Original Research Article

COMPUTERIZED ASSESSMENT OF READINESS(FOCOS/PRONTOS SYSTEM) AND ITS CAPACITY TO SCREEN FOR WORKER'S FATIGUE IN ITS MULTIFACTORIAL ASPECTS: Case-control and cross-sectional study

ABSTRACT

Introduction

Wepresent here a brief review of what has been published about fatigue, highlighting its multifactorial nature and the lack of objective markers that make it difficult to establish a consensus on measurement methods and presentthe Computerized Evaluation of Work Readiness (FOCOS/ProntosSystem), aiming to assess the correlation between the computerized assessment performance and signs of fatigue, using the Chalder instrument.

Materials and Methods

The study applied the Chalder Fatigue Scaleto 552 employees of a Brazilian mining company. Exclusion criteria were applied to remove inaccessible data from the fatigue scale and readiness assessment (Sistema FOCOS/Prontos, 2019) tests. After exclusions, the final sample consisted of 334 individuals divided into a 'clinical group' (G1) with signs of fatigue and a 'control group' (G0) without fatigue. The study aimed to analyze readiness profiles between the clinical and control groups using statistical tests like the Mann-Whitney U-test and Welch's t-test, with significance set at p-value <0.05.

Results

Results showed significant differences in daily readiness, cognitive impacts, and risky behaviors before and after self-reporting fatigue. The Prontos System demonstrated predictive value for fatigue-related risks and accident prevention measures, highlighting its role in enhancing workplace safety and productivity.

Conclusion

The study highlights the importance of daily and continuous fatigue assessment using the FOCOS/Prontos System to track signs of fatigue. The system's multidimensional approach enriches fatigue prediction and classification accuracy. Integrating instruments enhances fatigue management, allowing for proactive intervention based on temporal analysis of readiness parameters and behaviors associated with fatigue. The study emphasizes the complexity of fatigue and its correlation with accidents, advocating for ongoing monitoring as a preventive and performance optimization strategy, thus promoting a safer and healthier work environment.

Keywords:fatigue, computerized assessment, prevention, readiness.

1. Introduction

Throughout history, worker's health issues have evolved into increasingly in-depth and complex discussions, addressing various factors present in the workplace. Aspects such as shift length, workplace characteristics and the presence of stressors and/or distractors have been analyzed, also taking into account the interconnection between the worker's professional and personal life. In this context, quality of life, family relationships and physical and mental health conditions play a significant role in occupational health.

Among the risk factors for the physical and mental health of workers in various types of segments, fatigue stands out, defined as a "physiological state of reduced mental or physical performance capacity resulting from loss of sleep or prolonged wakefulness, circadian phase or workload [...]" (Rodrigues *et al.*, 2020). Therefore, fatigue is becoming an increasingly relevant and pressing issue in the workplace, as it can impact not only the personal lives of individuals, but also cause operational and organizational damage, reflected in a reduction in performance and/or daily performance, an increase in absenteeism, the development of work-related illnesses, the incidence of workplace errors and even accidents. These aspects can compromise the organizational environment, affecting productivity and generating financial losses for companies.

In this context, the use of instruments to assess the level of fatigue and work readiness has become essential for preventing fatigue and measuring it properly. An important tool that has been used in this context is the Computerized Work Readiness Assessment (FOCOS/Prontos System), widely used in various populations by more than 150 companies from different industrial sectors, such as mining, steel, logistics, transport, energy, among others. This methodology contemplates various worker categories, including operators, drivers, supervisors, analysts, electricians, mechanics, welders, among others, whose work activities can be affected by the effects of fatigue.

Although it is widely applied in Brazil, covering all regions of the country and more than 15 different states, this tool has also been adapted for other countries and cultures, such as Argentina, Mexico, the Dominican Republic, Oman and the United States. With more than 20 years of application and millions of evaluations recorded, the system has already been used by more than 70,000 people (Cabral *et al*, 2023). Due to the wide recognition and notoriety among user companies, integrating corporate Fatigue Management programs, according to publications, scientific events and awards won (Pereira *et al* 2023; RevistaProteção, 2021), this pioneering tool was selected as the object of study in this work.

Initially, we propose a brief review of what has been published about fatigue, highlighting its multifactorial nature and the lack of objective markers that make it difficult to establish a consensus on measurement methods. The aim is to analyze the readiness profile of groups with signs of fatigue, using the Chalder instrument, and comparing them with groups that denied feeling any signs of fatigue. To this end, readiness parameters, readiness levels, signs of readiness fatigue, well-being complaints and psychosocial aspects of readiness are analyzed.

1.1 The Comprehensive Dimensions of Fatigue

Fatigue can occur in different dimensions, such as peripheral, physical, mental, intellectual and emotional, but its definition still lacks consensus. Although cytokines have been identified as the main biological origin of fatigue, measurement still depends predominantly on the reports of affected patients. There is no objective marker consistently associated with this condition. In the case of Chronic Fatigue Syndrome, its etiology remains poorly established, with influences from genetic, epigenetic, immunological, infectious, psychosocial, psychiatric and neurological factors. Given the multidimensional and multifactorial nature of fatigue, it is crucial to use multiple instruments in its investigation. An effective approach to measuring fatigue involves adapting instruments to reality, which have been extensively tested on different populations, taking socio-economic and cultural variables into account. By assessing cognitive function and measuring various variables, these instruments can improve the accuracy of investigations (Azevedo *et al*, 2023).

Fatigue is a complex phenomenon that involves several biological processes, one of which is the synthesis of serotonin (5-HT). As pointed out by Rossi, Tirapegui, Shei and Mickleborough, cited by Vasconcelos (2019), serotonin plays a crucial role in regulating daily functions such as mood, circadian cycle, motor activity and cognitive functions. Decreased production of this neurotransmitter is associated with various symptoms of fatigue, especially central fatigue.

Furthermore, fatigue and depression are intrinsically linked, with a significant overlap in their symptomatology. Diagnostic criteria for depression, according to the American Psychiatric Association (2014), include physical tiredness, lack of energy, difficulty concentrating and lack of initiative to make decisions. This connection highlights the complexity and interrelationship between psychological conditions and the experience of fatigue.

Measuring fatigue is a challenge and is predominantly done through self-reported symptoms. Scales such as the Visual Analog Scale (VAS), according to Norheim (2011), are widely used, but the one-dimensional nature of this approach is the subject of discussion. All the scales, however, depend on self-reporting, highlighting the importance of information from the questions asked to patients.

Although there are several instruments available to assess fatigue, reviews by scholars such as Finsterer (2014), Gerber (2019) and Machado (2021) point to the lack of tools capable of assessing fatigue in a multidimensional and standardized way. The prevalence of fatigue reported in studies is influenced by the variety of measuring instruments, making it difficult to compare results based on different scales (Norheim, 2011). Therefore, there is a pressing need to develop new tools for a more comprehensive and uniform approach to measuring fatigue.

In this context, it is important to look for application methodologies that are short, objective and scalable. The development of scientifically-based technological tools can not only optimize the early identification of fatigue, but also play a key role in the therapeutic process, providing a basis for the implementation of preventive measures.

In short, although there are biological factors involved, there is still no precise marker to measure fatigue. A multidimensional and multifactorial approach is essential in research, and existing treatments, although effective, do not ensure complete remission of symptoms when applied alone. Therefore, a biopsychosocial approach is necessary to provide adequate care for these patients.

2. Methodology

The Portuguese version of the Chalder Fatigue Scale (1993), validated by Cho et al. (2007),was applied to 552 employees of a Brazilian mining company. Exclusion criteria included inaccessible data, both from the fatigue scale result and from the performance of the readiness assessment (Sistema FOCOS/Prontos, 2019) in the 30-60-90 tests applied before and 30-60-90 tests applied after the response to the Chalder Fatigue Scale. The final sample, made up of 334 individuals who performed the Prontos System *and* responded to the Chalder scale, was divided into two groups: the 'clinical group' (G1), which includes 26 workers with signs of physical and/or mental fatigue on the scale fatigue, and the 'control group' (G0), consisting of 308 employees who denied fatigue on the aforementioned scale.

The 552 employees belong to different functions related to mine operations, ranging from driving vehicles to analysis, supervision and maintenance. The main positions included in the sample, representing 87.14% of the total, are highlighted in the table below:

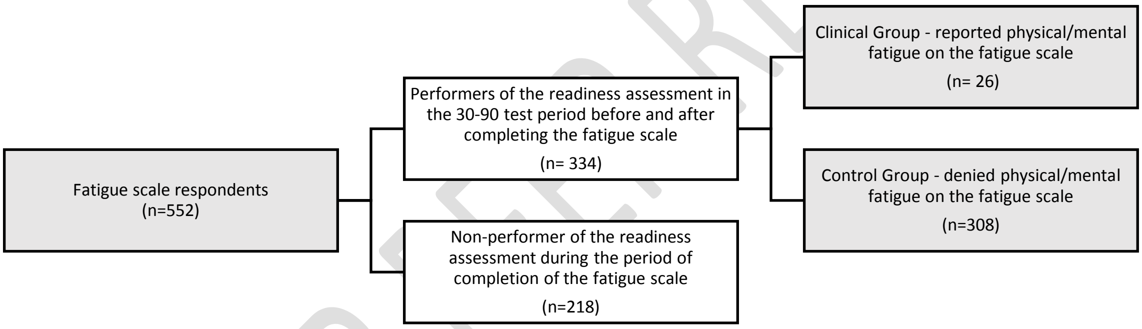
Table 1 – Predominant positions in the sample studied

Job Title/Role	**Representation in the sample**
EQUIPMENT FACILITIES OPERATOR	13.95%
MAINTENANCE TECHNICIAN	10.87%
ANALYST	8.70%
MECHANIC	8.51%
TECHNICAL ASSISTANT	4.89%
MECHANICAL TECHNICIAN	4.89%
SUPERVISOR	4.17%
PROCESS CONTROL TECHNICIAN	3.80%
ELECTRICAL & ELECTRONICS TECHNICIAN	3.80%
MACHINE OPERATOR	3.80%
ENGINEER	3.26%
INSPECTOR	3.26%
ASSISTANT	3.26%
ELECTRICIAN	2.17%
ELECTRICAL & MECHANICAL TECHNICIAN	2.17%
MINE AND GEOLOGY TECHNICIAN	2.17%
WELDER	1.81%
AUTONOMOUS OPERATOR	1,63%

The main position represented in the sample is Equipment Operator, which involves operating and maintaining the equipment used in mining facilities. These professionals play an important role in carrying out various tasks related to the extraction and processing of minerals, with an emphasis on the use of specific machinery and equipment, such as excavators, tractors, loaders, dump trucks and crushers, among others. They also move materials and other supplies, and have similar characteristics and responsibilities to drivers, who operate heavy vehicles and equipment. It is worth noting that the leadership positions included in the readiness assessment, such as Supervisor, were selected due to the critical nature of their activities, which involve driving vehicles within the company.

The aim is to analyze the readiness profile of groups with signs of fatigue using the Chalder Fatigue Scale, comparing them with groups without signs of fatigue in the same population. This analysis will be carried out on readiness parameters, readiness levels, signs of readiness fatigue, as well as well-being complaints and psychosocial aspects related to readiness.

Figure 1 - Sample distribution and composition of the clinical (G1) and control (G0) groups.



The databases, containing 6,2847 samples and 34 variables, were statistically analyzed using the Mann-Whitney U-test and Welch's t-test to determine whether or not the null hypothesis could be rejected (considering a 95% confidence level). These tests were chosen because they are non-parametric (Mann-Whitney U-test) and parametric (Welch's t-test), adding robustness to the results obtained, and p-value <0.05 was considered statistically significant[1]. The study is in line with Resolution CNS-466/12 and was approved by the CEP/EMESCAM, according to opinion number 6.326.074.

2.1 Chalder fatigue scale

[1] Statistical analysis conducted independently by Alexandre Rosseto Lemos, Master’s studentin Computer Science from the Federal University of Espírito Santo (Ufes), with an emphasis on Artificial Intelligence, Data Science, Machine Learning and Deep Leraning; and by Jade Barbosa Kill, PhD in Sciences from the Federal University of Espírito Santo (Ufes) with a research area in Signal Processing, Machine Learning and Biomedical Engineering.

The Chalder Instrument for fatigue analysis is a tool developed to assess the severity of fatigue in clinical and research contexts. Originally proposed by Chalder *et al*. in 1993, the questionnaire was designed to measure fatigue in patients with Chronic Fatigue Syndrome (CFS) and has been widely used in various studies on fatigue and related conditions. The instrument consists of an 11-item scale in which participants report how often they experience different symptoms of fatigue. These symptoms cover areas such as general tiredness, lack of energy and feeling exhausted after physical and mental activities. The total score obtained on the Chalder Fatigue Scale provides a quantitative measure of fatigue, allowing a more objective assessment of the impact of this condition on individuals.

Over the years, the Chalder Instrument has been adapted and validated for use in various populations and clinical contexts. Participants' answers are scored, providing a more comprehensive and measurable view of fatigue, helping both to identify clinical cases and to evaluate therapeutic interventions. The instrument's usefulness and reliability have made it a common choice in research exploring fatigue in different medical and psychological contexts.

2.2 Computerized readiness assessment (FOCOS/Prontos System)

Before starting their daily work activities, employees take part in an assessment using a computerized system, according to criteria established by each organization. This procedure, incorporated as part of the company's health and safety culture, is carried out in less than a minute every day before the start of the working day; but it is also repeated throughout the day, hours after the first application, especially during long, extended working hours or monotonous activities.

The computerized test used in this context was developed based on the Continuous Performance Tests (CPT) by Cabral (2019). During the test, alternating pictures appear on the screen, with one being marked as "correct for the day" and the other as "incorrect". The system evaluates more than 200 variables, which are summarized in four main parameters: impulse control, attention, reaction time and concentration. In addition, the system identifies unsafe behavior and temporal fluctuations, which allows it to generate a global parameter called a "risk predictor", based on machine learning techniques.

In addition to analyzing the parameters separately, this methodology also considers the association between them and other risk tendencies. The assessment is simple and objective and can be adapted to different audiences without requiring specific educational levels. The result is communicated to both the user and their leader immediately after the assessment is completed, as well as providing data and forwarding it to the organizations' health and well-being sectors. In cases of altered results, the employee is approached by the supervisor and may be released to work with reinforcement of the procedure, behavioral observation, or referred for a multidisciplinary health assessment.

The assessment flows provide referrals for clinical analysis, revealing, among the altered cases, various conditions of physical impairment and emotional health. This contributes to diagnoses of impaired visual acuity, hormonal disorders, signs of fatigue, emotional impacts, among others.

In addition, the system provides personalized feedback, such as guidance on sleep hygiene, quality of life habits, among others, to the employee. This promotes their self-development and increases their perception of security, while at the same time developing leadership and strengthening communication in the organization. The tool is certified to standards such as ISO 27001 and is audited by companies specializing in technology and information security.

Among its results, the FOCOS/Prontos System generates an indicator of signs of fatigue. Six objective and subjective variables are analyzed, considering the evaluation of the day compared to the previous one. Variations in behavior and cognition that represent declines in the parameters of attention, impulse control, reaction time and concentration are identified. Self-reported complaints such as sleep difficulties (poor night's sleep) or pain in different parts of the body are also considered.

Based on the analysis of the six variables, which are also made up of sub-variables that constitute the intellectual property of the method, an association score is generated that identifies declines suggestive of signs of fatigue for each evaluation carried out by the employees. This score consists of an algorithm that analyzes the parameters and complaints not only independently, but also in association and with different weights, based on scientific literature and the intelligence of feedback from the Prontos System database.

This and other population and individual analyses carried out by the method contribute to expanding prevention in work scenarios with exposure to risks, operational failures and productivity.

Finally, each evaluation carried out by the employee is then classified according to Table 2:

Table 2: Risk scores and classifications for signs of fatigue in Prontos.

Score	**Classification**
= 0	No signs of fatigue
= 1	Low risk of signs of fatigue
= 2	Moderate risk of signs of fatigue
>= 3	Increased risk of signs of fatigue

The variables analyzed by the Prontos System on a daily basis include attention, which can be affected by fatigue through tiredness and difficulty in maintaining attention on a task for long periods, resulting in lapses of attention and decreased vigilance. Studies show that sleep deprivation and fatigue are associated with deficits in sustained attention, difficulty concentrating and a reduced ability to stay focused on a task. Lack of adequate attention can increase the risk of accidents and errors in the performance of tasks, negatively impacting productivity at work, interfering in the performance of daily tasks and affecting quality of life. It can also generate frustration, stress and interpersonal problems due to communication difficulties and lack of focus (Magnus *et al*, 2022).

Fatigue has a negative impact on the ability to maintain concentration and perform complex tasks. When we are tired, our ability to process information and integrate knowledge is impaired. In addition, fatigue can lead to lapses in attention and difficulties in keeping up with cognitively demanding tasks. Fatigue negatively affects the ability to concentrate and cognitive performance. In addition, difficulty concentrating can cause anxiety, stress and negatively affect self-esteem (Habiburrahman*et al*, 2021).

Fatigue is also associated with an increase in reaction time, slowing down motor responses. Studies show that sleep deprivation and fatigue can negatively affect the brain's processing speed, resulting in longer reaction times and slower motor responses. Increased reaction time due to fatigue can result in lower performance in activities that require quick responses, such as driving. This can increase the risk of accidents and injuries, as well as causing frustration and concern regarding cognitive abilities (Williamson *et al*, 2011).

The Prontos System also analyzes impulse control, which is affected by fatigue due to the impulsive and risky behaviors that can make up the condition. Research suggests that lack of adequate sleep and fatigue are related to a decrease in behavioral inhibition, which can result in a greater propensity to make rash decisions and engage in impulsive behavior. Lack of impulse control due to fatigue can lead to self-destructive behavior, such as using harmful substances or engaging in risky behavior. This can have negative consequences for physical health, as well as generating stress, guilt and emotional problems (Barnes *et al*, 2004; Lock *et al*, 2018).

The Prontos System's fatigue interface also makes it possible to extend the analysis of the results to areas and people who carry out more than one assessment a day, i.e. carry out a second assessment during the working day in order to create more preventive barriers and understand the impact of the effects of the working day, especially in long shifts and monotonous activities - which is the case of the sample studied in this research. This allows us to evaluate the effects of rest and the inherent effects of work activity, understanding fatigue as an interrelationship between personal and professional life.

3. Results and discussion

The results found after the statistical analysis of the databases containing the clinical (G1) and control (G0) groups are presented, with regard to self-reported fatigue via Chalder (Cho et al., 2007), in comparison with the readiness variables: final classification, critical actions, well-being complaints, parameters and score of signs of fatigue.

The results show that, comparatively, in all four possible final classifications of the Prontos System, the clinical group (which signaled fatigue) showed highly significant deviations and changes in daily readiness than the control group (which denied fatigue), both in the analyses carried out on the 90 tests before self-reporting (Chart 1) and after self-reporting (Chart 2). These different degrees of alterations may show the temporal effects of fatigue on the cognitive aspects assessed by the instrument.

Table 3: Comparative analysis of the clinical and control groups 30, 60 and 90 tests BEFORE completing the Chalder Fatigue Scale (Cho et al., 2007).

Final classification Prontos System	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Significant alterations	4,871 ± 0,041	3,243 ± 0,014	* p < 0,001 ** p < 0,001	**5,247 ± 0,030**	**3,114 ± 0,010**	* p < 0,001 ** p < 0,001	5,408 ± 0,025	3,299 ± 0,008	* p < 0,001 ** p < 0,001
Alterationss	16,558 ± 0,071	10,820 ± 0,026	* p < 0,001 ** p < 0,001	**16,736 ± 0,051**	**10,896 ± 0,018**	* p < 0,001 ** p < 0,001	43,307 ± 0,056	35,950 ± 0,024	* p < 0,001 ** p < 0,001
Deviations	46,857 ± 0,091	37,972 ± 0,043	* p < 0,001 ** p < 0,001	**45,616 ± 0,067**	**36,420 ± 0,029**	* p < 0,001 ** p < 0,001	16,186 ± 0,042	10,945 ± 0,015	* p < 0,001 ** p < 0,001
Unsafe behavior	**2,637 ± 0,031**	**1,298 ± 0,009**	* p < 0,001 ** p < 0,001	1,651 ± 0,016	1,265 ± 0,006	* p < 0,001 ** p < 0,001	1,498 ± 0,013	1,301 ± 0,005	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

Table 4: Comparative analysis of the clinical and control groups 30, 60 and 90 tests AFTER completing the Chalder Fatigue Scale.

Final classification Prontos System	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Significant alterations	**3,817 ± 0,043**	**2,840 ± 0,016**	* p < 0,001 ** p < 0,001	3,395 ± 0,029	2,555 ± 0,011	* p < 0,001 ** p < 0,001	3,321 ± 0,024	2,378 ± 0,009	* p < 0,001 ** p < 0,001
Alterationss	12,175 ± 0,072	8,860 ± 0,028	* p < 0,001 ** p < 0,001	**11,648 ± 0,052**	**8,007 ± 0,019**	* p < 0,001 ** p < 0,001	11,104 ± 0,043	7,631 ± 0,016	* p < 0,001 ** p < 0,001
Deviations	**37,199 ± 0,105**	**27,469 ± 0,043**	* p < 0,001 ** p < 0,001	35,078 ± 0,079	27,334 ± 0,032	* p < 0,001 ** p < 0,001	33,884 ± 0,066	26,799 ± 0,271	* p < 0,001 ** p < 0,001
Unsafe behavior	**1,269 ± 0,024**	**0,943 ± 0,009**	* p < 0,001 ** p < 0,001	1,285 ± 0,018	0,950 ± 0,007	* p < 0,001 ** p < 0,001	0,997 ± 0,014	0,869 ± 0,005	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

In the analysis of the readiness assessments carried out before completing the fatigue scale (Chart 1), it can be seen that the control (G0) and clinical (G1) groups show a greater difference in frequency between them 60 tests before, when considering readiness changes at all levels (significantly altered, altered and deviations); and 30 tests before, when considering the frequency of the unsafe behavior classification. These findings may support the preventive perspective in identifying cognitive signs that may precede the self-declaration or subjective perception of physical or mental fatigue, reiterating the importance of the Prontos System as an objective method.

In the analysis of the readiness assessments carried out after completing the fatigue scale (Table 4), it can be seen that the control (G0) and clinical (G1) groups show a greater difference in frequency between them 30 tests later, when considering readiness changes at the significantly altered, deviant and unsafe behavior levels; and 60 tests later, when considering the frequency of altered classifications. The findings suggest that there are cognitive impacts after self-reporting/perceiving fatigue, although they are less frequent in both groups compared to the cognitive impact before fatigue is reported or denied.

In the temporal analysis focused on the clinical group (G1), the results (Table 5) indicate a high frequency of "significant alterations" – the most critical level of classification of readiness/attention to work – in the 90 tests before the fatigue scale was applied. The frequency of significant alterations decreases over the months, but throughout the period it remains above the frequency of the control group with high discriminatory power – therefore differentiating itself through readiness screening.

Table 5: Temporal analysis only of the clinical groups in the 30, 60 and 90 tests applied BEFORE and AFTER completing the Chalder questionnaire

Final classification Prontos System	**90 tests before**	**60 tests before**	**30 tests before**	**30 tests before**	**60 tests before**	**90 tests before**
Significant alterations	**5,41%**	5,25%	4,85%	3,81%	3,42%	3,31%
Alterationss	16,20%	**16,75%**	16,46%	12,20%	11,67%	11,09%
Deviations	43,32%	45,60%	**46,81%**	37,27%	35,09%	33,94%
Unsafe behavior	1,49%	1,66%	**2,66%**	1,31%	1,28%	1,00%

It is noteworthy that the deviations in readiness, which include not only significant changes, but also milder or borderline alterations, are more evident in the clinical group in the previous 30 tests. Also noteworthy in the same sample was the rise in the unsafe behavior index. This may highlight the association between the effects of fatigue and the risk of accidents, since this classification is indicative of certain risky behaviors such as inattention and error, but also of possible behaviors that circumvent protocols and challenge rules, which may incur a high risk to operations – thus demonstrating the potential of tracking fatigue with an emphasis on reducing accidents at work.

The reduction in alterations and deviations over time may also be indicative of the interventions carried out by the organization after the self-report was identified. Furthermore, the significant changes in readiness observed in the 30 to 90 tests before self-reporting highlight the need for instruments that are independent of the subjectivity of self-reporting. In the case of the Prontos System, they can be applied on a daily basis for prolonged, constant and consistent tracking, taking into account the effects of rest and working hours, which are changeable and circumstantial.

The variables shown in tables 6 and 7 result in actions that are parameterized according to each organization's policy, taking into account the resources available and the degree of risk of the activities. These actions can include measures such as removing the immediate risk, behavioral observation, dialogue with leadership, compensatory strategies such as breaks, interventions or referral for medical/psychosocial assessment.

The tables above highlight that the index of critical actions generated for the clinical group is consistently higher, in a statistically significant difference, compared to the control group throughout the time series. An important highlight is observed in the previous 30 tests, when alterations, deviations and unsafe behaviors alerted leaders and health and safety teams to the risks in the behaviors analyzed, allowing the inherent aspects of mental and physical fatigue to be tracked, but also accidents to be prevented and productivity to be increased.

Table 6: Comparative analysis of the critical actions generated for the clinical and control groups 30, 60 and 90 tests, BEFORE completing the Chalder questionnaire.

Prontos System Variables	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Critical actions generated	6,488 ± 0,046	3,911 ± 0,016	* p < 0,001 ** p < 0,001	5,821 ± 0,031	3,953 ± 0,012	* p < 0,001 ** p < 0,001	6,140 ± 0,027	4,002 ± 0,009	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

Table 7: Comparative analysis of the critical actions generated for the clinical and control groups 30, 60 and 90 tests AFTER completing the Chalder questionnaire.

Prontos System Variables	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Critical actions generated	4,078 ± 0,043	2,610 ± 0,015	* p < 0,001 ** p < 0,001	3,685 ± 0,030	2,336 ± 0,011	* p < 0,001 ** p < 0,001	3,281 ± 0,024	2,138 ± 0,008	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

The variables shown in tables 8 and 9 analyze the subjective data also mapped by the assessment of readiness following the test, in the form of a questionnaire in which employees can mark "yes" or "no" to certain complaints, also on a daily basis. These variables can and are used by organizations as indicators of well-being, quality of life, emotional health and, in association with changes in readiness, can generate more critical actions.

Table 8: Comparative analysis of the associated complaints (population averages) that stood out for the clinical and control groups at 30, 60 and 90 tests, BEFORE completing the Chalder questionnaire.

Prontos System Variables	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Sum of complaints	0,212 ± 0,001	0,087 ± 0,000	* p < 0,001 ** p < 0,001	0,178 ± 0,000	0,091 ± 0,000	* p < 0,001 ** p < 0,001	0,185 ± 0,000	0,098 ± 0,000	* p < 0,001 ** p < 0,001
Malaise	0,006 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001	0,007 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001	0,006 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001
Poor night's sleep	0,061 ± 0,000	0,020 ± 0,000	* p < 0,001 ** p < 0,001	0,051 ± 0,000	0,020 ± 0,000	* p < 0,001 ** p < 0,001	0,048 ± 0,000	0,021 ± 0,000	* p < 0,001 ** p < 0,001
Pain in part of the body	0,053 ± 0,000	0,028 ± 0,000	* p < 0,001 ** p < 0,001	0,046 ± 0,000	0,028 ± 0,000	* p < 0,001 ** p < 0,001	0,047 ± 0,000	0,028 ± 0,000	* p < 0,001 ** p < 0,001
Use of medication	0,050 ± 0,000	0,010 ± 0,000	* p < 0,001 ** p < 0,001	0,040 ± 0,000	0,009 ± 0,000	* p < 0,001 ** p < 0,001	0,037 ± 0,000	0,010 ± 0,000	* p < 0,001 ** p < 0,001
Sadness	0,012 ± 0,000	0,004 ± 0,000	* p < 0,001 ** p < 0,001	0,011 ± 0,000	0,006 ± 0,000	* p < 0,001 ** p < 0,001	0,008 ± 0,000	0,006 ± 0,000	* p < 0,001 ** p < 0,001
Family issues	0,002 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001	0,005 ± 0,000	0,003 ± 0,000	* p < 0,001 ** p < 0,001	0,015 ± 0,000	0,003 ± 0,000	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

Table 9 - Comparative analysis of the associated complaints (population averages) that stood out for the clinical and control groups 30, 60 and 90 tests AFTER completing the Chalder questionnaire.

Prontos System Variables	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Anxiety	0,010 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001	0,005 ± 0,000	0,003 ± 0,000	* p < 0,001 ** p < 0,001	0,004 ± 0,000	0,003 ± 0,000	* p < 0,001 ** p < 0,001
Problems at work	0,008 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,004 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,003 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001
Difficulty thinking	0,007 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,004 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,004 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001
Difficulty concentrating	0,008 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,005 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,003 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001
Drowsiness	0,006 ± 0,000	0,001 ± 0,000	* p < 0,001 ** p < 0,001	0,004 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001	0,004 ± 0,000	0,002 ± 0,000	* p < 0,001 ** p < 0,001
Sluggishness	0,010 ± 0,000	0,001 ± 0,000	* p < 0,001 ** p < 0,001	0,005 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001	0,003 ± 0,000	0,000 ± 0,000	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

Some complaints stand out in the clinical group in the 30-90 tests before the report of fatigue as indicated by Chalder, while other complaints are evident in the 30-90 tests after the report. This may indicate associated issues that can either contribute to or make up the fatigue picture (before), but also issues that can result from and/or be aggravated by prolonged fatigue (after).

In the tests and the period leading up to the report, the complaints with the greatest significant difference between the groups include feeling unwell at the start of the journey, sleepless nights, pain in different parts of the body, use of medication, feelings of sadness and family difficulties. All of these complaints are higher than the general trend observed in the control group population, in a highly significant way, with a greater accumulation ("sum of complaints") especially in the 30 tests that precede the self-report of fatigue using the Chalder.

In the period following the report of fatigue, in the 30-90 tests afterwards, other complaints are emphasized, such as anxiety and/or stress, as well as difficulties at work, which in turn can be effects of prolonged fatigue symptoms. During intra-shift assessments (the second test applied during the day, especially during long shifts), employees are also asked about other possible effects of fatigue, such as difficulty thinking, lack of concentration, drowsiness and sluggishness. These questions provide relevant and highly significant evidence in the clinical group, showing a clear association and demonstrating, once again, the effects of fatigue, especially in the 30 post-self-report tests on the Chalder.

Analyzing the percentage difference between the clinical group (with reports of fatigue) and the control group (without reports of fatigue), tables 10, 11 and 12 show that the parameters that make up the assessment of readiness and are generated by the Prontos System (Risk Predictor, Impulsivity and Lack of concentration) show a greater statistically significant association with reports of Fatigue, gradually increasing until reaching a peak in the 30 tests before the Chalder was applied. On the other hand, the parameters Inattention and Slowness initially show a lower association, up to 90 days before; however, they show a continuous increase in alterations in these parameters until they reach their peak in the 90 tests following the application of Chalder. This suggests that Inattention and Slowness may suffer a more prolonged effect, even after an improvement in overall results. It also reinforces the importance of the Prontos System method analyzing various parameters which, in combination, make the evaluation more predictive.

The Impulsivity and Lack of concentration parameters seem to be more predictive, anticipating reports of fatigue and therefore being important and highly significant in the preventive detection of fatigue. Alterations to these parameters can be associated with various conditions, such as poor quality and adequacy of sleep, sleep deprivation, decreased behavioral inhibition, use of harmful substances, stress, anxiety, among other emotional issues.

In association with work activities, impairment in these Prontos System parameters indicates that they can result in risky behavior, such as mistaken and hasty decision-making, as well as a reduction in the ability to maintain concentrated attention during long-term, repetitive and/or monotonous activities, again reiterating the emphasis on predicting and preventing accidents and improving productivity rates in different operations.

The association with the Risk Predictor shows how closely fatigue is related to the risk of possible accidents at work. This relationship is backed up by case studies that show an increase in the fatigue score in the Prontos System preceding accidents at work which, due to a lack of human intervention in the management of results, could not be avoided - which has led to organizations integrating more technologies in order to systemically block access to areas and/or equipment that pose a risk to life.

Table 10 - Comparative analysis of the parameters assessed by Prontos and which make up the results for the clinical and control groups 30, 60 and 90 tests BEFORE completing the Chalder questionnaire.

Prontos System Variables	**30 tests before**		**Statistical tests**	**60 tests before**		**Statistical tests**	**90 tests before**		**Statistical tests**
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Risk predictor	33,260 ± 0,008	21,798 ± 0,035	* p < 0,001 ** p < 0,001	32,830 ± 0,063	21,896 ± 0,025	* p < 0,001 ** p < 0,001	30,314 ± 0,051	23,794 ± 0,021	* p < 0,001 ** p < 0,001
Impulsiveness	26,217 ± 0,085	15,884 ± 0,031	* p < 0,001 ** p < 0,001	24,513 ± 0,054	15,621 ± 0,022	* p < 0,001 ** p < 0,001	22,997 ± 0,047	15,215 ± 0,017	* p < 0,001 ** p < 0,001
Lack of concentration	16,484 ± 0,070	10,503 ± 0,026	* p < 0,001 ** p < 0,001	16,325 ± 0,049	9,925 ± 0,017	* p < 0,001 ** p < 0,001	15,517 ± 0,040	10,144 ± 0,015	* p < 0,001 ** p < 0,001
Inattention	13,241 ± 0,064	11,444 ± 0,027	* p < 0,001 ** p < 0,001	12,955 ± 0,045	11,275 ± 0,020	* p < 0,001 ** p < 0,001	12,526 ± 0,037	11,305 ± 0,015	* p < 0,001 ** p < 0,001
Slow response	9,274 ± 0,055	7,522 ± 0,023	* p < 0,001 ** p < 0,001	7,077 ± 0,034	6,741 ± 0,015	* p < 0,001 ** p < 0,001	6,571 ± 0,027	6,543 ± 0,012	* p < 0,187 ** p < 0,07

*Mann-Whitney U-test; **Welch t-test.

Table 11 - Comparative analysis of the parameters assessed by Prontos and which make up the results for the clinical and control groups 30, 60 and 90 tests AFTER completing the Chalder questionnaire.

Prontos System Variables	30 tests before		Statistical tests	60 tests before		Statistical tests	90 tests before		Statistical tests
	Clinical group	**Control group**		**Clinical group**	**Control group**		**Clinical group**	**Control group**	
Risk predictor	21,541 ± 0,093	15,417 ± 0,034	* p < 0,001 ** p < 0,001	17,898 ± 0,062	15,053 ± 0,025	* p < 0,001 ** p < 0,001	16,380 ± 0,052	13,960 ± 0,021	* p < 0,001 ** p < 0,001
Impulsiveness	15,154 ± 0,081	11,537 ± 0,031	* p < 0,001 ** p < 0,001	14,170 ± 0,059	10,705 ± 0,022	* p < 0,001 ** p < 0,001	13,978 ± 0,048	10,609 ± 0,019	* p < 0,001 ** p < 0,001
Lack of concentration	10,573 ± 0,068	6,800 ± 0,024	* p < 0,001 ** p < 0,001	10,171 ± 0,049	7,391 ± 0,018	* p < 0,001 ** p < 0,001	9,354 ± 0,041	7,094 ± 0,015	* p < 0,001 ** p < 0,001
Inattention	12,729 ± 0,071	8,553 ± 0,026	* p < 0,001 ** p < 0,001	12,418 ± 0,055	8,427 ± 0,020	* p < 0,001 ** p < 0,001	12,406 ± 0,046	8,138 ± 0,016	* p < 0,001 ** p < 0,001
Slow response	6,298 ± 0,055	2,298 ± 0,014	* p < 0,001 ** p < 0,001	6,285 ± 0,039	2,715 ± 0,011	* p < 0,001 ** p < 0,001	6,165 ± 0,033	2,805 ± 0,010	* p < 0,187 ** p < 0,07

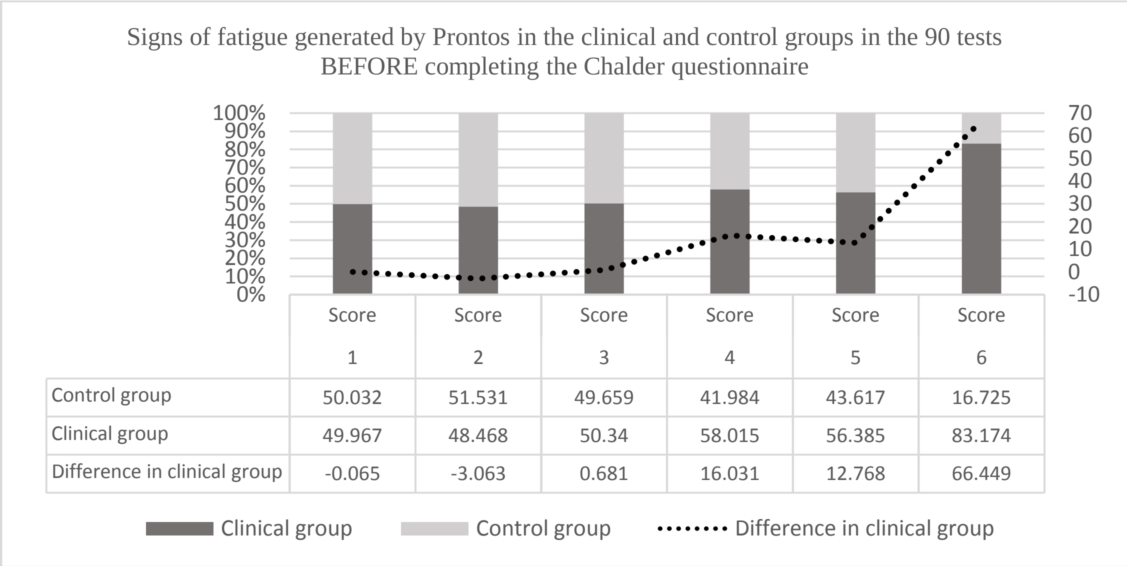
*Mann-Whitney U-test; **Welch t-test.

Table 12 - Temporal analysis of the clinical groups in the parameters assessed in the 30, 60 and 90 tests BEFORE and AFTER completing the Chalder questionnaire.

Final classification Prontos System	90 tests before	60 tests before	30 tests before	30 tests before	60 tests before	90 tests before
Risk predictor	30,30%	32,88%	**33,21%**	21,65%	17,86%	16,37%
Impulsiveness	23,01%	24,55%	**26,26%**	15,22%	14,16%	13,96%
Lack of concentration	15,55%	16,32%	**16,46%**	10,63%	10,18%	9,39%
Inattention	12,54%	12,96%	**13,23%**	12,73%	12,38%	12,40%
Slow response	6,58%	7,10%	**9,23%**	6,30%	6,33%	6,17%

The data analyzed and presented in Graph 1 shows the sensitivity of the "signs of fatigue" variable, illustrating how the proportion of changes in this variable increases in the clinical group as the score rises, with statistical significance. From score 3 onwards, the clinical group began to differ in terms of readiness results, with a greater contribution and association, rising in scores 4 and 5 (indicative of high signs of fatigue) with a 12-16% increase in the clinical groups compared to the control groups. In score 6, which concentrates a sample of rare cases with an association of multiple factors, the difference reaches 66%, showing a significant concentration of deviations in the clinical group, also a highly significant difference. As the data refers to the 90 tests before subjects self-reported fatigue on the Chalder questionnaire, the results demonstrate the high predictive power of this instrument.

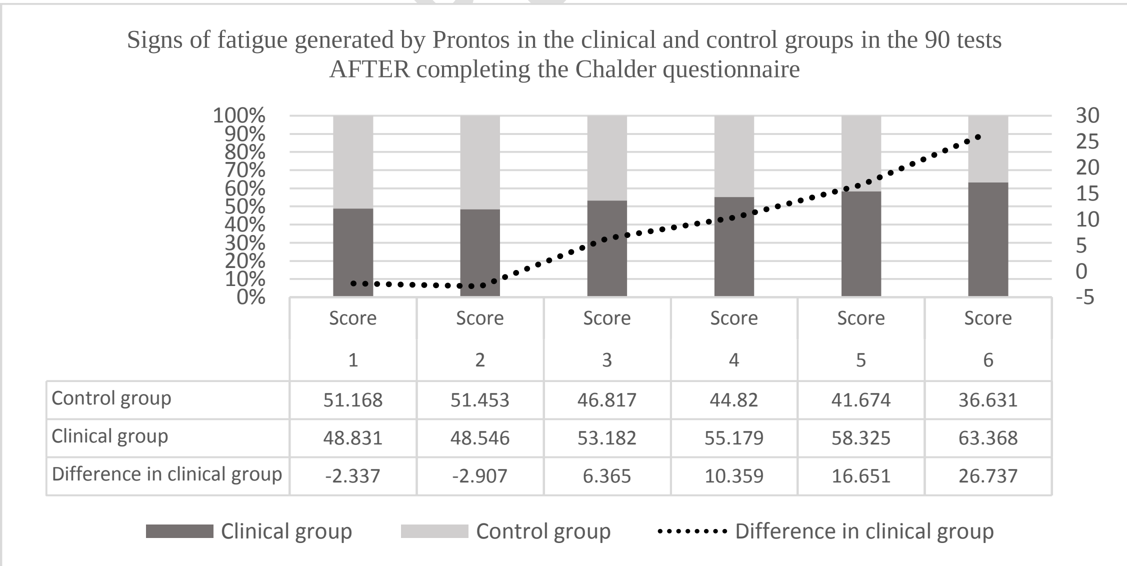
Graph 1: Comparative analysis of the signs of fatigue generated by Prontos in the clinical and control groups in the 90 tests BEFORE completing the Chalder questionnaire.



	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6
Control group	50.032	51.531	49.659	41.984	43.617	16.725
Clinical group	49.967	48.468	50.34	58.015	56.385	83.174
Difference in clinical group	-0.065	-3.063	0.681	16.031	12.768	66.449

Graph 2, which analyzes the results of the 90 tests after fatigue was reported on the Chalder questionnaire, shows a similar trend of an increase in the proportion of the clinical group as the signs of fatigue increase, albeit to a lesser degree, ranging from 10% to 27% in scores 4-6, indicative of high signs of fatigue. This reduction, compared to the 90 tests prior, can be attributed to the interventions applied by the organization after the diagnosis, but it also reinforces the more preventive and predictive nature of the instrument.

Graph 2: Comparative analysis of the signs of fatigue generated by Prontos in the clinical and control groups up to 90 days AFTER completing the Chalder questionnaire.



	Score 1	Score 2	Score 3	Score 4	Score 5	Score 6
Control group	51.168	51.453	46.817	44.82	41.674	36.631
Clinical group	48.831	48.546	53.182	55.179	58.325	63.368
Difference in clinical group	-2.337	-2.907	6.365	10.359	16.651	26.737

Table 13 - Temporal analysis of the clinical groups in signs of fatigue assessed in the 30, 60 and 90 tests BEFORE and AFTER completing the Chalder questionnaire.

Sign of Fatigue	90 tests before			Statistical tests	90 tests before			Statistical tests
	Clinical group	Control group	Percentage difference		Clinical group	Control group	Percentage difference	
Score 1	49,967 ± 0,021	50,032 ± 0,021	-0,065	* p < 0,001 ** p < 0,001	48,831 ± 0,027	51,168 ± 0,027	-2,337	* p < 0,001 ** p < 0,001
Score 2	48,468 ± 0,033	51,531 ± 0,033	-3,063	* p < 0,001 ** p < 0,001	48,546 ± 0,029	51,453 ± 0,029	-2,907	* p < 0,001 ** p < 0,001
Score 3	50,340 ± 0,056	49,659 ± 0,056	0,681	* p < 0,001 ** p < 0,001	53,182 ± 0,045	46,817 ± 0,045	6,365	* p < 0,001 ** p < 0,001
Score 4	58,015 ± 0,099	41,984 ± 0,099	16,031	* p < 0,001 ** p < 0,001	55,179 ± 0,088	44,820 ± 0,088	10,359	* p < 0,001 ** p < 0,001
Score 5	56,385 ± 0,249	43,617 ± 0,249	12,768	* p < 0,001 ** p < 0,001	58,325 ± 0,196	41,674 ± 0,196	16,651	* p < 0,001 ** p < 0,001
Score 6	83,174 ± 0,864	16,725 ± 0,864	66,449	* p < 0,001 ** p < 0,001	63,368 ± 0,832	36,631 ± 0,832	26,737	* p < 0,001 ** p < 0,001

*Mann-Whitney U-test; **Welch t-test.

In short, there is a high concentration of lower scores in the groups that do not show clinical signs of fatigue, according to Chalder, while in the group that is affected by signs of fatigue there is a higher concentration of fatigue indications tracked by the Prontos System. Normality is more present in the normal group and changes in readiness are much more frequent in the groups with symptoms of physical and mental fatigue according to the Chalder scale. The presence and concentration of higher fatigue scores identifies that the readiness assessment tool (Prontos System) has a positive correlation with individuals with signs of fatigue, in a robust and statistically significant way.

Conclusion

These results highlight the crucial importance of daily and continuous assessment, both before and during work activity, to identify and track signs of fatigue. The use of the FOCOS/Prontos System, with its multidimensional and adaptable method, proved to be a unique tool for monitoring workers' readiness. The data obtained in this study also contributes to enriching the intelligence of the predictive assessment of fatigue and the classifications generated by the instrument. The results obtained can thus feed back into the predictive assessment of the fatigue score in order to increase its accuracy, making the Prontos System tool increasingly robust in screening individuals at greater risk of showing signs and symptoms of fatigue or chronic fatigue, thus being able to adjust the weight of the variables. As the volume of data increases, in addition to that collected in this study, with larger samples, the coefficients become more and more up-to-date, demonstrating that the greater the amount of data and monitoring, the more reliable the fatigue prediction by the algorithm created.

The multifactorial aspect of fatigue reinforces that the integration of instruments strengthens fatigue management by enabling broader analyses, in which the association of data can be studied to increase prediction. This study not only reinforces the applicability of the FOCOS/Prontos System in corporate fatigue management, but also highlights the need for a continuous approach to the analysis and prevention of this phenomenon. Temporal analysis of the results revealed highly significant variations in readiness parameters and behaviors associated with fatigue, indicating the importance of constant monitoring for proactive intervention.

The relationship between the fatigue score and the clinical identification of mental/physical fatigue through the Chalder emphasizes the complexity of this phenomenon, which involves not only physical but also emotional and psychosocial aspects. The Prontos System's ability to identify specific patterns of complaints associated with different phases of fatigue offers valuable insights into a deeper understanding of the phenomenon and suggests that personalized interventions can be implemented based on these observations.

Furthermore, the correlation identified between an increase in the fatigue score and cases of accidents at work, which could be the subject of further study at a later date, highlights the importance of fatigue screening not only as a preventative measure for workers' health, but also as an effective strategy for reducing accidents at work. The predictive capacity of the FOCOS/Prontos System to identify cases and its positive correlation with workers showing signs and symptoms of fatigue highlight its usefulness as a daily monitoring tool.

In short, the continuous and predictive assessment of fatigue using the FOCOS/Prontos System not only strengthens its position as an effective tool for managing work-related fatigue, but also highlights the importance of daily monitoring strategies for early detection of signs and symptoms. Implementing these practices not only contributes to promoting workers' health, but is also vital in preventing accidents and optimizing work performance. This study provides a solid basis for future improvements in the approach to fatigue in the workplace, with the aim of promoting a safer and healthier environment for employees from different sectors and cultures.

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