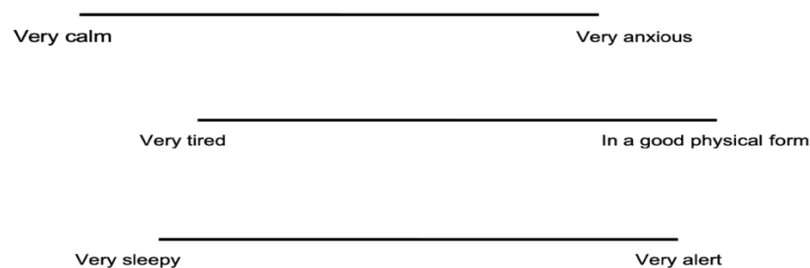


Figure 27. The Visual Analog Scale evaluating the level of anxiety (upper line), fatigue (middle line), and alertness (lower line).

Subjective questionnaire of sleep during the nap was administered immediately upon waking. Subjects were requested to answer some questions related to their estimated nap time (minutes), estimated sleep latency (minutes), nap depth (1, light to 5, deep), and their satisfaction with the nap (1, poor to 4, good) (Hayashi *et al.* 2005).

II. 1. 2. 3. 5. SLEEP VARIABLES DURING THE NAP

Electroencephalogram (EEG) was recorded from 9 scalp sites (FZ, FP1, FP2, C3, C4, T3, T4, referenced to linked mastoids A2 and A1) according to the international system 10-20 (Jasper 1958). Recording was performed with a portable polysomnography (Dream Medatec ®, Belgium), and the data was collected using the BrainNet software system (Figure 28). Electrooculograms (EOG) was placed 1cm above the outer canthus of the left eye, and below the outer canthus of the right eye. The electromyogram (EMG) was recorded from electrodes taped to the skin slightly above the mentalis muscles. Polysomnographic recordings during naps were scored visually in 20-s epochs according the guidelines updated in 2017 of the American Academy of sleep medicine (AASM) version. The measured polysomnographic sleep variables were the following: Total Sleep Time (TSL), Sleep Latency (SL), Sleep Efficiency (SE), Wake After Sleep Onset (WASO), and different sleep stages.

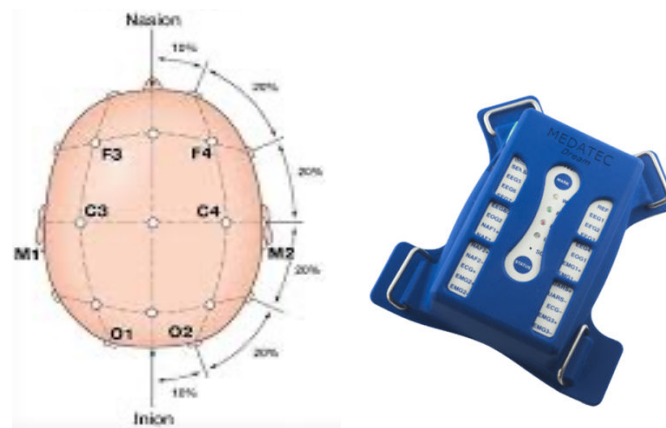


Figure 28. On the left: international system 10-20 system for electrode application. On the right: the portable polysomnography Dream Medatec device.

II. 1. 2. 3. 6. DRIVING SIMULATOR

The driving task was performed using VIGISIM driving simulator (Davenne *et al.* 2012). It is composed of a computer and a video game steering wheel (Logitech Momo Racing). The roadway illustrated in the simulation was a virtual daytime reconstruction of a real highway road (A62 between Agen and Langon, France), but, with no traffic. The car's speed was fixed by the experimenter to 130km/h. In order to obtain a scenario of driving close to real-road environment,

the topographic layout included lane widths, road marking, and landscapes. Besides, the roadway included imperceptible and smooth deviations to keep continuous attentional tracking and correction of the vehicle position. Participants were instructed to maintain a stable pathway, and drive in the center of the right travel lane, and not to cross the painted lines separating the lane (Figure 29). The simulated road-trip lasted for 104-min, and it consisted of a 52-min outgoing trip, followed by a 52-min return trip. Sustained attention was objectively measured by analyzing the following parameters:

Standard Deviation of the Lateral Position (SDLP). SDLP is defined as the location of the vehicle's longitudinal axis relative to a longitudinal road reference system (Porter *et al.* 2004). In this study, the longitudinal road reference system represents the virtual center line of the travel lane (Figure 29). SDLP was continuously monitored and stored in 1s interval.

Number of Inappropriate Line Crossing (NILC). NILC was counted every time the car crossed any of the roadway edge lines (Figure 29).

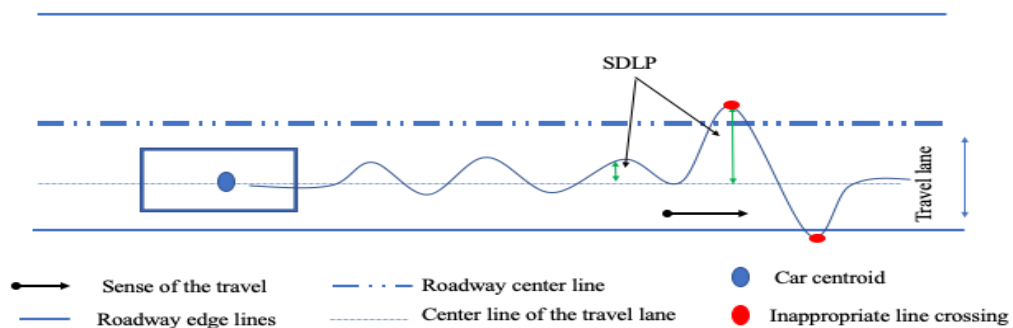


Figure 29. A schematic representation of the road highway: travel lane and roadway edge lines. Standard Deviation of the Lateral Position (SDLP).

II. 1. 3. STATISTICAL ANALYSIS

Multifactorial non-parametric analysis of variance for repeated measures was applied for variables (Noguchi *et al.* 2012) as the data showed disparities from both the normality assumption and the homoscedasticity and sphericity. The methods used were implemented in the R package nparLD (Noguchi *et al.* 2012). This non-parametric analysis technique is the most appropriate to the present data with repeated measures in factorial experiments and served for examining effects and possible interactions between the longitudinal factor (time) and the repeated factor for the following four nap conditions (bed, box, reclining chair, and the no-nap condition). This analysis was performed for analyzing the following variables: SDLP, NILC, CBT. The data related to the driving performance measure (SDLP and NILC) was sampled on 10-min intervals during a 104-min drive which made them 11-time blocks. CBT data may be biased by food and fluid intake (Roxane *et al.* 2018). Therefore, before the analysis the temperature values that are $< 36\text{ }^{\circ}\text{C}$ were replaced by the first value $\geq 36\text{ }^{\circ}\text{C}$ derived from a backward propagation. Then, raw data of CBT was normalized to start at 0. For the analysis, the data related to CBT during the nap was averaged on 150 seconds which made them 11-time blocks. The data of CBT during the driving task was sampled on 10-min intervals during a 104-min drive which made them 11-time blocks. All the above-mentioned parameters utilized repeated measures with 4 (nap conditions) \times 11 blocks (time on task). The subjective measures utilized 4 (nap conditions) \times 3 (time sessions: before the outgoing-trip, before return-trip, and at the end of the return-trip). The ELEP utilized 4 (nap conditions) \times 3 (time sessions). We fitted a full model for the "ld.f2" design for these data. A one-way repeated measure "ld.fl" was conducted to compare the following parameters: the nocturnal sleep variables for the nights before the different experimental visits, objective sleep variables during the nap, subjective sleep variables during the nap. If a significant effect was indicated by the ANOVA statistic, we proceeded to the second step with post-hoc testing using Wilcoxon tests. The p-values of the post hoc testing were adjusted by the FDR method to account for multiple comparisons. The level of statistical significance was set at ($p < 0.05$).

II. 1. 4. RESULTS

II. 1. 4. 1. MORNING MEASUREMENTS (BASELINE)

II. 1. 4. 1. 1. ACTIGRAPHY AND SLEEP DIARY

Mean and standard deviation values of sleep parameters for the nights prior to the experimental visits are presented in *Table 2*. No significant differences between conditions were found for the following sleep variables: Bed Time (df= 2.60; p>0.05), Fall Asleep Time (df= 2.67; p>0.05), Wake Up Time (df= 2.91; p>0.05), Total Time in Bed (df= 2.73; p>0.05), and Assumed Sleep Time (df= 2.80; p>0.05).

Table 2. Mean and SD values of nocturnal sleep parameters for the night preceding the four experimental visits.

Sleep variables (hour ± min)	Bed	Box	Reclining chair	No-nap
Bed Time	23:20 ± 37	23:20 ± 42	23:13 ± 35	23: 20 ± 41
Fall Asleep Time	23:36 ± 41	23: 34 ± 41	23: 27 ± 36	23:41 ± 47
Wake up Time	08:03 ± 38	07:59 ± 44	08:06 ± 45	07:58 ± 36
Total Time in Bed	07:46 ± 40	07: 32 ± 84	07: 52 ± 46	07: 36 ±51
Assumed Sleep Time	07:23 ± 24	07:22 ± 31	07: 21 ± 26	07: 20 ± 26

II. 1. 4. 1. 2. EXPLOSIVE LEG EXTENSOR POWER (ELEP)

The results showed non-significant differences for nap conditions (df= 2.47; p>0.05), for time on driving (df= 1; p>0.05), and for interactions (df= 2.24; p>0.05). Mean and standard deviation values for ELEP during TS 1 and TS 3 are presented in *Figure 30*, and summarized in *Annex B.1*.

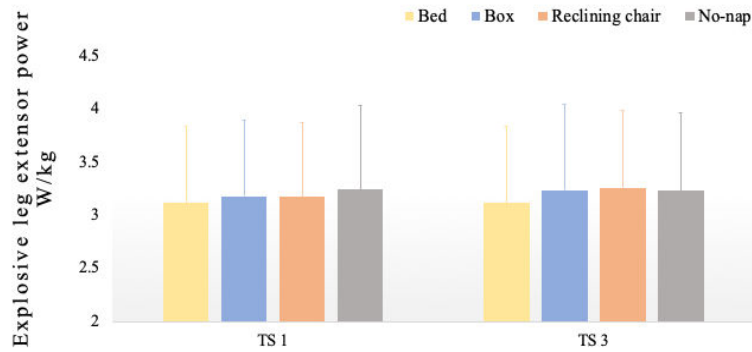


Figure 30. Mean ± SD values for Explosive Leg Extensor Power. TS 1: before the beginning of the morning driving task. TS 3: at the end of the morning driving task.

II. 1. 4. 1. 3. SUBJECTIVE MEASUREMENTS

Mean and standard deviation values for subjective measurements of sleepiness (KSS), anxiety, fatigue, and alertness (VAS) obtained during the morning session are provided in *Annex B. 2*.

II. 1. 4. 1. 3. 1. KAROLINSKA SLEEPINESS SCALE

The results showed non-significant differences for nap conditions ($df= 2.76$; $p>0.05$), significant differences for time on driving ($df=1.87$; $p<0.001$), and non-significant interactions ($df= 4.87$; $p>0.05$), (*Figure 31*). These results indicated that the subjective rating of sleepiness increased over the time of driving, with significantly higher values for TS 3 and TS 2 compared to TS 1 ($p<0.05$).

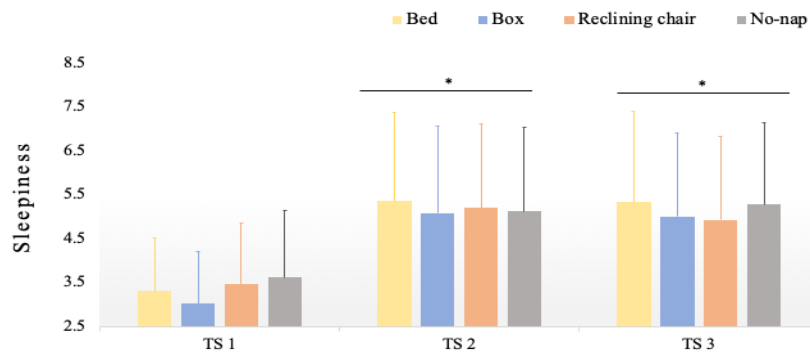


Figure 31. Mean ± SD for the subjective rating of sleepiness during driving. TS1: before the beginning of the outgoing-trip; TS2: before the beginning of the return-trip; TS 3: at the end of the return-trip. * Significant difference for TS1 compared to TS2 ($p<0.05$); * significant difference for TS1 compared to TS3 ($p<0.05$).

II. 1. 4. 1. 3. 2. ANXIETY

The results showed non-significant differences for nap conditions ($df= 2.69$; $p>0.05$), significant differences for time on driving ($df=1.79$; $p<0.001$), and non-significant interactions ($df= 3.96$; $p>0.05$), (Figure 32). These results indicated that the self-reported rate of anxiety increased over time on driving, with significantly higher scores for TS 3 compared to TS1 ($p<0.05$).

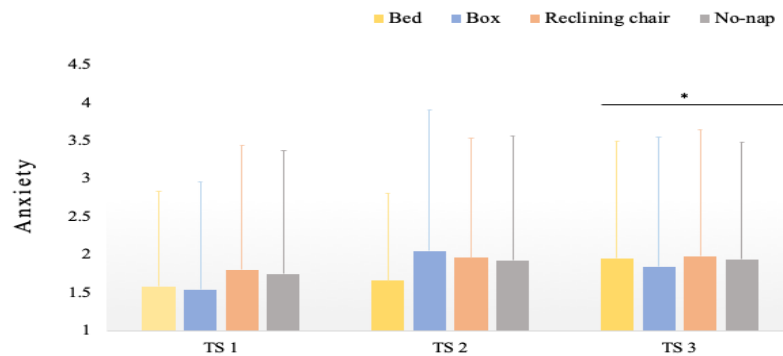


Figure 32. Mean \pm SD for the subjective rating of anxiety during driving. TS 1: before the beginning of the outgoing-trip; TS 2: before the beginning of the return-trip; TS 3: at the end of the return-trip. * significant difference for TS 1 compared to TS 3 ($p<0.05$).

II. 1. 4. 1. 3. 3. FATIGUE

The results indicated non-significant differences for nap conditions ($df=2.83$; $p>0.05$), significant differences for time on driving ($df= 1.43$; $p<0.001$), and non-significant interactions ($df= 4.58$; $p>0.05$), (Figure 33). These results indicated that the perceived level of fatigue increased over the course of driving, with higher scores for TS1 compared to TS 2 ($p<0.05$), and compared to TS 3 ($p<0.05$).

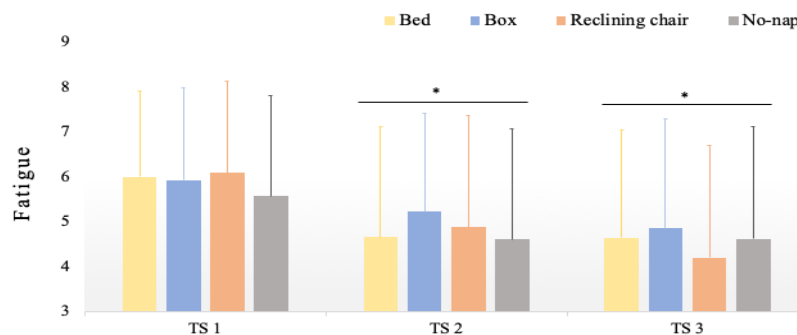


Figure 33. Mean \pm SD values for the subjective rating of fatigue during driving. TS1: before the beginning of the outgoing-trip; TS2: before the beginning of the return-trip TS3: at the end of the return-trip. * Significant difference for TS1 compared to TS2 ($p<0.05$); * significant difference for TS1 compared to TS 3 ($p<0.05$).

II. 1. 4. 1. 3. 4. ALERTNESS

The analysis showed non-significant differences for nap conditions ($df=2.67$; $p>0.05$), significant differences for time on driving ($df=1.78$; $p<0.001$) and non-significant interactions ($df= 4.79$; $p>0.05$), (Figure 34). These results indicated that self-reported feeling of alertness decreased over the course of driving, with higher scores for TS1 compared to TS2 ($p<0.05$), and TS 3 ($p<0.05$).

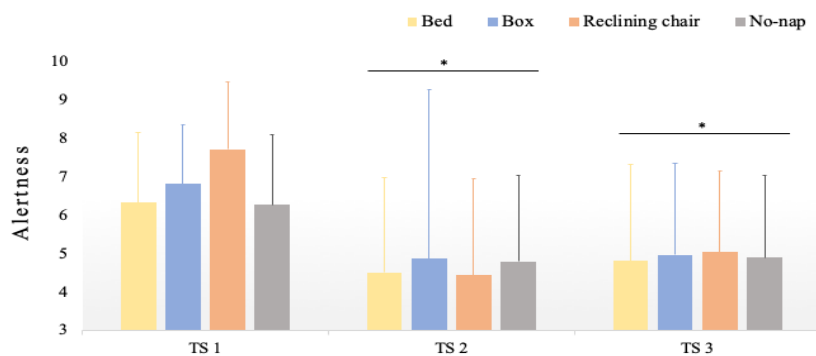


Figure 34. Mean \pm SD values for the subjective rating of alertness during driving. TS 1: before the beginning of the outgoing-trip; TS 2: before the beginning of the return-trip TS 3: at the end of the return-trip. * Significant difference for TS1 compared to TS 2 ($p<0.05$); * significant difference for TS1 compared to TS 3 ($p<0.05$).

II. 1. 4. 1. 4. DRIVING SIMULATOR

Mean and standard deviation values for SDLP and for NILC during the morning are displayed in Annex B.3.

II. 1. 4. 1. 4. 1. STANDARD DEVIATION OF THE LATERAL POSITION

The results showed non-significant differences for nap conditions ($df=2.585$; $p>0.05$), significant differences for time on driving ($df= 3.964$; $p<0.001$), and non-significant interactions ($df= 11.529$; $p>0.05$), (Figure 35). These results indicated that the SDLP increased over the time on driving.

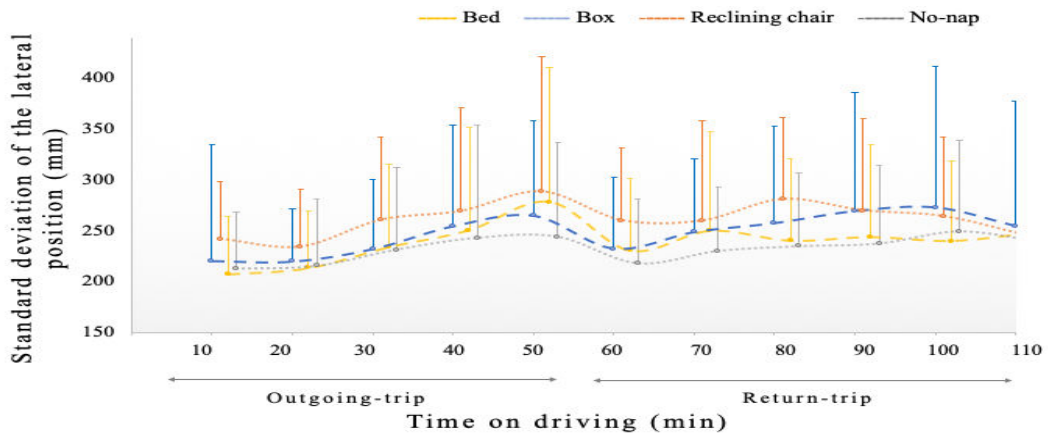


Figure 35. Mean \pm SD values for the Standard Deviation of the Lateral Position of the vehicle during driving.

II. 1. 4. 1. 4. 2. NUMBER OF INAPPROPRIATE LINE CROSSING

The results showed non-significant differences for nap conditions ($df=2.832$; $p>0.05$), significant differences for time on driving ($df= 6.648$; $p<0.001$), and non-significant interactions ($df= 13.625$; $p>0.05$), (Figure 36). These results indicated that NILC increased with the increasing time on driving.

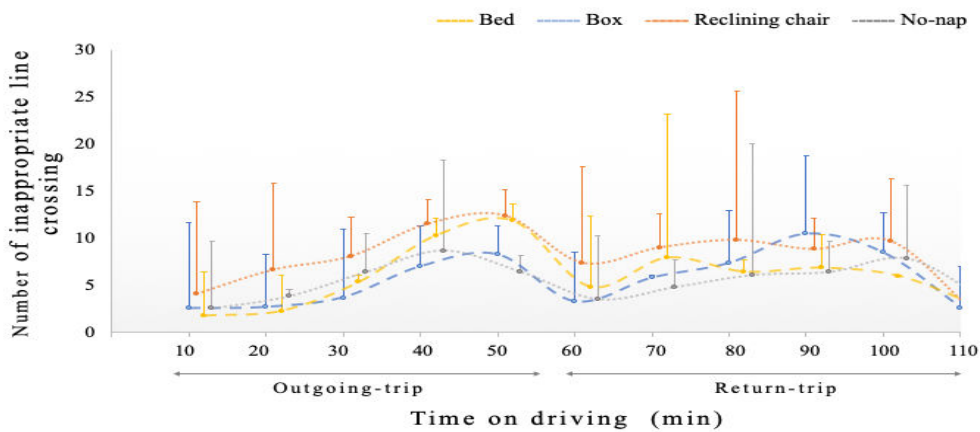


Figure 36. Mean \pm SD values for the Number of Inappropriate Line Crossings over time of driving.

II. 1. 4. 2. NAP SESSION

II. 1. 4. 2. 1. OBJECTIVE MEASUREMENTS OF SLEEP VARIABLES DURING THE NAP

Mean and standard deviation values for the sleep variables obtained during the nap are presented in *Table 3*. The results showed significant differences of TST for nap conditions ($p < 0.001$). The post-hoc analysis indicated that the duration of TST was longer in bed ($p < 0.001$), and in reclining chair ($p < 0.05$) conditions than in box condition. However, no significant differences were observed for the bed compared to the reclining chair ($p > 0.05$) conditions. Similar results were found for SE, with significant differences for nap conditions ($p < 0.001$). The post-hoc analysis indicated that SE in bed ($p < 0.001$), and in reclining chair ($p < 0.05$), were greater than in box condition. However, no significant differences were observed for SE in bed compared to reclining chair ($p > 0.05$) conditions. Moreover, no significant differences for nap conditions were observed for TTB, SL, and WASO ($p > 0.05$).

Regarding the sleep stages, the results indicated significant differences for conditions for the duration of sleep stage 2 ($p < 0.05$). The post-hoc analysis showed a strong tendency for a longer duration of sleep stage 2 in bed than in box conditions ($p = 0.056$). Besides, the results showed no significant differences for sleep stage 2 in reclining chair compared to bed and box conditions ($p > 0.05$). Furthermore, the results showed a tendency for conditions for the duration of sleep stage 3 ($p = 0.059$). Moreover, the results indicated no significant differences for conditions regarding sleep stage 1 ($p > 0.05$).

Table 3. Mean and SD values for objective measurements of sleep variables during the nap for the bed, box, and reclining chair conditions.

Variables	Nap conditions			P value	Post-hoc analysis		
	Bed	Box	Reclining chair		Bed vs Box	Bed vs Reclining chair	Box vs reclining chair
TTB (min)	24.95 ± 0.16	24.95 ± 0.16	24.92 ± 0.22	0.8561			
TST (min)	14.95 ± 3.59	11.75 ± 4.37	13.45 ± 4.14	0.0011	0.001	0.1495	0.0392
SL (min)	8.76 ± 3.64	9.82 ± 3.85	9.36 ± 3.30	0.3126			
SE%	59 %	47%	54 %	0.001	0.001	0.1586	0.0368
WASO	1.16 ± 1.06	1.37 ± 1.33	1.14 ± 1.04	0.9609			
Stage 1 (min)	4.56 ± 2.16	3.87 ± 2.14	4.30 ± 3.59	0.3055			
Stage 2 (min)	9.27 ± 3.33	7.33 ± 3.88	8.60 ± 3.55	0.036	0.0564	0.5884	0.1424
Stage 3 (min)	1.11 ± 1.49	0.54 ± 0.92	0.54 ± 0.89	0.0593			

TTB: Total Time in Bed; TST: Total Sleep Time; SL: Sleep Latency, WASO: Wake After Sleep Onset.

II. 1. 4. 2. 2. SUBJECTIVE MEASUREMENTS OF SLEEP VARIABLES DURING THE NAP

Mean and standard deviation values for subjective sleep variables are presented in *Table 4*. The results showed significant differences for conditions in the duration of TST ($p < 0.05$). The post hoc-analysis indicated that the perceived TST was longer in box than in reclining chair ($p < 0.01$). However, no significant differences for TST were observed in bed compared to box and reclining chair conditions ($p > 0.05$). Moreover, the results indicated significant differences for the self-reported satisfaction with the nap ($p < 0.001$). The post-hoc analysis indicated that the satisfaction with the nap was greater in bed and box conditions than in reclining chair condition ($p < 0.01$). However, no significant differences for nap conditions were observed for SL and for the perceived sleep depth ($p > 0.05$).

Table 4. Mean and SD values for subjective measurements of sleep variables during the nap for the bed, box, and reclining chair conditions.

Variables	Nap conditions			P value	Post-hoc analysis		
	Bed	Box	Chair		Bed vs box	Bed vs reclining chair	Box vs reclining chair
TST	10.63 ± 5.99	10.39 ± 7.64	8.13 ± 5.85	0.044	0.9711	0.087	0.008
SL	8.9 ± 5.1	8.9 ± 5.1	8.8 ± 4.6	0.903			
Sleep depth	2.67 ± 1.22	2.68 ± 1.15	2.34 ± 1.14	0.171			
Satisfaction with the nap	3.2 ± 0.8	3.12 ± 0.76	2.64 ± 0.8	0.001	0.452	0.007	0.007

TSL: Total Sleep Time; SL: Sleep Latency.

II. 1. 4. 2. 3. VARIATIONS OF CORE BODY TEMPERATURE DURING THE NAP

Mean and SD values for variations of CBT are presented in *Annex B.4*, and the results are schematized in *Figure 37*. The results showed non-significant differences for conditions ($df=2.585$; $p>0.05$), significant differences for time ($df= 2.258$; $p<0.001$), and significant interactions ($df= 7.20$; $p<0.001$). The post-hoc analysis indicated the following:

Compared to the no-nap condition, the results showed a strong tendency during the 7th block for higher differences of CBT for the bed and the box conditions compared to values of the no-nap condition ($p=0.052$). Moreover, during the 8th block, the results indicated a significantly higher differences of CBT for the bed and the box conditions compared to the no-nap, and these results lasted until the 11th block ($p<0.05$). However, no significant differences were observed for the reclining chair compared to no-nap.

Between nap conditions, the results indicated a significantly higher difference of CBT during the 7th and 8th blocks for the box compared to values of the reclining chair ($p<0.05$), with a tendency observed during the 9th block ($p=0.06$). Again, during the 10th and 11th blocks higher differences of CBT were observed for the box compared to the reclining chair condition ($p<0.05$). However, there were no significant differences for the bed compared to the box and the reclining chair conditions.

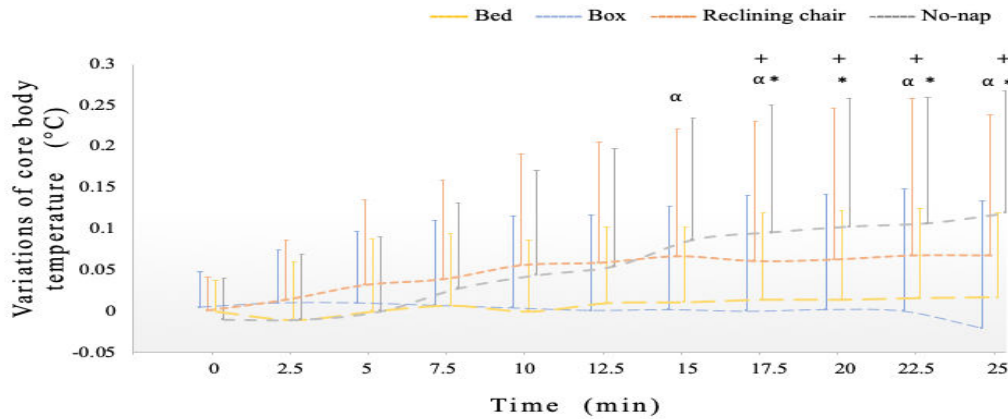


Figure 37. Mean \pm SD values for Variations of Core Body Temperature. * significant differences for the bed compared with the no-nap condition ($p < 0.05$). + significant differences for the box compared with the no-nap condition ($p < 0.05$). α significant differences for the reclining chair compared to the box ($p < 0.05$).

II. 1. 4. 3. POST NAP SESSION

II. 1. 4. 3. 1. EXPLOSIVE LEG EXTENSOR POWER (ELEP)

Mean and SD values for ELEP are presented in *Annex B.1*. The results showed non-significant differences for nap conditions during TS 6 ($df = 2.75$; $p > 0.05$).

II. 1. 4. 3. 2. VARIATIONS OF CORE BODY TEMPERATURE DURING THE DRIVING TASK

Mean and SD values for variation of CBT are presented in *Annex B.5* and the results are schematized in *Figure 38*. The results demonstrated non-significant differences for conditions ($df = 2.725$; $p > 0.05$), significant differences for time on driving ($df = 2.304$; $p < 0.001$), and significant interactions ($df = 8.518$; $p < 0.001$). The post-hoc analysis indicated the following:

Compared to the no-nap condition, the results indicated a significantly higher difference of CBT for the bed condition during the 5th block ($p < 0.05$), and a strong tendency observed during the 6th block ($p = 0.057$). Again, during the 9th block, the variations of CBT was higher in bed than in no-nap condition, with a tendency observed during the 10th ($p = 0.071$), and the 11th blocks ($p = 0.06$) respectively. Regarding the variations of CBT in box condition, the results indicated a

strong tendency during the 6th block (p=0.057), and a significant difference during 9th and the 11th blocks (p<0.05). Again, a tendency observed during the 10th block (p=0.071). Concerning the variations of CBT in the reclining chair, the results showed significantly higher differences of CBT during the 5th block (p<0.05), and a strong tendency during the 6th block (p=0.057). Again, during the 10th and the 11th blocks, the results showed a tendency for higher CBT in the reclining chair compared to the no-nap condition (p=0.07), (p=0.06) respectively.

Between nap conditions, the results showed non-significant differences for variations of CBT between nap conditions during the driving test.

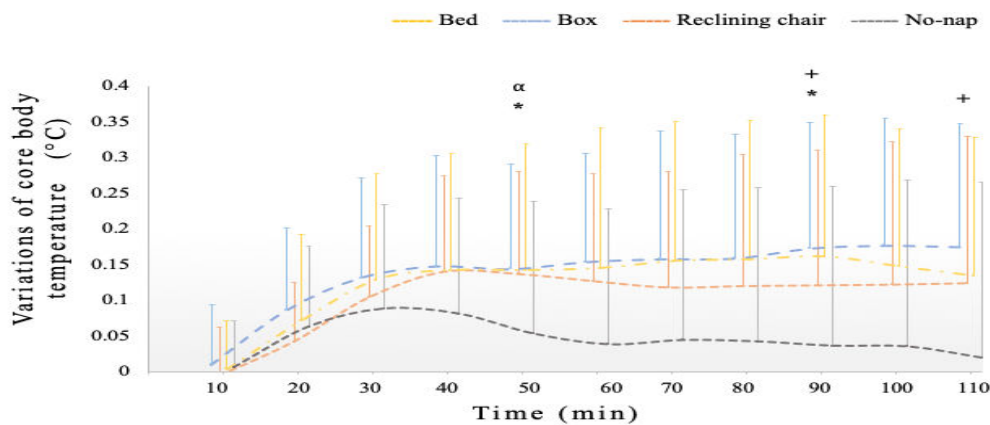


Figure 38. Mean \pm SD values for variations of core body temperature during the driving test. *significant differences compared to bed compared to the no-nap condition. + significant difference for the box compared to the no-nap condition (p<0.05). α a significant difference for the reclining chair compared to the no-nap condition (p<0.05).

II. 1. 4. 3. 3. SUBJECTIVE MEASUREMENTS

Mean and standard deviation values for subjective measurements of sleepiness (KSS), anxiety, fatigue and alertness (VAS) obtained during the post-nap session are provided in *Annex B. 6*.

II. 1. 4. 3. 3. 1. KAROLINSKA SLEEPINESS SCALE

The results showed significant differences for nap conditions (df=2.800; p<0.001), non-significant differences for time on driving (df=1.470; p>0.05), and significant interactions (df=4.994; p<0.001). (*Figure 39*). The post hoc analysis indicated the following:

Compared to the no-nap condition, the results demonstrated that during TS 4 non-significant differences for the subjective rating of sleepiness in all conditions. In addition, during TS 5 the subjective rating of sleepiness was higher in the no-nap condition than in bed ($p<0.001$), box ($p<0.01$) and reclining chair ($p<0.001$) conditions. The same results were found during TS 6 for the bed ($p<0.01$), box ($p<0.001$), and reclining chair ($p<0.01$) conditions.

Between nap conditions, the results indicated that during TS 4 the subjective rating of sleepiness was higher in the reclining chair than in the box condition ($p<0.05$). No other significant differences between nap all nap conditions were observed.

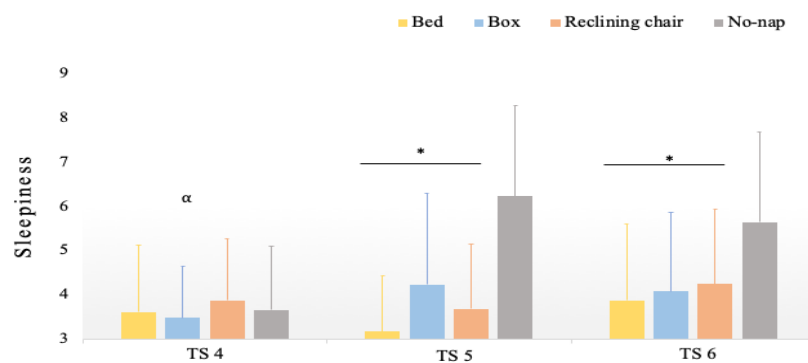


Figure 39. Mean \pm SD for the subjective rating of sleepiness during driving. TS 4: before the beginning of outgoing-trip; TS 5: before the beginning of the return-trip; TS 6: at the end of the return-trip. * significant difference for bed, box, reclining chair conditions compared to no-nap ($p<0.05$). * significant difference for bed, box, and reclining chair conditions compared to no-nap ($p<0.05$). α significant difference during TS 4 for the box compared to the reclining chair ($p<0.05$).

II. 1. 4. 3. 3. 2. ANXIETY

The results showed non-significant differences for nap conditions ($df=2.511$; $p>0.05$), non-significant differences for time on driving ($df=1.268$; $p>0.05$), or interactions (4.801 ; $p>0.05$), (Figure 40).

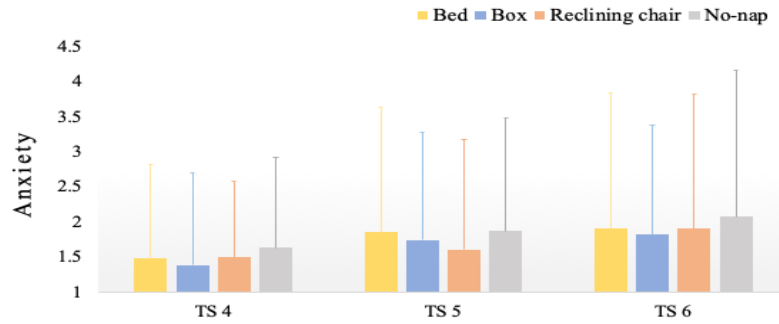


Figure 40. Mean \pm SD for the subjective rating of sleepiness. TS 4: before the beginning of the outgoing-trip. TS 5: before the beginning of the return-trip TS 6: at the end of the return-trip.

II. 1. 4. 3. 3. 3. *FATIGUE*

The results showed significant differences for nap conditions ($df=2.675$; $p<0.001$), non-significant differences for time on driving ($df= 4.575$; $p>0.05$), and significant interactions ($df= 4.791$ $p<0.001$), (Figure 41). The post hoc analysis indicated the following:

Compared to no-nap condition, the results demonstrated that during TS 4 no significant differences for the subjective rating of fatigue for conditions. Moreover, during TS 5 the results showed that the scores for the subjective rating of fatigue were lower in no-nap condition than in bed ($p<0.001$), box ($p<0.001$) and reclining chair ($p<0.001$) conditions. During TS 6, a strong tendency was observed for the bed, ($p=0.053$), and significant differences for the box ($p<0.01$), and the reclining chair ($p<0.05$) conditions.

Between nap conditions, no significant differences between all nap conditions were observed.

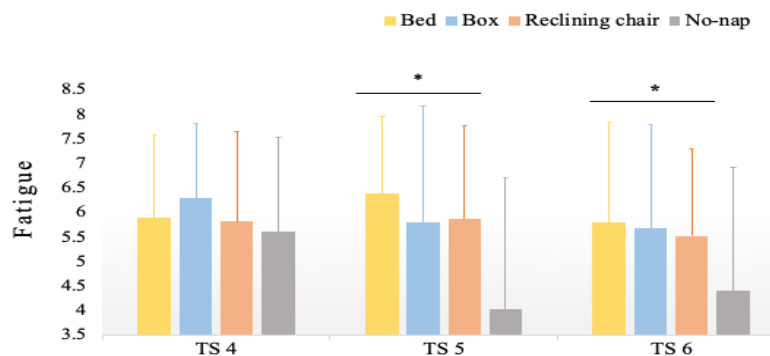


Figure 41. Mean \pm SD for the subjective rating of fatigue. TS 4: before the beginning of the outgoing-trip TS 5: before the beginning of the return-trip TS 6: at the end of the return-trip. * significant difference at TS 5 for bed, box, and reclining chair conditions compared to no-nap condition ($p < 0.05$). * significant difference at TS 6 for bed, box, and reclining chair conditions compared to no-nap condition ($p < 0.05$).

II. 1. 4. 3. 3. 4. ALERTNESS

The results showed significant differences for nap conditions ($df=2.9136$; $p < 0.001$), non-significant differences for time on driving ($df=1.770$; $p > 0.05$), and significant interactions ($df=5.042$; $p < 0.001$), (Figure 42). The post-hoc analysis indicated the following:

Compared to the no-nap condition, the results demonstrated that during TS 4 no significant differences for the subjective rating alertness were observed in all conditions. In addition, during TS 5 the results showed that the scores in the self-reported level of alertness were lower in no-nap condition than in bed, box, and reclining chair conditions ($p < 0.01$). Likewise, during the TS 6 the self-reported level of alertness was lower for the no-nap condition compared to bed, box, and reclining chair conditions ($p < 0.05$).

Between nap conditions, the results showed that there was a strong tendency for the subjective rating of alertness to be lower in the box compared to the bed ($p=0.059$). No other significant differences between all nap conditions were observed.

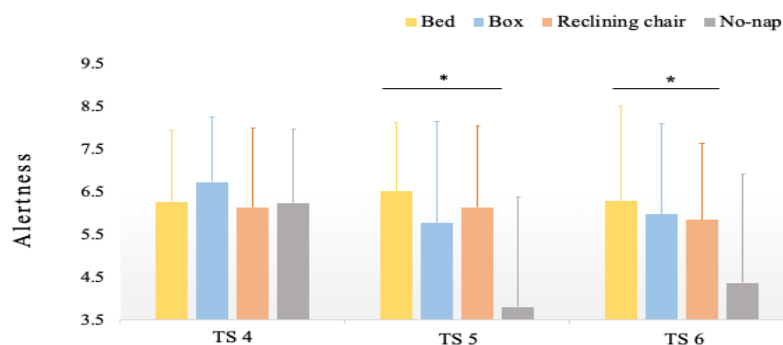


Figure 42. Mean \pm SD for the subjective rating of alertness. TS 4: before the beginning of the outgoing-trip task; TS 5: before the beginning of the return-trip TS 6: at the end of the return-trip. * significant difference at TS 5 for bed, box, and reclining chair conditions compared to the no-

nap ($p < 0.05$). * significant difference at TS 6 for bed, box, and reclining chair conditions compared to the no-nap ($p < 0.05$).

II. 1. 4. 3. 4. DRIVING SIMULATOR

II. 1. 4. 3. 4. 1. STANDARD DEVIATION OF THE LATERAL POSITION

Mean and standard deviation values of SDLP are displayed in *Annex B.7*. The results showed significant differences for nap conditions ($df = 2.723$; $p < 0.001$), significant differences for time on driving ($df = 4.047$; $p < 0.001$), and significant interactions ($df = 11.986$; $p < 0.001$), (*Figure.43*) The post-hoc analysis indicated the following:

Compared to the no-nap condition, during the 1st block of driving the results showed non-significant differences between all conditions. From the 2nd block of driving the results showed that SDLP was significantly lower in bed than in no-nap condition until the 11th block of driving ($p < 0.05$). Regarding the box condition, the results showed that SDLP was lower than the no-nap condition from the 2nd block until the 6th block of driving ($p < 0.05$), and during the 11th block of driving ($p < 0.05$). For the reclining chair condition, the results indicated a significantly lower SDLP from the 2nd block until the 5th block of driving ($p < 0.05$), and with a tendency observed during the 6th block ($p = 0.06$), and during the 11th block ($p = 0.06$) of driving.

Between nap conditions, compared to the bed, the results indicated a significantly higher SDLP values for the box for 6 blocks of driving ($p < 0.05$), and for the reclining chair for 7 blocks of driving ($p < 0.05$). In addition, no significant differences were observed between the box and the reclining chair conditions.

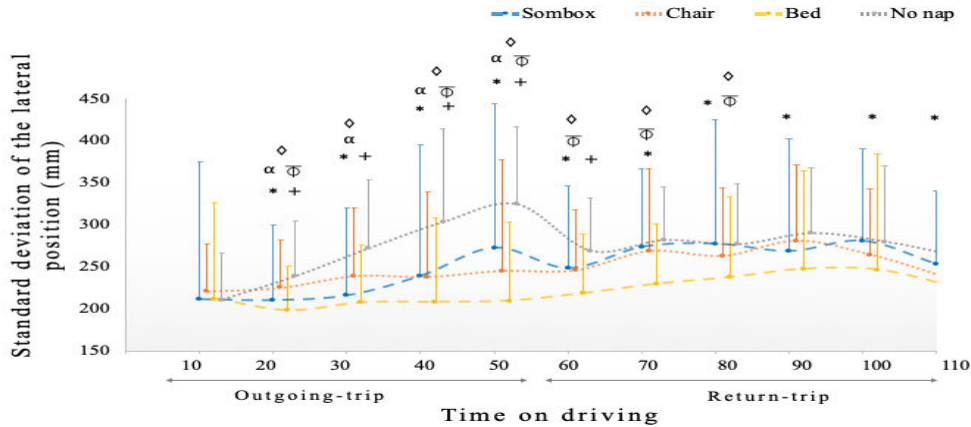


Figure 43. Mean \pm SD values of SDLP during driving. * significant difference for the bed compared to the no-nap condition ($p < 0.05$). + significant difference for the box compared to the no-nap condition ($p < 0.05$). α significant difference for the reclining chair compared to the no-nap condition ($p < 0.05$). \oplus significant difference for the bed compared to the box condition ($p < 0.05$). \diamond significant difference for the bed compared to the reclining chair condition ($p < 0.05$).

II. 1. 4. 3. 4. 2. NUMBER OF INAPPROPRIATE LINE CROSSING

Mean and standard deviation values of NILC are presented in *Annex B.8*. The results showed significant differences for nap conditions ($df = 2.856$; $p < 0.001$), significant differences for time on driving ($df = 5.175$; $p < 0.001$), and significant interactions ($df = 13.514$; $p > 0.001$). (*Figure.44*).

The post-hoc analysis indicated the following:

Compared to no-nap condition, during the 1st block of driving the results showed non-significant differences between all conditions. Furthermore, the results showed that NILC was significantly lower in bed than in no-nap condition from the 2nd block of driving until 6th block ($p < 0.05$), and tendency observed during the 7th block ($p = 0.06$). Again, a significantly lower NILC was observed during the 8th block of driving ($p < 0.05$). Concerning the box condition, the results showed a significantly lower NILC from the 3rd block until the 5th block of driving ($p < 0.05$). Similarly, in the reclining chair condition the results indicated a significantly lower NILC than the no-nap condition from the 3rd block until the 5th block of driving.

Between nap conditions, compared to the bed condition, the results demonstrated a tendency for higher NILC during the 7th block compared to the reclining chair ($p = 0.06$). Besides, no significant

differences between the bed and the box were observed ($p>0.05$). Compared to the box, the results showed a significantly higher NILC during the 3rd block of driving compared to the reclining chair.

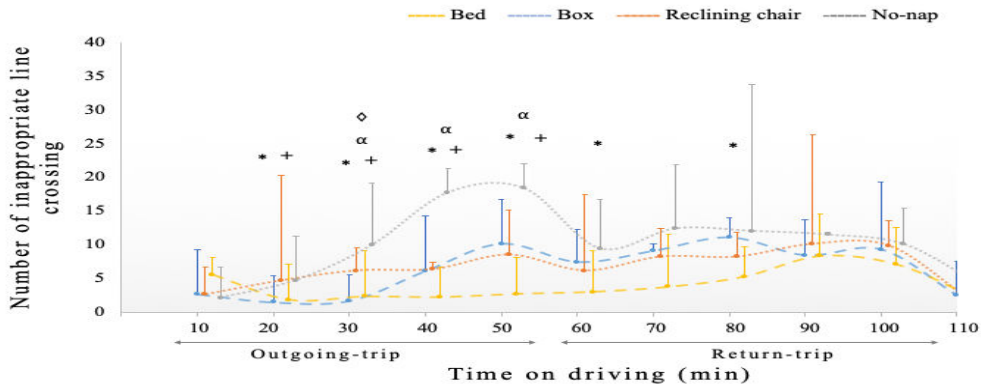


Figure 44. Mean and SD values for the NILC. * significant difference for the bed compared to the no-nap condition ($p<0.05$). + significant difference for the box compared to the no-nap condition ($p<0.05$). α significant difference for the reclining chair compared to the no-nap condition ($p<0.05$). \diamond significant difference for the box compared to the reclining chair condition ($p<0.05$).

I. 1. 1. 1. MORNING VS POST-NAP SESSION

II. 1. 4. 3. 5. EXPLOSIVE LEG EXTENSOR POWER

Mean and standard deviation values for ELEP during TS 1, TS 3 and TS 6 are presented in *Figure 45*, and summarized in *Annex B.1*. The results showed non-significant differences for nap conditions ($df= 2.510$; $p>0.05$), significant differences for time of the day ($df= 1.350$; $p<0.05$), and non-significant interactions ($df= 4.513$; $p>0.05$). The results indicated that ELEP increased over the time of the day with significantly higher values for TS6 compared to TS 1 ($p<0.001$), and for TS 6 compared to TS 3 ($p<0.01$).

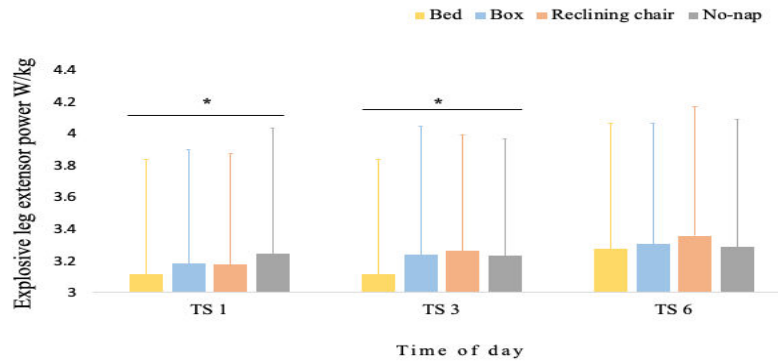


Figure 45. Mean \pm SD for the subjective rating of alertness. TS 1: before the beginning of the morning driving task; TS 3: before the beginning of the morning return-trip TS 6: at the end of the post-nap driving task. * Significant difference for TS6 compared to TS3 ($p < 0.05$); * significant difference for TS 6 compared to TS1 ($p < 0.05$).

II. 1. 4. 3. 6. STANDARD DEVIATION OF THE LATERAL POSITION

Mean and SD values of SDLP during the morning and the post-nap driving sessions are presented in *Figure 46*.

The results for the no-nap condition showed significant differences for time of day ($df = 1$; $p < 0.001$), significant differences for time of driving ($df = 4.936$; $p < 0.001$), and significant interactions ($df = 4.776$; $p < 0.05$). The post-hoc analysis indicated that the SDLP was significantly lower in the morning for 10 blocks of driving compared to the afternoon driving session ($p < 0.05$).

The results for the bed condition indicated non-significant differences for time of day ($df = 1$; $p > 0.05$), significant differences for time of driving ($df = 4.253$; $p < 0.001$), and significant interactions ($df = 3.804$; $p > 0.05$). The post-hoc analysis showed that SDLP was significantly higher in the morning session during the 4th ($p < 0.05$), and the 5th ($p < 0.001$) blocks of driving compared to the post-nap session.

The results for the box condition showed non-significant differences for time of day ($df = 1$; $p > 0.05$), significant differences for time of driving ($df = 4.351$; $p < 0.001$), and significant interactions ($df = 5.564$; $p > 0.05$). The post-hoc analysis showed no significant differences for SDLP between the morning and the post-nap sessions.

The results for the reclining chair condition demonstrated non-significant differences for time of day ($df= 1$; $p>0.05$), significant differences for time driving ($df= 6.44$; $p<0.001$), and non-significant interactions ($df= 5.564$; $p>0.05$). These results indicated that SDLP increased with the time on driving.

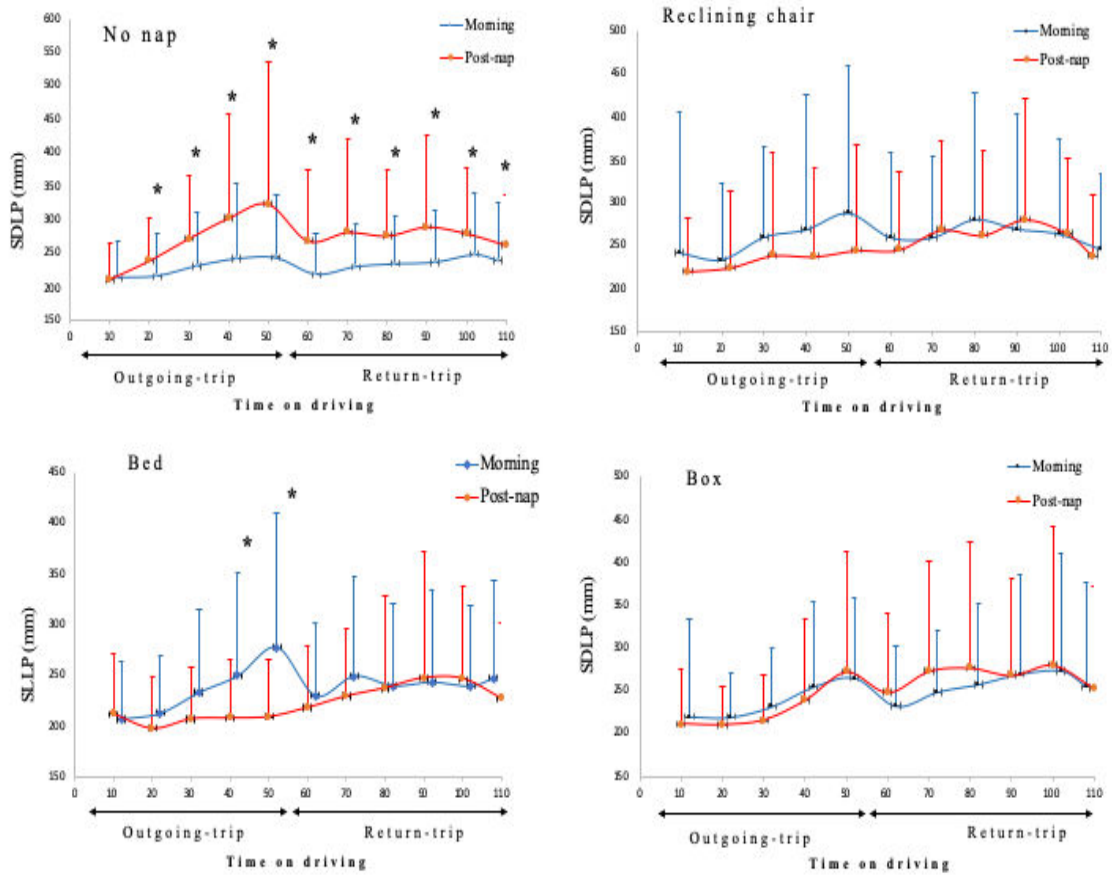


Figure 46. Mean and SD values of SDLP during the morning and the post-nap driving sessions.
* significant difference for the morning compared to the post-nap session ($p<0.05$).

II. 1. 4. 3. 7. NUMBER OF INAPPROPRIATE LINE CROSSING

Mean and SD values of NILC during the morning and the post-nap driving sessions are presented in *Figure 47*.

The results for no-nap condition showed significant differences for time of day ($df= 1$; $p>0.001$), significant differences for time of driving ($df= 6.02$; $p<0.001$), and non-significant interactions ($df= 6.3708$; $p>0.05$). These results indicated that during the morning driving session the NILC was lower compared to the afternoon driving session. Besides, the NILC increased over the time of driving.

The results for the bed condition indicated non-significant differences for time of day ($df= 1$; $p=0.053$), significant differences for time of driving ($df= 4.253$; $p<0.001$), and non-significant interactions ($df= 3.804$; $p>0.05$). These results demonstrated that the NILC increased over the time of driving.

The results for the box condition showed non-significant differences for time of day ($df= 1$; $p>0.05$), significant differences for time of driving ($df= 6.12$; $p<0.001$), and non-significant interactions ($df= 5.564$; $p>0.05$). These results indicated that the NILC increased over the time of driving.

The results for the reclining chair condition showed non-significant differences for time of day ($df= 1$; $p>0.05$), significant differences for time of driving ($df= 6.14$; $p<0.001$), and significant interactions ($df= 6.211$; $p>0.05$). These results indicated that the NILC increased over the time of driving. However, the post-hoc analysis showed no significant differences for NILC between the morning and the post-nap sessions.

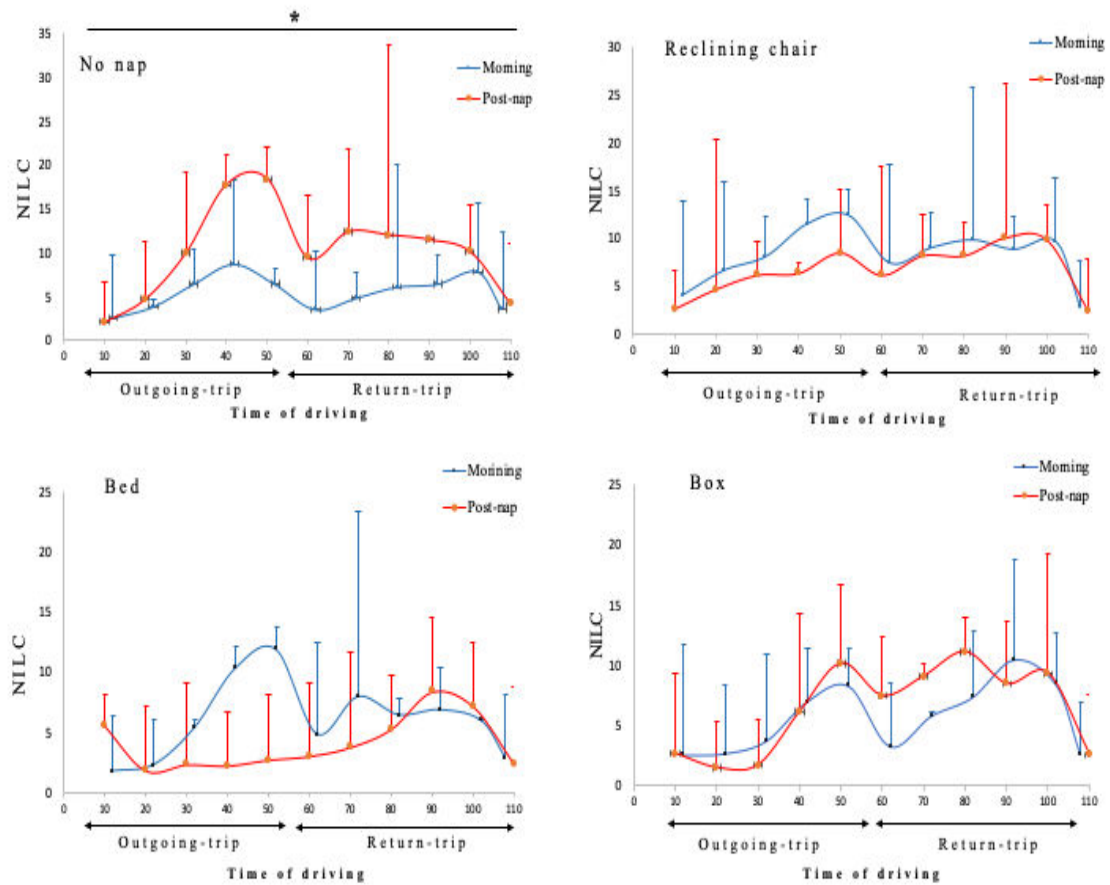


Figure 47. Mean and SD values of NILC during the morning and the post-nap driving sessions.
 * significant difference for the morning compared to the post-nap session ($p < 0.05$).

II. 1. 5. DISCUSSION

The focus of this study was to investigate the impacts of a 25-min midday nap on subjective ratings of anxiety, arousal, and fatigue, sustained attention, and muscular power in the afternoon after a normal night of sleep in healthy habitual nappers. The main objective was to examine the structure of the nap taken in different sleep environments and to investigate its impacts on subsequent cognitive and physical performances. The second objective was to compare cognitive and physical outcomes in the afternoon with the outcomes in the morning.

The results of the study showed that the structure of sleep during the nap varied according to the environment. For instance, the structure of the nap in the bed and reclining chair conditions were different from the box condition. However, the structure of the nap in bed was not different from the reclining chair. The duration of Total Sleep Time (TST) was higher, and Sleep Efficiency (SE) was greater in the bed and in the reclining chair than in the box condition. In addition, the duration of stage 2 sleep tended to be higher in the bed compared to the box. Furthermore, the results showed that regardless of the environment of sleep, the 25-min midday nap resulted in negligible effects of sleep inertia, alleviated daytime arousal, prevented mental fatigue, and improved sustained attention (i.e. reduced SDLP and NILC) during the simulated driving task. Besides, the results demonstrated that after taking a nap in the box or in the reclining chair, performance stability and the number of errors observed during the afternoon driving task were not different from the morning driving session. Finally, the results indicated that performance stability was greater in the afternoon after the nap than in the morning.

II. 1. 5. 1. MORNING SESSION

The analysis of the actigraphic recording and sleep diaries indicated non-significant differences in sleep variables for the nights before the experimental visits. These results indicated that the participants spent an equivalent amount of sleep during the nights preceding the different experimental visits. Besides, the results showed that the duration of total sleep time was more than 7-h and 30-min, and the assumed sleep time averaged above 7-h in all experimental

conditions. Together, these results revealed that the protocol of the study was fully respected. In this study, we implemented the morning session in order to control morning activities for all the participants in the different experimental visits. Accordingly, the data showed that the outcomes of the morning session were the same throughout the four experimental visits.

During the morning driving session, the results showed that subjective measures of anxiety, arousal, and fatigue were affected by the duration of the driving task. This means that the self-reported levels of anxiety, drowsiness, and fatigue increased with the increasing driving time. Besides, we also found that the self-reported level of arousal decreased with the increasing time of driving. Regarding the driving performance, the results showed that the prolonged duration of the task led increasing SDLP and NILC over the driving time. These findings entailed that performance stability decreased and the number of errors increased by the increasing time of driving.

These findings support the view that performing a continuous cognitive task over time is effortful and demanding (Helton and Warm 2008). In particular, these results are in line with the findings of several studies on driving performance indicating a gradual decrease in arousal and sustained attention caused by fatigue over time of driving (Otmani *et al.* 2005, Ryu *et al.* 2007, Rossi *et al.* 2011, Gastaldi *et al.* 2014, Morales *et al.* 2017, Wang *et al.* 2019). The over mental workload model was proposed to explain why it is difficult for one's mind to maintain a good performance level over time. The over mental workload model implies that the information-processing resources are limited. In this case, resources are viewed as "reservoirs" of mental energy devoted to performing a particular task, and the "replenishment of the resources" is the main cause behind the gradual decline in performance over time (Helton and Warm 2008). This view is further supported by several neuroimaging studies that employed measures of the cerebral blood flow as a "sensitive metabolic index of the utilization of information-processing resources" when performing a cognitive task (Hitchcock *et al.* 2003). Their results showed that the changes in the activation of the brain areas as revealed by the cerebral blood flow were accompanied by a parallel

decline in sustained attention performance over time (Heilman 1995, Mayleben 1999, Hitchcock *et al.* 2003).

In the realms of physical outcomes, no differences were observed between T1 (i.e. before the driving task) and T3 (i.e. after the driving task). Therefore, we conclude that mental fatigue induced by the driving task did not impair performance in the ELEP. The result is consistent with previous findings indicating that mental fatigue did not impact maximal force production and explosive power strength (Pageaux *et al.* 2013, Budini *et al.* 2014, Martin *et al.* 2015).

II. 1. 5. 2. NAP SESSION

The results demonstrated that the structure of sleep varied according to environmental conditions. In bed condition, the duration of TST was higher, SE was greater, and sleep stage 2 tended to be higher than in box condition. Besides, TST and SE were greater in reclining chair compared to the box. Even though participants in the box were lying in a bed, it is possible that the added instruments namely music and lights stood as the main factors behind reducing the duration of TST and decreasing SE during the nap. This interpretation is consistent with previous studies showing that music and light are great distractors that impaired both the quantity and the quality of sleep (Kawada 2011, Maas 2012, Halperin 2014). In addition, taking a short midday nap in a reclining chair did not affect the duration and the structure of sleep compared to the nap taken in a bed. These results are in line with the study of Zhao *et al.* (2010) that showed no differences in all sleep variables during a short midday nap taken either in a sitting position or lying down in a bed.

This study contributes to the scientific development and technological validation of the SOMBOX product which is a new sleep product consisting of small rooms designed for napping. The product involved a logic for sleep guidance during the nap, which is mainly based on changes in both the intensity of different light colors (i.e. white and red) and the volume of the music. Overall, the logic is best exemplified by a split of the sleep process into three distinct phases during the nap: Falling Asleep phase, Sleep phase, and Waking phase.

- (1) The Falling Asleep phase lasted about 7-min and involved an interplay between music and colors that gradually decreased over the falling asleep phase. For the colors, the process started with an intense white light that gradually faded and then switched into the red color that progressively went darker until becoming black.
- (2) The main Sleep phase lasted about 10-min during which there was a total absence of music and lights
- (3) Finally, the Waking phase lasted about 7-min and involved the opposite process of the falling Asleep phase. That is, the music and light progressively increased to reach the starting point.

Concerning the structure of sleep during the nap in box condition, SL averaged 7-min and was not different from the other nap conditions. Therefore, the 7-min technology introduced during the Falling Asleep phase corresponded to the duration of sleep latency during the nap. In addition, the total sleep duration averaged 12-min, which was 3-min less than the total sleep duration in the bed. Accordingly, the box technology was effective in reducing TST, however, it was not sufficient to reach the 10-min phase programmed in advance. Finally, given that the nap lasted for 24-min, the planned 7-min Waking phase was not achieved.

Even though the structure of sleep did not match the intended plan, the technology set in the box met one of the most required objectives which is the satisfaction of its users. Importantly, the self-reported satisfaction with the nap was similar to the bed and it was better than the reclining chair. Moreover, the perceived duration of TST in the box averaged 10-min which corresponded to the programmed Sleep phase. Besides, the perceived TST in the box was not different from the bed, but it was rated longer than the reclining chair. For note, the self-reported duration of sleep in all nap conditions did not match the EEG objective measures of sleep.

The variations of Core Body Temperature (CBT) during the 24-h are the result of a fine balance between heat production and heat loss derived from and regulated by the circadian biological clock (Coiffard *et al.* 2021). The data obtained in this work showed that the variations of CBT in the no-nap condition were different from the variations of CBT in the nap conditions (see, *Figure 37*). Indeed, in the no-nap condition, the results entailed a greater level of thermogenesis (i.e. heat

production) compared to variations of CBT observed during the nap. The decreasing level of thermogenesis (i.e. deceleration from baseline CBT) observed in the nap condition is in line with the common observation asserting that CBT fell after sleep onset (Weitzman and Czeisler 1978, Berger and Phillips 1995). However, in the no-nap condition, the results showed an increasing level of thermogenesis that followed the normal diurnal rise of heat production during the day (Refinetti and Menaker 1992, Barrett *et al.* 1993). Furthermore, the results assumed that sleep-related fall in CBT during the nap depended on the environment of sleep. The fall in CBT was observed in both the bed and the box, but not in the reclining chair. These results are congruent with previous studies indicating that postural changes could affect or mask the drop of CBT (Moul *et al.* 2002, Wakamura *et al.* 2009). What is of crucial importance is the correspondence observed between changes in CBT and the subjective ratings of the total sleep duration perceived in both the bed and box conditions. Remarkably, the significant fall in CBT in bed and box conditions lasted for 10-min. This duration exactly corresponded to the 10-min self-reported total sleep duration perceived in both the bed and box conditions, but not in the reclining chair condition. This correspondence suggests that the participants rated their total sleep duration based on changes in CBT.

II. 1. 5. 3. POST-NAP SESSION

The results showed distinct thermoregulatory changes in CBT during the afternoon after the nap compared to the no-nap condition (see, *Figure 38*). Whatever the condition, after the nap, CBT exhibited an increasing tendency in the thermogenesis process (i.e. increasing from baseline CBT) which was significantly different from the variations of CBT in the no-nap condition (*Figure 38*). The data suggest that a short midday nap served as an energy conservation that lowered heat production during the nap leading to an increase in heat production in the afternoon (Zammit *et al.* 1992). Moreover, the results indicated that the rise in the thermogenesis process that took place after the nap started approximately one hour after waking.

During the post-nap session, the results indicated that before the beginning of the driving task, the self-reported feelings of anxiety, arousal and fatigue, were the same in all conditions. During the course of driving, in the nap conditions, the subjective levels of anxiety, arousal and fatigue were not affected by the duration of the test, nor by the post-lunch-dip. On the contrary, in the no-nap condition, the self-reported ratings of drowsiness and fatigue were high and the self-reported levels of arousal were low. Interestingly, the present results are in line with previous reports indicating a strong relationship between the subjective measurements of arousal and fatigue and the outcomes (Oken *et al.* 2006, Goel 2011). First, it was found that during the first 10-min of driving, the SDLP and NILC were not different in all conditions, confirming therefore that the initial mental state of the participants was the same whether they napped or not. Second, during the course of driving, participants who napped gained better stability levels and made fewer errors compared to the no-nap condition. Together, These results support previous studies indicating that the nap counteracted the effects of the post-lunch dip and improved cognitive performances, after a normal night sleep (Hayashi and Hori 1998, Hayashi, Watanabe, *et al.* 1999, Hayashi and Abe 2008, Zhao *et al.* 2010).

Specifically, before the beginning of the outgoing-trip, and during the first 10-min of driving, no differences in the subjective ratings of arousal, fatigue, and performance were found between the nap and the control conditions. Given that the testing sessions was completed immediately after waking from the nap, it is possible that the effects of sleep inertia delayed or masked the benefits of the nap. Sleep inertia refers to a period of reduction or impairment in arousal and cognitive functioning following the waking from sleep (Hilditch *et al.* 2017). These results are consistent with previous studies showing no change in arousal and performance for the 15-min that followed the waking from a short midday nap (Kaida *et al.* 2003, Hayashi *et al.* 2004). In this context, it was posited that taking a nap in a sitting position can be a useful strategy to prevent the occurrence of sleep inertia after waking from the nap (Wakamura *et al.* 2009). However, the current findings oppose this observation since no differences were observed between the bed and the reclining chair. Instead, we recommend napping in the bed because of the greater self-reported satisfaction

resulting from it, rather than in the reclining chair. Here it is important to mention that the effects of sleep inertia were mild since we found no impairment or reduction in arousal and performances immediately upon waking from the short nap.

The impacts of napping on the dynamic changes in aspects of performances (i.e. SDLP and NILC) over time were modulated by the environment of sleep during the nap. ***Compared to the no-nap condition***, SDLP values were lower for 100-min in bed, and for 60-min in box and reclining chair conditions. Besides, the NILC was lower for 70-min in bed, 40-min in the box, and 30-min in the reclining chair conditions. Together, these results indicated that the 25-min midday nap resulted in negligible effects of sleep inertia, alleviated daytime arousal, prevented mental fatigue, and improved sustained attention (i.e. reduced SDLP and NILC) during the simulated driving task. These findings are in line with predictions found in the two-process model supporting that napping reduces the homeostatic sleep pressure and enhances arousal levels during the day (Borbély 1982, Borbély *et al.* 2016, Achermann *et al.* 2017).

The improvements resulting from these naps throughout the post-nap testing sessions suggest that the structure of sleep is an important contributor to these benefits. Accordingly, it seems that a 25-min nap containing 12- to 15-min of sleep, which includes a 4-min of stage 1 sleep, 7- to 9-min of stage 2 sleep, and no more than 1-min of stage 3 sleep, is beneficial for improving arousal and performance in the afternoon after a normal night of sleep. Together, these findings are in agreement with several studies showing that a short midday nap of a total sleep duration ranging from 7- to 20-min, mainly composed of stage 2 sleep and of a small amount of stage 3 sleep resulted in negligible effects of sleep inertia upon waking, and enhanced arousal and performance in the afternoon after a normal night of sleep (Takahashi *et al.* 1998, Hayashi, Ito, *et al.* 1999, Hayashi, Watanabe, *et al.* 1999).

The comparison between nap conditions showed that taking a nap in bed maintained higher levels of performance stability (i.e. SDLP) for 60-min compared to the box, and for 70-min compared to the reclining chair. In addition, the number of errors (i.e. NILC) during the course of driving was almost the same in all nap conditions. These findings are in accordance with

previous reports indicating that taking a nap in a reclining chair reduced sleepiness and enhanced arousal and performance compared to the no-nap condition (Horne and Reyner 1996a, Hayashi and Abe 2008, Zhao *et al.* 2010). However, it opposes the assumption that the benefits of a nap taken in a reclining chair are equivalent to a nap taken in a bed (Horne and Reyner 1996a). Instead, we support the finding that the benefits of napping are enhanced when the sleep posture is closer to the horizontal (Hayashi and Abe 2008).

The improvement in performance observed after the nap in the bed condition was different from both the box and reclining chair conditions. Therefore, one might suggest that there is a link between the performance and the structure of sleep according to the environment of the nap. In this context, Brooks and Lack (2006) showed that the benefits of a short midday nap after a normal night of sleep depended on the duration of TST and not on a particular sleep stage. On the other hand, other studies linked the beneficial effects of napping with the duration of sleep stage 2 (Hayashi *et al.* 2005, Hayashi and Abe 2008). However, in the present study, the duration of TST and the duration of stage 2 sleep were not different in the bed compared to the reclining chair condition. Therefore, we suggest that neither the duration of TST nor the amount of stage 2 sleep were behind the long-lasting benefits observed after taking a nap in the bed. Then, it is possible that the differences observed between the bed and the other nap conditions are related to the amount of EEG delta wave activity present during the nap. Delta wave activity represents the intensity parameter of the sleep process, and it is the physiological marker of the sleep homeostatic process (Borbély 1982, Borbély *et al.* 2016, Gompf and Anaclet 2019). In this context, although quantitative EEG analysis was not performed in this study, this interpretation was further supported by a number of studies asserting that the background delta wave activity is the main contributor to the improvement in performance after a short midday nap (Kaida *et al.* 2003, Brooks and Lack 2006, Zhao *et al.* 2010, Petit *et al.* 2018). In particular, the study of Zhao *et al.* (2010) examined the effect of a short midday nap according to the environment of sleep on arousal using the event-related potentials paradigm. Their results showed no differences in all sleep variables, however, the P300 amplitude was greater when the nap was taken in bed

compared to a nap taken in a sitting position. The authors attributed the potential impacts of a nap in a bed to the amount of delta wave activity during the stage 2 sleep and not to a particular sleep structure.

Concerning the physical outcomes, the results showed that the performance in the ELEP was neither affected by the mental fatigue induced by the driving task, nor by the post-lunch dip, nor by the nap. This result supports previous reports indicating that a short midday nap did not improve anaerobic performances (Petit *et al.* 2014, Tanabe *et al.* 2020), muscular power, and jump velocity (Tanabe *et al.* 2020) after a normal night of sleep.

II. 1. 5. 4. MORNING VS POST-NAP SESSION

The Comparison between the morning and the no-nap driving session showed a significant decrease in the level of performance stability (i.e. SDLP) and a remarkable increase in the number of incidents and errors (i.e. NILC) compared to the morning driving session. These results are in line with previous findings indicating a post-lunch dip in performance under normal night sleep conditions (Minors and Waterhouse 1981, Monk 2005, Bes *et al.* 2009).

The Comparison between the morning and the post-nap sessions revealed that taking a nap in bed helped to maintain higher levels of performance stability (i.e. SDLP) during the outgoing trip for 20-min compared to the morning driving session. Besides, the number of errors (i.e. NILC) observed during the afternoon session was not different from the morning driving session. These results delineated that after taking a nap in bed, the level of performance stability in the afternoon surpassed the morning level. Moreover, we found that after taking a nap in the box or in reclining posture, the driving performance (i.e. reduced SDLP and NILC) in the afternoon attained the morning levels.

Concerning the physical performance, the results demonstrated a diurnal variation for ELEP, with the best performance observed late in the afternoon (i.e. TS 6) compared to morning measures (i.e. TS 1 and TS 3). This finding is in line with a number of studies indicating a time of day variation between the morning and the afternoon in maximal-intensity and short duration task

performances after a normal night of sleep (Bernard *et al.* 1997, Souissi *et al.* 2002, 2007, Nicolas *et al.* 2007).

II. 1. 5. 5. CONCLUSION

Regardless of the environment of sleep during the nap, a 25-min midday nap resulted in negligible effects of sleep inertia upon waking, enhanced daytime arousal, prevented mental fatigue, and improved sustained attention (i.e. reduced SDLP and NILC) during the simulated driving task. A short midday nap in the box or in a reclining chair improved arousal and sustained attention, but both of them did not reach the efficiency level of a nap taken in a bed. We assume that taking a nap in a reclining posture or in the presence of music and lights reduced the potential impacts of the nap on arousal and sustained attention. Concerning the SOMBOX product, the results demonstrated that the technology set in the box met with the satisfaction of the participants. Besides, the improvement in arousal and performance were evident after the nap in the box compared to the no-nap condition. However, we might reconsider few readjustments in order to attain the same benefits acquired from the nap in bed. Therefore, we recommend few changes in the timing of the programmed set of the three sleep phases. More specifically, we suggest the extension of the period of the Sleep phase from 10 minutes to 15 minutes. Concerning the differences between the morning and the afternoon performances, the results showed that after taking a nap in bed, the level of performance stability in the afternoon surpassed the morning level. We also found that after taking a nap in the box or in reclining posture, the driving performance (i.e. SDLP and NILC) in the afternoon attained the morning levels.

II. 2. STUDY II: EFFECTS OF NAPPING ON COGNITIVE AND PHYSICAL OUTCOMES OF KARATE ATHLETES

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II. 2. 1. INTRODUCTION

Considerable attention has been paid to napping as an effective countermeasure for arousal decline and for improving cognitive performances. In literature, it has been demonstrated that naps which last less than 30-min undermine the deleterious impacts of sleep deprivation that affect arousal and performance. It has also been reported that naps enhance arousal levels even when the quantity and the quality of the previous nocturnal sleep are adequate (Takahashi *et al.* 1998, Hayashi, Watanabe, *et al.* 1999). It would be of interest to mention that the differences in results observed in previous researches depend on various factors that determine the benefits acquired when taking short naps. Indeed, factors like the quality of prior nocturnal sleep, sleep architecture, and the temporal placements of the nap during the day may determine the extent of benefits gained from short naps (Milner and Cote 2009). Furthermore, a number of interindividual differences embodied in the experiences with napping (Evans *et al.* 1977, Dinges 1992), such as individuals' abilities to produce slow waves (Faraut *et al.* 2017), the occurrence of sleep inertia (Tassi and Muzet 2000), and other factors like tests' characteristics might affect the benefits of napping (Evans *et al.* 1977). Compared to long naps (more than 30 min), short naps have negligible effects of sleep inertia upon waking (Tassi and Muzet 2000). Although a substantial number of studies on the benefits of napping were conducted outside of the sports sphere (Waterhouse *et al.* 2007), a short nap has commonly been recommended to be incorporated in an athlete's daily life, as it represents a practical strategy in enhancing recovery especially after the multiple training sessions performed by sportspeople (Venter 2014). Previous articles have focused on how circadian rhythms and prior sleep affect athletic performances. The circadian rhythms modulate physical abilities and several aspects of cognitive performance according to the time of day, with optimal

performances generally observed at the end of the afternoon (Drust *et al.* 2005). Prior sleep influences the capacity to perform. It has been reported that sleep extension improves performances (Mah *et al.* 2011), contrary to sleep deprivation which negatively affects the evening performance by decreasing the normal rise of athletic outcomes at that time (Souissi *et al.* 2003). Before an athletic event, nocturnal sleep has frequently been proved to be disturbed (Leeder *et al.* 2012). Besides, athletes in individual sports are more affected than athletes in team sports (Erlacher *et al.* 2011).

Given the overall detriments caused by sleep loss, napping is used as a behavioral countermeasure that limits the decrement in performances (Waterhouse *et al.* 2007, Halson 2008). Unfortunately, few studies have dealt with the effects of napping on athletes' cognitive and physical performances during daily training or before athletic events (Waterhouse *et al.* 2007). To the best of our knowledge, only two studies have examined the effects of naps on athletic performances. The first study, Waterhouse *et al.* (2007), has indicated that a postlaunch nap improves alertness and aspects of mental and physical performances after a partial sleep loss. The second study, Petit *et al.* (2014), has shown that napping has no effects on performances, in particular when assessing the effects of a 20-min postprandial nap on a short-term physical exercise in normal conditions.

It is relevant to better emphasize that athletic performances depend on the complexity and efficiency of the physical, psychomotor, and cognitive components required to perform a specific sporting task (Mori *et al.* 2002). Karate is a competitive sport with a high level of environmental uncertainty (Parlebas 1999). Furthermore, karate athletes have to perform simultaneously a mechanical work task with great physical exertion, and a high level of perceptual abilities (Mori *et al.* 2002). The need to offend and defend against the opponents' actions, requires (i) a great level of physical fitness, especially strength, aerobic fitness, muscle power, and speed (Chaabene *et al.* 2012), and (ii) developed cognitive skills, especially rapid anticipation, decision making, and fast reactions (Mori *et al.* 2002, Di Corrado *et al.* 2014). Additionally, the decrement in muscle performances and mental fatigue emerge as a major problem when bouts of intensive efforts are imposed on competitors especially that, during an official competition, competitors

have to perform several matches on the same day (Tabben *et al.* 2014). Several studies have provided insight into the negative effects of a fatiguing bout of an exercise simulating the costs of athletic efforts on physical outcomes (Oliver *et al.* 2008, Twist and Highton 2013), and on cognitive performances as well (Brisswalter *et al.* 2002). These effects are more noticeable under sleep deprivation (Fullagar *et al.* 2015). In this regard, it is worth pointing that the Karate-Specific Test (KST) is a recent and valid field test for assessing karate-specific endurance-fitness level (Tabben *et al.* 2014). The use of KST was relevant in this study because it (i) replicated a real karate combat pattern, and (ii) granted the opportunity to investigate the effects of sleep deprivation and/or nap on endurance performance that have never been assessed with this kind of test.

Therefore, the purpose of this study was to examine the effects of a 30-min midday nap on the subjective ratings of arousal and fatigue, and different aspects of cognitive and physical performances after a normal night of sleep. In a perspective of performance optimization, we also aimed to identify which aspect of the cognitive and/or physical performances is/are affected by sleep loss and could be recovered following a 30-min nap. Likewise, we aimed to investigate the effects of a nap on fatigue induced by a high-intensity intermittent specific karate test.

II. 2. 2. METHODS

II. 2. 2. 1. PARTICIPANTS

Thirteen international-level male karate athletes (age, 23 ± 2 yr; height, 175 ± 2.45 cm; mass, 68 ± 7.5 ; expertise, 15 ± 3) were volunteered to participate in the study. They were fully informed about the study information. Before participating, a written informed consent was obtained from every participant. The selection criteria for the participants were the following: subjects kept standard times for sleeping habits (bedtime, from 10:30 PM to 7:00 AM ± 1 h). All of them were habitual nappers. They were nonsmokers and nonalcoholic or caffeine consumers. They have been trained for nine sessions of about 2 h. Since circadian typology might affect the study outcomes, the selection of the players' chronotypes was based on the Horne and Osberg self-

assessment questionnaires (Horne and Östberg 1976). According to their answers to the questions related to their timing of sleep and their daily activities, subjects who presented an extreme morning or extreme evening type were eliminated. Instead, players who were “neither type” were involved in this study. The protocol of this study complied with Helsinki’s declaration for human experimentation and was approved by the University Ethics Committee.

II. 2. 2. 2. PROCEDURES

The experimental design is described in *Figure 48*. Two weeks before the beginning of the experimental period, the participants were familiarized with the equipment and the experimental procedures to minimize the learning effects during the course of the study. During habituation sessions, subjects took a short nap in the laboratory. Thereafter, in experimental sessions, athletes were randomly assigned to experience both nap and no-nap conditions, after either a full night sleep (RN) (>7 h) or a partial sleep deprivation (PSD) (sleep 11:00 PM to 3:00 AM). On the day before the experimental session, subjects came to the laboratory in the evening and had the same standardized dinner at 8:00 PM, and later, they went to bed at 10:30 PM. The nocturnal sleep and naps were monitored by actigraphic recording and sleep diaries. Besides, they were strictly supervised by two experimenters during experimental nights.

To keep the participants awake during the partial-sleep deprivation condition, they were allowed to watch television, read books, listen to music and use computers. The four protocol conditions were carried out at least one week apart. This period allowed them to have a sufficient recovery from one night of sleep loss. The nap condition included a 30-min nap period from 1:00 PM to 1:30 PM in bed after lunch. In the no-nap condition, participants were free to choose their activities. A 30-min period separated the nap or the rest condition from the assessment sessions. The post-nap testing took place in the National Center of the karate team of Tunisia. The post-nap testing session started at 2:00 PM, first by recording the Visual Analog Scales to quantify subjective alertness and fatigue. Then, it consisted of the following tests, respectively, before and after the KST:

- Cognitive performance tasks: Simple Reaction Time (SRT), Mental Rotation Test (MRT), Lower Reaction Test (LRT).
- Physical assessment session: Squat Jump, (SJ), Countermovement Jump (CMJ), KST.

Before the beginning of the physical testing session, subjects completed a standardized warm-up of 10-min, as recommended by Tabben *et al.* (2014), and it consisted of self-selected-intensity jogging, vertical jumping, and dynamic stretching (hip extensors, hamstrings, hip flexors, and quadriceps femoris), and later followed by a 5-min passive rest. The recovery time between every physical test was about 5-min, and 2-min between every trial in the same test.

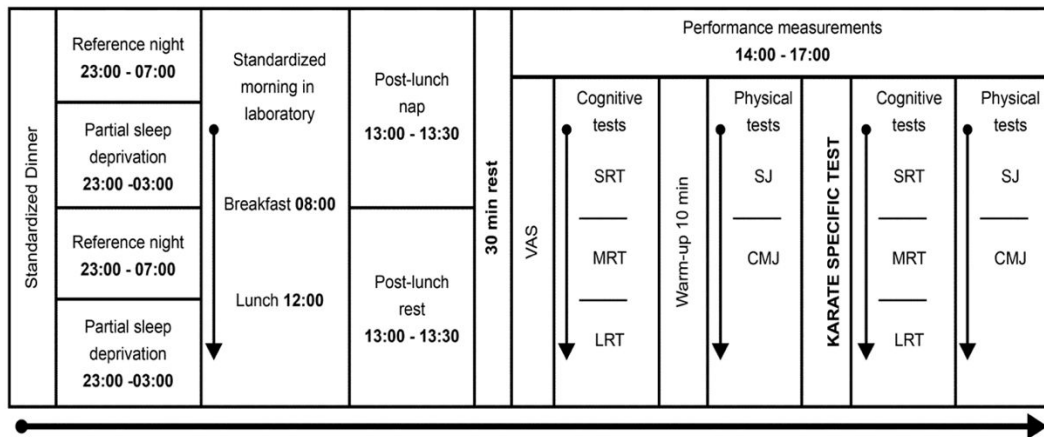


Figure 48. Design of the experimental protocol. Subjects experienced nap and no-nap conditions (4th column) on four different occasions, following a reference night or partial sleep deprivation (2nd column).

Different precautions were taken before the testing session. Instructions about sleep and diet were given to the subjects. During the period of investigation, they were prohibited from consuming food, beverages, or any known stimuli (e.g., caffeine) or depressants (e.g., alcohol) that would possibly enhance or compromise alertness. Throughout the experimental period, participants were requested to maintain their habitual physical activities and to avoid strenuous activities during the 24-h before the testing sessions. It was easy to control compliance with these directions because the participants were students in the same institution with the same daily schedules. The protocol of this study was made to be close enough to athletes' typical real-life routines.

II. 2. 2. 3. MEASUREMENTS

II. 2. 2. 3. 1. ACTIGRAPHY AND SLEEP DIARIES.

For objective sleep measurements, we used the MotionWatch 8® actigraphy system (MW8; camntech). To ensure that subject's sleep pattern throughout the course of the study was typical (i.e., not unusually restricted or extended), the actigraphic recording was edited with the information listed in the subjective sleep diaries. The MW8 data was downloaded and analyzed using MotionWare version 1.0.25 (camntech). A high-level sensitivity level was used for the estimation of sleep-wake patterns in 60-s epochs. To make sure that the protocol of the study was fully respected, the following sleep parameters of the night before the experimental session were analyzed. The parameters were: bedtime, fell asleep time, woke up time, total time in bed, and assumed sleep (the total elapsed time is between the “fell Asleep” and “woke up” times).

II. 2. 2. 3. 2. SUBJECTIVE ALERTNESS AND FATIGUE.

Subjective alertness and fatigue were evaluated using the Visual Analog Scale (Monk 1987). The VAS consisted of 100-mm long horizontal line with two endpoints to express extreme feeling. The endpoints were designated as “very sleepy” to “in a good physical form”, and “very sleepy” to “very alert”.

II. 2. 2. 3. 3. COGNITIVE TASKS

II. 2. 2. 3. 3. 1. SIMPLE REACTION TEST

When performing the reaction test, subjects were asked to respond as quickly as possible to a visual stimulus presented systematically at the center of the computer screen. Participants were asked to press a button with the index finger when a visual stimulus (Blue Square) appeared. The Simple Reaction Test was conducted using software Reaction, INRP free software (version 4.05).

II. 2. 2. 3. 3. 2. MENTAL ROTATION TEST

Participants were asked to compare two of the four stimuli samples presented on the screen and to state if they are identical, except the rotation, or are different from the reference figure

presented on the left of the screen. The stimuli used in this test are based on Shepard and Metzler stimuli (Shepard and Metzler 1971). The test required mental maintaining and manipulation of the presented figures with accuracy and speed. There were 20 items in the set, and 3-min were given for each subset of 10 items separated by a 2-min break. We used the same procedure as Peters *et al.* (1995) for scoring, giving one point for each item only if both answers were correct. This test was also conducted using software Reaction, INRP (version 4.05).

II. 2. 2. 3. 3. 3. LOWER BODY REACTION.

The simple acoustic-reaction time of the lower limb was measured using an optical jump system (Optojump Next, Microgate, Italy). The trial started inside the testing area. When receiving the acoustic sound, the subject must jump as quickly as possible. The sound was randomly generated by the measuring system and every stimulus lasted 1-s. Then, the Optojump system recorded the delay in time between the beginning of stimulus and the flight time (Time when the athletes left the testing area by jumping).

II. 2. 2. 3. 4. PHYSICAL TASKS

II. 2. 2. 3. 4. 1. SQUAT JUMP AND COUNTER-MOVEMENT JUMP

The CMJ included a leg flexion from the upright standing position with the hands on the hips and immediately followed by a quick descended position to 90° knee flexion, and instantly performed an explosive concentric action for maximal height with the hands-on the hips. The SJ consisted of a maximal jump held from a flexed knee position (approximately 90°) with the hands on the hips and without performing any countermovement before the beginning of the jump. These jump tests were monitored with an optical jump system (Optojump Next, Microgate, Italy). The apparatus comprises two bars placed ~1 meter apart, parallel to each other, and was interfaced with a microcomputer via a USB port. The optical system transmits infrared light 1–2 mm above the floor. When the light is interrupted by the feet, the units trigger a timer with a precision of 1ms which allows the measurement of flight time and contact time. For both tests after the signal, the subjects started whenever they felt ready to jump but not more than 4s for the SJ test. The

participants performed three trials in every test with a recovery time of 2 minutes between trials, and finally, the best one was recorded.

II. 2. 2. 3. 4. 2. KARATE-SPECIFIC TEST

The test protocol consisted of sequential sets composed of two attacks toward a body opponent bag. The first attack included a two-punch combination, lead straight punch followed by a rear straight punch (i.e., *kisamigyaku-zuki*), and the second attack used a rear roundhouse kick (i.e., *mawashigeri-chudan*). The test was packed with two auditory signals; the first was at the beginning of the bout of the exercise, and the second sound indicated the rest time. The time to complete the exercise remained the same (i.e., 3-s). However, the recovery time between bouts progressively decreased every 3-min. Every punch and kick had to be executed with the maximum power possible. The test stopped and the time to exhaustion (TE) was determined when the participants failed to complete the set of movements in the 3-s interval twice, or when there was a clear decrease in force or in performed techniques. They performed the KST wearing protections that are specifically designed for karate. The test was carried out on a tatami (i.e., competition karate floor). Karate athletes must use their favorite guards and were not allowed to change their guard during the test. Distance between the body opponent bag and the front foot was established and fixed before the beginning as 1.5 m.

II. 2. 3. STATISTICAL ANALYSIS

Statistical tests were processed using Statistica 7.1 (Statsoft, France). Data were reported as mean \pm SD. Paired t-tests were used for sleep variables between the control and the nap conditions after RN, and the control and the nap conditions after PSD. The data concerning the effects of napping on the performance was conducted using a two-way ANOVA analysis [2 (nap conditions) * 2 (sleep conditions)] with repeated measures. Data concerning the effect of napping on fatigue induced by KST was conducted using a two-way ANOVA analysis [2 (nap conditions) * 2 (sleep conditions)] expressed by calculating the difference between the performances after and before

KST. When the ANOVA indicated significant main effects, differences between the means were tested by Turkey's post-hoc tests. The level of statistical significance was set at ($P < 0.05$).

II. 2. 4. RESULTS

II. 2. 4. 1. PRIOR NOCTURNAL SLEEP

The actigraphic data indicated that equivalent amounts of the following sleep parameters (e.g., Bed Time, Fall Asleep Time, Wake Up Time, Total Time in Bed, Assumed Sleep Time) obtained during the nights preceding the testing under both the nap and no-nap conditions following a reference night and partial sleep deprivation night (*Table 5*).

Table 5. Sleep parameters of the night preceding the testing, after the nap and the no-nap conditions, and after a reference night and a partial sleep deprivation night (Mean \pm SD).

	No nap		Nap	
	RN	PDS	RN	PSD
Bed time	22 :49 \pm 00 :27	22 :50 \pm 00 :23	22 :56 \pm 00 :23	22 :55 \pm 00 :30
Fall asleep time	23 :13 \pm 00 :30	23 :19 \pm 00 :28	23 :20 \pm 00 :26	23 :24 \pm 00 :32
Wake up time	07 :05 \pm 00 :45	03 :03 \pm 00 :06	07 :24 \pm 00 :46	02 :55 \pm 00 :12
Total Time in bed	08 :20 \pm 00 :46	04 :13 \pm 00 :22	08 :27 \pm 00 :42	04 :09 \pm 00 :21
Assumed sleep time	07 :52 \pm 00 :48	03 :44 \pm 00 :27	08 :02 \pm 00 :48	03 :39 \pm 00 :27

II. 2. 4. 2. SUBJECTIVE ALERTNESS AND FATIGUE

Subjective alertness. The results showed a significant main effect for nap $F_{(1-12)} = 5.14$, $p < 0.05$; $\eta^2 = 0.30$), indicating that subjective alertness increased after the nap comparing to the no-nap condition. Moreover, there was a significant main effect for sleep $F_{(1-12)} = 66.50$, $p < 0.001$; $\eta^2 = 0.84$), indicating that sleep loss decreased the alertness level comparing to the reference night. However, there was no significant main effect for nap–sleep interaction ($p > 0.05$) (*Table 6*).

Subjective fatigue. The results showed that there was a significant main effect sleep $F_{(1-12)} = 85.69$, $p < 0.001$; $\eta^2 = 0.87$), indicating that subjective fatigue increased after the partial-sleep deprivation condition comparing to the reference night. However, there was no significant main effect for nap ($p > 0.05$), and for nap–sleep interaction ($p > 0.05$), (*Table 6*).

Table 6. Subjective alertness and fatigue following nap and no-nap conditions, after a reference night and a partial sleep deprivation (Mean \pm SD).

	No nap		Nap	
	RN	PSD	RN	PSD
Alertness	5,6 \pm 2,2	3,0 \pm 1,2***	7,1 \pm 1,3*	3,6 \pm 1,2***
Fatigue	4.4 \pm 0,8	7.4 \pm 1,2***	4.1 \pm 1,2	6.5 \pm 1,5***

Note: RN: reference night, PSD: partial sleep deprivation; * $p < 0.05$ significant difference in comparison with the no nap condition; *** $p < 0.01$ significant difference from RN.

II. 2. 4. 3. COGNITIVE PERFORMANCE

II. 2. 4. 3. 1. THE EFFECTS OF NAPPING ON PERFORMANCES.

II. 2. 4. 3. 1. 1. SIMPLE REACTION TIME

There was a significant main effect of nap $F_{(1-12)} = 5.34$, $p < 0.05$; $\eta^2 = 0.30$), indicating the improvement in SRT performance following the nap compared with the no-nap condition. However, there was no significant main effect for Sleep ($p > 0.05$), and for nap \times sleep interaction ($p > 0.05$) (*Table 7*).

II. 2. 4. 3. 1. 2. MENTAL ROTATION TEST

There was a significant main effect of nap $F_{(1-12)} = 5.03$, $p < 0.05$; $\eta^2 = 0.29$), indicating that the score in this test was better after the nap compared with the no-nap condition. Moreover, the results showed a significant main effect for Sleep $F_{(1-12)} = 5.28$, $p < 0.05$; $\eta^2 = 0.30$), stating that the performance decreased after the partial sleep deprivation compared with the reference night. However, there was no significant main effect for Nap \times Sleep interaction ($p > 0.05$) (*Table 7*).

II. 2. 4. 3. 1. 3. LOWER REACTION TEST

There was a significant main effect Nap ($F_{(1-12)}=6.86$, $p<0.05$; $\eta^2=0.36$), with an increase being observed after the nap compared with the no-nap condition. Moreover, the results revealed a significant main effect for Sleep ($F_{(1-12)}=4.69$, $p<0.05$; $\eta^2=0.28$), showing that the performance decreased after the partial sleep deprivation compared with the reference night. However, there was no significant main effect for Nap \times Sleep interaction ($p>0.05$) (Table 7).

Table 7. Cognitive and physical parameters measured following nap and no-nap conditions, after a reference night and partial sleep deprivation (Mean \pm SD).

Parameters	No Nap		Nap	
	RN	PSD	RN	PSD
SRT (ms)	290,8 \pm 35,3	300,9 \pm 22,7	278,7 \pm 24,9*	285,7 \pm 21,5*
MRT	20,8 \pm 8,4	16,9 \pm 7,6•	21,0 \pm 8,0*	21,7 \pm 8,6••
LRT (ms)	437,4 \pm 4,0	457,3 \pm 8,1•	342,2 \pm 4,3*	421,8 \pm 5,0*•
SJ	39,6 \pm 4,4	38,0 \pm 4,2	39,0 \pm 5,2	39,0 \pm 4,9
CMJ	42,7 \pm 4,2	41,5 \pm 4,7•	42,3 \pm 5,2	41,7 \pm 4,6•

Note: RN: Reference Night, PSD: Partial Sleep Deprivation, SRT: Simple Reaction Time, MRT: Mental Rotation Test, LRT: Lower Body Reaction Test; SJ: Squat Jump, CMJ: Counter Movement Jump. * $p<0.05$; significant difference in comparison with the no nap condition; • $p<0.05$; significant difference from RN.

II. 2. 4. 3. 2. THE EFFECTS OF NAPPING ON FATIGUE INDUCED BY THE KARATE SPECIFIC TEST

II. 2. 4. 3. 2. 1. SIMPLE REACTION TIME

The results showed that there was no significant main effect for Nap ($p>0.05$), Sleep ($p>0.05$), and for Nap \times Sleep interaction ($p>0.05$) (Table 8).

II. 2. 4. 3. 2. 2. MENTAL ROTATION TEST

The results showed that there was no significant main effect for Nap ($p>0.05$), Sleep ($p>0.05$), and for Nap \times Sleep interaction ($p>0.05$) (Table 8).

II. 2. 4. 3. 2. 3. LOWER REACTION TEST

There was a significant main effect for Nap \times Sleep interaction ($F_{(1-12)} = 5.58$, $p < 0.05$; $\eta^2 = 0.31$). However, there was no significant main effect for Nap ($p > 0.05$), and for Sleep ($p > 0.05$). The post-hoc test revealed that the effect of nap on fatigue after the KST depended on sleep condition. In fact, in the partial sleep deprivation condition, performance was the same with and without napping ($p > 0.05$). However, following the reference night performance was better with napping than without napping ($p < 0.05$) (Table 8).

Table 8. Δ Performance for cognitive and physical parameters measured following nap and no-nap conditions, after a reference night and a partial sleep deprivation (Mean \pm SD).

	No Nap		Nap	
	RN	PSD	RN	PSD
SRT (ms)	9,4 \pm 22,7	22,8 \pm 71,8	20,7 \pm 46,5	5,3 \pm 32,4
MRT	0,5 \pm 0,7	1,8 \pm 1,6	0,9 \pm 1,7	3,2 \pm -0,1
LRT (ms)	-24,0 \pm 39	6,2 \pm 76,9	27,7 \pm 36,7 \times	-3,0 \pm 24,3
SJ	-2,1 \pm 3,8	-1,9 \pm 1,8	-0,8 \pm 2,3*	-0,8 \pm 1,6*
CMJ	-3,6 \pm 1,7	-3,8 \pm 1,1	-3,1 \pm 1,3*	-3,1 \pm 1,2*

Note: RN: reference night, PSD: partial sleep deprivation, SRT: Simple Reaction Time, MRT: Mental Rotation Test, LRT: Lower Body Reaction Test; SJ: Squat Jump, CMJ: Counter Movement Jump; Δ Performance is expressed by calculating the difference between the performances after and before the KST. $\times p < 0.05$; significant difference in comparison with the no nap condition after RN; * $p < 0.05$; significant difference in comparison with the no nap condition.

II. 2. 4. 4. PHYSICAL PERFORMANCE

II. 2. 4. 4. 1. TIME TO EXHAUSTION DURING THE KARATE SPECIFIC TEST

There was a significant main effect for Nap ($F_{(1-12)} = 10.88$, $p < 0.01$; $\eta^2 = 0.47$), Sleep ($F_{(1-12)} = 10.37$, $p < 0.01$; $\eta^2 = 0.46$), and for Nap \times Sleep interaction ($F_{(1-12)} = 8.98$, $p < 0.01$; $\eta^2 = 0.42$). The post-hoc test demonstrated that the nap improved the time to exhaustion following the partial

sleep deprivation night ($p < 0.001$). However, napping did not improve the performance after the reference night ($p > 0.05$). Regarding the effect of sleep deprivation, during the no-nap condition, time to exhaustion was affected by sleep loss compared with the control condition ($p < 0.01$). After napping, the effect of sleep deprivation disappeared compared with the reference night ($p > 0.05$) (Figure 49).

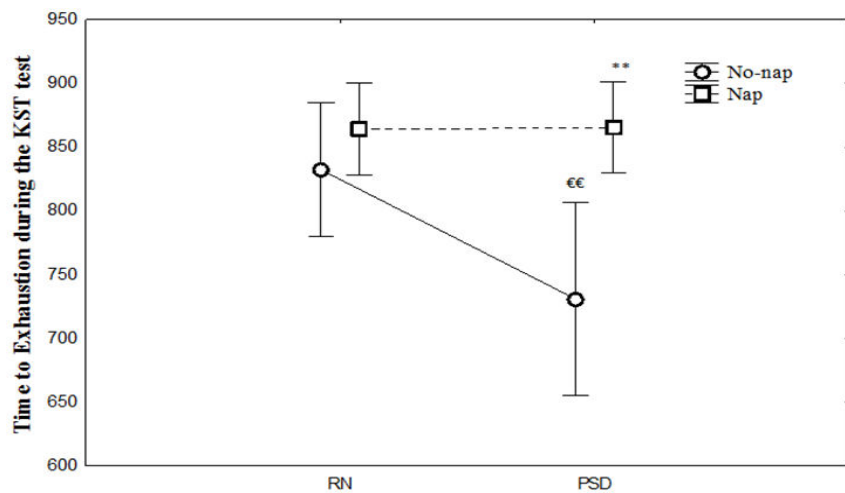


Figure 49. Mean \pm SD values of time to exhaustion during KST after the nap (\square) or the no-nap (\bullet), after RN (reference night), and PSD (partial sleep deprivation). **Significant differences from PSD without nap ($p < 0.01$); €€ Significant differences from RN without nap ($p < 0.01$)

II. 2. 4. 4. 2. THE EFFECTS OF NAPPING ON PERFORMANCES

II. 2. 4. 4. 2. 1. SQUAT JUMP

The results showed that there was no significant main effect for Nap ($p > 0.05$), Sleep ($p > 0.05$), and for Nap \times Sleep interaction ($p > 0.05$) (Table 7).

II. 2. 4. 4. 2. 2. COUNTER MOVEMENT JUMP

There was a significant main effect Nap $F_{(1,12)} = 6.15$, $p < 0.05$; $\eta^2 = 0.33$, indicating the improvement in CMJ performance following the nap comparing with the no-nap condition. However, there was no significant main effect for Sleep ($p > 0.05$), and for Nap \times Sleep interaction ($p > 0.05$) (Table 7).

II. 2. 4. 4. 3. THE EFFECTS OF NAPPING ON FATIGUE INDUCED BY THE KST

II. 2. 4. 4. 3. 1. SQUAT JUMP

There was a significant main effect Nap $F_{(1-12)} = 8.43$, $p < 0.01$; $\eta^2 = 0.41$), indicating an improvement in SJ performance following the nap comparing with the no-nap condition. However, there was no significant main effect for Sleep ($p > 0.05$), and for Nap \times Sleep interaction ($p > 0.05$) (Table 8).

II. 2. 4. 4. 3. 2. COUNTER MOVEMENT JUMP

There was a significant main effect Nap $F_{(1-12)} = 6.15$, $p < 0.05$; $\eta^2 = 0.33$), indicating the improvement in CMJ performance following the nap comparing with the no-nap condition. However, there was no significant main effect for Sleep ($p > 0.05$), and for Nap \times Sleep interaction ($p > 0.05$) (Table 8).

II. 2. 5. DISCUSSION

The focus of this study was to investigate the effects of a 30-midday nap on cognitive and physical performances in athletes after a normal night of nocturnal sleep. The first objective was to investigate the effects of napping on cognitive performances using reaction time tests with distinct complexity levels. The second aim was to examine the effects of napping on speed and directional ability in highly-trained athletes. The results showed that the nap improved the performance in the SRT and the DMST. However, it negatively affected the performance in the VST. Moreover, the results indicated that the nap improved the speed and directional ability of highly-trained athletes.

The analysis of actigraphic recording and sleep diaries for the nights before the experimental visits indicated that the total amount of nocturnal sleep averaged 8-h per night. According to the National Sleep Foundation, 8 hours of sleep per night is considered to be the appropriate sleep duration recommended for adults to ensure optimal neurobehavioral functioning during the day (Hirshkowitz *et al.* 2015). Second, based on the subjective survey of sleep during the nap, the results indicated that the perceived length of sleep during the nap averaged about 14-min. This result indicated that participants were able to sleep during the nap.

The improvement in reaction times during the SRT and DMST is in line with the previous research indicating that a short midday nap enhanced the information processing speed when performing attentional tasks after a normal night of sleep (Abdessalem *et al.* 2019, Boukhris *et al.* 2019, Tanabe *et al.* 2020). Particularly, these results congruent with the study of Petit *et al.* (2018) that provided objective measures of sleep during the nap and assessed the neuro-electric activity of the brain when performing the auditory oddball task. In this context, it is worth noting that the event-related P300 amplitude reflected the amount of allocated attention, and the latency of P300 reflected the time spent on the classification of the stimulus. Their results indicated that a short midday nap mainly composed of sleep stage 2 and sleep stage 3 increased the P300 amplitude and decreased P300 latency. Together, these findings imply that the amount of allocated attention was higher and the information processing speed was greater after a short midday nap compared with the no-nap condition. Undoubtedly, high levels of attention and accuracy in the information processing speed are critical aspects for optimal cognitive functioning (Petit *et al.* 2018). Therefore, the gains observed after a short midday nap across different cognitive tasks further encourage its use by athletes.

To date, it is important to mention that this study is the first that reports a negative impact of a short midday nap on athletes' visual processing speed as evaluated by the VST. The results demonstrated that the mean reaction time increased and the error rate remained unchanged compared to the no-nap condition. This finding indicated that the participants spent more time in the evaluation process of the stimuli, without producing any improvement in their performances. Here it is important to mention that perceptual-cognitive operations involving visual scanning, rapid recognition, and decision making are critical elements for achieving success in all sports fields in general (Williams *et al.* 2011), and in sports depending on perceptual abilities in specific (Di Russo *et al.* 2003). These findings are alarming especially when considering the results of Suppiah *et al.* (2019), showing that napping did not improve shooting performance in high-level pistol and rifle shooters. Nevertheless, it is possible that the increased difficulty level, which was imposed by the nature of the stimuli (i.e, non-representational shapes) might be another potential

factor diminishing the effects of short midday nap cognitive performance. However, the absence of a control condition that evaluates the effects of napping on the same task performance with a lower level of difficulty (i.e representational shapes) is considered a limitation of the present work.

Regarding the effects of a short midday nap on physical performance, the present results confirm the previous findings indicating that that nap improved speed and directional ability in physically active participants (Abdessalem *et al.* 2019, Boukhris *et al.* 2019), and extends them to high-level athletes. Together, these results further reinforce the observation that not all the performance measures are equally affected by a nap (Morita *et al.* 2016).

In conclusion, a short midday nap improved cognitive performance in tasks involving attentional functions but produced an unfavorable effect on perceptual-cognitive capacities involving visual scanning skills. Furthermore, the findings of this study further attest to the benefits of a short midday nap on physical performance implying speed and directional abilities on highly-trained athletes. Further research is required to extent testing the potential short- and long-term effects of a short midday nap scheduled after a normal night of nocturnal sleep on different physical and cognitive performances.

II. 3. STUDY III: THE IMPACTS OF A MIDDAY NAP ON REACTION TIME MEASURES AND ON SPEED AND DIRECTIONAL ABILITY IN ATHLETES

To be published in 2021

II. 3. 1. INTRODUCTION

Given that daytime drowsiness and deficit on performances reach a peak in the early afternoon hours (Monk *et al.* 1996, Carrier and Monk 2000), a short nap scheduled at that time is considered as an effective strategy to counteract the drawbacks of post-lunch dip and to regain arousal and performances throughout the day (Hayashi, Ito, *et al.* 1999, Hayashi, Watanabe, *et al.* 1999, Petit *et al.* 2018, Abdessalem *et al.* 2019, Boukhris *et al.* 2019, Tanabe *et al.* 2020). The recurrence of these beneficial effects on arousal and performance is of particular concern for athletes in everyday training or before an important athletic event. More importantly, a short nap can easily be merged into an athlete's daily life routine (Petit *et al.* 2014, Simpson *et al.* 2017).

Nevertheless, it is worth pointing out that the benefits acquired when taking a nap depend on several factors like the timing of the nap, its duration, and prior nocturnal sleep (Milner and Cote 2009). For instance, research findings that considered the temporal placement of the nap during the day indicated that a nap taken at noon or in early afternoon hours coincides with the circadian dip in alertness during the day (Lavie 1986). The latter was proved to be an ideal time window for sleep (Lavie and Weler 1989, Folkard and Åkerstedt 1992). Indeed, during this period, sleep latency is shorter and performance improvement is greater compared to a nap scheduled in the morning or late in the afternoon (Lavie and Weler 1989, Dinges 1992, Petit *et al.* 2018). Regarding the length of the nap, a short midday nap of about 30-min was confirmed to be as effective as a long nap in improving arousal and cognitive performances following a normal night of nocturnal sleep (Takahashi *et al.* 1998), or restricted nocturnal sleep (Tietzel and Lack 2002).

The task performance measure is an important factor that comes into play when considering the effects of napping on performance. For instance, task characteristics (difficulty level, duration), (Ru *et al.* 2019, Morita *et al.* 2016), task sensitivity to the prior waking period (Deboer 2018), as well as, the level of expertise of a person (Ru *et al.* 2019) are proved to modulate the extent of benefits obtained from a nap. These observations have led researchers to systematically investigate the impacts of a short midday nap on different cognitive and physical measures.

Regarding cognitive performance, Petit *et al.* (2018) tested the effects of a short midday nap on a battery of six reaction-test measurements to investigate the following parameters: alertness, divided attention, sustained attention, visual scanning, flexibility, and distractibility. Their results showed that the nap improved the performance only for the divided attention tasks. More recently, Tanabe *et al.* (2020) investigated the effects of a short midday nap on the visual simple reaction test, choice reaction test, and modified flanker test. Their findings indicated that the nap improved the simple and choice reaction time tests, but did not enhance the performance in the modified flanker test. The authors considered the difficulty level of the cognitive task as the potential factor confounding the impacts of napping on cognitive performances.

Concerning of physical performances, previous studies confirmed that a short midday nap reinstated the adverse effects of sleep disruption on physical performances (Waterhouse *et al.* 2007, Blanchfield *et al.* 2018, Hammouda *et al.* 2018, Keramidas *et al.* 2018, Daaloul *et al.* 2019). Nevertheless, its impacts after a normal night of sleep have not been decided yet. For instance, four studies demonstrated that napping did not improve several physical abilities in trained athletes, like aerobic performance (Blanchfield *et al.* 2018, Daaloul *et al.* 2019), anaerobic performance (Petit *et al.* 2014, Tanabe *et al.* 2020), muscular strength (Tanabe *et al.* 2020), and jump velocity (Daaloul *et al.* 2019). On the other hand, two studies showed that a short midday nap significantly improved speed and directional ability (Abdessalem *et al.* 2019, Boukhris *et al.* 2019). Interestingly, studies that reported a gain in physical performances after the nap included untrained subjects. Agility is an important fitness ability that involves rapid body movements and the complex interaction between motor and cognitive coordination (Sheppard and Young 2006).

Given that agility is an essential fitness for athletes' success in team sports, combat sports, or any other kind of sports (Sheppard and Young 2006, Sassi *et al.* 2009). It is of primary importance to determine whether the impacts of a short midday nap on speed and agility depend on the level of expertise of subjects, or the effects of napping on agility are task dependent.

Therefore, the focus of this study was to investigate the effects of a 30-min midday nap on cognitive and physical performances in athletes after a normal night of nocturnal sleep. The first objective was to investigate the effects of the nap on cognitive performances using reaction time tests with distinct complexity levels. The second objective was to examine the effects of the nap on speed and directional ability in highly-trained athletes.

II. 3. 2. METHODS

II. 3. 2. 1. PARTICIPANTS

Twelve male (age: 22 ± 1 year old; height: 175 ± 2.45 cm; body mass: 68 ± 7.5 kg; expertise: 13 ± 2 years) were selected to participate in this study. They had been trained for nine sessions of about 2h per week. The participants included in this study had a regular sleep-wake behavior (sleeping between 23:00 and 07:00 \pm 1:30 h), non-smokers, and were not addicted to caffeine or alcoholic beverages. The circadian typology was evaluated by the Horne & Ösberg self-assessment questionnaire (Horne and Östberg 1976). All the participants were identified as "intermediate type". Moreover, they claimed their willingness to take nap if appropriate conditions are granted (e.i. time, and environment). The protocol of this study complied with the standards set by the Declaration of Helsinki for human experimentation (World Medical Association 2001), and met the requirement of the National Observatory of Sport in Tunisia (ONS). The ONS is a governmental institution responsible for the experiments related to the domain of sport in Tunisia. It had scrutinized the form as well as the content of the research and had approved its design. Before signing the informed consent, subjects were informed about the benefits and risks of the study. And of course, all of them were informed about their rights to withdraw from the study at any time.

II. 3. 2. 2. PROCEDURES

The experimental design is described in *Figure 50*. Before the beginning of the experimental sessions, participants were familiarized with the experimental procedures. Throughout the experimental period, they were asked to maintain a regular sleep-wake pattern. Nocturnal sleep was monitored by actigraphic recordings, and sleep diaries. Additionally, for the 24-hour before each visit, athletes were requested to abstain from strenuous physical activities. For the main experimental trial, participants randomly experienced either a nap or a control condition on two separate occasions within a 48-hour-rest between sessions. The nap condition included a period of a 30-min nap from 13:00 to 13:30 in bed after lunch. In the control condition, participants were kept in the laboratory and were given the choice to practise their favorite activities such as reading books, watching videos, or chatting. Immediately after waking from the nap, they answered the questionnaire about their sleep during the nap. A 30-min period of time separated the nap or the rest condition from the assessment session. The testing session started at 14:00. It was composed of a set of three different reaction-time measurements and a physical assessment task. Before the beginning of the physical task, subjects completed a standardized warm-up of 10-min. It consisted of self-selected-intensity jogging, vertical jumping, and dynamic stretching, and then it was followed by 5-min of passive rest.

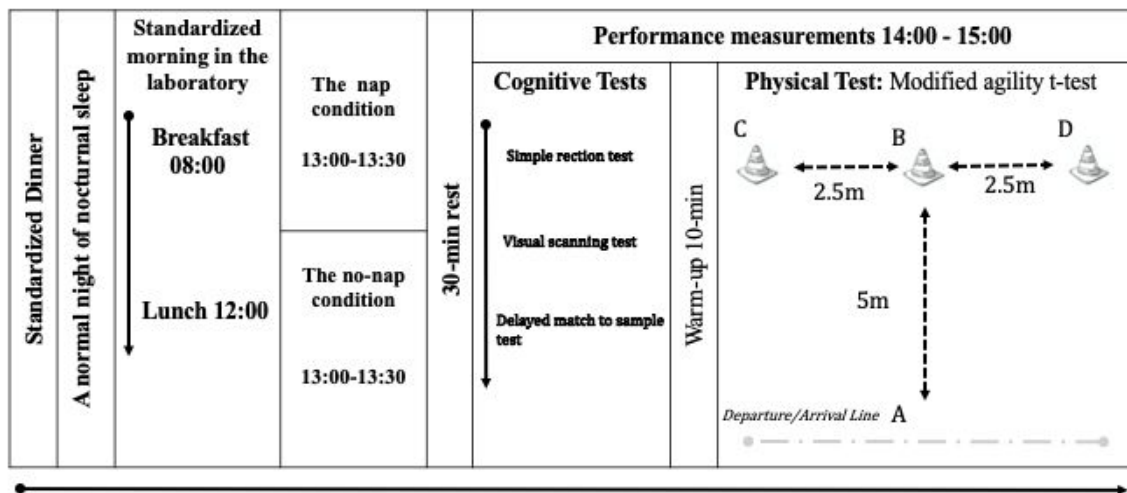


Figure 50. Design of the experimental protocol.

II. 3. 2. 3. MEASUREMENTS

II. 3. 2. 3. 1. ACTIGRAPHY AND SLEEP DIARIES

The measurements of sleep in this study included self-reported sleep diaries and objective measures of actigraphy (Sadeh 2011). We used the Motion Watch actigraphy system (MW8; camntech). All watches were configured to collect data in 60-second epochs. Subjects wore the actigraph continuously on their non-dominant wrists. The device recorded data from a movement-sensitive sensor and provided information concerning sleep parameters. The sleep variables examined for the night before the experimental session were edited manually within the information listed in the subjective sleep diaries and scored using the software Motion Ware (version 1.0.25). The sleep variables obtained in this study were the following: bedtime, fell asleep time, woke up time, total time in bed, and assumed sleep (the total period elapsed between the “fell Asleep” and “woke up” times).

II. 3. 2. 3. 2. SUBJECTIVE SURVEY OF SLEEP DURING THE NAP

Immediately upon waking from the nap, subjects were requested to answer some questions related to their estimated nap-time (minutes), depth (1, light to 5, deep), and satisfaction with the nap (1, poor to 4, good) (Hayashi *et al.* 2005).

II. 3. 2. 3. 3. REACTION TESTS

The reaction-time task is composed of a set of three tests: Simple Reaction Test (SRT), Visual Scanning Test (VST), and the Delayed Match to Sample Test (DMST). Each one of the three tasks contained a block of 10 trials. Subjects were asked to respond as quickly as possible to a visual stimulus by pressing the computer keyboard spacebar button with the index finger of their dominant hand. The mean reaction time and numbers of missed targets or errors were also calculated. The testing was performed in a quiet room using the same computer for all trials. The task was conducted using software Reaction (version 4.05) created by Tilquin (Monod-Ansaldi *et al.* 2012).

II. 3. 2. 3. 3. 1. SIMPLE REACTION TEST

The Simple Reaction Test is among the most basic measures of processing speed. Subjects were asked to respond to a specific visual stimulus (blue square) presented systematically on the screen.

II. 3. 2. 3. 3. 2. VISUAL SCANNING TEST

In this test, the stimulus and the response uncertainty were introduced to add the difficulty-level of the task. The stimulus was a pair of non-representational shapes containing a sort of interlaced random curves. Subjects were asked to quickly determine whether the pair objects are the same or two different draws.

II. 3. 2. 3. 3. 3. DELAYED MATCH-TO-SAMPLE TASK

The memory comparison operation presented in this task further increases the cognitive load as it requires advanced processing. The stimulus was a yellow scalene triangle presented for 3 seconds before the starting of the test. Immediately afterward, a series of pictures of the same triangle but in different positions showed up on the screen successively. The subject had to make a positive reaction whenever the memorized triangle appeared on the screen, and to make a negative response otherwise.

II. 3. 2. 3. 3. 4. MODIFIED AGILITY T-TEST

The modified agility t-test (Sassi *et al.* 2009) is a commonly used test that measures the speed with changes of direction. It mainly involves forward, lateral, and backward running (Figure 1). Participants started with both feet behind the starting line-A. At their discretion, each participant sprinted forward from cone-A to cone-B and touched it with the right hand. Facing forward and without crossing feet, the participants shuffled to the left to cone-C and touched its base with the left hand. After, they shuffled to the right to cone-D and touched its base with the right hand, and then they shuffled back to cone-B and touched its base with the left hand. Finally, they ran backward to the start position, the line-A. The trial was not considered in case the subject crossed one foot in front of the other while shuffling, or failed to touch the base of the cones. The recorded score for this test was the best time among the three successful trials, and there was a 2-minute

rest between each trial. The MAT performance was recorded in seconds using the photocells system (Brower Timing Systems, Salt Lake City, Utah, USA).

II. 3. 3. STATISTICAL ANALYSIS

Statistical tests were processed using Statistica 7.1 (Statsoft, France). A paired sample t-test was used for examining the differences between the nap condition and the control condition. Effect sizes of significant results were reported as partial eta-squared (η^2), which quantified the proportion of the variability in the dependent variable that was explained by the effect. Values of 0.01, 0.06, and 0.14 represent small, medium, and large effect sizes respectively (Cohen 1988). The level of statistical significance was set at ($p < 0.05$).

II. 3. 4. RESULTS

II. 3. 4. 1. SLEEP PARAMETERS

II. 3. 4. 1. 1. NOCTURNAL SLEEP PARAMETERS OF THE NIGHT BEFORE THE EXPERIMENTAL VISIT.

Actigraphic data showed that there were no significant differences ($p > 0.5$) for none of the sleep parameters obtained during the nights preceding the assessments (*Table 9*).

Table 9. Sleep variables for nights prior to the study

Parameters	Nap		No-nap		T-test value	P
	Mean	SD (min)	Mean	SD (min)		
Bed Time	22:54	22	22:51	27	0,652	ns
Fall Asleep Time	23:19	26	23:14	31	0,469	ns
Wake Up Time	07:25	46	07:06	46	0,425	ns
Total Time in Bed (min)	511.33	41	500	49	0,616	ns
Assumed Sleep Time (min)	486	48	472	49	0,574	ns

ns: non-significant at $p > 0.05$.

II. 3. 4. 1. 2. SUBJECTIVE SURVEY OF SLEEP DURING THE NAP

Subjective estimation of the amount of sleep during the nap averaged 13.75 ± 9.7 min. Their estimated sleep depth on a scale-out of 5 averaged 2.2 ± 1 . Finally, the satisfaction with the nap on a scale-out of 5 averaged 2.4 ± 0.8 .

II. 3. 4. 2. REACTION TESTS

The mean and SD values of reaction-time tasks are displayed in *Table 10*. During the SRT, the results showed a significant main effect of SRT for the nap ($F_{(1-11)} = 5.823$; $p < 0.05$; $\eta p^2 = 0.34$), indicating that the time spent during the SRT was shorter after the nap compared with the no-nap condition. Concerning the VST, the results showed a significant effect for the nap ($F_{(1-11)} = 9.736$; $p < 0.01$; $\eta p^2 = 0.46$) and demonstrated that the reaction time increased compared to the no-nap condition. Besides, the results showed no significant effect for the nap on missed targets or errors during this test ($p > 0.05$) compared with the no-nap condition. Regarding the DMST, the results revealed a significant main effect for the nap ($F_{(1-11)} = 6.511$; $p < 0.05$; $\eta p^2 = 0.37$), indicating that the mean reaction time was shorter after the nap than in the control condition. But, no significant differences for the numbers of missed targets or errors were observed following the nap ($p > 0.05$) compared with the no-nap condition.

II. 3. 4. 2. 1. MODIFIED AGILITY T-TEST

The mean and SD values of MAT are presented in *Table 10*. The results showed that there was a significant effect for the nap ($F_{(1-11)} = 10,103$ $p < 0.01$; $\eta p^2 = 0.47$) compared with the no-nap condition. This result implied that the short midday nap enhanced the performance in this task.

Table 10. Results for performance measurements after the nap and the no-nap conditions.

Parameters		Nap	No-nap	T-test values	P
Cognitive performance					
Simple Reaction	Time (ms)	280 ± 18.8	298 ± 8.5	0.034	< 0.05
Visual Scanning Test	Time (ms)	657.7 ± 40.4	614 ± 39.5	0.009	< 0.01
	Error rate	3 ± 1.1	3 ± 1	1.00	ns
Delayed Match to Simple Test	Time (ms)	491 ± 36.6	518.6 ± 47.2	0.026	< 0.05
	Error rate	1.6 ± 0.7	1.3 ± 0.8	0.304	ns
Physical performance					
Modified Agility t-Test (s)		5.74 ± 0.13	5.96 ± 0.23	0.008	< 0.01

Values are expressed in means ± SD. ns: non-significant at $p > 0.05$.

II. 3. 5. DISCUSSION

The focus of this study was to investigate the effects of a 30-midday nap on cognitive and physical performances in athletes after a normal night of nocturnal sleep. The first objective was to investigate the effects of napping on cognitive performances using reaction time tests with distinct complexity levels. The second objective was to examine the effects of napping on speed and directional ability in highly-trained athletes. The results showed that the nap improved the performance in the SRT and the DMST. However, it negatively affected the performance in the VST. Moreover, the results indicated that the nap improved speed and directional ability in highly-trained athletes.

The analysis of actigraphic recordings and sleep diaries for the nights before the experimental visits indicated that the total amount of nocturnal sleep averaged 8-h per night. According to the National Sleep Foundation, 8 hours of sleep per night are considered to be the appropriate sleep duration recommended for adults to ensure optimal neurobehavioral functioning during the day (Hirshkowitz *et al.* 2015). Based on the subjective survey of sleep during the nap, the results indicated that the perceived length of sleep during the nap averaged about 14-min. This finding demonstrated that the participants were able to sleep during the nap.

The improvement in reaction times during the SRT and DMST is in line with the previous research indicating that a short midday nap enhanced the information processing speed when performing attentional tasks after a normal night of sleep (Abdessalem *et al.* 2019, Boukhris *et al.* 2019, Tanabe *et al.* 2020). Particularly, these results are congruent with the study of Petit *et al.* (2018) that provided objective measures of sleep during the nap and assessed the neuro-electric activity of the brain when performing the auditory oddball task. In this context, it is worth noting that the event-related P300 amplitude reflected the amount of allocated attention, and the latency of P300 reflected the time spent on the classification of the stimulus. Their results indicated that the short midday nap, which was mainly composed of sleep stage 2 and sleep stage 3, increased P300 amplitude and decreased P300 latency. Together, these findings imply that the amount of allocated attention was higher and the information processing speed was greater after a short midday nap compared with the no-nap condition. Undoubtedly, high levels of attention and accuracy in the information processing speed are critical aspects for optimal cognitive functioning (Petit *et al.* 2018). Therefore, the gains observed after a short midday nap across different cognitive tasks further encourage its use by athletes.

To date, it should be stressed that this study is the first that reported a negative impact of a short midday nap on athletes' visual processing speed as evaluated by the VST. The results demonstrated that the mean reaction time increased and the error rate remained unchanged compared to the no-nap condition. This finding indicated that the participants spent more time in the evaluation process of the stimuli, without producing any improvement in their performances. Here it is important to mention that perceptual-cognitive operations involving visual scanning, rapid recognition, and decision making are critical elements for achieving success in all sports fields in general (for review, see Williams *et al.* 2011) and in sports depending on perceptual abilities in specific (Di Russo *et al.* 2003). These findings are alarming especially when considering the results of Suppiah *et al.* (2019), showing that napping did not improve shooting performance in high-level pistol and rifle shooters. Nevertheless, it is possible that the increased difficulty level, which was imposed by the nature of the stimuli, (i.e, non-representational shapes)

represented a potential factor masking the positive effects of the short midday nap on cognitive performances. However, the absence of a control condition that evaluates the effects of napping on the same task performance with a lower level of difficulty (i.e. representational shapes) is considered a limitation of the present work.

Regarding the effects of a short midday nap on physical performances, the present results confirm the previous findings indicating that that nap improved speed and directional ability in physically active participants (Abdessalem *et al.* 2019, Boukhris *et al.* 2019), and extended their relevance to high-level athletes. Together, these results further reinforce the observation that not all the performance measures are equally affected by the nap (Morita *et al.* 2016).

In conclusion, a short midday nap improved cognitive performance in tasks involving attentional functions, however, it produced an unfavorable effect on perceptual-cognitive capacities involving visual scanning skills. Furthermore, the findings of this study further confirm the benefits of the short midday nap on speed and directional abilities in highly-trained athletes. Future research is required to broaden the testing of the potential short- and long-term effects of a short midday nap scheduled after a normal night of nocturnal sleep on different physical and cognitive performances.

***III. GENERAL DISCUSSION CONCLUSION
AND PERSPECTIVES***

The present thesis covers the topic of the impacts of napping on performances from its fundamental perspective to empirical investigations. The challenge was to synergize these approaches with real-life occupational applications. The present work fully reflects the transdisciplinary nature of the research program at the laboratory of UMR-S 1075 INSERM/Unicaen COMETE as it involves different research disciplines in the fields of “Chronobiology”, Sport Sciences and Performance Optimization”, “Neurocognitive Science and Behavior”, “Public Health Issues”, and “Innovation and Technology”.

The objective of the present work was to investigate the impacts of energetic and restorative naps on arousal, cognitive and physical performances during the afternoon in healthy habitual nappers. The thorough investigation on the impacts of napping on performances was based on the two-process model (Borbély 1982, Borbély *et al.* 2016).

For recall, the two-process model originally proposed by Borbély (1982) to account for the reciprocal interaction between the homeostatic and the circadian regulatory processes. The homeostatic process (Process S) increases linearly during waking and dissipates during subsequent sleep. The circadian process (process C) cycles non-linearly within 24 hours, forming periods of maximum drive for wakefulness and periods of maximum drive for drowsiness (Strogatz 1987, Lavie 1989). The major peak for drowsiness is commonly placed at nighttime, and the minor peak for drowsiness occurs halfway between two successive major sleep phases, and it is labeled the post-lunch dip by Monk *et al.* (1996), or the secondary sleep gate by Lavie (1986). These two phases of maximum drowsiness are separated by phases of the greatest drive for wakefulness (Lavie 1989). The interaction between the homeostatic and the circadian processes determines the timing and the structure of sleep (i.e. nocturnal sleep and daytime naps). Particularly, the rising homeostatic sleep pressure is reflected in the number and amplitude of Slow Wave Activity (SWA) of the electroencephalogram during sleep, that is, the longer the duration of prior wakefulness, the higher the amount of SWA during subsequent sleep. This EEG variable is regarded as the indicator of sleep depth or sleep intensity (Borbély 1982, Goel 2011, Achermann *et al.* 2017). Given the influence of the process S on sleep regulation, the structure of

a short midday nap taken after a normal night of sleep (i.e. energetic nap) is different from a nap taken under intense sleep pressure, for example after extended wakefulness (i.e. restorative nap). Apart from determining the timing and the structure of sleep, the two-process model has been expanded to predict arousal levels and performance during the day. For instance, the model posits that the level of arousal at any given point in the diurnal phase of the day is modulated by the difference between the process S and C. Accordingly, a short distance between S and C indicates high arousal levels, and conversely, a large gap between the two processes indicated low levels of arousal. Notably, in the classical version of the two-process model, process S did not influence the functioning of process C. However, in a recently elaborated version of the model, Borbély *et al.* (2016) posit that the homeostatic and circadian processes are subjects to more complex and continuous interactions, that is, the amplitude of process C decreases when the level of process S is high, but increases when the level of process S is reduced (*Figure 18*).

Given that the circadian pressure for wakefulness reaches its nadir in the afternoon (i.e. post-lunch phase), the use of a short midday nap is effective in counteracting the drawbacks of the post-lunch dip, as it reduces the homeostatic sleep pressure at that time, and enhances arousal levels throughout the day. Here it is important to mention that the effects of a short midday nap on cognitive and physical performances are modulated by many factors, including the duration of prior wakefulness and sleep, interindividual variability, and the environment of sleep during the nap. To systematically investigate the effects of napping on distinct aspects of cognitive and physical performances in healthy habitual nappers, we differentiated between two types of naps based on the previous amount of sleep and wakefulness. We introduced the term energetic nap to designate a short midday nap taken after a normal night of sleep, and we used the term restorative nap to designate a short midday nap following sleep loss.

III. 1. THE IMPACTS OF ENERGETIC NAP ON PERFORMANCE

In the first study, we addressed the issue related to the environment of sleep during the nap and we attempted to examine the impacts of the energetic nap in different sleep environments on subsequent cognitive and physical performances. The findings of the first study showed that regardless of the environment of sleep during the nap, the nap enhanced daytime arousal and improved cognitive performance during the day, with longer lasting effects observed after taking a nap in the bed compared to a nap in the box or in the reclining chair. One of the ways to interpret these findings is that taking a nap in a reclining posture or the presence of music and lights reduced the potential impacts of the energetic naps. Accordingly, in the second and third studies, we implemented a nap in the bed on a selective basis, and we focused on the impacts of the energetic nap on distinct cognitive and physical aspects of performances.

Based on the two-process model (Borbély *et al.* 2016) (*Figure 51*), we speculated that when the normal amount of nocturnal sleep is preserved, the use of the energetic nap would reduce the level of the process S (*green curve*), which consequently would enhance daytime arousal and improve cognitive and physical performances in the afternoon (*blue curve*).

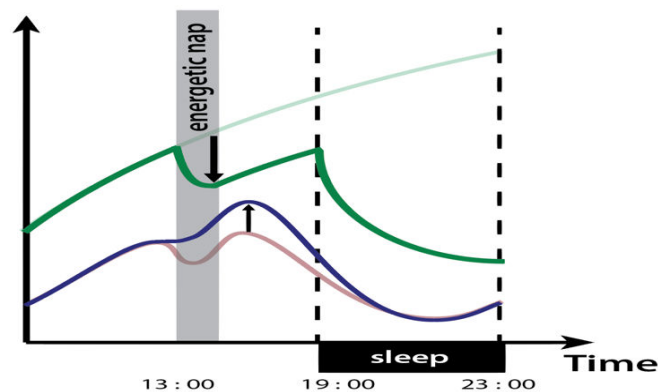


Figure 51. A schematic illustration of the changes in the homeostatic and circadian processes under the influence of the restorative nap.

III. 1. 1. COGNITIVE PERFORMANCES

Changes in subjective measurements or cognitive performances (i.e. improvement or decrement) represent a good marker for determining arousal levels at a given point in time during the day (Sander *et al.* 2015). For recall, cortical activation can be tonic or phasic depending on the cognitive task's demands (Cohen 2014). The tonic aspect refers to the general functioning of the arousal system during the day. The latter is intimately involved in sustaining attentional control, as well as, in providing the necessary cognitive tone for performing complex cognitive abilities (DeGutis and Van Vleet 2010). The phasic component refers to a rapid increasing change in arousal levels induced by a warning signal (Landry and Raz 2016). The latter is viewed as an important element in a wide range of human performances that require fast and precise responses.

In the first study, we focused on the effects of the energetic nap on the tonic aspect of arousal. Accordingly, we provided punctual and repetitive subjective testing sessions over the post-nap session. Besides, we implemented a simulated driving task to continuously monitor the sustained attention. In the second study, we deployed a mental rotation task to investigate the impacts of the nap on a complex cognitive ability that requires both tonic and phasic aspects of arousal. Finally, in the second and third studies, we employed a total number of five reaction time tests with different complexity levels to investigate the effects of the energetic nap on the phasic aspect of arousal.

The results of the first study confirmed that the level of arousal and sustained attention decreased in the afternoon. Besides, we demonstrated that the use of the energetic nap enhanced daytime arousal and prevented mental fatigue. The results also confirmed that the energetic nap improved performance in the sustained attention task. More specifically, the data indicated that the nap enhanced performance stability and reduced the number of errors during the simulated driving task. Moreover, we compared the cognitive performance in the afternoon after the nap with the morning performance. Intriguingly, we found that performance in the afternoon after the energetic nap have surpassed the morning levels.

The second and third studies, we found that the energetic nap improved the mental rotation test, simple reaction test, delayed match-to-sample test, and lower reaction test. Together, these results are consistent with previous reports indicating that a short midday nap improved the information processing speed when performing reaction tests (Hayashi, Ito, *et al.* 1999, Hayashi, Watanabe, *et al.* 1999, Petit *et al.* 2018, Abdessalem *et al.* 2019, Boukhris *et al.* 2019, Tanabe *et al.* 2020). However, it is important to foreground that the energetic nap negatively affected the visual scanning test. Precisely, we found that after the nap, the mean reaction time increased, and the error rate remained unchanged compared to the no-nap condition. This result entails that the participants spent more time in the evaluation process of the stimuli, without making improvements in their performances. We have attributed the lack of improvement in performance in this test to the increased difficulty level imposed by the nature of the stimuli (i.e, non-representational shapes).

III. 1. 2. PHYSICAL PERFORMANCES

In the present work, we have investigated the effects of the energetic nap on several aspects of physical performances. In the first and second studies, the results showed no improvement in physical performances following the energetic nap on muscular power which was measured by the explosive leg extensor power, maximum jump high assessed by the squat jump and the counter movement tests. Likewise, we found no improvement during the aerobic karate field test in which the participants replicated efforts of a real karate combat session. These results are in line with several studies proving that after a normal night of sleep a short midday nap did not improve aerobic performance (Blanchfield *et al.* 2018), muscular strength and jump velocity (Tanabe *et al.* 2020), and anaerobic performance (Petit *et al.* 2014). However, the results of the third study showed that the energetic nap enhanced the speed and directional ability during the modified agility T-test. On one level, these findings are in line with previous studies indicating that that the nap improved speed and directional ability in physically active participants (Abdessalem *et al.* 2019, Boukhris *et al.* 2019). On a greater level, we further extend the relevance of the findings from physically active participants to professional athletes. Altogether, we suggest that the

favorable effects observed in this particular fitness ability are due to the positive effects of the energetic nap on the cognitive components contributing to the accomplishment of the agility test. Again, all these findings demonstrated that the effects of the energetic nap on a particular task performance depend on the characteristics of the performed task.

III. 1. 3. CONCLUSION AND PRACTICAL APPLICATION

From a general standpoint, the present work supports previous findings indicating that the nap alleviated the effects of the post-lunch dip and improved the cognitive performances after a normal night sleep (Hayashi and Hori 1998, Hayashi, Watanabe, *et al.* 1999, Hayashi and Abe 2008, Zhao *et al.* 2010). As a particular highlight, the gain observed in sustained attention and in processing speed further encourages its use for mitigating the adverse effects of the post-lunch dip and for boosting the performance during the day. The findings are also in line with predictions found in the two-process model supporting that napping reduces the homeostatic sleep pressure and enhances arousal levels throughout the day (Borbély 1982, Borbély *et al.* 2016, Achermann *et al.* 2017). Therefore, we recommend the use of the energetic nap for improving work performance and for better ensuring safety. Regarding the environment of sleep, we strongly recommend the most effective and optimal condition revealed through the experiments, which is a nap in the bed condition. Nevertheless, if the latter is not at one's disposal, we still encourage the use of the energetic nap either in a reclining chair or in the box, especially after proving the effectiveness the SOMBOX sleep product.

Concerning physical outcomes, the results showed conflicting findings. On the one hand, the energetic nap did not improve muscular power, maximum jump high, and time to exhaustion during the endurance test. On the other hand, the energetic nap improved speed and directional ability. These findings suggest that the effects of energetic nap on performances are highly task-dependent.

The difference in results displayed throughout the cognitive and physical aspects of performances reflects the mutual interaction between the homeostatic and the circadian processes. Given that

the decrease in particular task performance over the day is assumed to be caused by its sensitivity to sleep pressure that increases in function of the previous waking period, the improvement in other performance tasks at any given point in time during the day is attributed to the input of the circadian process which counterbalances the effects of sleep pressure. Accordingly, we suggest that the beneficial effects of the energetic nap on a particular neurobehavioral function depend on a fine balance between the input of the circadian system and the sensitivity level to the homeostatic sleep pressure. In conclusion, task measure is an important factor that comes into play when considering the effects of napping on performance.

III. 2. THE IMPACTS OF RESTORATIVE NAP ON PERFORMANCE

In the second study, we addressed the issue related to the effects of napping under a sleep loss condition. Accordingly, we attempted to systematically examine the effects of the restorative nap on distinct aspects of cognitive and physical performances following a partial sleep restriction.

Based on the two-process model (Borbély *et al.* 2016) (Figure 52), we hypothesized that when the amount of nocturnal sleep is reduced, the increasing level of the process S would impair cognitive and physical performances (**pink curve**). Given that the dissipation of the homeostatic sleep pressure is thought to be an exponential process (Achermann and Borbély 1990), we also hypothesized that the restorative nap would restore the imbalance of the process S (**green curve**), and therefore would counteract the decrease in performance caused by sleep loss (**blue curve**).

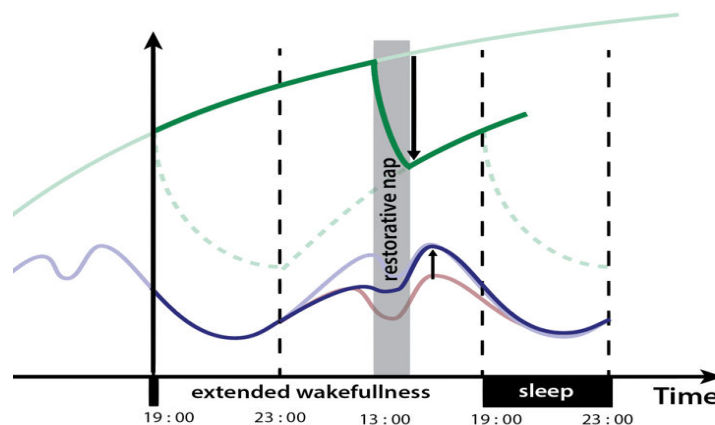


Figure 52. A schematic illustration of the changes in the homeostatic and circadian processes under the influence of the energetic nap.

III. 2. 1. COGNITIVE PERFORMANCES

In the second study, we mainly focused on the effects of the restorative nap on phasic aspects of arousal using two reaction tests. In addition, we sought to examine the effects of the restorative nap in a more complex cognitive performance using the mental rotation test. The results demonstrated that the nap helped to restore the impairment in performances caused by sleep loss. In particular, the restorative nap enhanced the information processing speed during the reaction time test and restored the score in the mental rotation test when compared to the no-nap condition. These results are in line with previous studies confirming the restorative effects of a midday nap on arousal and cognitive performance following extended wakefulness (DMSc and DMSc 2000, Tietzel and Lack 2001, 2002, Brooks and Lack 2006, Waterhouse *et al.* 2007). Furthermore, these findings comply with the two-process model predictions.

III. 2. 2. PHYSICAL PERFORMANCES

Along with the second study, we investigated the effects of the restorative nap after partial sleep deprivation on maximal vertical jump performance assessed by the counter movement jump and the squat jump tests. Besides, we investigated the restorative effects of the nap on time to exhaustion during an aerobic field test. We found that the restorative nap effectively counteracted the decrease in performance which was induced by partial sleep deprivation. These results are consistent with previous studies examining the impacts of the restorative nap on physical performances after partial sleep deprivation on physical performances (Waterhouse *et al.* 2007, Blanchfield *et al.* 2018, Hammouda *et al.* 2018). More specifically, we found that sleep loss reduced time to exhaustion during the aerobic test, impaired maximal vertical jump performance in the counter movement jump test, but did not affect the squat jump test. In the same perspective, the results demonstrated that changes in performances after the restorative nap were observed only in tasks that were impaired by sleep loss. Together, these findings further reinforce the

observation that the beneficial effects of napping on a particular task performance depend on its sensitivity to sleep pressure.

III. 2. 3. CONCLUSION AND PRACTICAL APPLICATION

Overall, the results of the second study showed that sleep loss impaired the output in almost all the performed tasks. Such negative impacts on performances are alarming when considering the fundamental needs for athletes' optimal functioning in everyday training or during a competition. Nevertheless, the results revealed that the restorative nap can effectively act as a countermeasure for the deficit in cognitive and physical performances induced by partial sleep deprivation in trained athletes. The gain acquired in the information processing speed after the restorative nap is noteworthy when considering the elite-sports context. Likewise, the restorative effects of napping on time to exhaustion during the aerobic test are remarkably important, knowing that we employed a reliable aerobic-specific karate field test for highly trained karate athletes. More specifically, the present results are in line with previous studies investigating the recuperative value of a short midday nap in athletes on cognitive (Waterhouse *et al.* 2007, Petit *et al.* 2018, Ajjimaporn *et al.* 2020), and physical (Waterhouse *et al.* 2007, Blanchfield *et al.* 2018, Hammouda *et al.* 2018, O'Donnell *et al.* 2018) performances under different conditions of sleep loss. As a particular highlight, these findings are particularly significant for highly-professional athletes, especially that napping does not violate doping regulations.

The decrement in performance observed after sleep loss was reflected in the limited physiological capacity to perform compared to the baseline condition (i.e. normal night of sleep). Together, these findings comply with the predictions of the two-process model suggesting that under conditions of prolonged wakefulness, high levels of sleep pressure reduced the circadian amplitude of many neurobehavioral functions when compared to baseline levels (Borbély *et al.* 2016). Furthermore, the results showed that the nap counteracted the decrease in performance in most of the tests. Again, these findings suggest that the nap helped to readjust the imbalance of process S and to restore the performance to baseline levels.

III. 3. PERSPECTIVES

- Despite the aforementioned benefits of the nap, regular napping has often been associated with negative consequences, such as increased drowsiness and decrement in cognitive performances during the post-lunch phase. In light of this assumption, it seems to be premature to prescribe napping on a regular basis. Thus, further research is necessary in order to decide whether napping should be recommended on a regular basis or not.
- There is evidence showing that individual differences in napping behavior modulate the structure of sleep during the nap and its subsequent effects on performances. It was reported that habitual nappers are more likely to benefit from the nap compared to no-nappers. According to this observation, some studies selected only non-habitual nappers, while others included only habitual nappers. This classification was made without providing any additional information about under what conditions the participants were selected as either nappers or non-napper. A valid questionnaire that permits to classify the participants into habitual nappers or non-nappers remains an issue that deserves to be properly reconsidered in future research.
- We present in *Annex A.5* a prime version of a questionnaire related to “napping typologies”. Therefore, we hope that we focus our research on the next objective which will be oriented towards developing and validating this version.
- Intriguingly, the results showed that, after a normal night, the post-lunch dip only affected the modified agility level. Contrary to all other physical performances which were not impacted by the post-lunch dip, the modified agility test was enhanced by the use of the energetic nap. Besides, the results showed that partial sleep deprivation impaired the maximum jump high in the counter movement jump test, however, it did not impact the squat jump test. These findings suggest that sleep pressure did not affect the performance at the neuromuscular level. Instead, we suggest that the differences in results displayed in response to sleep pressure were related to the sensorimotor control during a dynamic task. Therefore, the understanding of how movement patterns and joint coordination are affected by sleep pressure is likely to open new

research realm for a better comprehension of the possible impacts of sleep loss and/or napping on physical outcomes.

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ANNEXES

SECTION A. QUESTIONNAIRES

Annex A 1. Pittsburgh Sleep Quality Index (PSQI) : French version

Les questions suivantes ont trait à vos habitudes de sommeil pendant le dernier mois seulement. Vos réponses doivent indiquer ce qui correspond aux expériences que vous avez eues pendant la majorité des jours et des nuits au cours du dernier mois. Répondez à toutes les questions.

1/ Au cours du mois dernier, quand êtes-vous habituellement allé vous coucher le soir ?

➤ Heure habituelle du coucher :

2/ Au cours du mois dernier, combien vous a-t-il habituellement fallu de temps (en minutes) pour vous endormir chaque soir ?

➤ Nombre de minutes :

3/ Au cours du mois dernier, quand vous êtes-vous habituellement levé le matin ?

➤ Heure habituelle du lever :

4/ Au cours du mois dernier, combien d'heures de sommeil effectif avez-vous eu chaque nuit ? (Ce nombre peut être différent du nombre d'heures que vous avez passé au lit)

➤ Heures de sommeil par nuit :

5/ Au cours du mois dernier, avec quelle fréquence avez-vous eu des troubles du sommeil car ...

	Pas au cours du dernier mois	Moins d'une fois par semaine	Une ou deux fois par semaine	Trois ou quatre fois par semaine
a) vous n'avez pas pu vous endormir en moins de 30 mn				
b) vous vous êtes réveillé au milieu de la nuit ou précocement le matin				
c) vous avez dû vous lever pour aller aux toilettes				
d) vous n'avez pas pu respirer correctement				
e) vous avez toussé ou ronflé bruyamment				
f) vous avez eu trop froid				
g) vous avez eu trop chaud				
h) vous avez eu de mauvais rêves				
i) vous avez eu des douleurs				
j) pour d'autre(s) raison(s). Donnez une description :				
Indiquez la fréquence des troubles du sommeil pour ces raisons	Pas au cours du dernier mois	Moins d'une fois par semaine	Une ou deux fois par semaine	Trois ou quatre fois par semaine

6/ Au cours du mois dernier, comment évalueriez-vous globalement la qualité de votre sommeil ?

- Très bonne
- Assez bonne
- Assez mauvaise
- Très mauvaise

7/ Au cours du mois dernier, combien de fois avez-vous pris des médicaments (prescrits par votre médecin ou achetés sans ordonnance) pour faciliter votre sommeil ?

- Pas au cours du dernier mois
- Moins d'une fois par semaine
- Une ou deux fois par semaine
- Trois ou quatre fois par semaine

8/ Au cours du mois dernier, combien de fois avez-vous eu des difficultés à demeurer éveillé(e) pendant que vous conduisiez, preniez vos repas, étiez occupé(e) dans une activité sociale ?

- Pas au cours du dernier mois
- Moins d'une fois par semaine
- Une ou deux fois par semaine
- Trois ou quatre fois par semaine

9/ Au cours du mois dernier, à quel degré cela a-t-il représenté un problème pour vous d'avoir assez d'enthousiasme pour faire ce que vous aviez à faire ?

- Pas du tout un problème
- Seulement un tout petit problème
- Un certain problème
- Un très gros problème

10/ Avez-vous un conjoint ou un camarade de chambre ?

- Ni l'un, ni l'autre.
- Oui, mais dans une chambre différente.
- Oui, dans la même chambre mais pas dans le même lit.
- Oui, dans le même lit

11/ Si vous avez un camarade de chambre ou un conjoint, demandez-lui combien de fois le mois dernier vous avez présenté :

	Pas au cours du dernier mois	Moins d'une fois par semaine	Une ou deux fois par semaine	Trois ou quatre fois par semaine
a) un ronflement fort				
b) de longues pauses respiratoires pendant votre sommeil				
c) des saccades ou des secousses des jambes pendant que vous dormiez				
d) des épisodes de désorientation ou de confusion pendant le sommeil				
e) d'autres motifs d'agitation pendant le sommeil				

Score Global au PSQI	
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Annex A 2. Horne and Ostberg's Morningness-Eveningness (French version)

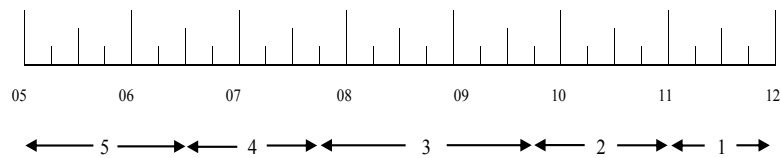
QUESTIONNAIRE DE TYPOLOGIE CIRCADIENNE DE HORNE & OSTBERG

Nom : _____ Date naissance : _____
Prénom : _____ Date : _____

•Instructions :

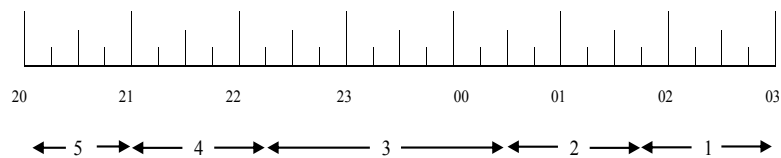
1. Lisez attentivement chaque question avant d'y répondre.
2. Répondez à toutes les questions.
3. Répondez aux questions dans l'ordre.
4. Vous pouvez répondre aux questions les unes indépendamment des autres. Ne revenez pas en arrière pour vérifier votre réponse.
5. Pour les questions à choix multiples, mettez une croix devant une seule réponse. Pour les échelles, placez une croix au point approprié.
6. Répondez à chaque question aussi sincèrement que possible. Vos réponses et les résultats de ce questionnaire resteront confidentiels.
7. Faites les commentaires que vous jugerez nécessaires dans la partie prévue sous chaque question.

- 1. Si vous viviez à votre rythme (celui qui vous plaît le plus), à quelle heure vous leveriez-vous étant entièrement libre d'organiser votre journée ?**



Commentaire :

- 2. Si vous viviez à votre rythme (celui qui vous plaît le plus), à quelle heure vous mettriez-vous au lit étant entièrement libre d'organiser votre journée ?**



Commentaire :

3. Si vous deviez vous lever à une heure précise, le réveil vous est-il indispensable ?

- pas du tout 4
- peu 3
- assez 2
- beaucoup 1

Commentaire :

4. Dans des conditions adéquates (environnement favorable, sans contraintes particulières, etc...) comment éprouvez-vous le lever du matin ?

- pas facile du tout 1
- pas très facile 2
- assez facile 3
- très facile 4

Commentaire :

5. Comment vous sentez-vous durant la demi-heure qui suit votre réveil du matin ?

- pas du tout éveillé 1
- peu éveillé 2
- relativement éveillé 3
- très éveillé 4

Commentaire :

6. Quel est votre appétit durant la demi-heure qui suit votre réveil du matin ?

- pas bon du tout 1
- pas bon 2
- assez bon 3
- très bon 4

Commentaire :

7. Comment vous sentez-vous durant la demi-heure qui suit votre réveil du matin ?

- très fatigué 1
- relativement fatigué 2
- relativement en forme 3
- très en forme 4

--

2

Commentaire :

8. Quand vous n'avez pas d'obligations le lendemain, à quelle heure vous couchez-vous par rapport à votre heure habituelle de coucher ?

- rarement ou jamais plus tard 4
- moins d'1 heure plus tard 3
- 1 à 2 heures plus tard 2
- plus de 2 heures plus tard 1

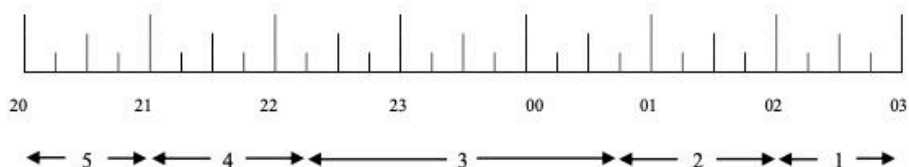
Commentaire :

9. Vous avez décidé de faire un sport. Un ami vous suggère de faire des séances d'une heure et ceci deux fois par semaine. Le meilleur moment pour lui est de 7 à 8 heures du matin. Ne considérant que le rythme qui vous convient le mieux, dans quelle forme penseriez-vous être ?

- bonne forme 4
- forme raisonnable 3
- vous trouvez cela difficile 2
- vous trouvez cela très difficile 1

Commentaire :

10. A quel moment de la soirée vous sentez-vous fatigué au point de vous endormir ?



Commentaire :

11. Vous souhaitez être au meilleur de votre forme pour un examen qui vous demande un effort intellectuel considérable durant deux heures. Vous êtes entièrement libre de le passer quand vous le souhaitez, quelle est l'heure que vous choisirez ?

- de 8 à 10 heures 6
- de 11 à 13 heures 4
- de 15 à 17 heures 2
- de 19 à 21 heures 0

Commentaire :

12. Si vous alliez au lit à 23 heures, à quel niveau de fatigue en êtes-vous ?

- pas du tout fatigué 0
- un peu fatigué 2
- relativement fatigué 3
- très fatigué 5

Commentaire :

13. Pour une raison quelconque, vous vous couchez quelques heures plus tard que d'habitude, mais vous n'êtes pas obligé de vous lever à une heure précise le lendemain. Laquelle des propositions suivantes choisirez-vous ?

- vous vous réveillez comme d'habitude et vous ne vous rendormez plus 4
- vous vous levez comme d'habitude mais vous vous recouchez par la suite 3
- vous vous réveillez comme d'habitude mais vous vous rendormez 2
- vous vous réveillez plus tard que d'habitude 1

Commentaire :

14. Pour effectuer une garde de nuit, vous êtes obligé d'être éveillé entre 4 et 6 heures du matin. Vous n'avez pas d'obligations le lendemain. Laquelle des propositions suivantes vous convient le mieux ?

- vous n'irez au lit qu'une fois la garde terminée 1
- vous faites une sieste avant et vous couchez après la garde 2
- vous vous couchez avant et faites une sieste après la garde 3
- vous dormez ce qu'il vous faut avant d'effectuer la garde et ne vous recouchez pas après 4

Commentaire :

15. Vous devez faire deux heures de travail physique intense, mais vous êtes entièrement libre d'organiser votre journée. Laquelle des périodes suivantes choisirez-vous ?

- de 8 à 10 heures 4
- de 11 à 13 heures 3
- de 15 à 17 heures 2
- de 19 à 21 heures 1

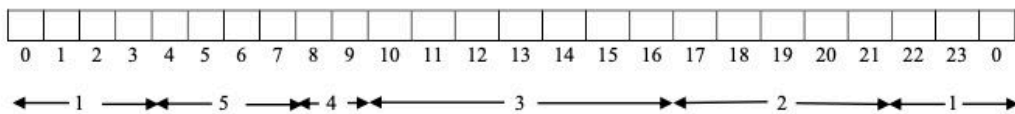
Commentaire :

16. Vous avez décidé de faire un sport. Un ami vous suggère de faire des séances d'une heure et ceci deux fois par semaine. Le meilleur moment pour lui est de 22 à 23 heures. Ne considérant que le rythme qui vous convient le mieux, dans quelle forme penseriez-vous être ?

- bonne forme 1
- forme raisonnable 2
- vous trouvez cela difficile 3
- vous trouvez cela très difficile 4

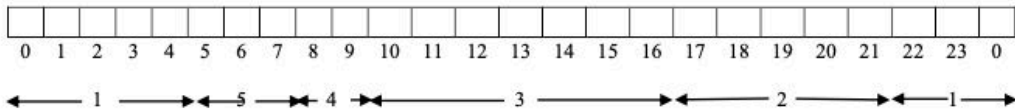
Commentaire :

17. Supposez que vous pouvez choisir les horaires de votre travail. Admettons que vous travaillez 5 heures par jour et que votre travail est intéressant et bien payé. Quelle séquence de 5 heures consécutives choisirez-vous ?



Commentaire :

18. A quelle heure de la journée vous sentez-vous dans votre meilleure forme ?



Commentaire :

19. On dit parfois que quelqu'un est un "sujet du matin" ou un "sujet du soir". Vous considérez-vous comme celui du matin ou du soir ?

- tout à fait un sujet du matin 6
- plutôt un sujet du matin 4
- plutôt un sujet du soir 2
- tout à fait un sujet du soir 0

Commentaire :

• **Score :**

Le score est la somme des chiffres portés à côté ou au-dessus des cases.

<i>Score</i>	<i>Typologie</i>
70-86	nettement du matin
59-69	modérément du matin
42-58	ni du matin, ni du soir
31-41	modérément du soir
16-30	nettement du soir

• **Bibliographie :** Horne J.A., Ostberg O. – A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. *Int. J. Chronobiol.*, 1976, 4, 97-110.

Annex A 3. Sleep Diary: French version

AGENDA DE VIGILANCE ET DE SOMMEIL



DATE	HEURES	Appréciation par : TB - B - Moy. - M - TM			TRAITEMENT ET REMARQUES PARTICULIERES																										
		QUALITE DU SOMMEIL	QUALITE DU REVEIL	FORME DE LA JOURNEE																											
Nuit du ... au...	<table border="1"> <tr> <td>20</td><td>22</td><td>24</td><td>2</td><td>4</td><td>6</td><td>8</td><td>10</td><td>12</td><td>14</td><td>16</td><td>18</td><td>20</td> </tr> <tr> <td>21</td><td>23</td><td>1</td><td>3</td><td>5</td><td>7</td><td>9</td><td>11</td><td>13</td><td>15</td><td>17</td><td>19</td><td></td> </tr> </table>	20	22	24	2	4	6	8	10	12	14	16	18	20	21	23	1	3	5	7	9	11	13	15	17	19					
20	22	24	2	4	6	8	10	12	14	16	18	20																			
21	23	1	3	5	7	9	11	13	15	17	19																				
EXEMPLE		M	TM	Moy																											

heure de mise au lit
 sommeil ou sieste
 heure du lever
 long réveil
 1/2 sommeil
S Somnolence dans la journée

Annex A 4. Karolinska Sleepiness Scale & Visual Analog Scale: French version

Veillez indiquer votre degré de somnolence au cours des 10 minutes précédant ce test en entourant le terme correspondant à votre état. Vous pouvez aussi utiliser les états intermédiaires :

1 = TRES EVEILLE

2

3 = EVEILLE, NIVEAU NORMAL

4

5 = NI EVEILLE, NI SOMNOLENT

6

7 = SOMNOLENT, MAIS SANS EFFORT POUR RESTER EVEILLE

8

9 = TRES SOMNOLENT, AVEC DE GRANDS EFFORTS POUR RESTER EVEILLE, LUTTANT CONTRE LE SOMMEIL

ECHELLE VISUELLE ANALOGIQUE

Mettez une barre verticale à l'endroit qui vous parait le mieux correspondre à votre état :

Very calm Very anxious

physical form Very tired In a good

Very sleepy Very alert

Annex A 5. Nappers' Preferences Questionnaire French version

Questionnaire de la Typologie de Sieste

Nom et Prénom

Date

1. Dans des conditions adéquates combien de sieste faite vous par semaine étant donné que vous êtes entièrement libre d'organiser votre journée et sachant que vous avez eu un sommeil complet et de qualité la veille ?

- Jamais
- Une seule fois
- Tous les jours

2- Pour des raisons quelconques (environnementales, travail, psychologiques, etc...), vous avez passé une mauvaise nuit de sommeil. Dans ce cas, vous :

- Attendez la nuit pour vous couchez tôt
- Faites une sieste dès que les conditions deviennent favorables
- Attendez votre heure habituelle de sieste pour en profiter

3- Vous avez profité d'un sommeil de bonne qualité la veille. Après le déjeuner, allez-vous somnoler:

- Jamais
- En regardant la télévision
- Assis sur une chaise

4- Vous avez décidé de faire une sieste pendant la journée, combien de temps mettez-vous avant de dormir

- Faible chance de dormir
- Un temps >20 minutes
- Un temps <20 minutes
- Je dors tout de suite

5- Quelle est la durée idéale d'une sieste selon vous

- Faible chance de dormir
- Une durée < 1h mais pas moins de 30 min

Une durée < 30min

Une durée > 1 h 30

6. Vous avez réussi à faire une sieste/ un petit somme pendant la journée. Que préférez-vous faire juste après

Rester allongé (sous la couette pour regarder un film)

Lire un roman ou faire des études

Faire du sport

7. Vous avez eu un bon sommeil la veille, Mais après le repas de midi vous vous sentez un peu fatigué. Pour faire face à cette situation, quelle solution vous semble la plus efficace ?

Je ne me sens pas du tout fatiguée au cours de la journée

Prendre un petit café

Faire une petite sieste

8. Vous manquez de sommeil la veille. Après le repas de midi vous vous sentez de plus en plus fatigué laquelle des situations suivantes vous semblent la plus appropriée en étant libre d'organiser votre emploi du temps.

J'attends le soir pour dormir tôt

Je fais une (longue) sieste pour récupérer (le sommeil qui m'a manqué la veille)

Je fais une sieste de courte durée et j'enchaîne ma journée

9. Après une sieste pris pendant la journée, combien de temps mettez vous pour vous remettre en forme

Je n'arrive pas à me remettre en forme

Plus qu'une heure

Moins d'une demi-heure

10. Selon votre expérience personnelle ; Est ce que la sieste vous semble une bonne solution pratique pour combattre la fatigue et ou la somnolence pendant la journée ?

Pas du tout

Rarement ... ca dépend

Tout à fait

11 : Vous avez pris une sieste au cours de la journée ; Est ce que cela affecte votre sommeil de nuit

Oui tout a fait

Rarement... Ca dépend de la durée de la sieste

Non jamais

12. Vous allez vous lever très tôt le lendemain, faites vous une sieste le jour qui précède pour compensé la dette sommeil qui aura lieu le lendemain

Non jamais ... Un petit café fera l'affaire

Oui très bonne idée

Je me contente de ma sieste habituelle

13. Comment évaluez-vous votre sommeil lors d'une sieste.

Un sommeil très profond d'une durée assez longue.

Un sommeil relativement profond

Un sommeil très léger

14. comment voyez-vous la sieste

Désagréable

Une solution pratique pour compenser la dette de sommeil

Un plaisir.

15. Parmi les réponses suivantes comment qualifier vous votre comportement a l'égard de la sieste

Je ne suis pas du tout fais pour la sieste

La sieste c'est une solution pour compenser une dette de sommeil

La sieste est un plaisir pour moi

16. Comment supportez-vous le manque de sommeil ?

Bien

Moyennement bien

Mal

Q17 : Si vous devez vous coucher tard

Vous récupèrerez la nuit suivante

Vous allez vous lever plus tard si possible

Vous allez faire si possible une sieste pour récupérer

Q18 : Si vous devez vous lever tôt

Vous récupèrerez la nuit suivante

Vous allez vous coucher plus tôt si possible

Vous allez faire si possible une sieste pour récupérer

SECTION B. RESULTS

Annex B. 1. Mean and SD values for Explosive Leg Extensor Power during TS 1, TS 3, and TS 6

		Nap conditions			
		Bed	Box	Reclining chair	No-nap
Explosive Leg Extensor Power (W/kg)	TS 1	3.11± 0.72	3.18 ± 0.71	3.17 ± 0.70	3.24 ± 0.97
	TS 3	3.19± 0.73	3.23± 0.81	3.26± 0.73	3.23 ± 0.73
	TS 6	3.27 ± 0.78	3.30 ± 0.75	3.35 ± 0.81	3.28 ± 0.80

TS 1: before the beginning of the driving session. TS 3: at the end of the morning driving task.

TS 6: at the end of the post-nap driving task.

Annex B. 2. Morning Session: Mean and SD values for subjective measurements of sleepiness, anxiety, fatigue and alertness.

		Nap conditions			
		Bed	Box	Reclining chair	No-nap
Sleepiness	TS 1	3.30 ± 1.21	3.02 ± 1.18	3.46 ± 1.4	3.61 ± 1.53
	TS 2	5.35 ± 2.01	5.07 ± 1.99	5.20 ± 1.9	5.11 ± 1.91
	TS 3	5.33 ± 2.06	5 ± 1.90	4.92 ± 1.92	5.27 ± 1.86
Anxiety	TS 1	1.58 ± 1.26	1.54 ± 1.42	1.80 ± 1.63	1.74 ± 1.62
	TS 2	1.66 ± 1.14	2.05 ± 1.85	1.96 ± 1.57	1.92 ± 1.63
	TS 3	1.95 ± 1.53	1.84 ± 1.71	1.98 ± 1.66	1.94 ± 1.53
Fatigue	TS 1	6 ± 1.921	5.93 ± 2.05	6.09 ± 2.03	5.56 ± 2.25
	TS 2	4.65 ± 2.46	5.22 ± 2.20	4.88 ± 2.48	4.6 ± 2.48
	TS 3	4.64 ± 2.41	4.85 ± 2.44	4.19 ± 2.50	4.62 ± 2.49
Alertness	TS 1	6.34 ± 1.836	6.83 ± 1.53	7.73 ± 1.77	6.27 ± 1.84
	TS 2	4.52 ± 2.47	4.88 ± 4.42	4.45 ± 2.51	4.79 ± 2.26
	TS 3	4.82 ± 2.52	4.98 ± 2.38	5.04 ± 2.12	4.91 ± 2.13

TS 1: before the beginning of the driving task; TS2: before the beginning of the return-trip TS 3: at the end of the driving task.

Annex B 3. Morning session: Mean and SD values for the standard deviation of the lateral position, and for the Number of Inappropriate Line Crossing during the course of driving.

Block	Time on task (min)	Standard Deviation of the Lateral Position				Number of Inappropriate Line Crossing			
		Bed	Box	Reclining chair	No-nap	Bed	Box	Reclining chair	No-nap
1 st	10	207.39 ± 56.44	220.28 ± 114.53	242.03 ± 163.68	212.98 ± 55.87	1.59 ± 4.61	2.59 ± 9.28	3.08 ± 7.85	2.62 ± 7.25
2 nd	20	213.40 ± 56.14	219.78 ± 52.15	234.41 ± 89.34	215.64 ± 65.33	2.29 ± 3.85	2.73 ± 5.74	6.35 ± 19.46	3.97 ± 10.89
3 rd	30	233.78 ± 81.40	232.10 ± 68.05	260.63 ± 104.12	231.47 ± 80.80	5.45 ± 10.87	3.81 ± 7.35	8.05 ± 14.41	6.62 ± 14.24
4 th	40	250.34 ± 101.35	254.54 ± 99.42	269.40 ± 156.12	242.97 ± 111.53	10.59 ± 22.07	7.16 ± 14.52	11.75 ± 22.92	8.94 ± 19.91
5 th	50	278.05 ± 132.57	264.84 ± 94.04	288.50 ± 172.21	244.18 ± 92.47	12.08 ± 22.07	8.54 ± 13.18	12.51 ± 23.04	6.62 ± 11.86
6 th	60	230.64 ± 71.44	232.59 ± 70.19	260.35 ± 97.75	218.31 ± 62.49	4.83 ± 7.69	3.32 ± 5.38	7.18 ± 10.30	3.62 ± 6.81
7 th	70	249.81 ± 98.29	248.85 ± 71.79	260.06 ± 93.56	230.23 ± 63.26	8.16 ± 15.49	5.97 ± 10.41	9.13 ± 13.79	4.94 ± 13.03
8 th	80	240.29 ± 80.39	257.73 ± 95.33	281.04 ± 147.93	234.77 ± 72.20	6.59 ± 11.44	7.51 ± 15.74	9.64 ± 16.09	6.13 ± 14.18
9 th	90	243.75 ± 90.97	269.54 ± 116.95	270.08 ± 133.47	237.47 ± 77.50	6.94 ± 13.71	10.54 ± 18.56	8.97 ± 13.52	6.32 ± 13.45
10 th	100	240.04 ± 78.58	273.07 ± 138.68	264.25 ± 110.27	249.21 ± 90.20	6.13 ± 10.19	8.62 ± 14.42	9.78 ± 16.91	7.73 ± 18.06
11 th	110	247.90 ± 95.66	254.81 ± 122.89	246.20 ± 88.08	239.38 ± 87.36	2.97 ± 5.30	2.48 ± 4.35	2.75 ± 5.08	3.67 ± 8.81

Annex B 4. Nap session: Mean and SD values for variations of Core body Temperature (°C) during the nap

Block	Time on task (min)	Nap conditions				Compared to no-nap condition			Between nap conditions		
		Bed	Box	Reclining chair	No-nap	Bed vs no-nap	Box vs no-nap	Reclining chair vs no-nap	Bed vs box	Bed vs reclining chair	Box vs reclining chair
1 st	0	-0.005 ± 0.03	0.005 ± 0.04	0.001 ± 0.04	-0.01 ± 0.05	0.6752	0.6061	0.6061	0.6061	0.6752	0.6752
2 nd	2.5	-0.014 ± 0.07	0.01 ± 0.06	0.014 ± 0.07	-0.012 ± 0.07	0.8811	0.4336	0.4336	0.4336	0.4336	0.8811
3 rd	5	-0.004 ± 0.08	0.01 ± 0.08	0.032 ± 0.10	0 ± 0.09	0.9869	0.9869	0.7923	0.81	0.7923	0.7923
4 th	7.5	0.007 ± 0.08	0.007 ± 0.10	0.039 ± 0.12	0.028 ± 0.10	0.7315	0.3907	0.9942	0.9942	0.7315	0.3907
5 th	10	0 ± 0.08	0.004 ± 0.11	0.056 ± 0.13	0.044 ± 0.12	0.2411	0.2064	0.9639	0.9639	0.2064	0.1135
6 th	12.5	0.01 ± 0.09	0.001 ± 0.11	0.059 ± 0.14	0.055 ± 0.14	0.3574	0.1766	0.9501	0.5812	0.298	0.0835
7 th	15	0.011 ± 0.09	0.002 ± 0.12	0.067 ± 0.15	0.087 ± 0.14	0.0529	0.0529	0.5496	0.5496	0.1706	0.0465
8 th	17.5	0.014 ± 0.10	-0.001 ± 0.14	0.061 ± 0.16	0.096 ± 0.15	0.036	0.036	0.2827	0.4283	0.2827	0.036
9 th	20	0.014 ± 0.10	0.002 ± 0.14	0.063 ± 0.18	0.103 ± 0.15	0.0405	0.0405	0.3024	0.5462	0.2618	0.0603
10 th	22.5	0.016 ± 0.10	-0.009 ± 0.14	0.068 ± 0.19	0.107 ± 0.15	0.0229	0.0229	0.3215	0.4043	0.2029	0.0239
11 th	25	0.017 ± 0.10	-0.029 ± 0.15	0.068 ± 0.17	0.119 ± 0.14	0.0053	0.0051	0.1527	0.1527	0.1107	0.0064

Annex B 5. Post-nap session: Mean and SD values for variations of Core body Temperature (°C) during the course of driving.

Block	Time	Nap conditions				Compared to no-nap condition			Between nap conditions		
		Bed	Box	Reclining chair	No-nap	Bed vs no-nap	Box vs no-nap	Reclining chair vs no-nap	Bed vs box	Bed vs reclining chair	Box vs reclining chair
1 st	10	0.004 ± 0.067	0.01 ± 0.084	-0.006 ± 0.068	0.006 ± 0.066	0.9115	0.9115	0.9115	0.9115	0.9115	0.9115
2 nd	20	0.072 ± 0.12	0.086 ± 0.115	0.042 ± 0.083	0.063 ± 0.113	0.9194	0.7065	0.2731	0.7065	0.2731	0.2731
3 rd	30	0.129 ± 0.148	0.132 ± 0.139	0.104 ± 0.1	0.088 ± 0.146	0.9136	0.9136	0.9857	0.9857	0.8193	0.9645
4 th	40	0.142 ± 0.164	0.148 ± 0.155	0.14 ± 0.134	0.081 ± 0.162	0.3423	0.456	0.3879	1	0.918	1
5 th	50	0.142 ± 0.178	0.144 ± 0.147	0.137 ± 0.144	0.053 ± 0.186	0.0483	0.1095	0.0483	1	0.8495	1
6 th	60	0.145 ± 0.197	0.154 ± 0.152	0.127 ± 0.15	0.038 ± 0.19	0.0572	0.0572	0.0572	0.8815	0.6039	0.7597
7 th	70	0.155 ± 0.195	0.158 ± 0.18	0.118 ± 0.163	0.044 ± 0.211	0.1287	0.1287	0.1287	0.858	0.3457	0.5571
8 th	80	0.157 ± 0.195	0.159 ± 0.174	0.12 ± 0.184	0.042 ± 0.216	0.0983	0.0983	0.1095	0.9762	0.1988	0.5571
9 th	90	0.161 ± 0.199	0.173 ± 0.176	0.121 ± 0.19	0.036 ± 0.224	0.0489	0.0489	0.1248	0.9881	0.3369	0.4103
10 th	100	0.147 ± 0.193	0.177 ± 0.178	0.122 ± 0.2	0.035 ± 0.234	0.0716	0.0716	0.0716	0.5016	0.4914	0.4914
11 th	110	0.134 ± 0.195	0.175 ± 0.173	0.124 ± 0.206	0.019 ± 0.247	0.0612	0.0244	0.0612	0.4388	0.5313	0.5313

Annex B 6. Post-nap session: Mean and SD values for subjective measurements of sleepiness, anxiety, fatigue and alertness.

Variables	Time of testing	Post-nap session				Compared to no-nap condition			Between the nap conditions		
		Bed	Box	Reclining chair	No-nap	Bed	Box	Reclining chair	Bed/ box	Bed /reclining chair	Box/reclining chair
Sleepiness	TS 4	3.61 ± 1.51	3.48 ± 1.16	3.87 ± 1.39	3.66 ± 1.45	0.2833	0.0966	0.8378	0.2997	0.0963	0.0243
	TS 5	3.17 ± 1.27	4.23 ± 2.07	3.69 ± 1.45	6.23 ± 2.04	0.0003	0.0017	0.0005	0.2997	0.6250	0.4040
	TS 6	3.87 ± 1.73	4.07 ± 1.79	4.25 ± 1.68	5.64 ± 2.03	0.0046	0.0006	0.0025	0.8111	0.9441	0.8111
Anxiety	TS 4	1.48 ± 1.33	1.38 ± 1.31	1.50 ± 1.07	1.63 ± 1.29						
	TS 5	1.85 ± 1.77	1.75 ± 1.52	1.61 ± 1.66	1.87 ± 1.61						
	TS 6	1.90 ± 1.93	1.82 ± 1.55	1.90 ± 1.91	2.07 ± 2.09						
Fatigue	TS 4	5.89 ± 1.68	6.29 ± 1.82	5.82 ± 1.83	5.61 ± 1.93	0.3833	0.0790	0.4355	0.7732	0.9518	0.3832
	TS 5	6.37 ± 1.60	5.79 ± 2.26	5.86 ± 2.11	4.02 ± 2.70	0.0010	0.0001	0.0007	0.9173	0.9518	0.8032
	TS 6	5.79 ± 2.05	5.67 ± 2.35	5.52 ± 2.07	4.40 ± 2.52	0.0532	0.0052	0.0168	0.9244	0.9518	0.9244
Alertness	TS 4	6.27 ± 1.69	6.73 ± 1.53	6.15 ± 1.84	6.25 ± 1.72	0.7742	0.0939	0.7742	0.0596	0.7742	0.1940
	TS 5	6.52 ± 1.60	5.78 ± 2.37	6.15 ± 1.91	3.81 ± 2.56	0.0010	0.0010	0.0021	0.7742	0.7742	0.9627
	TS 6	6.29 ± 2.21	5.97 ± 2.12	5.85 ± 1.79	4.38 ± 2.54	0.0048	0.0041	0.0095	0.7391	0.7391	0.9627

Annex B 7. Post-nap session: Mean and SD values for the Standard Deviation of the Lateral Position.

Time on task		Mean and SD values				Compared to non-nap condition					
Block		Bed	Box	Reclining chair	No-nap	Bed	Box	Reclining chair	Bed vs Box	Bed vs Reclining chair	Box vs reclining chair
1 st	10	212.08 ± 59.45	211.26 ± 64.26	220.87 ± 61.66	210.88 ± 54.75	0.9543	0.5601	0.344	0.8899	0.4864	0.344
2 nd	20	198.27 ± 50.72	210.19 ± 44.32	225.36 ± 88.14	239.02 ± 63.36	0.000	0.001	0.018	0.0304	0.030	0.328
3 rd	30	207.55 ± 50.52	215.89 ± 53.5	239.14 ± 119.36	272.41 ± 94.72	0.000	0.000	0.001	0.1941	0.027	0.183
4 th	40	208.35 ± 57.10	239.28 ± 95.03	238.30 ± 103.49	303.33 ± 153.78	0.000	0.000	0.000	0.0369	0.000	0.931
5 th	50	209.68 ± 56.59	272.56 ± 140.60	245.30 ± 122.82	324.68 ± 211.76	0.000	0.009	0.001	0.000	0.019	0.189
6 th	60	218.62 ± 61.20	248.23 ± 92.74	246.11 ± 89.62	269.31 ± 105.48	0.000	0.007	0.0655	0.0311	0.015	0.931
7 th	70	229.71 ± 66.33	273.63 ± 128.26	268.91 ± 103.03	281.94 ± 138.93	0.001	0.6491	0.9087	0.0297	0.016	0.908
8 th	80	237.70 ± 90.23	277.39 ± 146.87	263.23 ± 97.20	276.86 ± 97.77	0.000	0.273	0.273	0.0485	0.039	0.72
9 th	90	247.53 ± 124.94	268.60 ± 113	281.11 ± 139.70	290.16 ± 135.48	0.001	0.6555	0.4501	0.0994	0.163	0.908
10 th	100	246.61 ± 92.29	280.73 ± 162.06	264.62 ± 88.22	280.12 ± 96.96	0.003	0.4574	0.4855	0.2301	0.457	0.920
11 th	110	227.25 ± 75.41	252.92 ± 119.99	238.79 ± 70.76	262.57 ± 75.90	0.001	0.027	0.0638	0.1526	0.475	0.863

Annex B 8. Post-nap session: Mean and SD values for the Number of Inappropriate Line Crossing.

Block	Time on task	Nap conditions				Compared to non-nap condition			Between nap conditions		
		Bed	Box	Reclining chair	No-nap	Bed	Box	Reclining chair	Bed vs box	Bed vs reclining chair	Box vs reclining chair
1 st	10	5.60 ± 22.47	2.684 ± 6.64	2.65 ± 4.08	2.13 ± 4.64	0.881	0.881	0.881	0.881	0.881	0.881
2 nd	20	1.86 ± 5.33	1.5 ± 3.87	4.71 ± 15.67	4.76 ± 6.57	0.020	0.009	0.173	0.661	0.111	0.111
3 rd	30	2.34 ± 6.77	1.73 ± 3.75	6.18 ± 23.41	10 ± 19.16	0.001	0.000	0.009	0.808	0.098	0.035
4 th	40	2.26 ± 4.43	6.13 ± 18.17	6.39 ± 21.08	17.78 ± 33.47	0.002	0.002	0.002	0.138	0.441	0.441
5 th	50	2.73 ± 5.47	10.15 ± 26.51	8.52 ± 26.65	18.44 ± 33.63	0.002	0.020	0.026	0.099	0.197	0.866
6 th	60	3.05 ± 6.06	7.47 ± 14.88	6.18 ± 11.33	9.47 ± 17.22	0.004	0.092	0.124	0.092	0.092	0.857
7 th	70	3.78 ± 7.81	9.10 ± 21.08	8.23 ± 14.17	12.44 ± 29.42	0.060	0.512	0.378	0.182	0.060	0.638
8 th	80	5.31 ± 14.45	11.10 ± 22.93	8.23 ± 13.56	12.07 ± 21.76	0.007	0.637	0.164	0.104	0.097	0.764
9 th	90	8.39 ± 26.12	8.47 ± 15.19	10.13 ± 16.17	11.52 ± 20.32	0.132	0.660	0.660	0.218	0.178	0.660
10 th	100	7.18 ± 15.36	9.31 ± 19.98	9.89 ± 13.67	10.13 ± 15.30	0.106	0.434	0.665	0.665	0.434	0.434
11 th	110	2.39 ± 6.33	2.57 ± 4.97	2.44 ± 5.42	4.15 ± 6.98	0.076	0.218	0.076	0.481	0.695	0.964

ANNEX C. SOMBOX

Annex C 1. The objective of the Startup SOMBOX

Drowsiness is regarded as a major contributor to the increasing number of errors and accidents especially when driving. Sleep-related accidents occur in the early morning and the afternoon (Horne and Reyner 1996b, Garbarino *et al.* 2001). During these periods, the level of arousal declines, and performances naturally decrease. According to the World Health Organization (WHO), the number of road-traffic deaths reached 1.35 million in 2016 (World Health Organization. 2018). In Europe, the regional status report on road safety in 2019 declared more than 221 daily deaths on the road, most of them were children and young adults, and thousands more were severely injured or disabled, with long-lasting damages and physical disabilities (Passmore *et al.* 2019). Ten to thirteen percent of traffic-related accidents have been attributed to drowsiness at the wheel. WHO estimates that traffic injuries will rise to become the fifth leading cause of death by 2030 (Passmore *et al.* 2019). Moreover, the consequences of road traffic injuries are predicted to be more harmful than trachea, lung cancers, and diabetes. Therefore, drowsiness at the wheel stands as a predominant international public health issue (Nabi *et al.* 2006, Bioulac *et al.* 2017). Nevertheless, before advocating the use of naps to prevent sleepiness at the wheel, the problem related to the physical environment where the nap takes place is a major key issue that has received little interest. The first problem that comes to the shore is related to the disturbing effects on sleep induced by the sitting-sleep position. The second major issue is associated with traffic-related noise. Finally, finding a suitable place to nap on highways is challenging, especially for motor vehicle drivers.

To handle all issues stated above, the French startup SOMBOX has developed the first private nap rooms in France which are specifically designed to be implemented on highways to provide drivers and riders with the possibility to stop and to take a nap in suitable environmental conditions whenever they feel the need.

Annex C 2. Product design and architecture

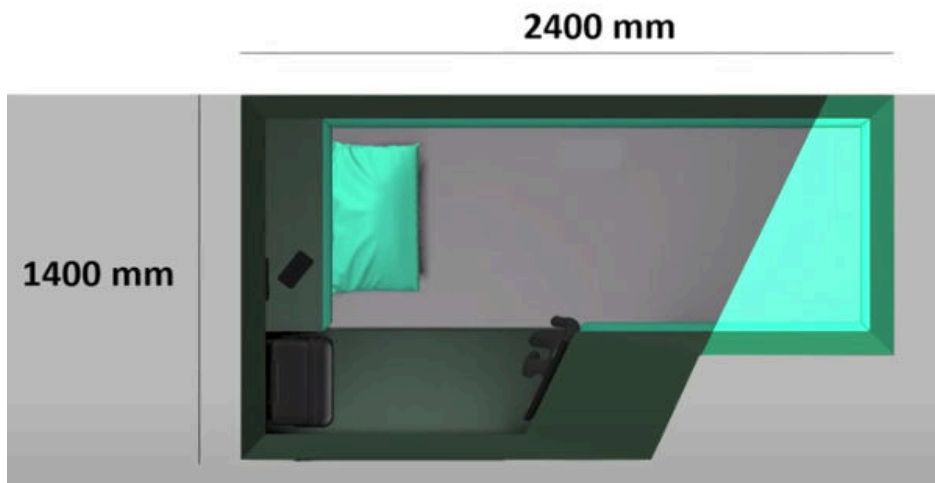
Exterior design

The product was designed by Peugeot Design Lab. The size of the nap room is about 2m². The degree of comfort and security provided in this small room are the markers of innovation and technology. Although it seems small, its size is suitable for one person who wishes to take a nap in a highly appropriate place.



Interior Design and Technology

The design of the box was carefully refined to fit not only the purpose of the room, but also the theme. The Startup stated that they have selected the best materials to best guarantee a good nap experience. Besides, the room is well-equipped with the basic power supplies that one may sometimes need to charge electronic devices



Mattress

The length and the width of the mattress are carefully determined by the ideal standards for a single mattress

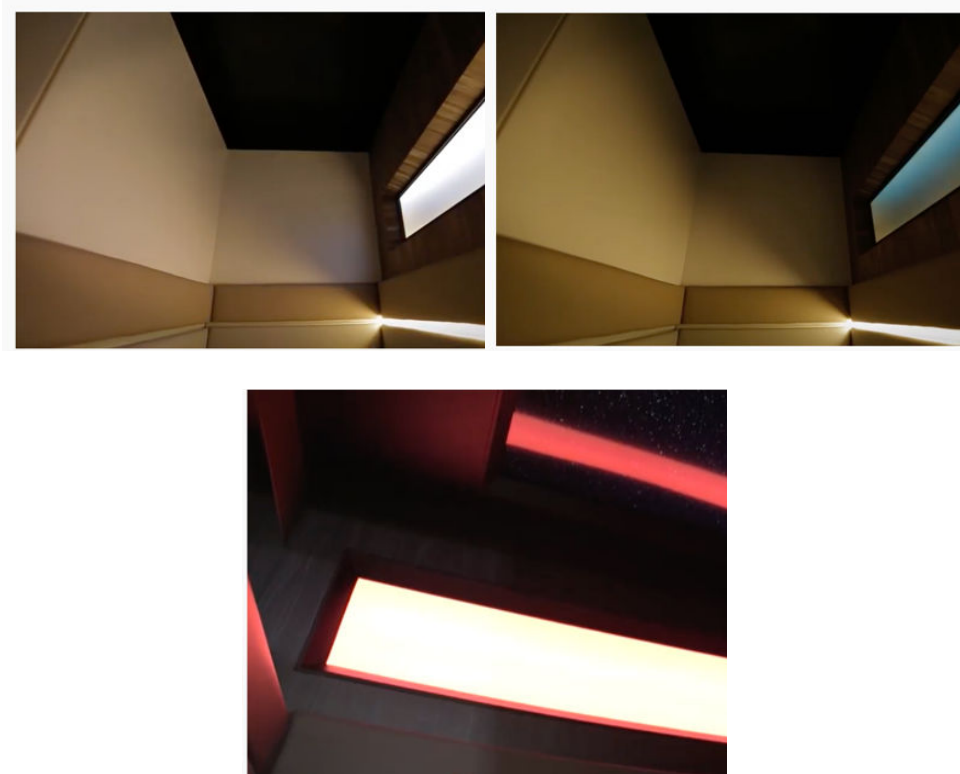


Annex C 3. Lights and Music Technology

Among the many integrated instruments and equipment, we find a very sophisticated lightening system with specific effects that are in tune with the different phases set for the nap experience, accompanied by background relaxing music and aromatic essences containing a combination of essential oils to further enhance the relaxation process during the nap.

The product involved a logic for sleep guidance during the nap, which is mainly based on changes in both the intensity of different light colors (i.e. white and red) and the volume of the music. Overall, the logic is best exemplified by a split of the sleep process into three distinct phases: Falling Asleep, Sleep, and Waking.

The Falling Asleep phase lasted about 7-min and involved an interplay between music and colors that gradually decreased over the falling asleep phase. For the colors, the process started with an intense white light that gradually faded and then switched into the red color that progressively went darker until becoming black.



The Sleep phase lasted about 10-min during which there was a total absence of music and lights.

The Waking phase lasted about 7-min and involved the opposite process of the falling Asleep phase. That is, the music and light progressively increased to reach the starting point.

Effects of Napping on Alertness, Cognitive, and Physical Outcomes of Karate Athletes

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ABSTRACT

DAALOUL, H., N. SOUISSI, and D. DAVENNE. Effects of Napping on Alertness, Cognitive, and Physical Outcomes of Karate Athletes. *Med. Sci. Sports Exerc.*, Vol. 51, No. 2, pp. 338–345, 2019. **Purpose:** It has been suggested that napping is the best recovery strategy for athletes. However, researches on the impacts of napping on athletic performances are scarce. The aim of this study was to determine the effects of a 30-min nap after a partial sleep deprivation, or a normal night condition, on alertness, fatigue, and cognitive and physical outcomes. **Methods:** Thirteen national-level male karate athletes were randomized to experience nap and no-nap conditions, after either a reference or a partial sleep deprivation night. The nap lasted 30 min at 1:00 PM. The postnap testing session started at 2:00 PM by quantifying subjective alertness and fatigue. Cognitive and physical performances were respectively measured before and after the karate-specific test (KST) by simple reaction time (SRT) test, lower reaction test (LRT), mental rotation test (MRT), squat jump (SJ), and counter movement jump (CMJ) tests. **Results:** After a reference night, the nap improved alertness and cognitive outcomes (SRT, LRT, and MRT). No effects on subjective fatigue and physical performances were found. After a partial-sleep deprivation, the nap restored subjective alertness and the decrement in performances caused by sleep loss in most of the tests (MRT, LRT, and KST), but no effects were observed in subjective fatigue and CMJ. After the fatigue induced by KST, there was an ergogenic effect of the nap on the physical performances (CMJ and SJ), and a partial psychogenic effect on the cognitive performances (LRT). **Conclusions:** A 30-min nap enhances cognitive outcomes. It is also an effective strategy to overcome the cognitive and physical deteriorations in performances caused either by sleep loss or by fatigue induced by exhaustive trainings in the afternoon. **Key Words:** NAP, ATHLETIC PERFORMANCE, PARTIAL SLEEP DEPRIVATION, KARATE-SPECIFIC TEST, FATIGUE, ALERTNESS

Considerable attention has been paid to napping as an effective countermeasure for arousal decline and for improving cognitive performances. The previous literature has demonstrated that naps less than 30 min undermine the deleterious impacts of sleep deprivation that affects arousal and performances (1–3). It has also been reported that naps enhance arousal levels even when the quality and the quantity of the previous nocturnal sleep are adequate (4,5). It would be of interest to mention that the differences in results found in previous researches depend on the diversity of factors that determine the benefits acquired when taking short naps. Indeed, factors, like the quality of prior nocturnal sleep, sleep architecture, and temporal placements of the nap during the day, may determine the extent of benefits gained through short naps (6). Likewise, a number of interindividual differences embodied in the experiences with napping (7,8), more

specifically, individuals' abilities to produce slow waves (9), the occurrence of sleep inertia (10), and other factors like tests' characteristics may affect the benefits of naps (7). Compared with long naps (more than 30 min), short naps have negligible effects of sleep inertia upon awaking (10). Although a substantial number of studies on the benefits of napping were conducted outside of the sports sphere (11), a short nap has commonly been favored to be incorporated in an athlete's daily life, as it presents a practical strategy in enhancing recovery when regarding the multiple training sessions performed by sportspeople (12).

Previous articles have focused on how circadian rhythms and prior sleep affect athletic performances; circadian rhythms affect physical abilities and aspects of cognitive functions according to the time of day, with optimal performances at the end of the afternoon (13). Prior sleep influences optimal outcomes since it has been reported that sleep extension improves performances (14), contrary to sleep deprivation which negatively affects the evening performances by decreasing the normal rise of athletic outcomes at that time (15). Noting that before an athletic event, nocturnal sleep has frequently been proved to be disturbed (16). Besides, athletes in individual sports are more affected than athletes in team sports (17).

Given the overall detriments caused by sleep loss, napping is used as a behavioral countermeasure that limits the decrement in performances (11,18). Unfortunately, few studies

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have dealt with the effects of napping on athletes' cognitive and physical performances during daily trainings or before athletic events (11). To the best of our knowledge, only two studies have examined the effects of naps on athletic performances. The first study, Waterhouse et al. (11), has indicated that a postlunch nap improves alertness and aspects of mental and physical performances after a partial sleep loss. The second study, Petit et al. (19), has shown that napping has no effects on performances, in particular when assessing the effects of a 20-min postprandial nap on a short-term physical exercise in normal conditions.

It is relevant to better emphasize that athletic performances depend on the complexity and efficiency of the physical, psychomotor, and cognitive components required to perform a specific sporting task (20). Karate is a competitive sport with a high level of environmental uncertainty (21). Furthermore, karate athletes have to simultaneously perform a mechanical work task with a great physical exertion, and a high level of perceptual abilities (20). The need to offend and defend against the opponents' actions, requires (i) a great level of physical fitness, especially strength, aerobic fitness, muscle power, and speed (22) and (ii) developed cognitive skills, especially rapid anticipation, decision making, and fast reactions (20,23). Additionally, the decrement in muscle performances and mental fatigue emerge as a major problem when bouts of intensive efforts are imposed on competitors especially that, during an official competition, competitors have to perform several matches on the same day (24). Noting that, several studies have provided insight into the negative effects of a fatiguing bout of exercise simulating the costs of athletic efforts on physical outcomes (25,26), and on cognitive performances as well (27). These effects are more noticeable under a sleep deprivation condition (28). In this regard, it is worth pointing that the Karate-Specific Test (KST) is a recent and valid field test for assessing karate-specific endurance-fitness level (29). Karate-Specific Test was relevant in this study because it (i) replicated the real karate combat pattern, and (ii) granted the opportunity to investigate the effects of sleep deprivation and/or nap that have never been assessed with this kind of test.

Therefore, the purpose of this study was to examine the effects of a postlunch short nap, after a full night sleep, on subjective alertness and fatigue, and aspects of mental and physical components. In a perspective of performances' optimization, we also aimed to identify which aspect of the cognitive and/or physical performances is/are affected by sleep loss, and could be recovered after a 30-min nap. Likewise, we aimed to investigate the effects of a nap on fatigue induced by a high-intensity intermittent specific karate test.

METHODS

Participants

Thirteen international-level male karate athletes (age, 23 ± 2 yr; height, 175 ± 2.45 cm; mass, 68 ± 7.5 ; expertise, 15 ± 3)

were volunteered to participate in the study. They were fully informed about the study information. Before participating, a written informed consent was obtained from every participant. The selective criteria for the participants were the following: subjects kept standard times for sleeping habits (bed time, from 10:30 PM to 7:00 AM ± 1 h). All of them were habitual nappers. They were nonsmokers and nonalcoholic or caffeine consumers. They have been trained nine sessions of about 2 h. Since circadian typology might affect the study outcomes, the selection of the players' chronotypes was based on the Horne and Ösberg self-assessment questionnaires (30). According to their answers to the questions related to their timing of sleep and their daily activities, subjects who presented an extreme morning or extreme evening type were eliminated. Instead, players who were "neither type" were involved in this study. The protocol of this study complied with Helsinki's declaration for human experimentation, and was approved by the University Ethics Committee.

Procedure

The experimental design is described in Figure 1. Two weeks before the beginning of the experimental period, the participants were familiarized with the equipment and the experimental procedures to minimize the learning effects during the course of the study. During habituation sessions, subjects took a short bout of nap in the laboratory. Thereafter, in experimental sessions, athletes were randomly assigned to experience both nap and no-nap conditions, after either a full night sleep (RN) (>7 h), or a partial sleep deprivation (PSD) (sleep 11:00 PM to 3:00 AM). On the day before the experimental session, subjects came to the laboratory in the evening and had the same standardized dinner at 8:00 PM, and later they went to bed at 10:30 PM. The nocturnal sleep and naps were monitored by actigraphic recording and sleep diaries. In addition, they were strictly supervised by two experimenters during experimental nights.

To keep the subjects awake during the partial-sleep deprivation condition, they were allowed to watch television, read books, listen to the music and use computers. The four protocol conditions were carried out with at least 1 wk apart. This period allowed them to have a sufficient recovery from one night of sleep loss. The nap condition included a 30-min nap period from 1:00 PM to 1:30 PM in bed after lunch. In the no-nap condition, participants were free to choose their activities. A 30-min period separated the nap or the rest condition from the assessment sessions. Postnap testing took place in the National Center of the karate team of Tunisia. The postnap testing session started at 2:00 PM, first by recording the visual analogue scales to quantify subjective alertness and fatigue. Then, it consisted of the following tests, respectively, before and after the KST:

Cognitive performance tasks: simple reaction time (SRT), mental rotation test (MRT), lower reaction test (LRT).
Physical assessment session: squat jump, (SJ), counter movement jump (CMJ), KST.

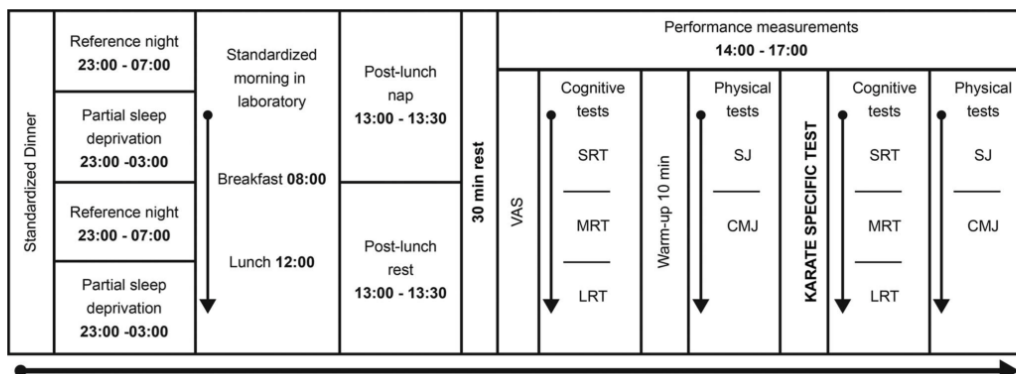


FIGURE 1—Design of the experimental protocol. Subjects experienced nap and no nap conditions (4th column) on four different occasions; following a reference night, or a partial sleep deprivation night (2nd column).

Before the beginning of the physical testing session, subjects completed a standardized warm-up of 10 min, as recommended by Tabben et al. (29), and it consisted of self-selected-intensity jogging, vertical jumping, and dynamic stretching (hip extensors, hamstrings, hip flexors, and quadriceps femoris), and later followed by a 5-min passive rest. The recovery time between every physical test was about 5 min, and 2 min between every trial in the same test.

Different precautions were taken before the testing session. Instructions about sleep and diet were given to the subjects. During the period of investigation, they were prohibited from consuming food, beverages, or any known stimuli (e.g., caffeine) or depressants (e.g., alcohol) that would possibly enhance or compromise alertness. Throughout the experimental period, participants were requested to maintain their habitual physical activities, and to avoid strenuous activities during the 24-h before the testing sessions. It was easy to control compliance with these directions because the participants were students in the same institution with the same daily schedules. The protocol of this study was made to be close enough to athletes' typical real life routines.

Performance Measurements

Actigraphy and sleep diaries. For objective sleep measurements, we used the MotionWatch 8[©] actigraphy system (MW8; camntech). To ensure that subject's sleep patterns throughout the course of the study was typical (i.e., not unusually restricted or extended), actigraphic recording was edited with information listed in the subjective sleep diaries. The MW8 data was downloaded and analyzed using MotionWare version 1.0.25 (camntech). A high-level sensitivity was used for the estimation of sleep-wake patterns in 60-s epochs.

To make sure that the protocol of the study was fully respected, the following sleep parameters of the night before the experimental session were analyzed. The parameters were:

Bed time, Fell asleep time, Woke up time, Total time in bed, and Assumed sleep (the total elapsed time is between the "Fell Asleep" and "Woke Up" times).

Subjective alertness and fatigue. Subjective sleepiness and fatigue were evaluated using the 100-mm-long visual analog scale (31). The values ranged from 0 (very alert or in peak physical condition) to 100 (very sleepy or very tired).

Cognitive Tasks

Simple reaction test. When performing the reaction test, subjects were asked to respond as quickly as possible to a visual stimulus presented systematically at the center of the computer screen. Participants were asked to press a button with the index finger when a visual stimulus (Blue Square) appeared. Simple reaction test was conducted using software Reaction, INRP free software (version 4.05) created by Tilquin (32).

Mental rotation test. Participants were asked to compare two of the four stimuli samples presented on the screen and to state if they are identical, except the rotation, or are different from the reference figure presented on the left of the screen. The stimuli used in this test are based on Shepard and Metzler stimuli (33). The test required mental maintaining and manipulation of the presented figures with accuracy and speed. There were 20 items in the set, and 3 min were given for each subset of 10 items separated by a 2-min break. We used the same procedure as Peters et al. (34) for scoring, giving one point for each item only if both answers were correct. This test was also conducted using software Reaction, INRP (version 4.05) created by Tilquin (32).

Lower body reaction. The simple acoustic-reaction time of the lower limb was measured using an optical jump system (Optojump Next, Microgate, Italy). The trial started inside the testing area. When receiving the acoustic sound, the subject must jump as quickly as possible. The sound was

randomly generated by the measuring system and every stimulus lasted 1 s. Then, the Optojump system recorded the delay in time between the beginning of stimulus and the flight time (Time when the athletes left the testing area by jumping).

Physical Tasks

SJ and CMJ. The CMJ included a leg flexion from the upright standing position with the hands on the hips and immediately followed by a quick descended position to 90° knee flexion, and instantly performed an explosive concentric action for maximal height with the hands on the hips. The SJ consisted of a maximal jump held from a flexed knee position (approximately 90°) with the hands on the hips and without performing any countermovement before the beginning of the jump. These jump tests were monitored with an optical jump system (Optojump Next, Microgate, Italy). The apparatus comprises two bars placed ~1 m apart, parallel to each other, and was interfaced with a microcomputer via a USB port. The optical system transmits an infrared light 1–2 mm above the floor. When the light is interrupted by the feet, the units trigger a timer with a precision of 1 ms which allows the measurement of flight time and contact time. For both tests after the signal, the subjects started whenever they felt ready to jump but not more than 4 s for SJ test. The participants performed three trials in every test with recovery time of 2 min between trials, and finally, the best one was recorded.

Karate-Specific Test

The test protocol consisted of sequential sets composed of two attacks toward a body opponent bag. The first attack included a two-punch combination, lead straight punch followed by a rear straight punch (i.e., *kisamigyaku-zuki*), and the second attack used a rear roundhouse kick (i.e., *mawashigeri-chudan*). The test was packed with two auditory signals; the first was in the beginning of the bout of the exercise, and the second sound indicated the rest time. The time to complete the exercise bout remained the same for 3 s; however, the recovery time between bouts progressively decreased every 3 min. Every punch and kick had to be executed with the maximum power possible. The test stopped and the time to exhaustion (TE) was determined when the participants failed to complete the set of movements in the 3-s interval twice, or when there was a clear decrease in force or in performed techniques. They performed the KST wearing protections that are specifically designed for

karate. The test was carried out on a tatami (i.e., competition karate floor). Karate athletes must use their favorite guards and were not allowed to change their guard during the test. Distance between the body opponent bag and the front foot was established and fixed before the beginning as 1.5 m.

Statistical Analysis

Statistical tests were processed using Statistica 7.1 (Statsoft, France). Data were reported as mean \pm SD. Paired *t*-tests were used for sleep variables between the control and the nap conditions after RN, and the control and the nap conditions after PSD. The data concerning the effects of napping on the performance was conducted using a two-way ANOVA analysis [2 (nap conditions) \times 2 (sleep conditions)] with repeated measures. Data concerning the effect of napping on fatigue induced by KST was conducted using a two-way ANOVA analysis [2 (nap conditions) \times 2 (sleep conditions)] expressed by calculating the difference between the performances after and before KST. When the ANOVA indicated significant main effects, differences between the means were tested by Tukey's *post hoc* tests. The level of statistical significance was set at ($P < 0.05$).

RESULTS

Prior Nocturnal Sleep

The actigraphic data indicated that equivalent amounts of five sleep parameters (e.g., bed time, fall sleep time, wake up time, time in bed, assumed sleep) obtained on the night preceding testing under both the nap and no-nap conditions following a reference night and partial sleep deprivation night (see Table 1).

Subjective Alertness and Fatigue

Subjective alertness. There was a significant main effect nap ($F_{(1-12)} = 5.14$, $P < 0.05$; $\eta_p^2 = 0.30$), indicating that subjective alertness increased after the nap comparing to the no-nap condition. Moreover, there was a significant main effect for sleep ($F_{(1-12)} = 66.50$, $P < 0.001$; $\eta_p^2 = 0.84$), indicating that sleep loss decreased the alertness level comparing to the reference night. However, there was no significant main effect for nap–sleep interaction ($P > 0.05$) (see Table 2).

TABLE 1. Sleep parameters of the night preceding the testing, after the nap and the no-nap conditions, and after a reference night and a partial sleep deprivation night (mean \pm SD).

	No Nap		Nap	
	RN	PSD	RN	PSD
Bed time	10:49 PM \pm 00:27 min	10:50 PM \pm 00:23 min	10:56 PM \pm 00:23 min	10:55 PM \pm 00:30 min
Fall asleep time	11:13 PM \pm 00:30 min	11:19 PM \pm 00:28 min	11:20 PM \pm 00:26 min	11:24 PM \pm 00:32 min
Wake up time	7:05 AM \pm 00:45 min	3:03 AM \pm 00:06 min	7:24 AM \pm 00:46 min	2:55 AM \pm 00:12 min
Time in bed	8:20 AM \pm 00:46 min	4:13 AM \pm 00:22 min	8:27 AM \pm 00:42 min	4:09 AM \pm 00:21 min
Assumed sleep time	7:52 AM \pm 00:48 min	3:44 AM \pm 00:27 min	8:02 AM \pm 00:48 min	3:39 AM \pm 00:27 min

Mean \pm SD values of sleep parameters of the night preceding the testing, following nap and no-nap conditions, after a reference night and a partial sleep deprivation. Data were calculated by wrist activities. There were no significant differences ($P > 0.5$) in any sleep parameters during the reference nights and partial sleep deprivation nights, following nap and no-nap conditions, indicating good experimental reproducibility.

TABLE 2. Subjective alertness and fatigue following nap and no-nap conditions, after a reference night and a partial sleep deprivation (mean \pm SD).

	No Nap		Nap	
	RN	PSD	RN	PSD
Alertness	5.6 \pm 2.2	3.0 \pm 1.2*	7.1 \pm 1.3**	3.6 \pm 1.2***
Fatigue	4.4 \pm 0.8	7.4 \pm 1.2*	4.1 \pm 1.2	6.5 \pm 1.5*

Mean \pm SD values for subjective alertness, fatigue following nap and no-nap conditions, after a reference night and a partial sleep deprivation.
 * $P < 0.05$ significant difference from RN.
 ** $P < 0.05$ significant difference in comparison with the no nap condition.

Subjective fatigue. The results showed that there was a significant main effect sleep ($F_{(1-12)} = 85.69, P < 0.001; \eta_p^2 = 0.87$), indicating that subjective fatigue increased after the partial-sleep deprivation condition comparing to the reference night. However, there was no significant main effect for nap ($P > 0.05$), and for nap-sleep interaction ($P > 0.05$) (see Table 2).

Cognitive Performance

The effects of napping on performances.

Simple reaction time. There was a significant main effect of nap ($F_{(1-12)} = 5.34, P < 0.05; \eta_p^2 = 0.30$), indicating the improvement in SRT performance after the nap compared with the no-nap condition. However, there was no significant main effect for sleep ($P > 0.05$), and for nap-sleep interaction ($P > 0.05$) (see Table 3).

Mental rotation test. There was a significant main effect of nap ($F_{(1-12)} = 5.03, P < 0.05; \eta_p^2 = 0.29$), indicating that the score in this test was better after the nap compared with the no-nap condition. Moreover, the results showed a significant main effect for sleep ($F_{(1-12)} = 5.28, P < 0.05; \eta_p^2 = 0.30$), stating that the performance decreased after the partial sleep deprivation compared with the reference night. However, there was no significant main effect for nap-sleep interaction ($P > 0.05$) (see Table 3).

Lower reaction test. There was a significant main effect of nap ($F_{(1-12)} = 6.86, P < 0.05; \eta_p^2 = 0.36$), with an increase being observed after the nap compared with the no-nap condition. Moreover, the results revealed a significant main effect for sleep ($F_{(1-12)} = 4.69, P < 0.05; \eta_p^2 = 0.28$), showing that the performance decreased after the partial sleep deprivation compared with the reference night. However, there was no significant main effect for nap-sleep interaction ($P > 0.05$) (see Table 3).

TABLE 3. Cognitive and physical parameters measured following nap and no-nap conditions, after a reference night and a partial sleep deprivation (mean \pm SD).

Parameters	No Nap		Nap	
	RN	PSD	RN	PSD
SRT (ms)	290.8 \pm 35.3	300.9 \pm 22.7	278.7 \pm 24.9*	285.7 \pm 21.5*
MRT	20.8 \pm 8.4	16.9 \pm 7.6**	21.0 \pm 8.0*	21.7 \pm 8.6***
LRT (ms)	437.4 \pm 4.0	457.3 \pm 8.1**	342.2 \pm 4.3*	421.8 \pm 5.0***
SJ	39.6 \pm 4.4	38.0 \pm 4.2	39.0 \pm 5.2	39.0 \pm 4.9
CMJ	42.7 \pm 4.2	41.5 \pm 4.7**	42.3 \pm 5.2	41.7 \pm 4.6**

Mean \pm SD values for cognitive and physical parameters measured before the KST following nap and no-nap conditions, after a reference night and a partial sleep deprivation.
 * $P < 0.05$; significant difference in comparison with the no nap condition.
 ** $P < 0.05$; significant difference from RN.

The effects of napping on fatigue induced by the KST.

Simple reaction time. The results showed that there was no significant main effect for nap ($P > 0.05$), sleep ($P > 0.05$), and for nap-sleep interaction ($P > 0.05$) (see Table 4).

Mental rotation test. The results showed that there was no significant main effect for nap ($P > 0.05$), sleep ($P > 0.05$), and for nap-sleep interaction ($P > 0.05$) (see Table 4).

Lower reaction test. There was a significant main effect for nap-sleep interaction ($F_{(1-12)} = 5.58, P < 0.05; \eta_p^2 = 0.31$). However, there was no significant main effect for nap ($P > 0.05$), and for sleep ($P > 0.05$). The *post hoc* test revealed that the effect of nap on fatigue after the KST was depended on the sleep condition. In fact, in the partial sleep deprivation condition, performance was the same with and without napping ($P > 0.05$). However, following the reference night performance was better with napping than without napping ($P < 0.05$) (see Table 4).

Physical Performance

Time to exhaustion during the KST. There was a significant main effect for nap ($F_{(1-12)} = 10.88, P < 0.01; \eta_p^2 = 0.47$), sleep ($F_{(1-12)} = 10.37, P < 0.01; \eta_p^2 = 0.46$), and for nap-sleep interaction ($F_{(1-12)} = 8.98, P < 0.01; \eta_p^2 = 0.42$). The *post hoc* test demonstrated that the nap improved the time to exhaustion after the partial sleep deprivation night ($P < 0.001$). However, napping did not improve the performance after the reference night ($P > 0.05$). Regarding the effect of sleep deprivation, during the no-nap condition, time to exhaustion was affected by sleep loss compared with the control condition ($P < 0.01$). After napping, the effect of sleep deprivation disappeared compared with the reference night ($P > 0.05$) (see, Fig. 2).

The effects of napping on performances.

Squat jump. The results showed that there was no significant main effect for nap ($P > 0.05$), sleep ($P > 0.05$), and for nap-sleep interaction ($P > 0.05$) (see Table 3).

Counter movement jump. There was a significant main effect of sleep ($F_{(1-12)} = 7.04, P < 0.05; \eta_p^2 = 0.37$), indicating that the partial sleep deprivation significantly decreased the performance in CMJ compared with the reference night.

TABLE 4. Δ performance for cognitive and physical parameters measured following nap and no-nap conditions, after a reference night and a partial sleep deprivation (mean \pm SD).

	No Nap		Nap	
	RN	PSD	RN	PSD
SRT (ms)	9.4 \pm 22.7	22.8 \pm 71.8	20.7 \pm 46.5	5.3 \pm 32.4
MRT	0.5 \pm 0.7	1.8 \pm 1.6	0.9 \pm 1.7	3.2 \pm -0.1
LRT (ms)	-24.0 \pm 39	6.2 \pm 76.9	27.7 \pm 36.7*	-3.0 \pm 24.3
SJ	-2.1 \pm 3.8	-1.9 \pm 1.8	-0.8 \pm 2.3**	-0.8 \pm 1.6**
CMJ	-3.6 \pm 1.7	-3.8 \pm 1.1	-3.1 \pm 1.3**	-3.1 \pm 1.2**

Mean \pm SD values for Δ performance of cognitive and physical parameters following nap and no-nap conditions, after a reference night and a partial sleep deprivation.
 Δ Performance is expressed by calculating the difference between the performances after and before the KST.
 * $P < 0.05$; significant difference in comparison with the no nap condition after RN.
 ** $P < 0.05$; significant difference in comparison with the no nap condition.

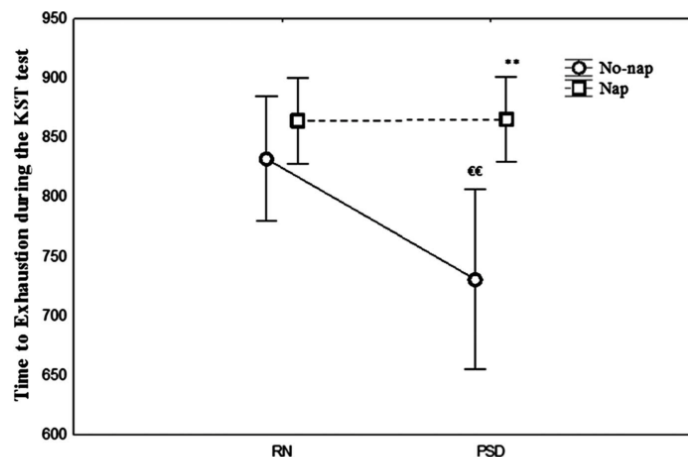


FIGURE 2—Mean \pm SD values of time to exhaustion during KST with nap (□) and without nap (●), after RN (reference night) and PSD (partial sleep deprivation). **Significant difference from PSD without nap ($P < 0.01$); €€Significant difference from RN without nap ($P < 0.01$).

However, there was no significant main effect for nap ($P > 0.05$), and for nap–sleep interaction ($P > 0.05$) (see Table 3).

The effects of napping on fatigue induced by the KST.

Squat jump. There was a significant main effect nap ($F_{(1-12)} = 8.43$, $P < 0.01$; $\eta_p^2 = 0.41$), indicating an improvement in SJ performance following the nap comparing with the no-nap condition. However, there was no significant main effect for sleep ($P > 0.05$), and for nap–sleep interaction ($P > 0.05$) (see Table 4).

Counter movement jump. There was a significant main effect nap ($F_{(1-12)} = 6.15$, $P < 0.05$; $\eta_p^2 = 0.33$), indicating the improvement in CMJ performance following the nap comparing with the no-nap condition. However, there was no significant main effect for sleep ($P > 0.05$), and for nap–sleep interaction ($P > 0.05$) (see Table 4).

DISCUSSION

This study is the first in our knowledge that aims to evaluate the effects of a 30-min nap after lunch on subsequent alertness, fatigue, cognitive and physical performances in karate athletes after two nocturnal regimens (i.e., RN and PSD). Our results have revealed that a 30-min nap after RN has led to significant improvements in alertness and in cognitive performances. However, there has been no significant change in physical performances. Indeed, our results have demonstrated that a PSD has led to a significant alteration in alertness, fatigue, as well as in cognitive (MRT, LRT) and physical (KST, CMJ) evening performances. Nevertheless, the 30-min nap has restored the decrement in performances caused by sleep loss in most of the performed tests. Regarding the effects of napping on fatigue induced by the KST, the results have revealed that short naps have

had ergogenic effects on physical performances (CMJ, and SJ) and a partial psychogenic effect on cognitive performances (LRT).

Compared with no-nap condition, the results of the present study have revealed that after RN, the 30-min nap has significantly improved alertness and cognitive performances (i.e., SRT, LRT, and MRT). These results are consistent with the previous reports indicating that short naps produce a wide range of benefits from increasing alertness to improving cognitive outcomes (4–6). What is noteworthy in this study is the noticeable improvement in response times as assessed by the SRT and LRT. The gain acquired in the information processing speed is relevantly meaningful to an elite athlete in the context of high-level sports. Therefore, these findings seem to be of great usefulness when considering that a small change in the context of highly professional levels can make all the difference. However, no significant change has been observed after the nap on fatigue and on physical performances (i.e., SJ, CMJ, and KST). These results are in line with Petit et al. (19) study that has demonstrated that napping has no beneficial effects on physical performances. In this context, it is important to mention that the absence of effects on physical performances may also indicate that the period of 30 min that separates the nap from the assessment session is sufficient to avoid any negative effect of sleep inertia (11). Evidently, optimal alertness levels and cognitive skills are integral parts of the abilities required to reach the highest elite-sport performances. Indeed, the present findings indicate that napping is an efficient strategy that needs to be taken into consideration among elite sportspeople in their pursuit of excellence, especially when napping does not violate doping regulations.

Along with the present study, the results have also indicated that PSD leads to a significant decrease in subjective levels of alertness and fatigue. In the same way, the scores in

MRT and LRT are negatively affected by sleep loss. These findings are consistent with previous studies attesting that sleep deprivation has negative impacts on subjective alertness, fatigue, and cognitive performances (28,35). However, no significant change is observed in SRT and this might be due to the limited duration of this test (35).

Regarding the effects of partial sleep deprivation on the physical performances, the results have showed a decrease in CMJ, while no change in performance is observed in SJ. These results can be explained by the fact that the CMJ has a higher sensitivity to detect neuromuscular fatigue compared with the SJ (36). Added to that, the results have revealed that time to exhaustion during KST is negatively affected by sleep deprivation. Noting that, the KST measures the maximal aerobic capacity of karate athletes (29). Therefore, the decrement in performance observed in this test may reflect the limited physiological capacity of sleep-deprived athlete to perform a physical work-load level. These results are in line with of Souissi et al. (15), and Bougard and Davenne (37) studies, that have revealed a decrease in the evening performances as a consequence of lower circadian rhythm amplitude caused by sustained wakefulness. Accordingly, the present data suggest that the impairments in Karatekas' outcomes during competitions can be explained by the decrease in cognitive and physical evening performances caused by sleep loss. However, the decrease in performances is restored after the nap in most of the tests.

In other respects, the results of the present study have indicated that short daytime naps (i.e., 30 min) are effective to counteract the deleterious effects of partial-sleep deprivation on alertness and performances for high-level athletes. In fact, the impairment of time to exhaustion during KST is suppressed after the nap. This finding can be regarded as one of the main results of the present study. Likewise, the decrement in the performances observed in LRT and MRT is restored by the nap. These findings are congruent with previous researches showing that short naps have the possibility to restore the impairment in alertness and performance caused by sleep loss (1–3), and more specifically, the present data support Waterhouse et al. (11) findings attesting that a postlunch nap improves alertness and aspects of mental and physical performances after a partial-sleep deprivation. According to our hypothesis, these findings can be placed in a professional context by implementing napping as a strategy to overcome the drawbacks of performances' deterioration caused by sleep loss especially for high-ranking athletes. However, the nap does not restore the decrease in subjective fatigue and the performance in CMJ test. A possible explanation is that a short nap opportunity for highly active athletes is not a suf-

ficient duration to restore subjective fatigue and the performance in CMJ test.

In the current study, the results have revealed that the nap reduces performances deficits caused by KST in SJ and CMJ tests. Indeed, the decrease in LRT performance depends on sleep conditions. In fact, the nap restores the performance in this test only after RN. These results can partially confirm to Pelka et al. (38) study, which examines the effects of different relaxation strategies on physical performances in terms of recovery between two equal sprint protocols. Their results have demonstrated that the use of breathing regulation and a power nap leads to improved running speed comparing to the control condition, yoga and progressive muscle relaxation. A variety of strategies have been proposed to have an ergogenic potential for athletes such as caffeine consumption (39), light exposure modalities (40), and more recently, the cupping therapy (41). However, there is no research available on napping as a strategy to counteract performances' deterioration caused by fatigue in a context of high level sport. Let us recall that fatigue in this study was induced by a specific intermittent field test simulating the karateka's maximal physiological exertion (29) and, the present results prove that short naps have ergogenic and partial psychogenic potentials for athletes, as it can be considered as an effective strategy for the management of fatigue.

In summary, the present results have demonstrated, first, that napping is a potential strategy that ensures better performances levels among elite sportspeople in their pursuit of excellence. Second, short daytime naps are effective to counteract the deleterious effects of partial sleep deprivation. Again, these findings can be placed in a professional context by implementing napping as a strategy that aims at managing the fatigue induced by the exercise. Noting that, these results may suit the professionals' goals, and without violating doping regulations. Nevertheless, future researches are required to give insight into the neurophysiological mechanism responsible for the improvement of the athletic performance gained from such naps.

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Impacts of a midday nap on cognitive and physical performances according to the nap environment and prior nocturnal sleep

The objective of the present work was to investigate the impacts of energetic and restorative naps on subjective levels of arousal, and on aspects of cognitive and physical performances in the afternoon in healthy habitual nappers. To meet our objective, three experimental studies were implemented. We investigated the impacts of the nap in different sleep environments, namely the bed, the reclining chair, and the SOMBOX sleep product which we contributed to its development and validation. We found that regardless of the sleep environments, all the naps enhanced daytime arousal and improved cognitive performances, with longer lasting effects observed after taking a nap in the bed compared to a nap in the box or the reclining chair. Accordingly, we recommend napping in a bed. Regarding the impacts of the energetic nap on cognitive performances, we found that the nap enhanced daytime arousal and improved sustained attention, mental rotation, and information processing speed in the simple reaction time and the delayed match-to-sample tests. However, a negative impact of napping was observed in the visual scanning test. Concerning the effects of the energetic nap on physical performances, the results demonstrated that there were no improvements in muscular power, maximal jump high, and endurance performances compared to the no-nap condition. Nevertheless, the nap enhanced speed and directional ability. Together, these findings suggested that the effects of the energetic nap on cognitive and physical performances are highly task-dependent. Regarding the effects of the restorative nap, we found that the deficit in cognitive and physical performances induced by partial sleep deprivation was restored following the nap. We assume that the beneficial effects of the energetic and restorative naps on performances depend on a fine balance between the input of the circadian system and the sensitivity level of the performed task to the homeostatic pressure.