ORIGINAL ARTICLE

Field study of sleep and functional impairments in solo sailing races

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Abstract

Multi-day single-handed sailing races put exceptional strain on sailors, requiring high cognitive functioning and 24 h per day readiness to perform. Fatigue from sleep loss, circadian misalignment, workload and other factors is of significant concern, jeopardizing competitiveness as well as safety. Almost no research has been devoted to this, in part because collecting data on sleep and performance in solo sailors during races at sea is challenging. The present study aimed to contribute valuable data on the issue by assessing sleep–wake patterns and functional impairments in a total of 16 sailors during a two-leg transatlantic race. Each sailor recorded sleep periods and functional impairments during the two legs of the race. Self-reported sleep duration per 24 h was 4.1 ± 0.4 h in the first (shorter) leg and 4.6 ± 0.4 h in the second (longer) leg. Sleep was polyphasic and varied in a normal circadian pattern – sleep propensity was highest (about 50%) in the middle of the night, with a smaller (nearly 15%) secondary peak in the middle of the afternoon. Significant functional impairments were reported throughout the race including technical errors, mood changes and hallucinations. These impairments are consistent with the typical effects of substantial sleep loss and are likely to reduce the safety margin. Single-handed sailors could benefit from the development of innovative tools to help them to manage sleep and fatigue and thereby improve safety and effectiveness.

Key words: circadian rhythm, extreme conditions, fatigue risk management, neurobehavioral performance, single-handed offshore sailing races, sleep.

INTRODUCTION

Solo offshore sailboat racing is a sport activity where race duration can exceed weeks and even months and demands on the sailors are extreme. Only a few published studies on single-handed sailors have described sleep during multi-day offshore races.[1–4] Such races place sustained physical and psychological demands on the skipper, which can result in exhaustion and chronic loss of sleep.[5] Since sustained sleep restriction has been shown to affect alertness, vigilance, attention, memory, mood and executive functioning adversely,[6–9] sleep loss may be a critical issue for single-handed sailors for both safety and competitiveness.

Due to the inherent difficulty in obtaining field data during single-handed racing, sleep amounts and sleep patterns as well as associated functional impairments

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have not been clearly documented in single-handed off-shore sailors. There also are no published studies on the possible influence of race duration (days at sea) in this context. Sailors often adopt wake–sleep schedules composed of ultra-short naps.[1] However, the accumulation of daily amounts of sleep through such schedules and the effects these schedules may have on functional impairments are not known. A study of sleep patterns in single-handed sailing could provide new insights into how napping schemes may play a role in sleep management for this and other exceptionally demanding, long-duration activities (e.g., long-distance sports competitions and expeditions) and operations (e.g., in the military).

Published studies of offshore sailors have thus far not specifically demonstrated a significant effect of sleep loss on alertness, performance or safety. However, Theunynck and colleagues[10] discussed a possible link in a study of a solo sailor during a race of 104 days around the world, during which the sailor was faced with serious functional impairments at the same time as experiencing strong subjective feelings of fatigue. Yet, the possible risk of functional impairments from sleep loss is not well managed by most solo sailors.

The complexity of performing sleep and performance studies under the extreme conditions of offshore sailin, makes it difficult to accurately assess sleep durations and relationships with functional impairment. Actigraphy has been used during sailing races, but proved challenging as a tool for measuring sleep duration at sea[2,10] due to motion artifacts from boat movements, equipment loss, and perceived inconvenience to sailors. For the present study, we used a diary to estimate sleep/nap durations and record significant functional impairments in real time. This approach accommodated the demanding schedules of single-handed sailors, and boosted their willingness to participate in the study. For data quality control, we performed post-race interviews to verify sleep and functional impairment outcomes and clarify the meaning of the sailors' log entries.

The aim of the study was to examine self-reported sleep–wake schedules (duration and time of day of naps) and self-assessments of functional impairments for single-handed sailors during two legs of a transatlantic race. We hypothesized that single-handed offshore sailing involves cumulative sleep loss and results in decreased cognitive alertness, leading to impaired performance and well-being and threats to personal safety.

METHODS

Participants

Sailors competing in a single-handed transatlantic race were invited to participate in the study. Sixteen participants (mean ± standard deviation of age: 34.8 ± 8.9 years; 13 males, 3 females; self-estimated habitual sleep duration: 7.7 ± 0.8 h) completed data collection in either or both legs of the race. They had 3.0 ± 1.6 years of solo sailing experience; three of them had previously participated in a transatlantic race. Prior to the race, all sailors completed a qualification course of 1000 nautical miles (one week at sea). Twelve of the participants contributed data in the first (shorter) leg, and eight contributed data in the second (longer) leg. Among them, four contributed data in both legs of the race.

The ethics committee of Nord Ouest IV (Lille, France) reviewed the study and raised no objections; and the medical staff of the race also assented to the study. Participants gave written informed consent to participate in the study and agreed to publication of (de-identified) study results.

Single-handed transatlantic race with two legs

The study was performed during a single-handed transatlantic race with two legs – the "Transat 650" race. All sailors used the same type and length of yacht (20-ft Mini "series"; one sailor used a "prototype"), making the race comparable across racers. There are no major strategic options in the race, making sailing conditions essentially the same for all competitors. Sailors had no outside assistance during the entire duration of the race.

Figure 1 shows the route of the two legs of the race. The first leg of the race started from the port of La Rochelle, France, at 12:00 (noon) on September 18, 2007. It lasted from 6 to 8 days, covering more than 1100 nautical miles, and ended in the port of Funchal, Madeira Island, Portugal. After a rest period of at least 11 days (longer for sailors finishing the first leg earlier), the second leg started at 13:00 on October 6, 2007 from Funchal. It lasted from 18 to 24 days, covering more than 3100 nautical miles, and ended in the port of Salvador de Bahia, Brazil.

Diary

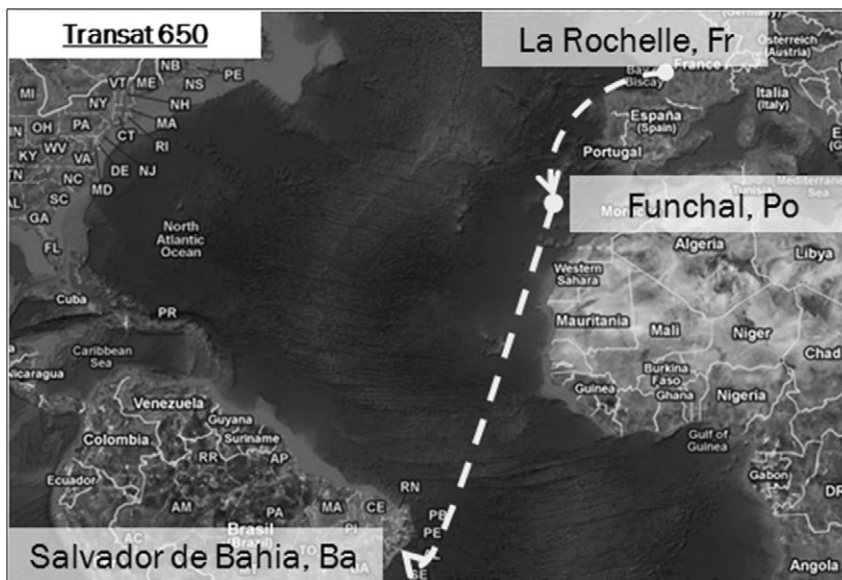At sea, sailors are required to keep an on-board log to keep track of position (longitude, latitude) and

Figure 1 Orthodromic route of the Transat 650 race.

environmental conditions, several times a day. A diary was developed for the participants, in which every 24-h period was covered by two adjacent pages for efficient recording of polyphasic sleep patterns and significant events. Participants were asked to use the diary and the on-board log as a single tool. They were instructed to record their sleep times (in local time) as soon as possible every time after they slept. They were also instructed to record any incidents, self-assessed performance impairments and technical errors experienced, as well as environmental conditions such as wind speed and swell height. The diary data were the sole data source analyzed in this study.

From the diary, the following sleep data and self-reported functional impairments were extracted, and categorized as follows:

- *Sleep timing and duration:* Each subject's (polyphasic) sleep pattern was tabulated as minutes of sleep in each 1-h block across all times of day over all days at sea.
- *Events classified as psychomotor impairments:* Severe technical errors (omissions, clumsiness and severe wipe-outs when steering the boat), breakage or loss of equipment (e.g., tearing of a spinnaker, but not normal wear-and-tear, power problems, etc.), and life-threatening situations (man overboard, fire on board, etc.) were recorded.
- *Events classified as difficulties waking up:* Inability to be awakened by an alarm (with the boat drifting freely) and self-reported significant impairments after awak-

ening or inability to distinguish dream from reality (severe sleep inertia) were logged.

- *Events classified as hallucinations:* Impression that the skipper was not alone on board, etc., and delirium were logged.
- *Events classified as mood disturbances:* Self-reported bad mood and/or feelings of sadness were recorded.

Interview

Within 48 h of the end of each leg a semi-structured interview, which included a page by page reading of the diary, was conducted with each participant to clarify/verify the written information and ascertain the time of day of each of the written entries. Interviews took approximately 1 h for the short leg, and 2 h for the long leg. All interviews were conducted by the same investigator (the first author of this paper).

Data set

In order to analyze data within the same temporal window for every sailor, for each leg of the race the sleep data set was started at 08:00 on the start day and ended at 08:00 on the day when the first sailor finished. Sleep data collected by other participants after the first sailor had finished were not used for analyses. As determined by the earliest time of day of arrival, days were defined as 24 h periods starting at 08:00 for the sleep data
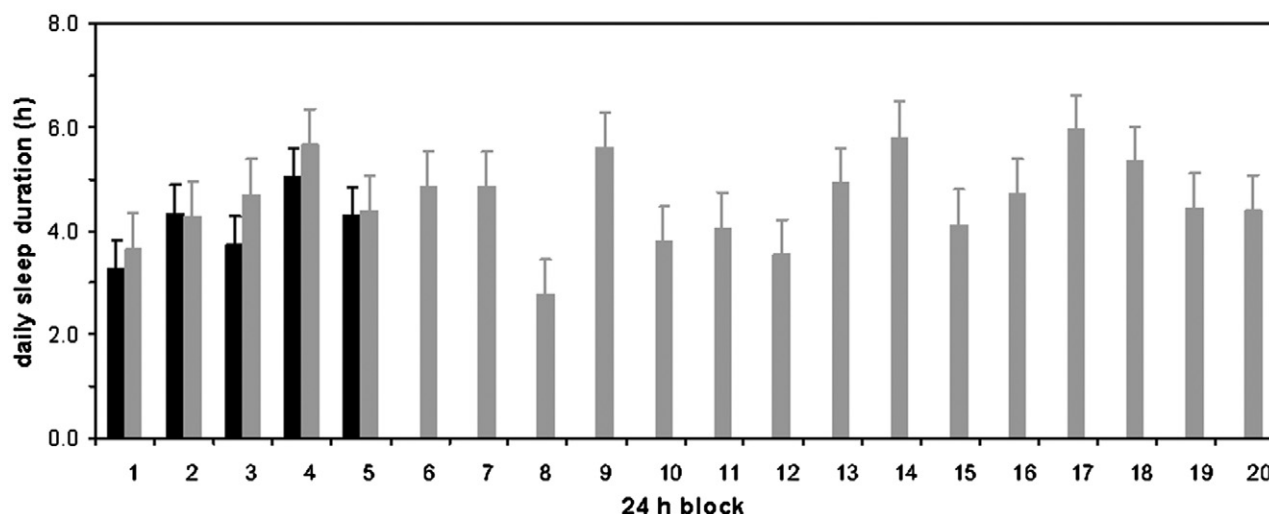
Figure 2 Sleep duration by day in race. Daily means (and standard errors) of sleep duration are shown as a function of days (24-h blocks from 08:00 until 08:00), for the first leg (black) and the second leg (gray).

analyses. There were 5 such 24 h periods in the data set for the first leg, and 20 for the second leg.

No time of day was recorded by the sailors for the functional impairment data (psychomotor impairments, difficulties waking up, hallucinatory experiences, and mood disturbances). The functional impairment data were therefore stratified by days defined from midnight to midnight, and this data set was ended on the day before the first sailor finished. As with the sleep data, there were 5 days in the functional impairment data set for the first leg, and 20 for the second leg. Official race ranking was used to quantify sport performance.

Statistical analyses

Data were analyzed with SAS 9.2 (SAS Institute Inc., Cary, NC). Primary analyses of the sleep data for each leg were performed with mixed-effects analysis of variance (ANOVA) over days at sea and over time of day.[11] Secondary analyses compared the sleep data between the two legs using mixed-effects ANOVA over leg by days and over leg by time of day, accounting for the fact that some participants contributed data to both legs. Analyses of the functional impairments involved linear regression of aggregated event frequencies against days at sea, for each leg separately and accounting for the number of participants contributing data.

RESULTS

Sleep

Total mean sleep duration per 24 h was 248 ± 21 min (4.1 ± 0.4 h) for the 12 participants in the first (shorter) leg of the race and 276 ± 21 min (4.6 ± 0.4 h) for the 8 participants in the second (longer) leg. During both legs, sleep amounts varied significantly across days ($F_{19,5360} = 2.28$, $P = 0.001$). See Figure 2.

There was a distinct 24 h rhythm in sleep propensity, as observed in terms of average minutes of sleep per 1 h block by time of day collapsed over days ($F_{23,5337} = 51.59$, $P < 0.001$). Sleep propensity was highest (about 50%) nocturnally at around 03:00, with a smaller (nearly 15%) secondary peak approximately 12 h later (see Fig. 3).

Participants' race ranking in the first and second legs, analyzed as a covariate, was not significantly related to total mean sleep duration ($F_{1,5262} = 0.34$, $P = 0.56$).

Functional impairments

A total of 33 functional impairments were reported by the 12 participants in the first leg during the 5 days analyzed. A total of 21 functional impairments were reported by the 8 participants in the second leg during the 20 days analyzed. Table 1 shows the distribution of these impairments among the categories of
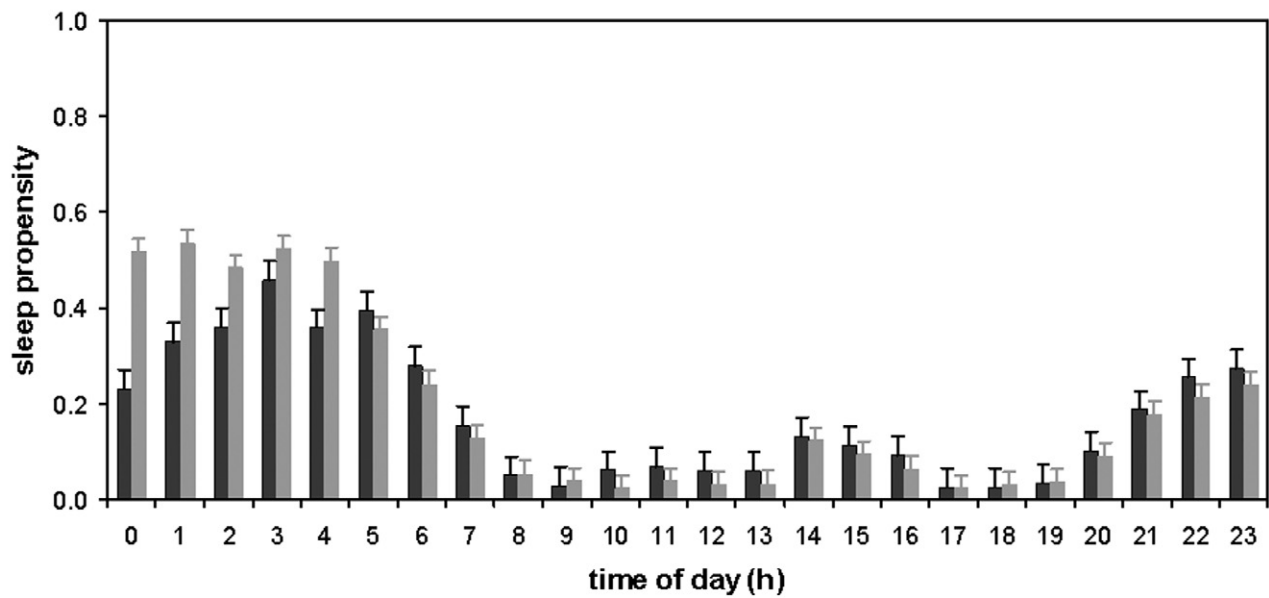
Figure 3 Sleep propensity by time of day. Means (and standard errors) for the fraction of sleep observed in each 1-h block are shown as a function of time of day, for the first leg (black) and the second leg (gray).

Table 1 Number and frequency of functional impairment reports in the two legs of the race

Descriptive events logged by sailors	Number in first leg	Average events / subject-day*	Number in second leg	Average events / subject-day*
Psychomotor impairments	15	0.25	12	0.08
Spinnaker rolled around forestay	5		2	
Broach (severe wipe-out with spinnaker)	3		3	
Equipment breakage (human error)	2		2	
Bad maneuver (jibe or tack)	2		1	
Torn sail	1		1	
Man overboard	1			
Equipment overboard	1		1	
Injury			1	
Onboard fuel spill			1	
Difficulties waking up	7	0.12	6	0.04
Did not hear alarm	4		3	
Reverie	2			
Sluggishness	1		3	
Hallucinations	5	0.08	0	0.0
Auditory	4			
Visual	1			
Mood disturbances	6	0.10	3	0.02
Sadness	5		3	
Low motivation	1			

*A total of 12 participants × 5 days = 60 subject-days were included for the first leg, and 8 participants × 20 days = 160 subject-days were included for the second leg.
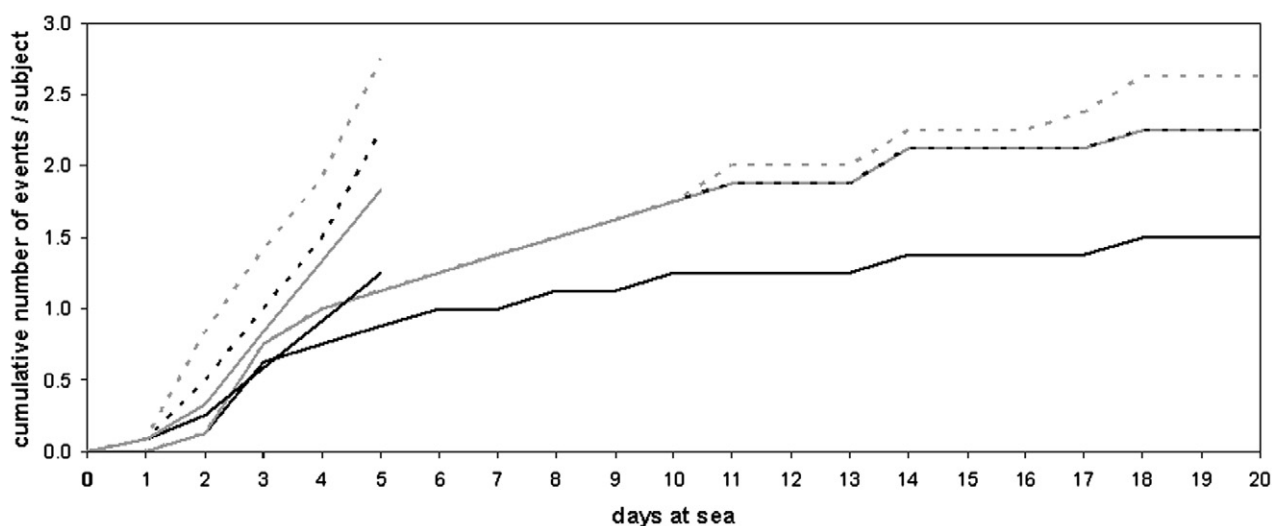
Figure 4 Cumulative number of functional impairments per subject by day in race. Short (5-day) curves are from the first leg (with 12 participants). Long (20-day) curves are from the second leg (with 8 participants). Impairment categories are stacked for each leg. Solid black = psychomotor impairments; solid gray = difficulties waking up; dashed black = hallucinatory experiences; dashed gray = mood disturbances.

psychomotor impairments, difficulties waking up, hallucinations, and mood disturbances.

There was a significant increase of the frequency of functional impairments across days in the first leg ($F_{1,17}$ = 5.48, P = 0.035), but not in the second leg ($F_{1,17}$ = 0.21, P = 0.65). See Figure 4. Diaries did not reveal any potentially confounding special weather conditions, such as storms, during either leg.

Comparison between race legs

As a secondary analysis, we compared the data from the race between the two legs. Total mean sleep duration did not differ significantly between the two legs ($F_{1,5383}$ = 1.89, P = 0.17). The interaction of legs by days for daily sleep duration was also not statistically significant ($F_{4,5360}$ = 0.30, P = 0.88). The 24 h profile of sleep propensity differed significantly between the two legs (see Fig. 3), as evidenced by a significant interaction effect ($F_{23,5337}$ = 3.76, P < 0.001). Increased nocturnal sleep propensity began earlier (around midnight) in the second (longer) leg than in the first (shorter) leg.

For all four categories of events, impairments were reported at least three times as frequently (per unit time) in the first leg as in the second leg (see Table 1).

DISCUSSION

This study contributed valuable data on sleep–wake schedules and functional impairments in single-handed offshore sailing racing. In a relatively large sample as compared to the published literature in this area, polyphasic sleep patterns during a two-leg transatlantic race were found to be governed by the circadian rhythm in sleep propensity. The primary (nocturnal) and secondary (mid-afternoon) sleep gates[12] and the forbidden zone for sleep (evening) were clearly present (Fig. 3). As such, sailors appear to be subject to the same sleep–wake and circadian regulatory principles as is typical for adult humans in other settings.[13]

In the second (longer) leg of the race, the nocturnal rise in sleep propensity (as averaged over days) began earlier than in the first (shorter) leg. The reason for this is a matter of speculation; it could be associated with the crossing of time zones, the different day lengths experienced at different latitudes, or other systematic zeitgeber (i.e., circadian entrainment cue) effects. Because single-handed sailing races constitute such a challenging research environment, no attempt could be made to assess markers of circadian rhythm, and the extent to which participants stayed synchronized is therefore not known. Yet, the pronounced circadian rhythm in sleep propensity in both legs of the race, irrespective of leg

duration and distance traveled, suggests that the research participants continued to be substantially synchronized to the day–night cycle throughout the race.[14]

Average sleep amounts during the race accumulated to between 4 and 5 h per day (Fig. 2). Although the sleep data were only self-reported and, some confidence in the results can be inferred from the fact that they are within the range of results reported by others. Stampi[1] reported mean sleep duration of 6.3 h per day for a 31-day transatlantic race as derived from interviews with 99 sailors. Tiberge[3] found mean sleep duration of 2.8 h per day for a 3-day offshore race among 5 sailors recorded with polysomnography. While such severe sleep restriction would be possible over a period of 3 days,[15] mathematical modeling has revealed that obtaining less than 4 h of sleep per day would not be sustainable over longer periods.[16] In that sense, the participants in this study may have pushed the limits of wake extension to a level they could barely yet feasibly sustain. Noteworthy in this regard is that there was no significant relationship between participants' sleep duration and their rankings in the race, suggesting that extreme sleep curtailment may not be a prerequisite or even a facilitating factor for victory in the race.

No information on sleep setting while at sea was documented. Equipment tends to considerably limit space for sleeping, and duvet and pillow are typically used for comfort, being the only items that fit on board. We did not have the ability to measure sleep intensity and sleep quality under such circumstances. Regardless, sleeping between 4 and 5 h per day on average is substantially less than what would be needed to maintain optimal neurobehavioral functioning across days.[8,15,17] Although there are considerable, trait-like individual differences in vulnerability to sleep loss,[18] even highly select groups operating in extreme environments (e.g., active-duty jet fighter pilots) are not systematically immune to functional impairments from sleep loss.[19] Importantly, there is a discrepancy between self-reported sleepiness and objective assessments of performance under conditions of sustained sleep restriction[9,20] and in the context of individual variability.[21,22] Sailors in single-handed races should therefore not rely on their own subjective assessments of whether or not they can forego sleep.

Self-reported impairments due to human error (Table 1) indicated that the sailing race had a significant impact on neurobehavioral functioning. The nature of the impairments is consistent with the typical consequences of sleep loss.[7,23] The rate at which functional impairments occurred was greater (and escalating over days) in the first (shorter) leg as compared to the second (longer) leg of the race (Fig. 4). Lacking objective records, the source of this difference is a matter of speculation. Although circadian variation in error, incident and accident rates are widely documented,[24] we do not know if circadian factors can explain the difference in functional impairments because no time of day information was recorded. Hectic preparations and associated sleep insufficiency prior to departure may have played a role. This appeared to be a more substantive problem for most participants when they departed for the first leg, as contrasted with their departure following a relatively leisurely break prior to the second leg. That said, the accumulation of functional impairments was relatively fast in the first few days of the second (longer) leg as well, and only later in the race leveled off. As the second leg progressed, the separation between boats generally became bigger, which may have affected the sailors' behavior and modulated the risk of impairments.

Successfully striking an optimal balance between time awake for high-performance sailing on the one hand, and time asleep for maintaining optimal performance capability and safety on the other hand, may yield a competitive advantage. The issue of how much sleep can be traded for wakefulness to achieve optimal operational effectiveness has been debated,[25] approached with model-based optimization schemes,[26] and theorized to depend on the performance task at hand,[27] but presently it cannot readily be quantified.

For sailors, this issue could be addressed heuristically with the concept of "Wakefulness Made Good" (WMG) – analogous to the sailing term "Velocity Made Good" (VMG). VMG is the component of a yacht's velocity that is in the direction of the destination, when the direction of the wind does not allow sailing to the destination in a straight line. Under such circumstances, a skipper needs to find an optimal balance between velocity towards the destination and angle relative to the wind, so as to reach his or her destination fastest. Likewise, WMG implies that a skipper needs to find an optimal balance between wakefulness (and thus sleep loss) and functional impairment (due to sleep loss), so as to sail most effectively. The longer the race, the more relevant this concept may be, not only for competitiveness but also for safety while at sea. This puts a premium on developing innovative tools to help sailors manage their WMG.

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