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# A neural network to classify fatigue from human–computer interaction

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ABSTRACT

Fatigue, especially in its mental form, is one of the most worrying health problems nowadays. It affects not only health but also motivation, emotions and feelings and has an impact both at the individual and organizational level. Fatigue monitoring and management assumes thus, in this century, an increased importance, that should be promoted by private organizations and governments alike. While traditional approaches are mostly based on questionnaires, in this paper we present an alternative one that relies on the observation of the individual's interaction with the computer. We show that this interaction changes with the onset of fatigue and that these changes are significant enough to support the training of a neural network that can classify mental fatigue in real time. The main outcome of this work is the development of non-invasive systems for the continuous classification of mental fatigue that can support effective and efficient fatigue management initiatives, especially in the context of desk jobs.



## 1. Introduction

In most of the so-called developed countries people have nowadays increasingly busier lifestyles. This makes them stretch their limits to find time for work, leisure, family and friends. This necessary extra time is frequently obtained at the expense of smaller periods of sleep or rest, and with a cost in terms of pressure and stress. This, together with other issues such as increasing workloads or harsher work conditions, results in the emergence of fatigue as one of the most worrying health conditions of this century [1,2]. Although the effects of fatigue may not be readily visible, they have consequences at many levels other than health, including emotions, productivity, performance, social behaviour, among others [3].

Generally, the term fatigue is used to describe a series of manifestations that range from drowsiness or lack of concentration to lack of physical strength or agility [4]. Thus, the concept of fatigue is very broad and subjective. It can be seen as a combination of symptoms, including impaired performance (loss of attention, slowed reaction and response times, impaired decision making, and poor performance on tasks that usually reflect good performance), and subjective feelings of sleepiness and tiredness [5,6]. It can also be divided in two main types [7]: mental fatigue (when it is our cognitive abilities that are decreased) and physical fatigue (when we become physically impaired due to an excess of a specific physical activity). In this paper we focus on mental fatigue, although a relationship between the two types, that sometimes interact, is acknowledged.

Fatigue can be seen all around us, on an everyday basis: students approaching an exam that sleep less in order to have more time to study, office or industrial workers working long, night or consecutive shifts, healthcare professionals subject to long hours of highly wearing conditions, drivers of heavy machinery, or specialized personnel such as the military or fire fighters. Either in trivial tasks or in more specialized ones, fatigue is regarded as one of the main causes of human error [2]. It may lead, especially in the aforementioned scenarios, to serious life-or-death situations, when people working in risky jobs have their performance, attention or motivation impaired due to fatigue.

Fatigue can occur at any time during the day and is not necessarily related to the circadian rhythm [8] alone but results of more complex set of factors that include time of rest, motivation, physical or cognitive impairments or social environment [9]. Depending on its duration and intensity, fatigue can make the carrying out of daily tasks increasingly hard or even impossible [10]. In severe or prolonged cases it can cause illnesses such as depression or chronic fatigue syndrome, with an impact at a personal, social and economic level. Given all this, it is nowadays clear that the detection, monitoring and management of fatigue should

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be considered as a priority in the healthcare domain, with organizations having a special responsibility in their human resources management strategies.

This paper deals with the issue of fatigue monitoring, with the aim of providing a non-intrusive, reliable and easy to use tool that can be used freely in organizations, without changing or interfering with the established work routines. Specifically, we look at desk jobs and others similar, in which people spend long hours interacting with the computer.

In preliminary work we have established that our interaction patterns with the computer, measured in terms of the use of the keyboard and mouse, change when under fatigue [11]. In this paper we take this work a step forward by presenting a service-based architecture, suited for the collection of data for the purpose of classifying fatigue. We detail the whole process, from the definition of the architecture to the real-time collection of data. Finally, we describe the process through which soft computing techniques are used to classify fatigue, in real-time, from the interaction with the computer. Specifically, we train a neural network that takes as input features that describe the user's interaction patterns and provides as output an estimation of the user's mental fatigue.

The paper is structured as follows. Following this introductory section we analyse related work in what concerns the analysis and detection of fatigue, both using subjective and objective measures. As we do this, we analyse existing approaches and compare them with the one proposed in this paper. The paper then moves on to describe the service-based architecture developed to implement the collection of data. The following section is devoted to a specific case-study, in a real environment, concerning the detection of fatigue. It details the process of data collection and analysis. Finally, the paper ends with the analysis and discussion of the results attained with this work, and with the concluding remarks and analysis of future directions for this line of research.

## 2. Related work

From the existing literature it is possible to conclude that there are three main types of approach to the problem of mental fatigue detection and monitoring. The first relies in quantifications of cognitive performance, often measured as the combination of the speed and success or accuracy of an individual when carrying out a task. The second approach consists on subjective ratings of mental workload and mental fatigue. Finally, physiological indicators can also reveal subtle but precise aspects of mental fatigue that are often not revealed by performance measures or subjective ratings.

### 2.1. Performance measures

Task performance may be defined as the relative competence of the individual's interpretation of task-associated stimuli, and the effectiveness of his responses on the task. Excessive mental and physical workload and very low workload (observed in monotonous tasks) are frequent scenarios in which performance decrements are observed. Perhaps the most widely used indicator of fatigue is the degradation of task performance over time or in response to changes in task demands. Welford [12] distinguished four types of performance changes that may occur, namely:

- impairment of sensory or perceptual functions;
- slowing of sensory-motor performance;
- irregularity of time; and
- the disruption of performance.

Performance decrement due to fatigue may be considered as the total quantity and/or quality of work performed as a function of time on task [6]. Cognitive performance is often measured as the combination of the accuracy per response time of an individual when carrying out a task. This combination is often called throughput [13]. Response speed is the inverse of response time and is more normally distributed that response time in data collected from fatigued operators. Both speed and accuracy are usually acceptable when the individual has normal cognitive skills, and one or the other or both are decreased when these skills are impaired or diminished by fatigue. When mental fatigue takes place, human performance is not consistent, with changes in speed, accuracy and variability [14]. These changes allow us to measure the performance of an individual on a task and are the base of the work proposed in this paper further ahead.

### 2.2. Subjective measures

Subjective measures of mental workload are often used to assess the mental workload associated with a task [15,16]. Obtaining mental workload levels during task performance can be a difficult procedure. However, estimations of subjective workload levels can help isolate task characteristics that affect performance. The two instruments of this type most often used in research were developed in parallel in the 1980s, one at the NASA-Ames Research Center in California and the other in the U.S. Air Force Human Factors Research Group in Wright-Patterson AFB, Ohio.

The NASA Task Load Index (NASA-TLX) is a multidimensional assessment tool [15]. The main seven-point scale is:

*Overall performance: How successful were you in performing the task? How satisfied were you with your performance?*

The TLX has five seven-point sub-scales that help identify difficult task characteristics. The sub-scales are as follows:

- *Mental demand*: How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?
- *Physical demand*: How much physical activity was required? Was the task easy or demanding, slack or strenuous?
- *Temporal demand*: How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?
- *Frustration level*: How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?
- *Effort*: How hard did you have to work (mentally and physically) to accomplish your level of performance?

The Subjective Workload Assessment Technique (SWAT) uses a three-dimensional model of workload: time load, mental effort load, and psychological stress load. There are three rating levels for each dimension: low, medium and high. Usually, subjects perform a pre-sort of the 27 possible combinations of the dimensions and their sort is transformed into an interval scale of workload ranging from 0 to 100. For the actual task, each activity or event is rated by assigning a value of 1–3 on each of the three dimensions. The pre-sort scale value associated with this combination becomes the workload value for that activity or event.

A seven-point mental workload scale was created by the Crew Performance Branch of the USAF School of Aerospace Medicine in the late 1970s, and then re-examined, linearized, and verified by the Human Factors Engineering Branch of the Air Force Flight Test Center [17]. This is the easiest rating instrument to use in high workload environments, but it provides less insight than the TLX or SWAT instruments. Individuals choose one of seven sets of statements describing their average mental workload during the preceding work period: