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Development of the NASA-TLX Multi Equation Tool to Assess Workload

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Abstract. The NASA-TLX method has been used more than 20 years to assess mental workload. NASA-TLX is a multidimensional technique to provide a score based on six subscales: mental demand, physical demand, temporal demand, performance, effort, and frustration level. Although some researchers have developed software to facilitate the application of the method, all the versions created use a single form of evaluation. Throughout a literature review, four different equations to apply NASA-TLX where identified. The objective of this investigation is to develop the NASA-TLX Multi Equation Tool (MET) programmed with the four different equations. The software was created in HTML format with JavaScript. As a result, the software shows the workload assessment with the four different equations.

Keywords: NASA-TLX, method, mental, workload, ergonomic, software, development, human, factors, multidimensional, tool.

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1 Introduction

Nowadays, modern complex systems demand high requirements or workload from the workers, new technologies have introduced to cover the task demands which are considered as hard or very hard, both linked with high demands of production [1]. However, an excess of automation in the processes can lead to the elimination of humans, and despite it, not to reduce the workload. At the same time, the workload can increment from low to high levels of demand that go beyond human cognitive capacities and decision-making capacities. The mental workload can be identified when the tasks demand to be alert and concentrated on an activity or a group of activities during a period of time [2]. Another problem associated with the evaluation and measurement of the mental load is the null definition of units of measure [3]. If we understand the workload as "the set of psycho-physical requirements to which the worker is subjected throughout the working day", we have to admit that making a correct assessment of the task implies to consider the two aspects reflected in the definition, the physical and the mental aspects since both coexist in variable proportion in any task [4].

1.1 Context of the Investigation

The workload produced by an activity is composed of both physical and mental workload [5], and it is a construct that involves the capacity of the human to interact with complex systems considering the equipment, the training, the organizational, the environmental limitations, among others. Because of this, the workload implies different perceptions and responses by the workers [6]. Any task requires a specific level of attention and concentration depending on the signals and requirements to be addressed, the inferences to be made, the level of accuracy of the response, and the organizational aspects, especially those that refer to the organization of the working time.

In this context, Mental Workload (MW) is defined as the amount of mental effort that must be developed to achieve a concrete result, and it is linked to the needs of information processing and decision making for the execution of the task [7], [8]. On the contrary, Physical Workload (PW) is defined as the set of physical requirements developed by the person to perform defined tasks. Many authors indicate that the type of work and the age of the individual have a significant influence on the physical capacity of the worker [9] [10].

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The aim of this paper is to propose the development of the NASA-TLX Multi Equation Tool to assess workload, using HTML and JavaScript for the created software, who is explained in this paper. The rest of this paper is organized as follows: Section 2 describes the assessment and methods for mental workload, section 3 describes the NASA-TLX Multi Equation Tool, section 4 presents the results, section 5 presents the discussion and section 6 describes the conclusions of this paper.

2 Assessment of Mental Workload

2.1 Effects of Mental Workload

Current jobs require that people attend multiple tasks at the same time, make decisions, and solve problems effectively in stable and emergency situations. The increasing role of technology and the use of complex procedures have led to a greater demand imposed in the worker [11]. The cognitive demands imposed during the performance of many jobs have made the concept of mental load acquired significant importance of multiple research areas. Increasingly, the current working conditions have resulted in high levels of workload, mental fatigue, and stress causing a decrement of performance and attention. At the same time, another effect is the number of errors, forgetfulness, and confusion increasing the probability of accidents or negative alterations during the tasks performed [12], [13], [14]. [15], [16], [17], [18].

Also, the negative or harmful consequences for worker´s health should not be forgotten. For example, the decrease in labor motivation, emotional instability (irritability, anxiety, depressive states), low self-esteem, somatic, and sleep disturbances or increased consumption of tobacco, drugs, and alcohol [19]. However, in recent years, a certain degree of agreement has been reached regarding the content of the subjective mental workload, and the result is three large dimensions or factors: (a) the aspects related to the temporal pressure of the task (time available, time needed); (b) the amount of processing resources demanded by the task (mental, sensory, type of task, etc.) and (c) the aspects of an emotional nature (fatigue or frustration) [20].

To assess the mental workload, different methods and techniques have been developed during the last 50 years. Table 1 shows the most common methods found in the literature.

Table 1. Methods to Assessment of Mental Workload

Mental Workload
Cooper Scale (Cooper & Harper, 1969)
SWAT (Reid & Nygren, 1988)
NASA-TLX (Hart & Staveland, 1988)
Beaufort Scale (Roscoe & Ellis, 1990)
Overall Workload (Vidulich, Ward, & Schueren, 1991)
Work Load Profile (Tsang & Velazquez, 1996)
Method of Evaluation of Psychosocial Factors INSHT (Nogareda, 1998)
MWE (Miyake, 2001)
ESCAM (Rolo, Díaz, & Hernández, 2009)

2.2 NASA-TLX Method

2.2.1 Fundament

NASA-Task Load Index (TLX) was developed by Hart & Staveland [21] and distinguishes six dimensions of workload: mental demand, physical demand, temporal demand, performance, effort, and frustration, from which a global index of the mental load is calculated. In various laboratory and field investigations, NASA-TLX has proven to be reasonably easy to use and reliably sensitive to experimentally important manipulations over the past 20 years, specifically, in different levels of effort. The six subscales provide independent information about its structure [22], [23], [24], [25]. [26], [27], [28], [29], [30], [31].

NASA-TLX is a multidimensional and subjective instrument, and its application consists of developing two phases: a scoring phase and a weighting phase. The scoring phase intends to create an individual assessment of the six subscales. The weighting phase has the objective to define the load source. It consists in presenting to the people the fifteen combinations in order to compare them by pairs (binary comparison) and choose for each pair, which is the element that is generating the greater source of the load. Figure 1 shows the typical table to apply the NASA-TLX method.

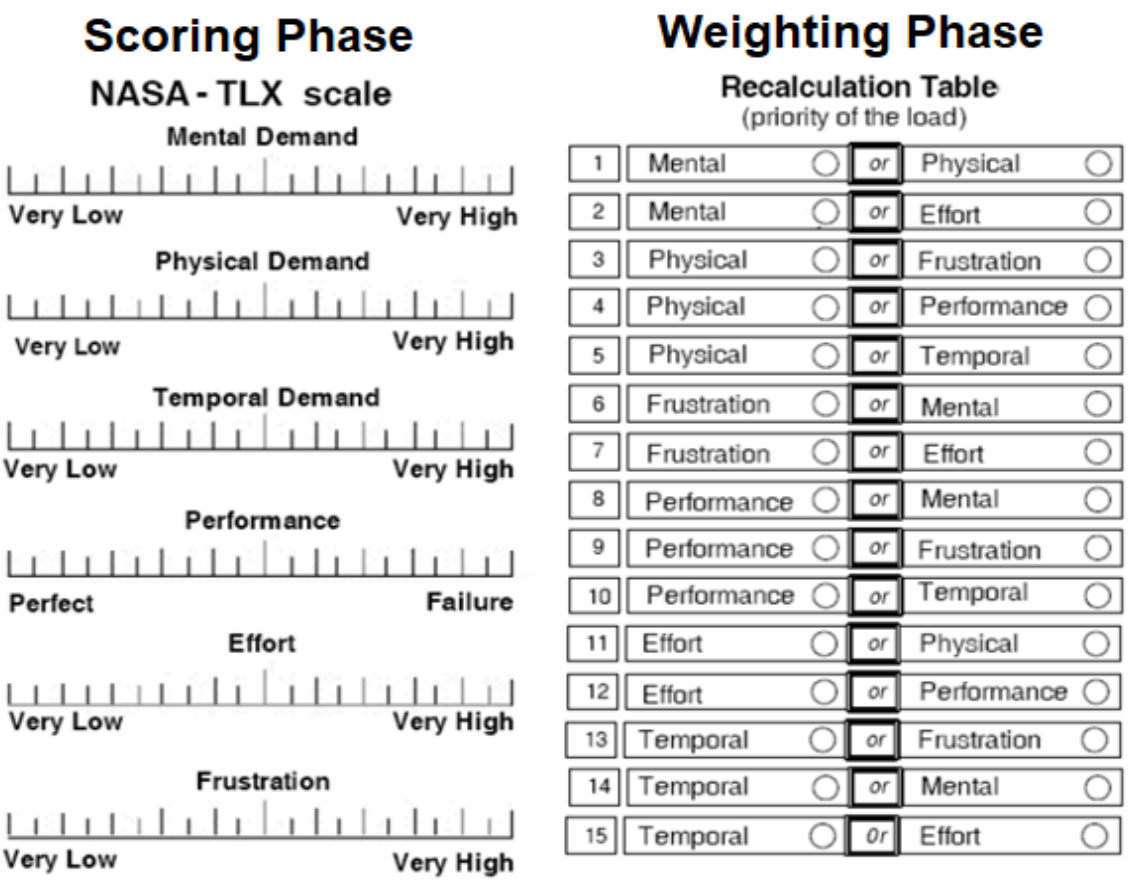

Fig. 1. NASA-TLX evaluation Phases. Adapted from Hart & Staveland (1988)

2.2.2 Applications.

NASA TLX has been successfully used to assess workload in various environments such as aircraft cockpits [32], command [33], control [34], and communication workstations [35], supervisory and process control [36], and simulations and laboratory tests [37], [38]. Also, one of the most important applications of NASA-TLX has been to validate new methods and techniques to assess workload [39], fatigue [40], and stress [41].

2.3 Software to Apply NASA-TLX

The use of software facilitates the application of the method allowing a quick and accurate evaluation. Through the literature review, eight different software of NASA-TLX has been identified. Table 2 shows the name of the software, the authors, and the country of development. All of them have in common that only includes the traditional algorithm [42]. However, 4 different equations have been found in the literature [43], [44], [45].

Table 2. Software Developed to Apply NASA-TLX

Name of the software	Authors	Country
Visual Studio App	(Cao, Chintamani, Pandya, & Ellis, 2009)	United States
Pocket PC Version	(Cao, Chintamani, Pandya, & Ellis, 2009)	United States
Windows Version	(Cao, Chintamani, Pandya, & Ellis, 2009)	United States
Flash-Player Version	(Sharek, 2009)	United States
Desktop Version	(Hart, 2006; Sharek, 2009)	United States
Online Web Version	(Sharek, 2011)	United States
JAVA-Script Version	(Sharek, 2011)	United States
App in iOS	(Gore & Kim, 2017)	United States

3 NASA-TLX Multi Equation Tool

3.1 Development

The NASA-TLX Multi Equation Tool (MET) was developed using the original version of the method [21] and the three formulas mentioned in the next section. The tool includes HTML code and JavaScript, starting with programming variables like results, scales, and a description for each of these scales that the subject should read before rating. An array is required to store the data, a function for saving the scales and creation of the tables, etc. During the use of the program, every data is stored in a temporal file. In the end, the program calculates the mental workload and shows 4 different results representing the formulas explained in the next section. The 4 different formulas were added to the program code; they use an equation to calculate the final score showed to the user at the end.

3.2 Different Formulas for NASA-TLX

As already mentioned, four different equations to apply the NASA-TLX method have been identified in the literature [43], [21], [45]. The equations provide different general results and interpretations depending on the scale used. Table 3 shows the four different formulas identified, the authors, and the year of development.

Table 3. Equations Identified

Author	Equation	Scale Range	Scale Interpretation
(Hart & Staveland, 1988)	$IC = \frac{(\sum pi\ x\ Xi)}{15}$ Equation 1 – 2 NASA-TLX	0-100	0-25 Low 26-50 Medium 51-75 High 76-100 Very High
(DiDomenico & Nussbaum, 2008; Şeker, 2014)	$IC = \frac{(\sum pi\ x\ 100\ )}{30}$ Equation 3 Unweighted Score	0-100	0-25 Low 26-50 Medium 51-75 High 76-100 Very High
(Enríquez, 2018)	$IC = \frac{(\sum pi\ x\ Xi\ x\ 5)}{15}$	0-25	0-6 Low 7-12 Medium

	Equation 4 Scale assessment (Scale 5) NASA-TLX		13-18 High 19-25 Very High

Where:
IC: Load Index
Ci: Weighted score
a: Weight
b: Raw rating
15 Number of binaries comparisons
Pi: Weight obtained for each dimension in the binary table (weighting)
Xi: Score obtained by the dimension in the evaluation stage

4 Results

Figure 2 shows the main screen of the software NASA-TLX Multi Equation Tool (MET) where the user or the evaluator feeds the workload scores of the six items considered by the method. In this case, a Visual Analog (VA) scale with two expressions (at the left: low/good; at the right: high/poor) divided into 20 points was used.

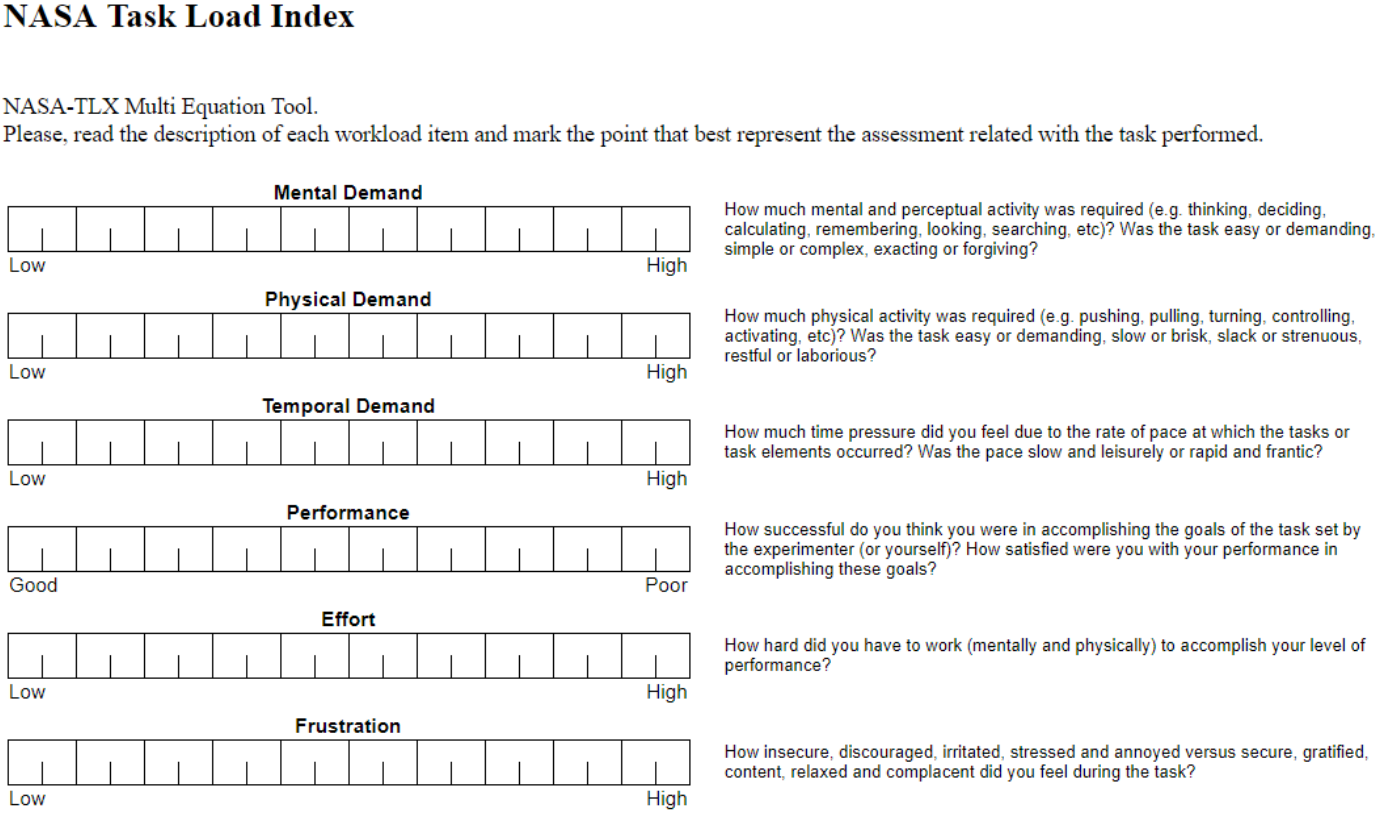

Fig. 2. Main screen – Workload rating scales.

Figures 3, 4, and 5 shows examples of the 15 comparisons between the six workload items. Figure 2 shows a comparison between Frustration and Effort. Using the mouse, the user should click on the item that represents more contribution of workload during the task developed.

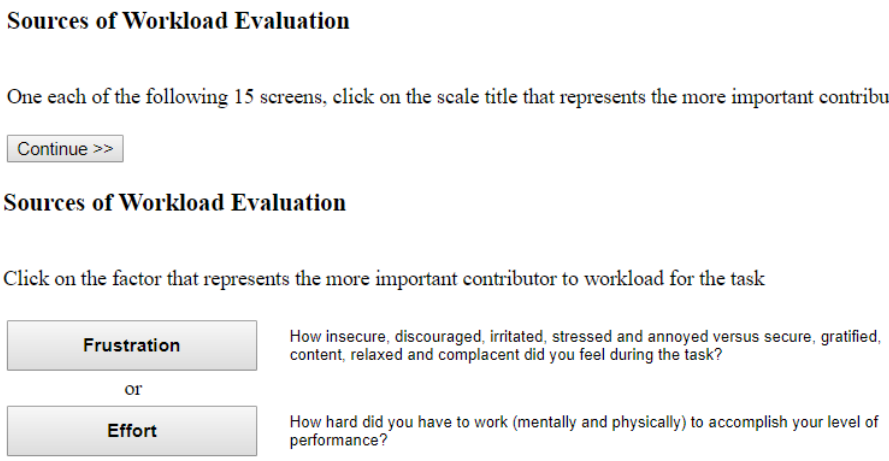

Fig. 3. Workload Evaluation screen – Frustration vs Effort screen.

Equal to Figure 3, in Figures 4 and 5 the comparison between Performance and Frustration and Mental Demand and Effort, respectively, are shown.

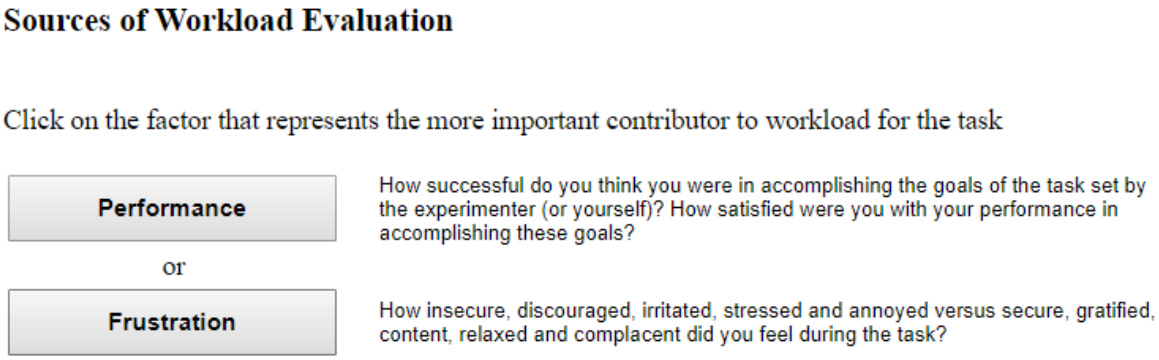

Fig. 4. Workload Evaluation screen – Screen of example 2 of the 15 combinations of questions.

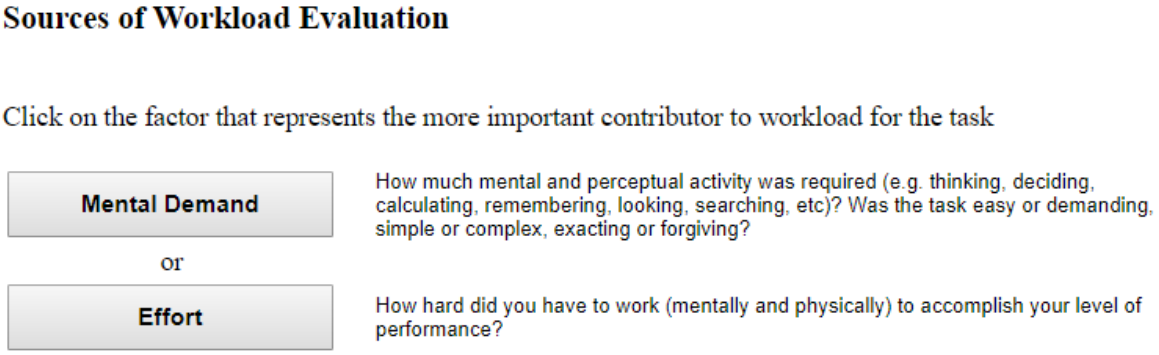

Fig. 5. Workload Evaluation screen – Screen of example 3 of the 15 combinations of questions.

Table 4 shows the report of results of the NASA-TLX MET. First, on top, the rating, the tally, and the weight of the six workload items are shown. On the bottom, the results of the 4 different equations are shown.

Table 4. Final results of the 4 equations

Scale Title	Rating	Tally	Weight
Mental Demand	80	2	0.13333333333333333
Physical Demand	55	2	0.13333333333333333
Temporal Demand	80		0.26666666666666666
Performance	90	1	0.06666666666666667
Effort	50	2	0.13333333333333333
Frustration	85	4	0.26666666666666666

Overall Equation 1 = 74.66666666666666
Overall Equation 2 = 72.66666667
Overall Equation 3 = 60
Overall Equation 4 = 14.53333333

5 Discussions

Through the JavaScript language, the software performs the capture of data and the operations, which gives a result presented in detail to the user. The code contains more than fifty lines that allow its operation. Also, it is possible to add new functions in the software in the future. This software was created using the full and original version of the existing NASA-TLX method [21], adapted to an HTML version for better management in any computational field. It was modified to add the different equations presented in this article [43], [44], [45].

Because it can be accessed online through a web browser, this software could be used in any device like PC, tablets, and cellphones. Former versions only include after install the software in a personal computer in limited operating systems and fulfilling hardware requirements.

Compared to other existing software, who only calculate one final result based on the original method, this software presents the four different final scores of mental workload. The final score shows, in detail, the six factors evaluated during the different stages of mental workload evaluation, showing the value of each factor, the weighing, and the rating.

6 Conclusions

The main contribution of the NASA-TLX MET is the inclusion of the 4 different equations identified in the literature. This advantage helps researchers to get reliable data and to perform comparisons among many variables such as tasks, genders, jobs, shifts, teams, occupations using the four different equations. Also, another advantage of this software is the possibility to evaluate any task in any work environment, just needs to adopt the text part according to the needs to evaluate.

Because the results are not deployed on the same scale, the comparison of the results among the four different formulas identified can be only visually. In order to develop a statistical comparison, a data transformation is needed. This is an opportunity to improve the software in the short term. Another point to improve is the possibility of including users and saving data to manage records. The use of the software during a qualitative evaluation allows faster and more accurate results, in this case, using a traditional standard method to evaluate mental workload. This software can be upgraded for use in any cellphone using an HTML browser, also it has the possibility for adding new evaluation methods for a better and complete evaluation.

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