Comparative Analysis of Methods of Evaluating Human Fatigue

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Sleep Sci

Abstract

The present study used four different methods to estimate fatigue. Forty-seven volunteers (45 men and 2 women), 41.3 ± 7.5 years old, truck operators for 11.5 ± 6.0 years, were included. All participants accepted the invitation to be included in the study. Actigraphy and core temperature were evaluated. The 5-minute psychomotor vigilance test, the Karolinksa Sleepiness Scale (KSS), and the postural assessment using the Light Sonometer™ (Belo Horizonte, Minas Gerais, Brazil) were performed. Fatigue prediction was performed using the Fatigue Avoidance Scheduling Tool (FAST) program. In response to the Pittsburgh Sleep Quality Index (PSQI), 51.06% had good sleep quality and 48.94% had poor sleep quality with an average efficiency of 81.6%. In response to the actigraphy, workers slept an average of 7.2 hours a day with 93.5% efficiency. The workers' core body temperature (CBT) cosinor analysis showed a preserved circadian curve. Core body temperature showed differences between the 6 hours worked in each shift. Similarly, the light sound level meter showed lower risk scores for fatigue in day shifts. Only the variable of the fastest 10% of the Psychomotor Vigilance Test (PVT) showed worse results, while no significant differences were observed by the KSS. The risk analysis by FAST showed a strong influence of the circadian factor. In conclusion, each method has positive and negative points, and it is up to the evaluator/manager to identify the method that best suits the purpose of the evaluation, as well as the local culture and conditions. We recommend using different methods of risk assessment and management in combination with fatigue prediction by Sonometer as well as carrying out assessments, which enable researchers to estimate performance and fatigue throughout the working day, since these may change over the duration of the working day.

Keywords
- fatigue
- disorders of excessive somnolence
- shift worker schedule
- sleep

Introduction

Work fatigue was defined as tiredness, which reduces functional capacity and is experienced during or after the workday.[1] Considered as a multifactorial process, three different fatigue conditions were identified.[1] Physical fatigue, representing reduction of ability to carry out physical efforts;[2] mental fatigue, which is a condition of low alertness and reduced ability to solve problems;[3] and emotional fatigue, which represents a reduced ability to engage in emotional

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activities.[1] Not only work-related, fatigue can be understood as a state of tiredness after a certain period of effort/stress, mental, physical, or emotional, characterized by a decrease in the ability to perform tasks and a reduction in efficiency to respond to stimuli and inability to execute functions with due efficiency and safety.[4]

There is significant evidence that mental task performance related declines in feelings of energy and fatigue reduce balance control and modify gait.[5] Sleep restriction is one of the main factors associated with fatigue.[6] The more restricted the sleep, the greater the physical and cognitive damage, which leads to worsening of information processing and decision making,[7,8] working memory, and executive functions.[9] Bauerle et al. (2018)[10] suggested that fatigue should be inferred through measurable and observable characteristics, as it manifests itself in different ways, such as: psychological (tiredness and lack of motivation induced by stress); physiological (loss of strength and endurance), cognitive (longer reaction time, forgetfulness); and behavioral (closing eyelids, slower speech). In this way, fatigue can be evaluated in a self-reported way,[11] through the Psychomotor Vigilance Test (PVT), which evaluates performance in vigilance, sustained attention, and is related to fatigue.[12] Another possibility of assessing fatigue is through postural balance, which correlates with the level of sleepiness and is affected by sleep deprivation.[13,14] Other more complex assessments of fatigue use mathematical models that consider multiple parameters (homeostatic and circadian) for inference or prediction of fatigue.[15,16] Interest in fatigue assessment should focus on identifying risk conditions for accidents and maintaining performance at safe levels.[17]

Another possibility is the monitoring of core body temperature (CBT), which is a marker of the circadian rhythm.[18] which correlates with performance[19] and is altered under conditions of sleep deprivation.[20] Core body temperature has a nadir at dawn, the moment of greatest propensity to sleep, drowsiness, postural sway, and lower alertness and attention, and greater attention, alertness, and quick response to a stimulus are observed during acrophase.[19,21,22] Thus, CBT may indicate circadian moments of lower motor and cognitive performance and greater sleepiness,[23] which directly impact the risk of accidents.

Fatigue and drowsiness are safety hazards,[6] it is estimated that 21.9% of accidents are related to drowsiness.[24] Traffic crashes caused by drowsiness are more likely to be serious or cause death.[25] In Brazil, around 45,000 people die each year in land transport accidents,[26] which represent a cost of BRL 50 billion, while in Australia the damage caused by fatigue represents 1.55% of the gross domestic product.[27] Thus, validated strategies to improve recovery, sleep hygiene, and alertness management can mitigate fatigue,[6] reduce accident rates, injuries, and costs.

In summary, objective measures of performance and subjective fatigue-related parameters are used to estimate the level of fatigue due to its complexity. Thus, the objective of this study is to present comparative results of four different methods used to estimate fatigue, as well as to present the benefits and limitations of each method.

Materials and Methods

Ethical Aspects

This study was submitted and approved by the Research Ethics Committee of the Federal University of Minas Gerais under protocol CAAE n° 97394818.6.0000.5149. After all the procedures, risks and benefits had been informed, as well as the right to secrecy about their identity and to withdraw at any time, all volunteers who consented to participate in the research signed the Free and Informed Consent Term (TCLE, in the Portuguese acronym).

Sample Selection

The population was composed of 600 workers. Fifty-two people agreed to be recruited, and 5 of them were excluded due to work reasons. The sample of the study consisted of 45 men and 2 women (representing 7.8% of population), with a mean age of 41.3 ± 7.5 years, of all work shifts, who had been working as truck operators for 11.5 ± 6.0 years, in shift work fast reverse rotary (4×1). The 4×1 shift is organized into 4 working days followed by 1 day off. The workload for each shift is 6 hours, including a 12-hour break between shifts. The shifts are organized as follows: day 1 - from 6 pm to 12 am; day 2 - 12 pm to 6 pm; day 3 - 6: am to 12 pm, and day 4–12 am to 6 am; day 5–day off, including a rest period of 60 hours between leaving work on the 4th at 6 am and returning to work on the 6th at 6 pm.

All volunteers work for a large mining company, in a city of approximately 120,000 inhabitants in the state of Minas Gerais, Brazil. They were randomly selected by the mining company. In the first meeting, the volunteers were introduced to the study and invited to participate in the research; those who agreed to participate signed the TCLE. As an inclusion criterion, the volunteer should present at least 3 months of return from vacation due to the body's adaptations to the work routine. In the same way, the volunteer could not have a vacation scheduled for the period in which the evaluations were being carried out. Participants who reported consumption of illicit drugs and/or sleeping pills that could bring about any change in attention or alertness, in addition to those who spontaneously gave up participating in the research, were excluded in the study. Workers who did not perform the procedures properly or who were absent from the service for more than a week during collections were also excluded from the study.

Study Design

All workers answered a structured questionnaire with personal and work-related information in addition to the Pittsburgh Sleep Quality Index (PSQI).[28] In addition, they were submitted to sleep assessment for 15 days using the actigraphy method and sleep diary and core temperature assessment for 5 days. For 4 days during this period, the evaluated subjects were submitted to a sequence of evaluations in the 20 minutes that preceded the beginning of the workday. Sustained attention test for 5 minutes using the PVT, response from the Karolinksa Sleepiness Scale (KSS), and postural assessment using the Light Sonometer™. In

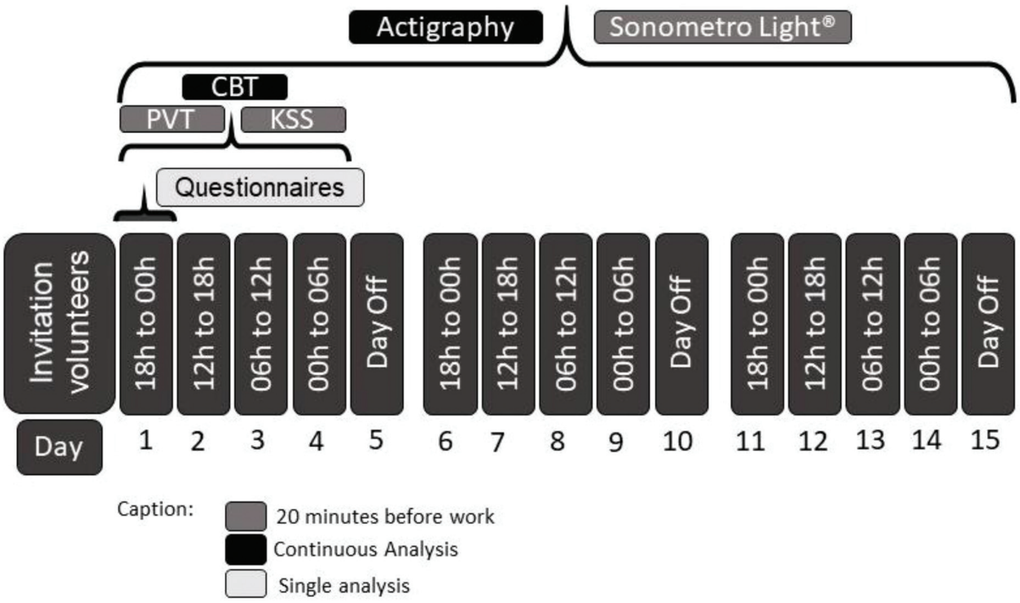

Fig. 1 Study design.

addition, fatigue prediction was performed using mathematical models by the Fatigue Risk Management System (FRMS) named Fatigue Avoidance Schedule Tool (FAST). Sleep data obtained from the 15-day actigraphy assessment associated with the work schedule were entered into FAST for the mathematical prediction of fatigue (►**Fig. 1**).

Pittsburgh Sleep Quality Index

The PSQI was developed by Bertolazi AN, 2008,[29] and it evaluates sleep habits in the 30 days prior to application and the possible presence of some sleep disorders. The index contains 19 self-assessment items and 6 for their roommate to answer, divided into 7 components in total. The result can vary from 0 (zero) to 21 points, classified as good sleep quality (0–5), poor sleep quality (6–10), and indication of sleep disturbance (above 10). In addition, it is still possible to identify the total sleep time as well as self-reported sleep efficiency.

Actigraphy

Actigraphy is a technique that objectively evaluates the sleep-wake cycle, through a device placed on the wrist (similar to a watch) which allows the recording of motor activity through movements[30]. Additionally, using specific algorithms in computer software programs,[31] the following parameters can be estimated: sleep efficiency (SE), sleep latency (SOL), total sleep time (TST), and micro-arousals after sleep onset (WASO).[30]

All participants used the Actiwatch Spectrum Plus actigraph (Philips Respironics, Murrysville, PA, USA) and completed a printed sleep diary for 15 days. The volunteers were instructed to use the device for as long as possible and remove the actigraph only for bathing, physical contact activities, or in an aquatic environment, and press the button called "event" when they were ready to sleep. In the sleep diary, the start and end times of naps, main sleep, and withdrawals from the device were noted. The sleep diary was used to help differentiate periods of silent wakefulness (with low movement), improving the accuracy of identifying the onset of sleep when analyzing and interpreting the data[31] through the Philips Actiware V.6.

Core Temperature Monitoring

The CBT was obtained by measuring the gastrointestinal temperature after swallowing a pill and using the CorTemp EliteTM Data Recorder telemetric system (CorTemp™, HQinc, USA). The swallowed pill transmits low-frequency radio waves that vary in wavelength depending on body temperature. This radio wave is received and converted into digital form by a data recorder. The data recorder has been configured to perform automatic CB recordings every 20 minutes.

Core body temperature was evaluated for 5 days (4 × 1 scale period), in which the participant ingested a pill on the first day of work and when the pill was evacuated, the participant would receive as many other pills as necessary to evaluate the 5 days. Each pill was properly calibrated according to the manufacturer's guidelines. All procedures followed the recommendations proposed by Waterhouse J, 2005,[32] who highlighted the validity and reproducibility of this method for recording CBT.

Psychomotor Performance

The PVT assesses sustained attention and vigilance that are related to fatigue and alertness.[12] The portable equipment model 192 (Ambulatory Monitoring Inc., Ardsley, NY, USA) was used in the present study. The test records response times to visual stimuli that occur at random intervals of 2 to 10 seconds over a 5-minute period. Among the data obtained, the average reaction time stands out, which should normally be between 100 ms and 500 ms, while values above 500 ms are considered lapses of attention.[33] The PVT is reliable for measuring attention lapses under conditions of sleep restriction/deprivation.[34]

During the evaluation, the participant remained alone in a quiet room, sitting in a comfortable chair for the 5-minute test.[12,34] Evaluations with the PVT may present worse values with the accumulation of fatigue or at the end of the work shift; in addition, there may be different results according to circadian performance variations. The data collected during the evaluation were stored in the equipment's memory and transferred to a computer and later analyzed using the software React (Ambulatory Monitoring Inc.).

Alert/drowsiness Assessment

Participants were assessed for their perceived sleepiness using the KSS.[35] This instrument assesses the level of alertness/sleepiness at the time of the assessment and was answered at the beginning of each day of the 4 × 1 shift (6 PM – 12 PM – 6 AM – 12 AM). The KSS consists of scores from 1 to 9, with 1 being *extremely alert*, 5 being *neither alert nor drowsy,* and 9 being *very sleepy, struggling with sleep, a lot of effort to stay alert*. Considering the KSS responses, ideally, the score should be as low as possible, which indicates an increased level of alertness.

Assessment of Postural Balance - Sonometro Light

Postural sway is positively correlated with the level of sleepiness obtained using the KSS,[14] and can be used to estimate the level of fatigue of workers before their workdays. Analyzing postural sway is a method that is considered effective and robust for assessing awake time (awake) and, consequently, fatigue.[13] Staying awake for 17 to 19 hours is associated with the performance of a person with 0.05% blood alcohol concentration, and 24 hours of wakefulness can equate to 0.10% blood alcohol concentration,[36] causing reduced attention, and increased response time and attention lapses. Thus, the Sonômetro Light uses postural sway, associated with sleep time in the last 48 hours and information on the workday to predict the risk of fatigue at the beginning, middle, and end of the workday. A score between 0 and 5 indicates that the worker is rested and able to work, a score between 6 and 12 indicates a worker with similar performance as a person with 17 to 19 hours awake or with 0.05% alcohol in the bloodstream, while scores greater than 12 indicate similar performance to a person with more than 20 hours of wakefulness or 0.10% alcohol in the blood.

For the Sonometro Light™ evaluation, each evaluated person makes a small record that includes personal information, mainly about the start and end times of sleep, the commute to work, and the start and end time of the workday to be carried out on the day. The evaluation was carried out using a device (►**Fig. 2**) that is fixed a little higher than the waistline and records the postural sway. After the device is attached to the subject's waist, the device is connected to a cell phone via bluetooth that controls the evaluations via the Sonometro Light™ cell phone application available on the PlayStore. The assessment itself consists of standing in an orthostatic position 4 meters from a monochromatic wall with a point for visual fixation. The subject must maintain the posture as stable as possible for 30 seconds (indicated by sound signals from the device attached to the waist). This 30-second assessment was performed twice at the beginning of each workday assessed.

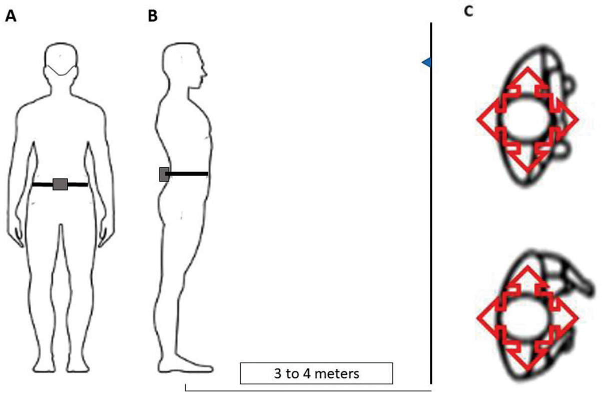

Fig. 2 Illustration for the use of Sonometro Light™ (*A:* Rear view; *B:* Side view, and *C:* Upper view).

Fatigue Analysis by the Fatigue Avoidance Schedule Tool (FAST)

Hursh et al, 1996 developed the first program for monitoring fatigue based on the sleep-wake cycle combined with fatigue and performance prediction algorithms. The FAST computer program allows the entry of sleep and work data,[38] returning with the prediction of performance and fatigue in diverse populations.[39–43] In the present study, information from the 4 × 1 work scale was inserted into FAST, in addition to information on the individual activity-rest cycle obtained using the actigraph for 15 days. Numerical values of effectiveness were extracted from FAST, which is the representative value of performance and risk in a single FAST score. The numerical values considered for the statistical analysis were the effectiveness at the beginning and end of each day. In order to obtain the averages for the beginning and end of the night (18 h to 00 h), afternoon (00 h to 06 h), morning (06 h to 12 h), and early morning (00 h to 06 h).

Statistical Analysis

An analysis of the quality of sleep obtained by the PSQI, the data of TTS, SE, SOL, and WASO obtained in the actigraphy was carried out. From the PVT, the average reaction time, the number of attention lapses and false triggers, in addition to the 10% fastest for each turn start, as well as the KSS response, were used. For the CBT, the averages and standard deviations were used every hour, and for the assessment of postural sway, the fatigue score calculated by the Sonômetro Ligth software was used. For FAST, the effectiveness value will be analyzed.

First, a descriptive analysis of the data from each instrument was performed, describing the means and standard deviation of the evaluated variables. As these are continuous measurements, the generalized linear model (GLM) was applied to describe the effect of time between assessments (18 h, 12 h, 06 h and 00 h) and interquartile (IQ) values for choosing the distribution of data for each instrument. The

Table 1 Sleep results evaluated by the Pittsburgh Sleep Quality Index.

Score ≤ 5	Score ≥ 6	Score ≥ 11	TB (hours)	TST (hours)	SE (%)
24	17	6	8.5 ± 1.3	6.9 ± 1.3	81.6 ± 12.1

Abbreviations: SE, sleep efficiency; TB, time in bed; TST, total sleep time.

Table 2 Sleep data evaluated by actigraphy.

Evaluated days	SOL (min)	WASO (min)	TST (hours)	SE (%)
15.5 ± 1.1	2.7 ± 1.5	17.2 ± 7.4	7.2 ± 0.9	93.5 ± 2.5

Abbreviations: SE, sleep efficiency; SOL, sleep latency; TST, total sleep time; WASO, micro-arousals after sleep onset.

adopted significance level was $p > 0.05$, and the Bonferroni correction was adopted for pairwise comparisons, when applicable. The IBM SPSS Statistics for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA) and GraphPad PRISM V.9.0 software (GraphPad Software Inc., La Jolla, CA, USA) were used for data analysis.

Results

Self-reported Sleep – PSQI

►**Table 1** shows that the worker's perception is that they slept an average of 6.9 hours a day in the previous 30 days, with an average efficiency of 81.6%. In addition, 51.06% had good sleep quality and 48.94% had poor sleep quality.

Measured Sleep – Actigraphy

►**Table 2** presents the results of the sleep assessment for 15 days of using the actigraph. Sleep latency, TST, WASO, and SE were evaluated. In addition, we can highlight that sleep time was different on different workdays. It should be noted that, on the night before the first shift (18 h to 00 h), workers slept on average 7:47 ± 02:00 hours, in the 12 hours between the departure of the first shift at 00 h and the beginning of the subsequent shift at 12 h. Workers slept on average 6h 42 min ± 1h 12 min, and in the 12 hours between leaving the shift at 18 h and returning to work at 06 h, workers slept on average 5h 45 min ± 1h 06 min, and, finally, between 12 h and the beginning of the last shift at 00 h, the workers slept on average 3h 43 min ± 01h 12 min. In this cut between 22 h the day before the shift from 18 h to 00 h until the beginning of the last work shift, there is a window of 74 hours, with workers sleeping 23:57 on average in this interval.

CBT Monitoring

Core body temperature was assessed continuously for 5 days. Based on the quasi-likelihood under the independence model criterion (QIC), the GAMMA distribution was adopted for the generalized linear model. The working day from 12 h to 18 h had a higher CBT value in the 1st hour of the workday than all other days ($p < 0.05$) and also presented a higher CBT than the workday from 00 h to 06 h during the 3rd, 4th, 5th, and 6th hour of the working day ($p < 0.05$). Additionally, the CBT was even higher than the journey from 18 h to 00 h in the 5th and 6th hour of the working day ($p < 0.05$). The workday from 06 h to 12 h had a higher CBT value in the 1st hour of the workday than the workday from 00 h to 06 h ($p < 0.05$), and also presented a higher CBT than the workday from 00 h to 06 h and 18 h to 00 h during the 5th and 6th hour of the working day ($p < 0.05$).

►**Figure 3** presents a graphic with the results of the CT comparison in the 6 hours of the shift in each of the workdays of the 4 × 1 scale. On the other hand, in the shift that starts at 6 AM, there is an increase in CBT over the hours in the shift, while there is a decrease in CBT after the beginning of the shift at 18 h.

In parallel, the workers' CBT cosinor analysis was performed. The CBT showed a preserved circadian curve, indicating that the 4 × 1 scale workers are already adapted to the scale routine and present preserved nadir and acrophase moments and at circadian moments compatible with what is expected (►**Fig. 4**). There was also no effect of working hours on CBT throughout the working day, indicating that regardless of the working hours, CBT maintained the expected circadian rhythm.

Postural Balance - Sonometro Light

►**Figure 5** presents the results of fatigue according to the score proposed by the Sonômetro Light. Based on the QIC

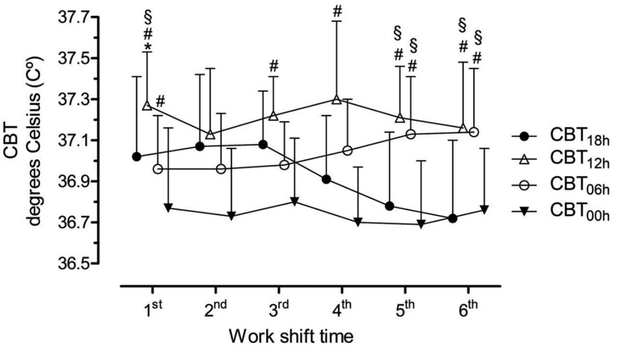

Fig. 3 Average core body temperature (CBT) per hour, from the beginning to the end of the work shifts in each of the four shifts of the 4 × 1 scale. It presents the average and standard deviation of the CBT per hour, during the 6 hours of the work shift in the four work shifts of the 4 × 1 scale. Core body temperature 18 h: CBT shift from 18 h to 00 h; CBT 12h: CBT shift from 12 h to 18 h; CBT 6 AM: CBT shift from 06 h to 00 h; CBT 00 h: CBT shift from 00 h to 06 h. §: different from the CBT 18 h shift; *: different from shift CBT 18 h; #: different from journey CBT 12 h.

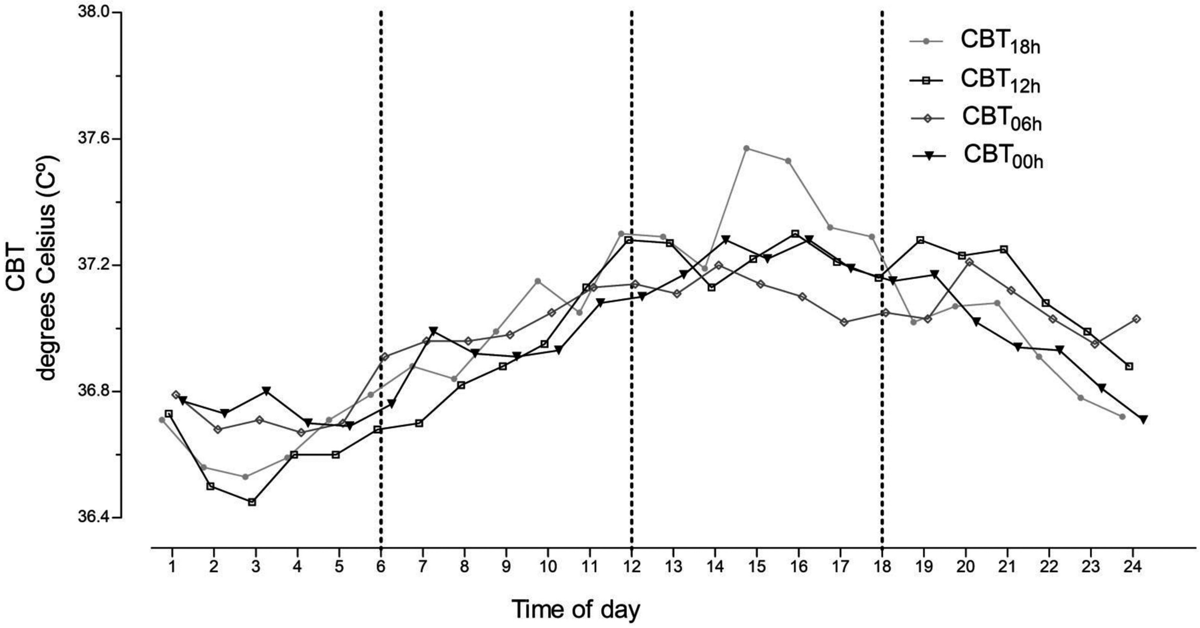

Fig. 4 Core body temperature (CBT) average over 24 hours a day, in the 4 work shifts. Displays the average CBT every hour per day, during the 4 working days in which it was monitored. Caption: CBT, day 1 of the 4 × 1 scale (workday 18 h to 00 h); CBT, day 2 of the 4 × 1 scale (workday 12 h to 18 h); CBT, day 3 of the 4 × 1 scale (workday 06 h to 12 h); CBT, day 4 of the 4 × 1 scale (workday 00 h to 06 h).

values, the GAMMA distribution was adopted for the generalized linear model. At the beginning of work, the shift from 12 h to 18 h presented a higher fatigue score by the Sonômetro Light than all the shifts from 12to 6 PM and the shift from 06 h to 12 h ($p < 0.05$). For the estimation of fatigue in the middle of the day and at the end of the day, the journey from 00 h to 06 h presented a statistically higher risk of fatigue than all other evaluated journeys ($p < 0.05$). It is possible to observe from the values of the scores that the shifts from 18 h to 00 h and from 00 h to 06 h, present greater risks and an increasing characteristic of fatigue throughout the shift. On the other hand, the shifts from 06 h to 12 h and 12 h to 18 h had the lowest fatigue and risk scores, in addition to the characteristic of maintaining the score throughout the working day. ►**Figure 5** shows the average and standard deviation of CBT per hour, during the 6-hour work shift in the four work shifts of the 4 × 1 scale.

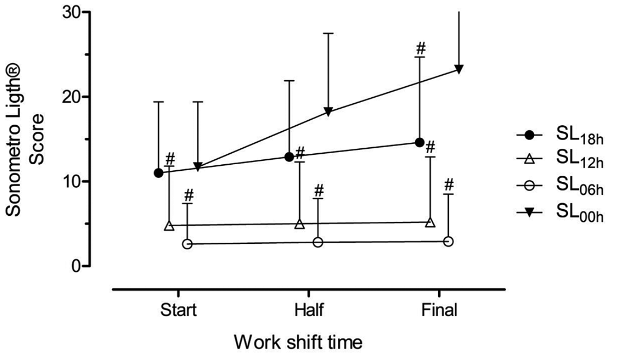

Fig. 5 Fatigue analysis at the beginning, middle and end of the day performed using the Sonômetro Light in the 4 different shifts. SL 18 h = Light sound level meter shift from 6 PM to 12 AM; SL 12 h = Light sound level meter shift from 12 to 6 PM; SL 06 h = Light sound level meter shift from 06 h to 12 h; SL 00 h = Light sound level meter shift from 12 to 06 AM. # = different from journey SL 00 h.

Sustained Attention Test - PVT

Fatigue was also objectively inferred at the beginning of the shift by the PVT (►**Fig. 6**) and self-reported by the KSS (►**Fig. 7**). Based on the QIC values, the GAMMA distribution was adopted for the generalized linear model in both analyses. Of the variables evaluated by the PVT, the results showed performance levels at considerable acceptable levels, and only the 10% fastest [B] showed worse results in the shift from 00 h to 06 h ($p < 0.05$).

Assessment of Self-reported Sleepiness - KSS

Drowsiness assessed by KSS showed levels of alertness considered acceptable (from 1–3). No significant differences were observed between self-reported sleepiness values by KSS.

Effectiveness (FAST)

The FAST effectiveness variable was analyzed for the beginning and end of each journey (night, afternoon, morning, and dawn). Based on the QIC values, the GAMMA distribution was adopted for the GLM to analyze the effectiveness at the beginning and end of the journeys. All the days evaluated showed statistical difference between them ($p < 0.05$) at the beginning of the shift, except for the day from 12 h to 18 h compared to the day from 18 h to 00 h. Similarly, all the days evaluated showed statistical difference between them ($p < 0.01$) at the end of the shift, except for the day 06 h to 12 h compared to the day from 18 h to 00 h (►**Fig. 8**).

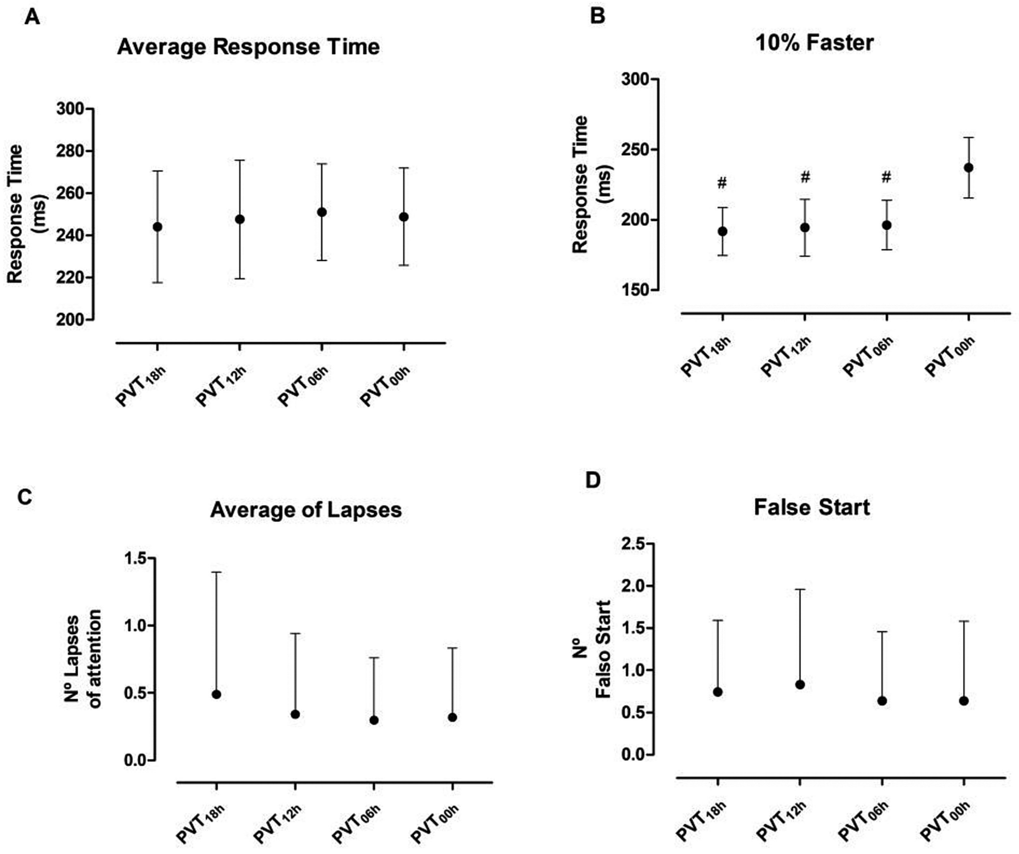

Fig. 6 Mean and standard deviation of the four variables analyzed by the Psychomotor Vigilance Test (PVT). A) average response time. B) 10% faster. C) Average of lapses. D) False starts. PVT 18 h = PVT shift from 18 h to 00 h; PVT 12 PM = PVT shift from 12 h to 18 h; PVT 06 h = PVT shift from 06 h to 12 h; PVT 00 h = PVT shift from 00 h to 06 h. # = different from journey PVT 00 h.

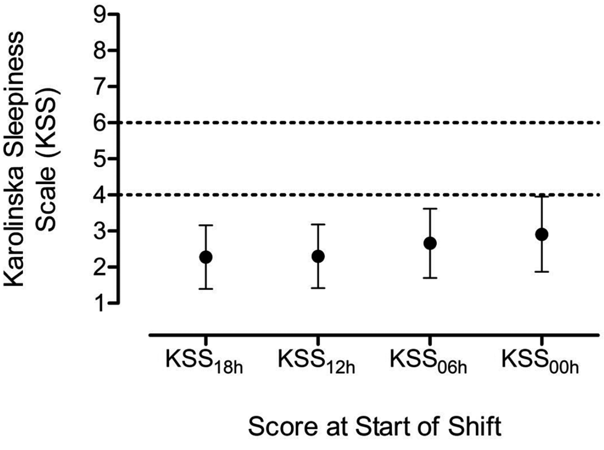

Fig. 7 Drowsiness assessed by Karolinska Sleepiness Scale (KSS) showed levels of alert considered acceptable (from 1–3). No significant differences were observed between self-reported sleepiness values by KSS: KSS 18 h = KSS shift from 18 h to 00 h; KSS 12 h: KSS shift from 12 h to 18 h; KSS 06 h: KSS shift from 06 h to 12 h; KSS 00 h: KSS shift from 00 h to 06 h.

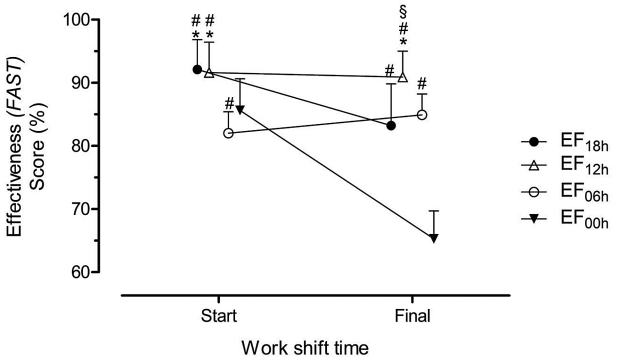

Fig. 8 Mean and standard deviation of the effectiveness calculated by FAST, at the beginning and at the end of the work shift, in the four work shifts of the 4 × 1 scale. EF 6 PM: Effective shift from 18 h to 00 h; EF 12 h: Effective shift from 12 h to 18 h; EF 06 h: Effective shift from 06 h to 12 h; EF 12 h: Effective shift from 00 h to 06 h. §: different from the CBT 18 h shift; *: different from shift CBT 06 h; #: different from journey CBT 00 h.

Discussion

In recent decades, a significant reduction in the total sleep time of the entire world population has been observed,[44–46] as well as an increase in the number of people who invert their biological rhythm, especially through night work.[47,48] A night of sleep deprivation results in impaired cognitive abilities, such as attention, concentration, planning, decision-making, inhibitory control, and can affect neuromotor centers.[49] Thus, monitoring fatigue associated with work, especially at night, becomes a necessity for greater safety and occupational performance. The worker in a state of fatigue increases health and safety risks and reduces productivity and quality of work.

The previously reviewed fatigue assessment methods found a wide variety of options, in which some do not differ fatigue from drowsiness.[10,50–52] In addition, the different forms of fatigue (cognitive, emotional, and physical) are difficult to identify separately.[53] Likewise, there is still no single test capable of jointly considering all forms of fatigue in a single assessment.

Reaction and psychomotor vigilance tests are widely disseminated as forms of performance assessment associated with fatigue and sleepiness in different populations,[54] with an emphasis on workers.[55] However, in our analyses, the 5-minute PVT, performed only at the beginning of the working day, identified significant changes in performance in only 1 (TR10%) of the 4 variables analyzed, which presented worse results only in the last day of the 4 × 1 scale, from 12 to 6 AM. These results are corroborated by the KSS analysis and by the sleep of workers who sleep before the start of the workday and when arriving to start the shift, they showed a state of alertness and sustained attention at levels considered adequate. In an addendum, it is highlighted that in the 12-hour interval between shifts on the 4 × 1 scale, workers slept for at least 3h 43min.

It should be noted that the assessed group has been truck operators at the company for 11.5 ± 6.0 years, which suggests that they are already used to the work routine, function, and are adapted to the scale. However, it is noteworthy that these analyses assess performance and subjective alertness only at the beginning of the workday and do not consider accumulated fatigue. A worker with chronic sleep restriction may, for example, arrive at work without signs of fatigue and show a sharp drop in performance after a few hours of work that could not be detected in tests of sustained attention at the beginning of the day or even by self-reported sleepiness.

In addition to the limitations of subjective sleepiness analyses and sustained attention at the beginning of the workday, Folkard and Tucker[56] identified that the relative risk of accidents increases with the hours worked, so that shifts with 12 hours of work present almost twice the risk of accidents than shifts with 5 hours of work. Similarly, Meijman TF., et al, 1977 found that just 3.5 hours of exposure to predominantly cognitive tasks are enough to reduce information processing capacity. Thus, different work functions may require different forms of analysis and monitoring of fatigue during the working day, or software capable of estimating fatigue during the working day, such as Sonômetro Light.

Despite the inconveniences associated with self-reports, which depend on the perception of the individual who is responding, these are still important methods, since they are simpler options to be used in practice.[11] A recent review suggested that subjective sleepiness assessment (Epworth Sleepiness Scale) may be a slightly better predictor of traffic accidents than objective sleepiness assessed by the multiple sleep latency test.[58] In this sense, an education program with workers and a system that allows workers to indicate their level of alertness or drowsiness in a simple way, such as KSS more than once during the working day, can be an easy and applicable tool for detecting and managing worker fatigue. For this, it is necessary to have a fatigue management program that will indicate the workers' recovery measures once fatigue is reported through self-report. It is noteworthy that strategic breaks in times of fatigue reported by the worker during the working day can be an effective measure to reduce the likelihood of occupational accidents. In this sense, it is necessary to encourage the worker to always truthfully report the information and that, in case of detection of fatigue, there is a process of reception and orientation to the worker and not of punishment. This procedure aims to establish a routine of trust and commitment in the relationship between the worker and the company.

Assessments by mathematical models consider multiple parameters (homeostatic and circadian) for fatigue inference.[15,16] Sonometro Light, for example, considers declarative responses regarding sleep time in the last 24 and 48 hours, as well as body balance, the circadian timing of the working day, the worker's chronotype, and the presence of sleep complaints, in order to predict sleep fatigue. The results of these evaluations in this study indicate that the fatigue scores presented by the Sonômetro Light presented similar behavior to the CBT, which is a robust marker of human performance. Excessive drowsiness and increased pressure to sleep, due to circadian (eg times of drop in core temperature) or homeostatic factors (sleep restriction and/or long periods of wakefulness)[59] have been identified as responsible for the increase in errors and accidents, especially among night shift workers, such as nurses, doctors, police, firefighters, drivers, and miners.[7,10,25,58] Sonômetro Light is a tool that allows you to assess accumulated fatigue, considering homeostatic and circadian factors in your test that allows you to indicate the level of fatigue at the time of assessment and infers fatigue until the end of the work shift. Such an assessment may have an advantage in monitoring fatigue, as it makes it possible to identify workers who may have higher levels of fatigue throughout the working day.

The FRMS is interesting and has the potential to manage general fatigue.[60] Analyses by FRMS can be interesting to identify moments of risk in different work schedules and thus propose monitoring strategies at moments considered critical, in addition to allowing the comparison of different models of work schedule either with simulated data or associated with actigraphy. These systems make it possible to identify the moments of greatest risk in the work schedule and direct which shifts and times the manager should focus more efforts on monitoring fatigue. In addition, the FRMS allows the performance of various simulations that can help managers to identify conditions that may present greater risks and that must be monitored more carefully.

Finally, analysis of the fatigue process requires a multifactorial approach encompassing specific aspects of work and the worker. Motivated, attentive workers, less sleepy, and with a better quality of life have a lower risk of accidents and lower cost for employers.[61] Thus, expenses with sick leave (occupational accidents), idleness of workers, maintenance of machines, or days with machines stopped due to misuse are reduced.[62] Workers' perceptions of weekly working hours influence how work will impact the accumulation of fatigue[63] and worker motivation.[64] This happens because energy and fatigue are distinct in perceptual states.[65] The negative effects of shift work on health and absenteeism can be reduced when workers feel comfortable with their work schedules.[66] Satisfied workers and a flexible work schedule can be a promising tool for maintaining the health and well-being and work/non-work balance of employees.[67] Being comfortable with work start times can moderate the negative impact of work schedules[68] and help reduce the conflict between work and social and family demands.[69]

As previously exposed, fatigue has several causes and, likewise, occupational accidents are also multifactorial.[70] Reason J., 2000 defends the model in which the occupational accident is represented by the Swiss cheese, in which each slice presents barriers or defenses against accidents, and the holes represent the failures of the system. In this way, the holes tend to increase and expand; however, normally, they do not present great risks for accidents when isolated (that is, when the fault appears only in a single slice) but only when they coincide in successive layers. Thus, analyzing, designing, implementing, and correcting a fatigue risk management program is fundamental, so that daily fatigue assessment actions are only for extreme cases and not something routine and presented as a way of mitigating accidents. In this way, monitoring fatigue by different methods can guarantee greater security in the detection of risk conditions, but the implementation of mitigation measures that present a good education and training plan for the entire multidisciplinary team that works in the prevention of fatigue, in the evaluation process of the worker, in the legal guidelines for the company and the worker, among other actions, become fundamental so that the daily analysis of fatigue, when detected, is the exception and not the routine and the main action to be implemented to minimize and prevent the possible accidents.

The KSS applied only at the beginning of the day was not enough to identify worker fatigue. This result can be explained because the KSS is an evaluation that only considers the perception at the time it is applied and since the workers always slept before the work shifts, they would arrive with little drowsiness. However, the accumulated fatigue factor that may indicate different patterns of fatigue throughout the working day is not considered in this assessment.

In summary, the core temperature analysis identified that the shift between 00 h to 06 h was the one with the lowest core temperature from its beginning to the end when compared to the shifts from 12 h to 18 h (which presented higher CBT values) and the shift from 06 h to 12 h (which presented an ascending TCC characteristic). While the shift from 18 h to 00 h showed a descending characteristic of CBT and difference only in the last two hours for the shifts from 12 h to 18 h and from 06 h to 12 h. In a similar way the Sonômetro Light identified a higher fatigue index in the shift between 00 h to 06 h when compared to the shifts from 12 h to 18 h and the shift from 06 h to 12 h and, as observed in the CBT (in an inversely proportional way), it is possible to identify an ascending characteristic of fatigue for the shifts from 00 h to 06 h and from 18 h to 00 h and maintenance of fatigue throughout the shifts from 12 h to 18 h and the shift from 06 h to 12 h. Corroborating the data, the PVT identified a worsening of the worker's performance in only one variable and only on the day when the shift starts at 12 AM, which is the last shift of the 4 × 1 scale.

Study Limitations

The main limitation of the present study is the impossibility of comparing methods that present scores and results that are different in their scalar magnitudes, and thus are difficult to be analyzed in a single comparative statistics. In addition, the study did not manipulate a condition (eg. studies of sleep deprivation > 24 h) that actually induce fatigue in the worker and subjected him to different tests. As there is no gold standard test to identify fatigue, it is not possible to say that one method is more effective than another and it is not possible to say whether the worker was fatigued when carrying out the evaluations. The fact that we considered only one definition of fatigue justifies the discussion about the results found.

Final Considerations

Sleep is a fundamental factor for humans and directly influences drowsiness and fatigue. Sleep restriction increases the possibility of errors and accidents and injuries, which can generate high costs for governments and companies. Because it is a complex and multifactorial construct, accurately assessing fatigue becomes an equally complex task.

As expected, the different methods proposed in this study, except the KSS, identified the work shift from 00 h to 06 h with the highest levels of fatigue. Each method has positives and negatives, and it is up to the evaluator/manager to identify the method that best suits the purpose of the evaluation as well as the culture and local conditions. Thus, using different risk and fatigue assessment and management methods in combination can favor the collection of data which allow fatigue management, and work planning, aiming at maintaining performance and reducing accidents and injuries.

In addition, carrying out assessments that allow estimating performance and fatigue throughout work can be a differential since, as presented by CBT, performance and fatigue may change throughout the working day, either due to circadian or homeostatic factors. In addition, quick assessment strategies during the working day can be an alternative for monitoring during the shift, and for this the worker must be a central part of the process of education, and adaptation of the work schedules, since the worker's feeling in relation to the work directly impacts their motivation, fatigue, and risk of accidents.

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Conflict of Interests

The authors have no conflict of interests to declare.

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Referências

1 Frone MR, Tidwell MO. The meaning and measurement of work fatigue: Development and evaluation of the Three-Dimensional Work Fatigue Inventory (3D-WFI). J Occup Health Psychol 2015; 20(03):273–288

2 MESH. Muscle Fatigue 1995 [cited 2020 11/12/2020]. Available from: https://www.ncbi.nlm.nih.gov/mesh/68018763

3 MESH. Mental Fatigue 1995 [cited 2020 11/12/2020]. Available from: https://www.ncbi.nlm.nih.gov/mesh/68005222

4 MESH. Fatigue [cited 2020 11/12/2020]. Available from: https://www.ncbi.nlm.nih.gov/mesh/68005221

5 Grobe S, Kakar RS, Smith ML, Mehta R, Baghurst T, Boolani A. Impact of cognitive fatigue on gait and sway among older adults: A literature review. Prev Med Rep 2017;6:88–93

6 Caldwell JA, Caldwell JL, Thompson LA, Lieberman HR. Fatigue and its management in the workplace. Neurosci Biobehav Rev 2019; 96:272–289

7 Gates M, Wingert A, Featherstone R, Samuels C, Simon C, Dyson MP. Impact of fatigue and insufficient sleep on physician and patient outcomes: a systematic review. BMJ Open 2018;8(09): e021967

8 Belenky G, Wesensten NJ, Thorne DR, et al. Patterns of performance degradation and restoration during sleep restriction and subsequent recovery: a sleep dose-response study. J Sleep Res 2003;12(01):1–12

9 Rosa JPP, Rodrigues DF, Silva A, et al. 2016 Rio Olympic Games: Can the schedule of events compromise athletes' performance? Chronobiol Int 2016;33(04):435–440

10 Bauerle T, Dugdale Z, Poplin G. Mineworker fatigue: A review of what we know and future decisions. Min Eng 2018;70(03):33

11 Gawron VJ. Overview of self-reported measures of fatigue. Int J Aviat Psychol 2016;26(3-4):120–131

12 Basner M, Dinges DF. Maximizing sensitivity of the psychomotor vigilance test (PVT) to sleep loss. Sleep 2011;34(05):581–591

13 Pham Q-C, Mello MTd, Narciso FV, et al. Robust evaluation of time since awakening using force platform posturography. Rev Bras Eng Bioméd 2014;30:322–329

14 Narciso FV, Barela JA, Aguiar SA, Carvalho AN, Tufik S, de Mello MT. Effects of Shift Work on the Postural and Psychomotor Performance of Night Workers. PLoS One 2016;11(04):e0151609

15 Asgari-Targhi A, Klerman EB. Mathematical modeling of circadian rhythms. Wiley Interdiscip Rev Syst Biol Med 2019;11(02): e1439

16 Powell RI, Copping AG. Measuring fatigue-related impairment in the workplace. Journal of Engineering, Design and Technology 2016;14:507–525

17 Darwent D, Dawson D, Paterson JL, Roach GD, Ferguson SA. Managing fatigue: It really is about sleep. Accid Anal Prev 2015; 82:20–26

18 Weinert D, Waterhouse J. The circadian rhythm of core temperature: effects of physical activity and aging. Physiol Behav 2007;90 (2-3):246–256

19 Reilly T, Edwards B. Altered sleep-wake cycles and physical performance in athletes. Physiol Behav 2007;90(2-3):274–284

20 Waterhouse J, Drust B, Weinert D, et al. The circadian rhythm of core temperature: origin and some implications for exercise performance. Chronobiol Int 2005;22(02):207–225

21 Atkinson G, Reilly T. Circadian variation in sports performance. Sports Med 1996;21(04):292–312

22 Atkinson G, Todd C, Reilly T, Waterhouse J. Diurnal variation in cycling performance: influence of warm-up. J Sports Sci 2005;23 (03):321–329

23 Schmidt C, Collette F, Cajochen C, Peigneux P. A time to think: circadian rhythms in human cognition. Cogn Neuropsychol 2007; 24(07):755–789

24 Garbarino S, Nobili L, Beelke M, De Carli F, Ferrillo F. The contributing role of sleepiness in highway vehicle accidents. Sleep 2001;24(02):203–206

25 Stahl SM, Sigua NL. Sleepiness and Driving. Am J Respir Crit Care Med 2020;201(02):3–P4

26 Carvalho CHRd. Custos dos acidentes de trânsito no Brasil: estimativa simplificada com base na atualização das pesquisas do Ipea sobre custos de acidentes nos aglomerados urbanos e rodovias. 2020

27 Hillman D, Mitchell S, Streatfeild J, Burns C, Bruck D, Pezzullo L. The economic cost of inadequate sleep. Sleep 2018;41(08):

28 Bertolazi AN. Tradução, adaptação cultural e validação de dois instrumentos de avaliação do sono: Escala de Sonolência de Epworth e Índice de Qualidade de Sono de Pittsburgh. 2008

29 Buysse DJ, Reynolds CF III, Monk TH, Berman SR, Kupfer DJ. The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research. Psychiatry Res 1989;28(02):193–213

30 Sadeh A. The role and validity of actigraphy in sleep medicine: an update. Sleep Med Rev 2011;15(04):259–267

31 Martin JL, Hakim AD. Wrist actigraphy. Chest 2011;139(06): 1514–1527

32 Byrne C, Lim CL. The ingestible telemetric body core temperature sensor: a review of validity and exercise applications. Br J Sports Med 2007;41(03):126–133

33 Van Dongen HP, Dinges DF. Sleep, circadian rhythms, and psychomotor vigilance. Clin Sports Med 2005;24(02):237–249, vii–viii

34 Basner M, Mollicone D, Dinges DF. Validity and Sensitivity of a Brief Psychomotor Vigilance Test (PVT-B) to Total and Partial Sleep Deprivation. Acta Astronaut 2011;69(11-12):949–959

35 Kaida K, Takahashi M, Åkerstedt T, et al. Validation of the Karolinska sleepiness scale against performance and EEG variables. Clin Neurophysiol 2006;117(07):1574–1581

36 Dawson D, Reid K. Fatigue, alcohol and performance impairment. Nature 1997;388(6639):235

37 Hursh SR, Munro I, Redmond DP, Conlan RW, Eds. Development of a Cognitive Performance Monitoring System. Proceedings of the Human Factors and Ergonomics Society Annual Meeting; 1996: SAGE Publications Sage CA: Los Angeles, CA

38 Hursh S. Sleep, Activity, Fatigue and Task Effectiveness (SAFTE) Model and the Fatigue Avoidance Scheduling Tool (FAST). Air Force Research Laboratory Presentation; 2003

39 Hursh SR, Balkin TJ, Miller JC, Eddy DR. The fatigue avoidance scheduling tool: Modeling to minimize the effects of fatigue on cognitive performance. SAE Trans 2004;•••:111–119

40 Hursh SR, Raslear TG, Kaye AS, Fanzone JF Jr. Validation and calibration of a fatigue assessment tool for railroad work schedules, final report. 2008

41 Hursh SR, Eddy DR, Eds. Fatigue modeling as a tool for managing fatigue in transportation operations. Proceedings of the 2005

International Conference on Fatigue Management in Transportation Operations, September 2005; 2005

42 Gertler J, Hursh S, Fanzone J, Raslear T, America QN. Validation of FAST model sleep estimates with actigraph measured sleep in locomotive engineers. United States: Federal Railroad Administration; 2012

43 Roma PG, Hursh SR, Mead AM, Nesthus TE. Flight attendant work/rest patterns, alertness, and performance assessment: Field validation of biomathematical fatigue modeling. Federal Aviation Administration Oklahoma City Ok Civil Aerospace Medical Inst; 2012

44 National SF. Sleep in America Poll: Summary of findings. Washington (DC)2009:1–70

45 Pires ML, Benedito-Silva AA, Mello MT, Pompeia SdelG, Tufik S. Sleep habits and complaints of adults in the city of São Paulo, Brazil, in 1987 and 1995. Braz J Med Biol Res 2007;40(11): 1505–1515

46 Tufik S, Santos-Silva R, Taddei JA, Bittencourt LR. Obstructive sleep apnea syndrome in the Sao Paulo Epidemiologic Sleep Study. Sleep Med 2010;11(05):441–446

47 Sargent C, Halson S, Roach GD. Sleep or swim? Early-morning training severely restricts the amount of sleep obtained by elite swimmers. Eur J Sport Sci 2014;14(Suppl 1):S310–S315

48 Juliff LE, Halson SL, Peiffer JJ. Understanding sleep disturbance in athletes prior to important competitions. Journal of Science and Medicine in Sport/Sports Medicine Australia 2015;18(01):13–18

49 Frey DJ, Badia P, Wright KP Jr. Inter- and intra-individual variability in performance near the circadian nadir during sleep deprivation. J Sleep Res 2004;13(04):305–315

50 Pilcher JJ, Morris DM. Sleep and organizational behavior: implications for workplace productivity and safety. Front Psychol 2020;11:45

51 Shriane AE, Ferguson SA, Jay SM, Vincent GE. Sleep hygiene in shift workers: A systematic literature review. Sleep Med Rev 2020; 53:101336

52 Richter K, Acker J, Adam S, Niklewski G. Prevention of fatigue and insomnia in shift workers-a review of non-pharmacological measures. EPMA J 2016;7(01):16

53 VAN Cutsem J, DE Pauw K, Buyse L, Marcora S, Meeusen R, Roelands B. Effects of mental fatigue on endurance performance in the heat. Med Sci Sports Exerc 2017;49(08):1677–1687

54 Chellappa SL, Morris CJ, Scheer FAJL. Daily circadian misalignment impairs human cognitive performance task-dependently. Sci Rep 2018;8(01):3041

55 Wickens CD, Hutchins SD, Laux L, Sebok A. The impact of sleep disruption on complex cognitive tasks: a meta-analysis. Hum Factors 2015;57(06):930–946

56 Folkard S, Tucker P. Shift work, safety and productivity. Occup Med (Lond) 2003;53(02):95–101

57 Meijman TF. Mental fatigue and the efficiency of information processing in relation to work times. Int J Ind Ergon 1997;20(01): 31–38

58 Bonsignore MR, Marrone O, Fanfulla F. Sleep Apnea, Sleepiness, and Driving Risk. Sleep Med Clin 2019;14(04):431–439

59 Borbély AA, Daan S, Wirz-Justice A, Deboer T. The two-process model of sleep regulation: a reappraisal. J Sleep Res 2016;25(02): 131–143

60 Dawson D, Searle AK, Paterson JL. Look before you (s)leep: evaluating the use of fatigue detection technologies within a fatigue risk management system for the road transport industry. Sleep Med Rev 2014;18(02):141–152

61 Hui SK, Grandner MA. Trouble Sleeping Associated With Lower Work Performance and Greater Health Care Costs: Longitudinal Data From Kansas State Employee Wellness Program. J Occup Environ Med 2015;57(10):1031–1038

62 Rosekind MR, Gregory KB, Mallis MM, Brandt SL, Seal B, Lerner D. The cost of poor sleep: workplace productivity loss and associated costs. J Occup Environ Med 2010;52(01):91–98

63 Techera U, Hallowell M, Stambaugh N, Littlejohn R. Causes and Consequences of Occupational Fatigue: Meta-Analysis and Systems Model. J Occup Environ Med 2016;58(10):961–973

64 Nijp HH, Beckers DG, Kompier MA, van den Bossche SN, Geurts SA. Worktime control access, need and use in relation to work-home interference, fatigue, and job motivation. Scand J Work Environ Health 2015;41(04):347–355

65 Loy BD, Cameron MH, O'Connor PJ. Perceived fatigue and energy are independent unipolar states: Supporting evidence. Med Hypotheses 2018;113:46–51

66 Nätti J, Oinas T, Härmä M, Anttila T, Kandolin I. Combined effects of shiftwork and individual working time control on long-term sickness absence: a prospective study of Finnish employees. J Occup Environ Med 2014;56(07):732–738

67 Nijp HH, Beckers DG, Geurts SA, Tucker P, Kompier MA. Systematic review on the association between employee worktime control and work-non-work balance, health and well-being, and job-related outcomes. Scand J Work Environ Health 2012;38(04):299–313

68 Tucker P, Bejerot E, Kecklund G, Aronsson G, Åkerstedt T. The impact of work time control on physicians' sleep and well-being. Appl Ergon 2015;47:109–116

69 Grönlund A. More Control, Less Conflict? Job Demand–Control, Gender and Work–Family Conflict. Gend Work Organ 2007;14 (05):476–497

70 Reason J. Human error: models and management. BMJ 2000;320 (7237):768–770