

Article

Workers' Aging Management—Human Fatigue at Work: An Experimental Offices Study

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Featured Application: This paper deals with the possibility to enhance the ageing management using technologies applied, so far, to the drivers' safety. So, the main application of the tools and methods here presented are related to the industrial and service operations management, when this managerial facet is treated with the age variable and its relation to the cognitive fatigue.

Abstract: The aging issue in the work context is becoming a significant element of the future sustainability of service and industrial companies. It is well known that with increasing worker age the problem of maintaining the performance and the safety level when fatigue increases is a crucial point, and fatigue increases with the age. Due to social and political developments, especially in Western countries, the retirement age is increasing and companies operate with a higher workforce mean age. Therefore, the problem of recognizing and measuring fatigue has become a key aspect in the management of aging. Note that in the scientific engineering field, the problem of fatigue evaluation when a worker is performing his/her work activities is an important issue in the industrial and service world and especially in the context of the researchers that are investigating the human reliability assessment. As it is clear from the literature, the industrial operations management are suffering from some misleading concepts that only the medicine scientific context can clarify. Therefore, the aim of this paper is to define what are the open issues and the misleading concepts present in the classical fatigue evaluation methods, and second to define two experimental curves of fatigue that will help the decision makers to minimize the impact of fatigue on the workers, thus maximizing the sustainability of the working tasks assigned. This aim is achieved by examining the medical literature about the measurement of a particular kind of fatigue related to the circadian cycle, i.e., the cognitive one; after that, a survey about the possible technologies for measurements is performed. On the basis of technology selection, an experiment on real work activities is performed and some remarkable results about the fatigue in the workers observed and the technology use and its limitations are defined.

Keywords: aging; humans at work; fatigue; measurement tools; PERCLOS

1. Introduction

As reported by Lassus et al. (2015) [1], the aging of the workforce in modern Western economies is posing several hard questions to the political and industrial decision-makers, such as which can be the right ration of turnover between the aged and not-aged workers to balance the incomes and outcomes of the welfare states? How can the aged workers be helped to achieve and to realize their working tasks?

In this general context, a great role is played by the fatigue, in fact especially for the aged workers there is a problem about the fatigue management, that modify their capacity to realize their tasks in nominal time [2] as designed by the industrial or service planning managers. There exists two types of fatigue for the people, one related to the musculoskeletal aspects [3–5] and one related to the cognitive aspects [6,7].

In this paper, we will focus on the cognitive fatigue and how this kind of fatigue can be measured. Before to do so, let us to introduce the importance and the main aspects of the human impacts on the industrial and service tasks. One of the main effects of the humans' behavior on the industrial and services systems is related to the compliance or not of the product or service realized, i.e., the possibility to make an error or not in their task execution. This facet is strongly related to their reliability, known in the engineering context as Human Reliability.

Unintentional human errors in the workplace, also including mistakes by operators, are the most root cause of accidents, significantly contributing to between 30% and 90% of all serious incidents across industries [8–10]. Human errors in industrial systems can also seriously reduce the operation's performances, in terms of quality, productivity, and efficiency [11,12]. In fact, human error has a direct impact on productivity because errors affect the rate of rejection of the product, thereby increasing the cost of production and possibly reduce subsequent sales [13,14]. In the last years, high interest on these topics has been aroused, particularly to understand the origin of human error and to prevent the possibility to make it in the workplace.

From engineers and ergonomics literature, the way to deal with the effect of human error in systems and industry is to use human reliability analysis (HRA) [8,15–17]. HRA methods have the purpose of assessing the likelihood of human error based on models that describe, in a rather simplistic way, the complex mechanism that underlies the single human action that is potentially subject to error. One of the undisputed assumptions in these methods is that human performance depends on the conditions under which the tasks or activities are carried out [18–20]. These conditions characterize significant facets of human error, and they are determined by the individual characteristics of the human being, the environment, the organization or the activity that enhances or decreases human performance and increases or decreases the likelihood of human error.

One performance factor that influences human reliability and is often a contributing factor in human error is fatigue [21]. In fact, the effect of fatigue on human performance has been observed as an important factor in many industrial accidents. The research results presented by Mariana et al., (2018) [22] displayed very clear links between fatigue and human errors for shift workers in petrochemical, oil, and gas plant operations. This has led researchers to believe that the company needs to involve a fatigue and human error analysis in its safety and health policy to prevent accidents at the workplace, to ensure the continuity of operations and to optimize the utilization of workforce to meet the expected operability, safety, health, and productivity.

However, current HRA methods do not explicitly include this factor. Griffith and Mahadevan (2011) [23] discussed the importance of the effects of fatigue on performance and the difficulties associated with defining and measuring fatigue, highlighting the need of inclusion of fatigue specifically sleep deprivation, in HRA methods. The authors stated that the inclusion of fatigue could refine HEP and thereby improve risk assessments. Only Rasmussen and Laumann (2020) [24] assessed whether fatigue should be among the PSFs included in Petro-HRA, suggesting four possible PSFs based on the causes of are suggested: Sleep deprivation, Shift-length, Non-day shift, and Prolonged task performance.

This gap is mainly due to the difficulty that the definition and measurement of fatigue are not easily achievable. Over the past several decades, much research has been conducted on human

fatigue prevention, focusing on two main thrusts. The first one is to understand the physiological mechanism of human fatigue and how to measure fatigue level [25] and in fact, neurobiological studies have provided bio-mathematical models to predict fatigue. The second thrust focuses on developing technological devices to detect and monitor human fatigue, as fatigue appears as the major cause of accident and error in the working setting. Several ways to measure this parameter are present in the scientific and industrial field, but also in real life as the cars' system for the identification of the sleepiness of the driver installed on several cars' brands [26–29].

Starting from the possibility to measure the fatigue of the humans when they are doing their job, this paper addresses the possibility to include a neuro-behavioral measure of fatigue to improve the possibility to involve this measure in the real system of performance measurement in a working activity. For this reason, this paper aims to present a first experimental results set using the algorithm for the sleepiness identification through easily available technology and then the fatigue in humans involved in work activities. For this purpose, no particular technological implementations were used, but only common and available technologies such as small cameras for eyes pointing and the interface of these cameras. Note that the knowledge improvement offered by this paper is mainly focused on the use of a technology (used in car accident prevention) in a very different context such as a workplace and finally to identify a first tentative curve for the fatigue during the normal work shifts for a specific category of workers. Finally, the limitations and future possible developments in use that these experiments revealed are reported.

Therefore, starting from the literature and lack of knowledge about the use of fatigue in traditional engineering HEP methods, an open issue about the fatigue measurement at work is identified and on this basis a technology able to measure its effect is selected. After that, using this technology a real experiment on office workers is conducted to understand which is a possible fatigue curve during a real work shift for this kind of workers.

In perspective, the fatigue measurements and their consideration in job assignments to different age workers could be of great impact to the improvement of the social sustainability of the companies that will consider the new aging accountability in their mission. It is worth to underline that the possibility to implement a system able to recognize fatigue, as the one here proposed, can lead the workers and their communities to a better life. This improvement in life experience can be given by the reduction of injuries caused by fatigue and by the possibility for the workers to achieve their objectives minimizing the cognitive effort and maximizing their activity in the communities out of the work.

Moreover, the results of this paper will help designers and decision-makers improve workplaces, especially for some specific sectors that suffer from cognitive fatigue. These sectors, namely the aeronautical or the truck services, could implement the technological and methodological results of this paper to improve the safety conditions of the specific workplace for the pilots and drivers respectively. Looking at the impact of this work on the generality of the workplaces, it could be possible to rethink the possibility to integrate into the workplaces the video-capture technologies needed to understand the fatigue level of the workers.

The rest of this paper is organized as follows. Section 2 presents a literature background on fatigue in working contexts. Section 3 illustrates the proposed approach. Section 4 describes the experimental study. Section 5 discusses the results, and Section 6 presents some final remarks for future developments.

2. Fatigue in Working Contexts

Fatigue is a term widely used throughout government, industry, labor, and the public to indicate the effects of working too long or having too little rest and being unable to sustain a certain level of performance on a task [30]. These problems overlap with those that relate to sleepiness and its performance effects [31], and consequently, for the sake of communication, the terms are often used interchangeably. Wakefulness and sleep are regulated by two primary endogenous neurobiological forces that shape the time course of subjective activation, performance, and other neurobehavioral variables.

The first process is the sleep homeostat that try to balance the time spent awake and time spent asleep. During periods of wakefulness homeostatic pressure for sleep increase and this pressure is dissipated during sleep. The second process is the endogenous circadian rhythm (Figure 1) which is driven by biological clock, located in the suprachiasmatic nuclei of the hypothalamus [32]. Within and among consecutive 24 h periods, the circadian pacemaker and the drive for sleep interact to determine the level of alertness and performance associated with rest-activity patterns [32–38]. The alternation of sleep and wakefulness is regulated fairly precisely and humans can voluntarily choose to temporarily ignore the homeostatic and circadian signals for sleep [39], altering the normal sleep/wake cycle, not without consequences.

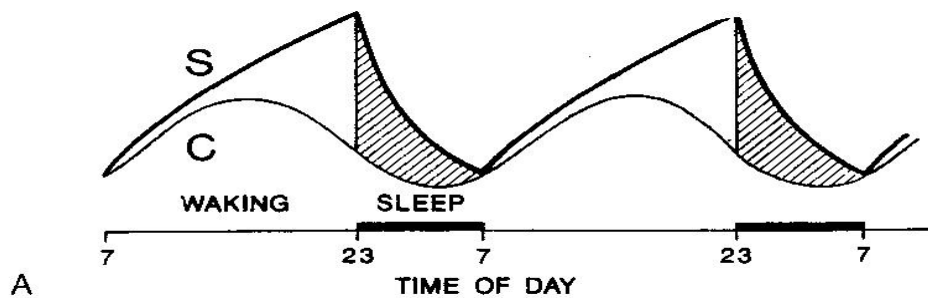


Figure 1. Circadian rhythm [32].

Some conditions associated with a temporal misalignment of these two endogenous processes include shift work, jet lag, and other circadian rhythm sleep disorders. The results are pronounced negative effects on sleep, subjective and physiological sleepiness, diminished performance, and accident risk [40]. In the same way, acute and chronic partial sleep deprivation produce increasing levels of performance impairment similar in nature to alcohol impairment [41], sleepiness, and cognitive performance deficit, particularly when sleep debt is allowed to accumulate over extended periods with limited opportunity for recovery [39,42,43].

According to these models, it is of extreme importance to consider all these aspects in the workplace. The modern society with changes in the global economy and working life have increased the speed of business, and the rhythm of work has become more intense and faster-paced, mostly organized in a 24/7 schedule [44,45]. Often work is required to be done at any time and fatigue, psychosocial workload, and insufficient sleep have been recognized as major consequences of increased work intensity among working populations [46,47].

The possible consequences of fatigue in real-world settings have been widely documented [48–54]. Fatigue, particularly at work, has been linked to an imbalance between the intensity and duration and timing of work with recovery time. This imbalance is often related to working for extended periods and subsequent inability to required performance on the task [30]. Moreover, fatigue/sleepiness has been documented as a risk factor for performance error and accident in occupational settings [30,55–57]. Fatigue/sleepiness is particularly evident in connection with early morning and night shift [58,59] and has been identified as a significant risk factor increasing the probability of accident and injury [60,61].

One way in which sleepiness/fatigue has been implicated in workplace activity includes studies of human error as a function of time of day. The two pronounced peaks found are on the night shift and during the afternoon [31,62,63], suggesting that sleepiness is probably associated with performance error because it is the prime neurobehavioral consequence of the endogenous circadian pacemaker [30]. The biological clock, modulates our hour-to-hour waking behavior, as reflected in fatigue, alertness, and performance, generating circadian rhythmicity in almost all neurobehavioral variables [64]. While circadian pacemaker contributes to the regulation of sleepiness within each day, sleep loss of as little as 2–3 h a night can contribute to sleepiness across days, in a cumulative manner [65,66].

However, when sleep deprivation is continued for several days, the negative effects of sleep drive on alertness and performance continue to increase but the circadian process modulates the changes daily and can mitigate some effects of sleep loss during times of circadian peak [67]. This process predicts a nonlinearity of neurobehavioral performance, in contrast to the assumption that the longer one works the more fatigued one will become [68]. Indeed, several models developed in fatigue risk management are based on the amount of sleep obtained and on circadian phase as they dynamically interact over time modulating performance capability [49,69].

These mathematical models are currently used to predict fatigue and to identify work schedules that pose a sleep deprivation risk and to estimate the magnitude of the risk [49]. However, the absence of feedback from actual values of neurobehavioral performance to improve the accuracy, is recognized as a limited [70]. Moreover, finding a model that predicts a momentary change of fatigue/sleepiness is very difficult. As recently suggested by Abe and colleagues (2014) [68], integrated use of sleepiness prediction and detection technologies could be used to mitigate accidents and the risk of errors more effectively.

As noted above the neurobehavioral effect of sleep loss and circadian periodicity follow a nonlinear time course within and between days, moreover there are individual differences in vulnerability to sleep loss and in circadian rhythm. Healthy adults show interindividual differences in circadian amplitude [71,72], and circadian phase [71–74], in part due to genetic influences [72].

Chronotype defined as morningness–eveningness type, is the most common interindividual variation in circadian rhythmicity. Morning and evening types differ in the circadian phase in their biological clocks [71,73]. Generally, the morning type wakes up, feels better, and does well in the early hours, but feels sleepiness relatively early. Conversely, evening type prefers to wake up late in the morning and feel better at the end of the day (evening hours). To define chronotype, a self-report questionnaire such as the Horne–Östberg morningness–eveningness questionnaire [75], and the Munich ChronoType Questionnaire, [76,77], are used to differentiate timing of activities on workdays versus free days. Chronotypes are also affected by age [76,78] particularly, adolescents tend towards evening types, they go to bed considerably later in the evening (particularly if they have access to television or live in latitudes where summer evenings can be very long) and so tend to be sleep-deprived on school days, whereas elderly become more of morning, while over 35 years old the most frequent chronotype is the morning one.

What can be stated is that individuals are likely to have problems if they adopt an early lifestyle (retiring and rising earlier than average) but have a circadian system that tends to run later than average (for whatever reason), or vice versa. Such disparities can be important for those working shift systems [79]. Considering this, for example, morning types are expected to be less tolerant of night shift work than their evening counterparts [77]. Moreover, the number of older shift workers is growing in most developed countries due to the general aging of the working population, finally, employees with insufficient coping behaviors who are scheduled to work at times incompatible with their chronotype are more vulnerable to psychological problem [80]. However, as reported by some studies, coping strategies such as daytime napping before a night or morning shift, can contribute to improve alert and performance in shift work [59,81], but few real-life shift work studies are available [82–84], and only one assisted the effect of chronotype in shift work [85], finding that morning chronotype were more likely to nap before starting night shift.

Technologies for Human Fatigue Estimation and Detection

Starting from the fact that the fatigue can be detected and identified in different parts of the day for the different chronotypes, the development and validation of technologies for detecting fatigued operators on a job is an important area of development [86]. There are different technologies to detect sleepiness/fatigue, including both objective and subjective measures, but they not always are applicable in a real-world setting. A variety of subjective measures of sleepiness/fatigue and alertness are available that request ratings about the near-immediate state of the subject. These include visual analogue scales [87], Likert-type rating scales such as the Stanford Sleepiness Scale [88], and the

Karolinska Sleepiness Scale [89], and certain fatigue-related subscales of standard adjective checklists such as the Activation–Deactivation Adjective Check List [90], and Profile of Mood States [91].

Despite structural differences among these scales, all self-reports of sleepiness are highly intercorrelated and because they are relative psychometrics, they are subject to several sources of variance, including different uses of the scale response range by different subjects [92]. Subjective measures are considered vulnerable to numerous confounding factors influences that can “mask” their circadian rhythmicity and to be influenced by expectation, mind-sets, and intentional manipulation. Although there are considerably less convincing than objective measures, it has certain usefulness to be a simple alternative in many studies to detect repeated subjective ratings of sleepiness [93]. This is particularly effective in the real-life contexts and in work hours, in which this measure need not interrupt other activities for more than 10–15 s, and may be used frequently during the day. Moreover, in a recent review, Akerstedt and colleagues, (2014) [93], comparing different studies found a diurnal U-shaped pattern of sleepiness, with high KSS value in the morning and late evening with great stability across years. Furthermore, the results concerning to relation between of both KSS and sleep deprivation, and objective measures and KSS, drive the authors to conclude that subjective ratings of sleepiness are as sensitive and valid an indicator of sleepiness as objective measures.

Polysomnographical (PSG) measurement, such as electroencephalography (EEG) and the multiple sleep latency test (MSLT), has been a gold standard objective measures of sleepiness [94]. However, these electrophysiological variables are difficult to implement in real-life contexts and require equipment. Vigilant attention tasks are among the most sensitive measures of sleep loss and circadian periodicity; PVT, in particular, has proven to be very sensitive to all types of sleep loss and to be an example of probed performance fitness for duty test [95].

Psychomotor vigilance performance can be measured with the psychomotor vigilance task (PVT) [96], a portable, easily usable reaction time test with a high stimulus load (visual or auditory) that can yield rapid (i.e., in 10 min) and reliable assessments of psychomotor vigilance impairment [44,97]. The PVT has been used in the laboratory to precisely measure, at brief intervals (typically every 2 h of wakefulness), the changes in psychomotor vigilance performance caused by sleep loss and circadian rhythmicity. The standard 10 min-PVT [95], and the briefer 3-min PVT (the brief PVT: PVT-B) [98] have been extensively validated to be sensitive to both acute and chronic partial sleep deprivation, revealing the temporal dynamics of sleep homeostatic and circadian interactions. The 10 min PVT version has become the most widely used measure of behavioral alertness and it has also been validated as a reliable measure to identify fatigue in occupational settings [99]. However, the 10 min PVT is often considered impractical for operational settings because of its duration, and the shorter version seems to be too short to detect relevant deterioration in vigilant attention in subjects with moderate impairment whose performances deteriorate only later during a test, whereas the longer versions may be unnecessarily long for other subjects who apparently fully alert or severely impaired [98]. Another version of PVT is the adaptive PVT (PVT-A), which is modified PVT with duration dependent on the subject’s performance [98], which in contrast with the fixed duration of PVT and PVT-B, its duration is variable. In a validation experiment, the test duration of the PVT-A averaged less than 6.5 min (SD 2.4) for a training data set and 6.4 min (SD 1.7) for a validation data set. Moreover, PVT-A was shown to be highly accurate, sensitive, and specific relative to 10 min PVT performance. Future studies are needed to show its feasibility and usefulness in professional screeners and operational environment as a fitness for duty test [68].

Considering all the aspects cited so far, as emerged in the recent literature the most comprehensive way to detect fatigue relative seems to be continuous monitoring of the operator. Technologies for predicting and detecting sleepiness/fatigue have the potential to predict and prevent operator errors and accidents in safety-sensitive occupations, as well as physiological and mental diseases due to inadequate sleep and circadian misalignment.

Particularly, the validation of measure of slow eyelid closures (slow eye blinks), referred to as Percentage of eyelid closure (PERCLOS), proportion of time that the eyes are closed over a certain interval, is evaluated in different studies [96,100–102]. In fact, PERCLOS has been found to be the

most reliable and valid measure of a person's alertness level among many drowsiness detection measures [27,68]. It measures the percentage of eyelid closure over the pupil over time and reflects slow eyelid closures (droops), in order to reflect momentary fluctuations of vigilance. To validate PERCLOS, Dinges et al., (1998; 2002) [96,100] systematically evaluated the validity of a number of putative sleepiness-detection technologies. These included brain wave (electroencephalogram [EEG]) algorithms, eye-blink rate devices, a measure of slow eyelid closures (i.e., PERCLOS), and a head position sensor, as well as individuals' ratings of their sleepiness. In a series of tightly controlled, double-blind experiments, they evaluated the extent to which each technology detected the alertness of subjects over a 40-h period of wakefulness, as measured by PVT lapses of attention—a well-validated measure of behavioral alertness. Human-scored PERCLOS proved superior to all other detection technologies in blindly predicting when PVT lapses of attention were occurring across the 42 h awake time each subject underwent.

Nevertheless, it is important to underline that the PERCLOS method and its technological needs in the current configuration is difficult to be implemented in the production workplace. In fact, the industrial work operations can represent a research frontier as it is represented that the worker is widely variable in anthropometric and psychological conditions, so devices able to fix a specific point in the workplace (something like it is done in the cars sleepiness sensors) is not possible since the worker moves itself in the workplace and establish a reference on what the fatigue means for a subject not necessarily means define an absolute measure valid for all the subjects. Given these preliminary considerations a reactive possible solution to this issue is described at the end of this paper where the possible future developments are depicted to make applicable this fatigue measurement also to some non-static workers as the production or the yard workers.

3. Proposed Approach

The analysis of scientific literature highlights that the problem of fatigue can be focused only if the sleepiness of the subject is the key to measure fatigue, and a way to measure this factor is the evaluation of the PERCLOS. Several ways to measure this parameter are present in the scientific and industrial field [101–104], the reader can easily think to the cars' system [105–108] for the identification of the sleepiness of the driver now installed on several car's brands that are capable to control in real-time the sleepiness of the drivers as reported in 2015 by [108].

The industrial application can represent a research frontier since the worker is widely variable in anthropometric and psychological conditions, so devices able to point a specific point in the workplace, as it is done in the cars with sleepiness sensors, is not possible since the worker moves in the workplace. PERCLOS method, instead, fixes a method that is useful to go over these specific aspects that represent a limitation of the fatigue measure. It is worth to note that nowadays some algorithms able to recognize the sleepiness of a human are available and they were developed in an open and free source using a C++ code embedded in MATLAB® based on the PERCLOS method. The measurement used in the case of the sleepiness detector for the drivers uses the same principle of the PERCLOS software available on the internet and that is usable thanks to the MATLAB®, it is possible to get at the following link: <https://it.mathworks.com/matlabcentral/fileexchange/55152-drowsiness-detection-using-a-binary-svm-classifier>.

The PERCLOS method is based on the evaluation of the awaking time in a single subject, so the software gives a measure of this assessment calculating the number of frames of a record in which the subject is recognized as awake and comparing this number to the total number of record frames,

$$PERCLOS = \frac{N_m - N_a}{N_m} \cdot 100 \quad (1)$$

where N_m is the total frames number of the record and N_a is the number of the frame in which the subject is recognized as "awake", so with the eyes open and without yawing phenomenon. The yawing phenomenon is when a man that is engaged in doing an action repeatedly has an increasing cognitive fatigue and the sleepiness is growing up, so the brain gives the input to increase the oxygen saturation in blood to retard the sleep, so the yawing is a symptom of sleepiness.

The problem to use this kind of algorithm is the validation of their use in an industrial context. For this reason, this paper aims to present a first experimental results set using the algorithm for the sleepiness identification through easily available technologies, such as small cameras for eyes pointing and the interface of these cameras. The limitations in use that these experiments revealed and a first curve of fatigue characterization for a single subject during an entire time span of the work shift are reported. The fatigue measurement method using the PERCLOS is very similar to the one used for example in other application fields such as the one of sleepiness definition for the driver of a car, in this case, the measurement system works as described in the following Figure 2.

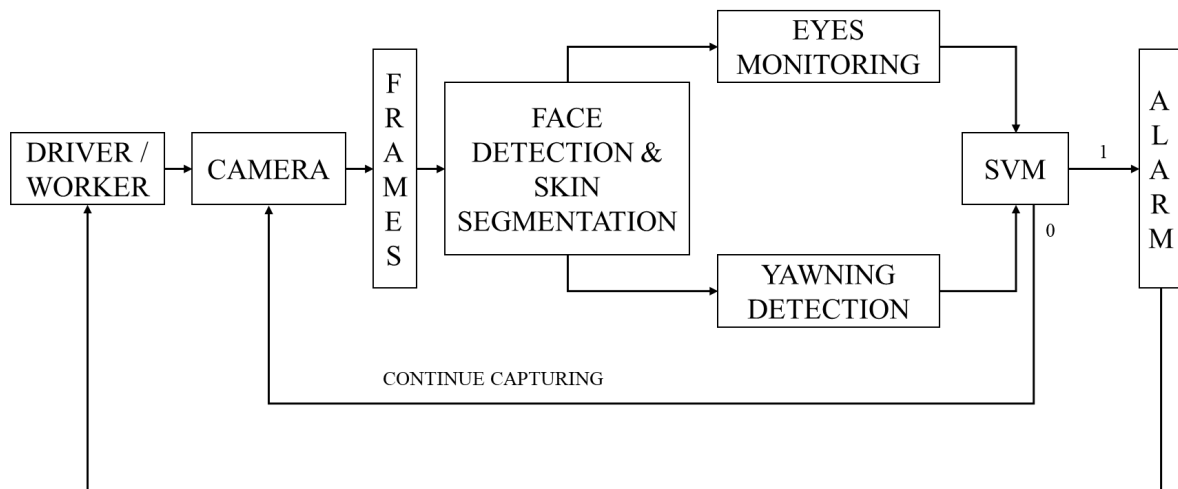


Figure 2. Logical framework of the proposed approach.

As reported in Figure 2, the system acts through a camera that is pointing at the worker’s eyes and the image of her/his face is elaborated trying to capture the eyes movements and the yawing of the driver. The recorded videos are then divided into frames in order to allow us the face detection and skin segmentation processes. In these steps, the false detections in identifying facial expressions are minimized and the positions of the eyes and the mouth are accurately determined. Furthermore, through the skin segmentation, the face and non-face images are recognized and then separated.

The collected data are used for monitoring the eyes and for detecting the possible yawing phenomenon, and a software (SVM) elaborates these monitored elements, and when the elaboration is done, having an assessment of the sleepiness the SVM gives an alarm or if it does not detect any problem, it continues to capture the face of the worker.

The assessment of the sleepiness is made on the image comparison. In particular, the eyes and the mouth are compared to the images present in a database embedded in the software, so the software associates the detected image to a specific image present in the database to which it is, finally, associated with a sleepiness level. The status and the specific region of the eyes are identified in every frame through the correlation coefficient template matching method, and by considering the variations to the connected pixels and the similarity ratio to the eye pixels. In Figure 3, it is reported, for example, the parameters used for the sleepiness assessment about the eyes.

	Eye Region	Area (no. of pixels)	Template	Avg. Height	Ratio
Full Open		201		7.62	2.87
Half Open		156		6.79	3.04
Closed		115		6.02	3.17

Figure 3. Example of eye-opening ratio calculation.

For detecting the yawning phenomenon, instead, the mouth area is identified used K means clustering and tracked using correlation coefficient template matching. In the following figure, we represent what it is recognized as sleepiness and not sleepiness when the software evaluates the yawing and the eyes closing. We chose to classify the outcomes as follows.

- Non-Fatigue (NF): the program detects that the subject is not fatigued; both eyes are recognized as open while the mouth is closed (there is no yawn).
- Fatigue (F): the program detects fatigue in the subject, detecting poor opening or closing of the eyelids and possibly yawning, both eyes, even if scarcely open, are recognized as closed.
- Not Detected (ND): the program cannot identify the subject's face, so it is impossible to extract the images related to eyes and mouth; in the console, the outcome of the last survey carried out remains visible.
- False Fatigue (FF): the program recognizes the fatigued subject even when it is not shown by a visual check. This happens when the direction of the gaze changes, especially downwards.

In the condition represented in Figure 4 it is possible to see a redundancy of signals given by the yawing and the eyes' closure in the same instant, this condition, for sure, is identified as very dangerous and the software will give the command to start the alarm to avoid any consequence to the sleepiness arising.

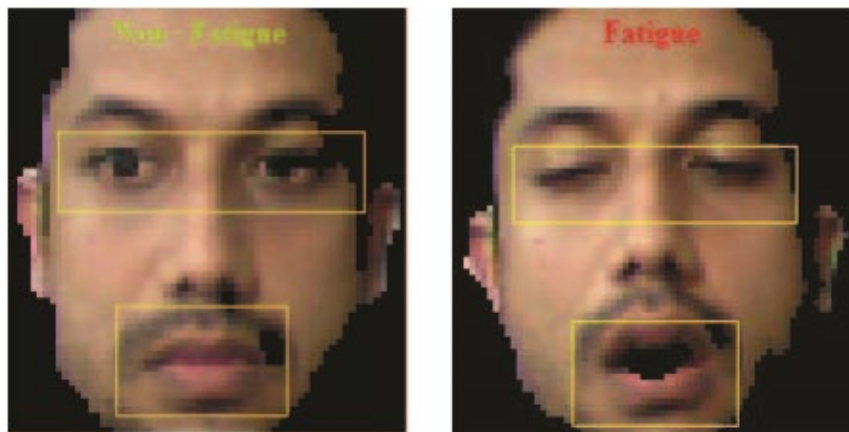


Figure 4. Face areas identified by the software for an avatar (eyes and mouth).

This program was selected from the possibilities available, as the Matlab® computing environment was considered the most versatile and appropriate to the concepts of Machine Learning. It was also found to be the simplest to use without requiring any specific expertise, a feature that can be considered interesting for possible future use in production contexts where training for the use of these technologies could be expensive.

As underlined in the introduction to this paper the problem of the fatigue detection in the production context is a worth issue to be faced to properly face the issues related to the safety and productivity during all the time span of a working shift that can be performed in the morning, in the afternoon and the night. As it is not possible to modify the circadian rhythm of each worker that could lead to a modification of the fatigue curve, this study wants to cover a lack of the actual HRA methods about the fatigue assessment, that are linked, as previously demonstrated to the sleepiness of a person, trying to give a measure of the sleepiness. From this measure and other signals, the production or the safety manager can decide to act some changes in the production organization to avoid any safety or productivity problem.

4. Experimental Study

The experimental tests were carried out in two phases: the data acquisition phase and the sleepiness evaluation phase, in order to determine any critical issues related to the use of some types of technologies and the evaluation program itself. The subjects involved in the tests have patiently

accepted to register through the cameras of their Personal Computers during their research and/or work activities, which is largely definable “in the office”. This condition was preferred to others because it was better suited to a long video recording.

According to the characteristics of technologies needed to measure the fatigue using the PERCLOS method, the office working type (using a laptop or a PC) was chosen because this kind of job allows us to easily observe the mouth and the eyes of the observed subject. The kind of task performed by the workers is related to normal design and typing activities that assure the possibility to have an effect of the cognitive fatigue easily measured by the PERCLOS method. The work shift duration goes from 8 am to 5 pm of every day from Monday to Friday.

The subjects investigated are 30 and they are from 25 to 59 years old and about a third of them are female: in this way it was considered to have taken into account the different chrono-types found in the literature. The total number of records expected are almost 640, since the request to the subjects was to record their work activity for 7 days 3 times per day for 30 min per time. Unfortunately almost the 8.5% of this expected experiments number was useless or not present for several personal reasons such as someone was not present at work during the time spans for measurement or had a posture not good for the experiment, and at the end, only 585 experiments were available for the present study. All the experiments were then divided firstly for chrono-type, then for three-time span during the work hours. As anticipated the records took place in three-time span, i.e., mainly in the morning (on average between 10.30 and 11), post-lunch break (between 14.30 and 16.00) and in the hour before the end of the shift (between 16.30 and 18.00). These records were then evaluated by the research team to the objective to detect the erroneous assessments, which as will be seen have been of a significant number. The recording time was divided according to the time of issue of the result by the program with evaluation, case by case, of its correctness.

The results were, then, summarized in an average trend, while the results of the observations are divided in Fatigue (F), Not-fatigue (NF), Not-detectable (ND), and False Fatigue (FF). These results are given accordingly to the PERCLOS algorithm and its MATLAB implementation, so evaluating the eyes and mouth shape the software automatically gives us one of the results F, NF or ND, while the FF is a result built by us from the analysis of the single state of the software noted as F. For the methods criticalities after exposed this phase of control was needed and in fact it identified these cases. It is worth to anticipate that at the end of this paper a first possible solution to this kind of problem is identified.

Following we proceed with the presentation of the results, commenting on them from time to time and setting out the critical points of the system.

5. Results and Discussions

The results from the experimental campaign had as first objective the possibility to confirm or not the general expected output of what is commonly accepted as a “normal” behavior of the persons that belong to the morning or evening chrono-type circadian, i.e., it could be important to validate the use of the previously introduced technology that the experiment confirms what is commonly expected by the people in terms of fatigue appearance. To measure the results of the experimental campaign in this sense, we decided to count the number of the outcomes for each person of two main sets, constituted by the morning and evening circadian chrono-types, and then divide this count for the total number of the experiments performed. With this main objective, the experimental set was tested as previously introduced and some comforting results were collected.

First, let us to show the results for the people that belong to the morning circadian chrono-type. As it is possible to understand in the international literature about the chrono-types, the morning circadian chronotype generally includes subjects over the age of 35; in them, there is a lower level of fatigue found in the morning compared to the evening circadian rhythm. In the experiments this trend was confirmed having a continuous fatigue increases during all the time span of observation from the morning to the evening, so it is possible to say that the experimental campaign results confirm what is available in the literature about the fatigue answer by this kind of chrono-types. In particular, note that in the recordings made after the lunch break, a level of fatigue almost double

compared to the morning, continuing to increase until the afternoon but with less intensity. The subjects interviewed following the outcome of the analysis, confirmed an effective perception of personal drowsiness was found very accentuated precisely in that time slot (i.e., from 14 to 14.30). Most of the non-detected category is due to the frequent distractions in the workplace (such as phone calls, social interaction with colleagues) that are quite common for the category of employment chosen for the analysis. It is also interesting to note that after such distractions, in most cases the evaluation of the program was of Non-Fatigue. Following the results for the morning (Figures 5–7), the first period after lunch and the closing hours of the working day are represented and finally, a general diagram for the fatigue level in the time horizon of the working day is presented.

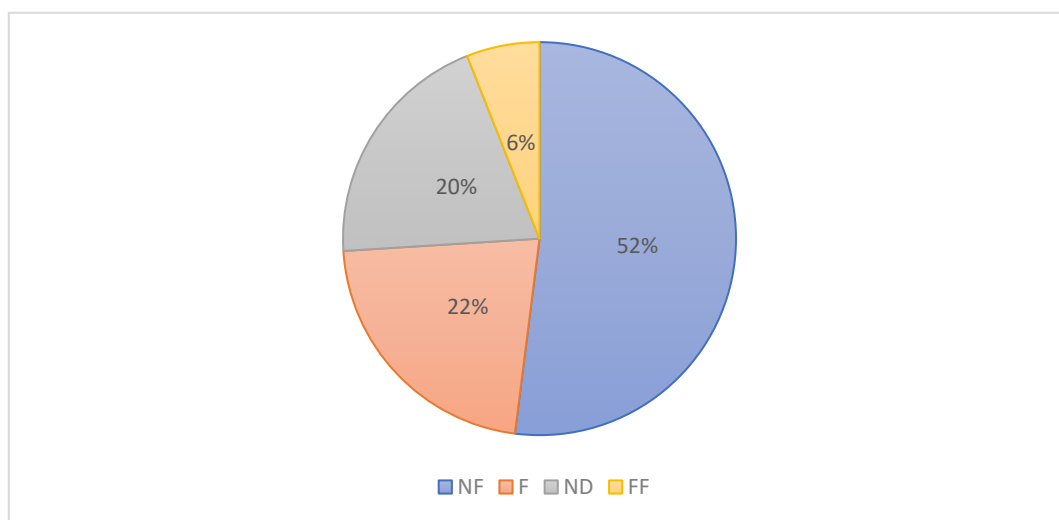


Figure 5. Results of the experiments in the morning for the morning circadian chrono-type.

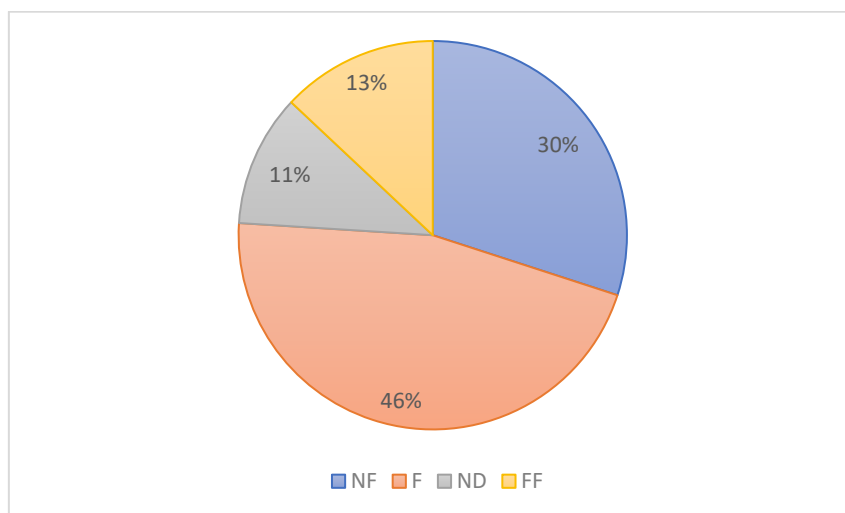


Figure 6. Results of the experiments in the first period after lunch for the morning circadian chrono-type.

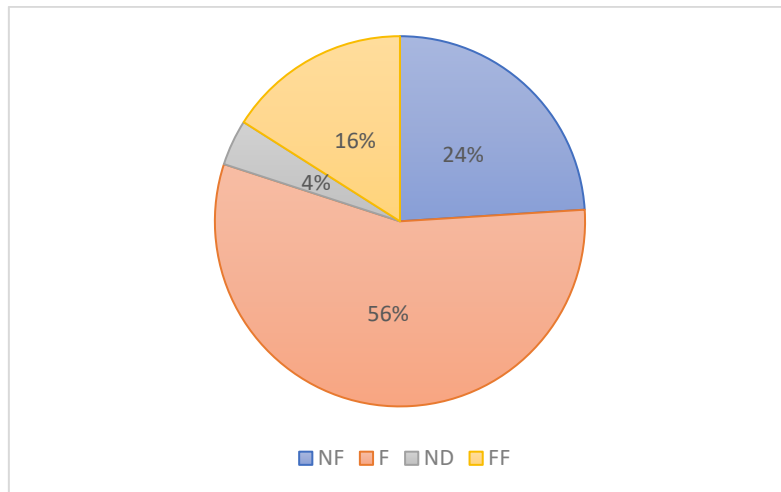


Figure 7. Results of the experiments in the afternoon for the morning circadian chrono-type.

After the presentation of the experimental results for the morning circadian chrono-type, let us introduce the results for other main experimental sets, i.e., the evening circadian chrono-type (Figures 8–10). In this category all subjects under the age of 35 are grouped and the number of subjects investigated is homogeneous with the other main set. The subjects, belonging to this kind of chrono-type are, generally, characterized by showing a slightly higher level of fatigue during the morning. They have an almost constant trend even in the post-lunch break time, in fact, the program detects a level of fatigue almost equal to the one observed in morning records. In the records carried out in the time slots between 4.30 and 5.00 pm there is a noticeable increase in fatigue which, however, is lower than the same as in the morning rhythm. Moreover, in this case, the subjects interviewed in the post lunchtime slot, do not feel excessive fatigue; it is, however, worth to note that many of them declare to consume light lunches, so maybe this chrono-type is also characterized by different habits.

The trend of the daily fatigue observed is also foreseeable in the scientific literature, so the fatigue follows the expected trend. Following the results for the morning, the first period after lunch and the closing hours of the working day are represented and finally, a general diagram for the fatigue level in the time horizon of the working day is presented.

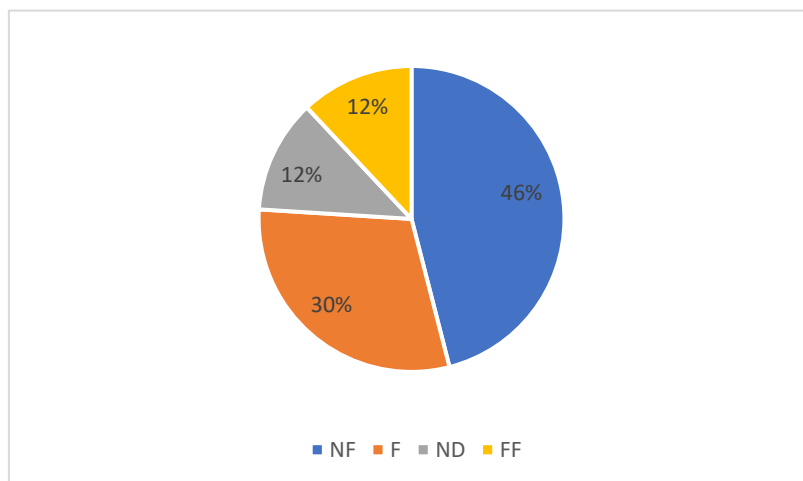


Figure 8. Results of the experiments in the morning for the evening circadian chrono-type.

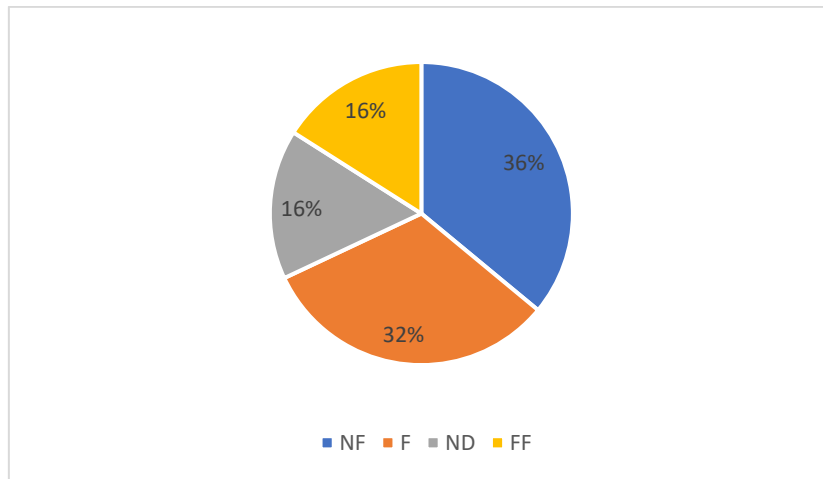


Figure 9. Results of the experiments in the period after lunch for the evening circadian chrono-type.

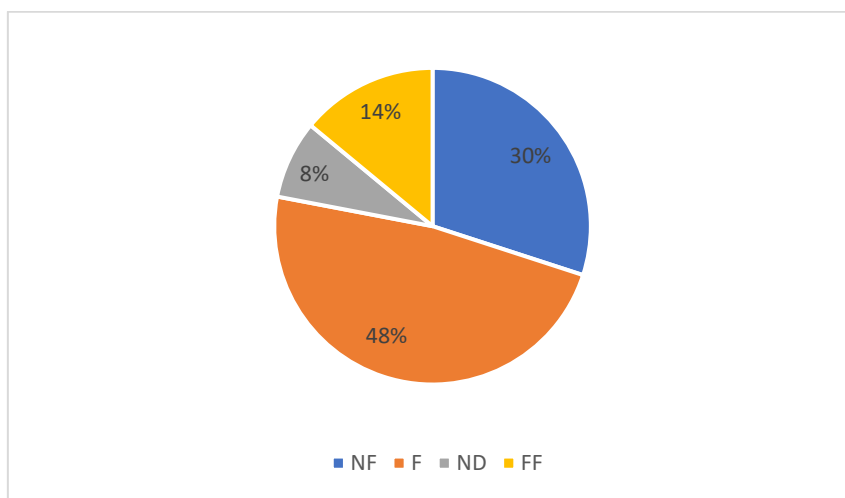


Figure 10. Results of the experiments in the afternoon for the evening circadian chrono-type.

The results obtained through the experiments confirm what it is present in the literature for the chrono-types analyzed in this research. All subjects investigated have less sleepiness at the beginning of the shift while the maximum level occurs at the end of the shift, following an increasing trend differentiated between the two main investigated sets of chrono-types. Subjects considered to belong to the morning rhythm have a lower level of fatigue during the morning compared to subjects characterized by an evening rhythm, which, however, have a lower level of fatigue at the end of the shift. Of particular interest is the very marked increase that occurs in people over the age of 35 in the post-lunch break interval: unlike the other category, their fatigue level is double, compared to the morning one; in practice, the fatigue appears not reduced by the lunch break. The motivations of this phenomenon could be their eating habits, behavioral, or in the different personal management of sleepiness. It is worth to note that these last issues will not be faced in this research, as it is focused on the technological experimentation for fatigue detection. In all the afternoon records it is possible to notice a decrease in the non-detected result related to the lighting that increases due to the lighting of the artificial lights. Therefore, it is possible to affirm that the software is very sensitive to these environmental factors.

In the last figure (Figure 11) it is reported a comparison diagram in which it is possible to understand the different shape of the curves for the two chrono-types analyzed in this experimental study and also the differences in absolute values of fatigue for both of them during the entire time span of a working day.

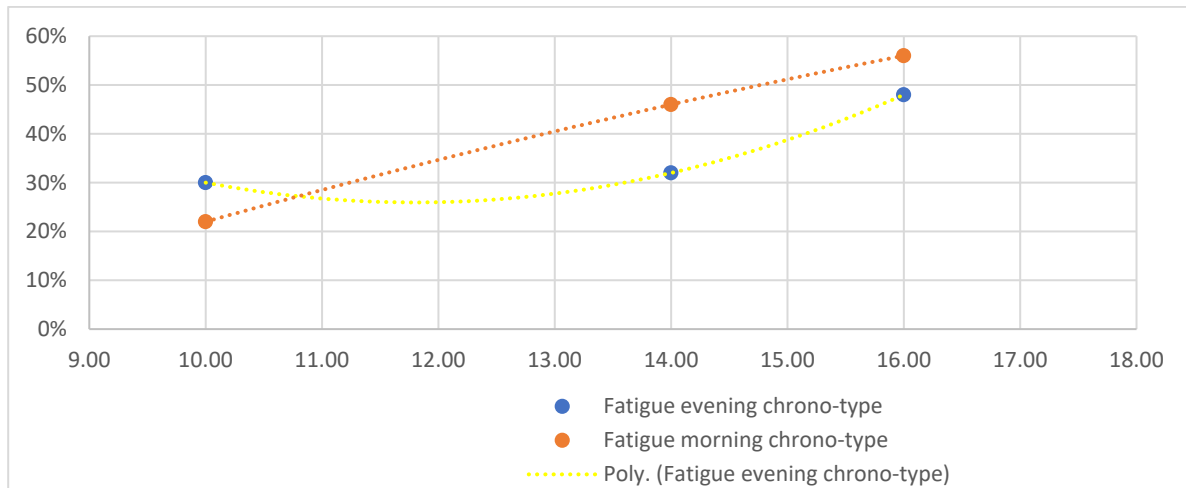


Figure 11. Comparison of the variations of the fatigue during the working day for the evening and morning circadian chrono-type.

The FF (the false fatigue results of experiments) result is linked to intrinsic criticalities of the software used for the analysis and is common to all registrations; an exhaustive list follows. The program used, even though it has many features that could make it usable in productive contexts, has several critical issues that have to be fixed for its full application in the production context:

- One of the most significant critical points is the sensitivity to the rotation of the face and the direction of the gaze: when the subject focuses his gaze in a direction different from that of the camera, the eyes appear to have a different opening, although this is not associated with any state of fatigue. In this case, the program gives the result of “fatigue” as the eye is recognized as closed. This criticality was recognized in the experiments and to avoid it, all the experiments records were analyzed and when this criticality was recognized the experiment result was indicated as “False Fatigue”. The presence of beard in the subject, especially if thick, often results in “Fatigue”, recognized through visual verification as False Fatigue, as the mouth is incorrectly detected as open, generating the alarm associated with yawning. This criticality is probably due to the limited presence of bearded individuals in the database.
- The ambient lighting was very incisive in the evaluation, especially in the late afternoon recordings causing the majority of the non-detected results. Another criticality of the software was identified in the difficulties to read the face and eye shape when the subject analyzed has glasses. Another improvement of the software when it is applied to the production context could be related to the yawning detection that in the driving sleepiness detection could be of interest, but in the production context not necessarily. This suggestion is motivated by the fact that the software sometimes when the subject yawns give the result of “non-detected” instead of “fatigue”, so the yawning detection in production context could be misleading from the sleepiness detection.

Starting from these criticalities, we tried to solve some of them, fixing the camera on a support in front of the subject investigated that in the trial was performing a small activity of manual work, different from the office activity investigated in our experiment. The results show an overcoming of some of the previously introduced criticalities. In particular, the first attempt to improve the performance of detection was to use a support usable as an hat on which the camera is mounted looking to the worker face; in this way the camera moves accordingly to the face orientation. In the following figure the support was simply chosen using a hat visor to mount a small camera that focus on worker face. Applying this simple improvement (represented in Figure 12), the following results were obtained.

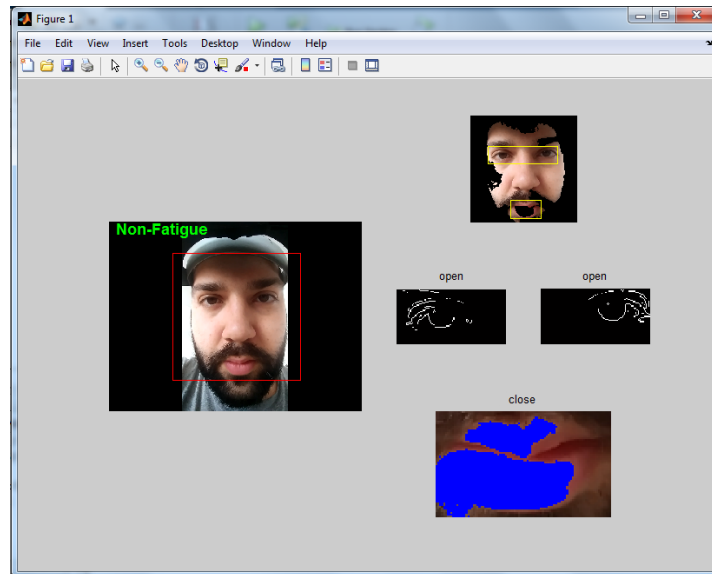


Figure 12. Improvement in face parts detection using the new positioning technique for the camera.

- The problems related to the rotation of the face have almost been solved; those attached to the gaze direction remain.
- Criticalities related to lighting were very attenuated and the results not detected, almost present due to sporadic adjustments of the hat by the subject, were almost eliminated.
- The critical issues attached to the erroneous fatigue warnings due to states of the open mouth caused by the presence of thick beard were also attenuated: the greater closeness to the face allowed the program a greater definition of the contours.

The improvement of the image detection is possible to be seen also in the following image. This improvement allowed us to think to a possible future development in the definition of worker hat support for the cameras.

The creation of a mechanism to make simultaneous the movement of the face and the camera can give reasonable hopes to import this method of face detection also in production context in which the worker moves himself and so the face detection could be a constraint in the use of this technological solution to identify the fatigue.

The possible future developments allow to think also to a redefinition of the rest scheduling models that could base their results also on the data acquisition from system such the ones here presented.

6. Conclusions

As recognized in the previous sections a great sustainability issue in the industrial and service companies is arising about the management of the workers' aging due to several social and political aspects. To this end, it is crucial to start to analyze one of the main influencing variables, i.e., the fatigue. It is recognized that people can have physical or cognitive fatigue and in this paper it is evidenced and analyzed the last one, proposing a way to measure it and trying also to have a measurement confirmation of what is normally expected by different age workers. The experiments, which were conducted using simple cameras and a freeware MATLAB program to analyze the images, revealed the effectiveness of this kind of measurement and confirmed what was expected.

As it was possible to understand, there is a lack in the actual product and service production knowledge about the right way to measure a very important variable as fatigue, especially when the production or the service system analyzed is a manual one. In this case, it is well known for the practitioners the effects of cognitive fatigue on the performances of a worker, but no ways to measure this parameter in an industrial context have appeared so far. This paper aimed to identify a method

to measure cognitive fatigue measuring one of its effect, which is the sleepiness, using a structured method as the PERCLOS method is.

The application of this method and the use of cameras to record the eye and face feature were applied to about 450 practical experiments that revealed some important results. The 450 experiments were persons involved in offices work, divided into different age groups, in particular, the youngest were from 18 to 35 years old, the middle age was from 36 to 55 years old and the oldest group was from 56 to 65. As it was possible to understand the age of the subject has a great influence on the circadian rhythm that is one of the main factors in the fatigue arising in the people. On this assumption, it was possible to imagine a different answer to the cognitive fatigue related to the age set. The expected shapes of the fatigue curves for the two types of chrono-types, divided into the different age groups, are confirmed from the experimental survey, even if more points of interpolation will reinforce the actual verified shape; therefore, the circadian age effect on the cognitive fatigue is confirmed. After this result, it was understood that in some cases that the presence of barb or glasses could modify the results of the recording and image elaboration leading to an error of measure, but the previous problem could be overcome if the camera is integrated with the face orientation of the observed subject.

The limitations of this work and the possible solutions also depicted here can reinforce the possibility to create new detection systems able to improve the decision making of the managers about the work shift assignment, the job rotation, and so on about the single worker. The impact of the application of these technologies to some specific work types, such as the pilots and the drivers, or less sensitive works to the cognitive fatigue can be significant especially in the context of the risk reduction and the productivity performance of the workers.

These results confirm and encourage to go beyond the actual level of knowledge about the measure of the fatigue in the real production context, so moving from the service companies (in which this experiment was performed) to the industrial ones. Thus, the next work would be oriented to the enlargement of the number of observations of the subjects during the working and the change of work tasks from the office activities to the assembly ones. This study and the results obtained give great hope for the future of aging management, and in particular for the different responses by different age workers to fatigue. The paper also revealed the necessity to distinguish between different circadian rhythms that generally are associated with different ages of the workers. This possibility to manage the assignment of the tasks to the people considering their age in the first phase (as the age is strongly related to the circadian rhythm and the cognitive fatigue arising during the work shift) and after to change this assignment if the fatigue measurement reveals an increase of fatigue can lead to a great improvement in terms of social sustainability of the modern industrial and service company.

Therefore, it is possible to imagine a new way to schedule the activities and tasks, no more focused only on the execution time but also on the effective capacity of the worker that is modified by the cognitive fatigue. Future works about this topic could be of great interest because this paper demonstrates that a quantitative measure of cognitive fatigue is possible and effective, so it is possible to imagine a new way to integrate this facet in the HRA models and in the scheduling problems related to the human tasks since the fatigue is measurable. When these models will be applicable, it would be possible to pursue a real improvement in the social sustainability of the industries and service companies.

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