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CONTENT

ANTHROPOMETRY

COGNITIVE ERGONOMICS

ASSESSMENT OF MENTAL WORKLOAD IN SETTING UP FUSED FILAMENT FABRICATION EQUIPMENT

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Resumen. El objetivo del presente capitulo fue evaluar la carga mental generada por la tarea de puesta a punto de los equipos de impresión de Fabricación por Filamento Fundido (FFF) previo al proceso de impresión. La razón de la evaluación se debe a la proporción de recursos demandados por la tarea. Estos recursos resultan en la degradación del desempeño, si la ejecución de las tareas no se realizan adecuadamente, generando como resultado problemas tangibles en el proceso de impresión y por consecuencia repetición de las tareas de preparación del equipo. La tarea analizada consistió en la puesta a punto de quipo de impresión 3d (MDF o FFF). Las actividades de la tarea fueron, conexión del equipo a terminal eléctrica, encendido del equipo, nivelación de la cama de impresión, precalentamiento del equipo y alimentación de material. Se integró un grupo de diez participantes, los cuales demostraron tener experiencia en el manejo de los equipos de FFF ya que participan como ayudantes de investigación en los laboratorios de prototipado y diseño ergonómico de la UACJ. La metodología empleada se integró en tres fases; 1) análisis jerárquico de la tarea, 2) evaluación de la carga mental con NASA-TLX, y 3) análisis de resultados. Los resultados obtenidos describen que la demanda mental, la demanda temporal y el esfuerzo fueron las sub-escalas con puntuación promedio más altas (79, 59, 57). Lo cual significa que los participantes manifestaron un nivel alto de carga mental debida a la demanda mental (generada por pensar en la secuencia de actividades, decidir el tipo de ajuste, observar los resultados de las pruebas de ajuste y buscar soluciones a problemas con el equipo), demanda temporal (presión del tiempo producida por el tiempo de ajuste máximo requerido) y el esfuerzo (el cual se debe principalmente a actividades mentales). Con base en los resultados se concluye que el uso de metodologías de evaluación de carga mental facilita la identificación de elementos generadores de carga mental asociados a una tarea específica, lo que permite proponer modificaciones a los equipos para reducir el efecto de carga mental en los usuarios de las tecnologías de MA.

Palabras clave: Carga mental, NASA-TLX, equipos de Fabricación por Filamento Fundido.

Relevancia para la ergonomía: La información obtenida presenta un escenario de desempeño del factor humano ante el uso de la Manufactura Aditiva desde el punto de vista de carga mental.

Abstract: The objective of this chapter was to assess the mental load generated by the task of setting up an FFF printer, before the printing process. The reason for this evaluation is due to the portion of the resources demanded by the task. These resources result in the degradation of performance if the execution of the task is not carried out correctly, resulting in real problems in the printing process, and as a consequence the repetition of the setting up tasks. The task analyzed consisted of setting up 3d printing equipment. The activities that integrate the task were: connection of the equipment of electrical terminal, turn on the equipment, leveling of the printing bed, preheating of the equipment, and feeding of material. A group of ten participants was integrated; each participant had experience in the handle of FFF equipment. The participants develop activities of prototyping in FFF as their activities of researcher assistants in prototyping lab and ergonomic design lab in UACJ. Three phases integrated the methodology; 1) Hierarchical Task Analysis (HTA), 2) assessment workload with NASA-TLX and 3) analysis results. The results describe that mental demand, temporal demand, and effort were the sub-scales with higher punctuation (79, 59, and 57). That means that participants manifest workload due the mental demand (generated by thinking about the sequence of activities developed and for develop, deciding the type of equipment adjustments, observing the results of the fit tests, and looking for solution to problems with the equipment), temporal demand (pressure of the time produced by the maximum time allowed by the setting up), and effort (generated firstly by mental activities). Based on the results, it is concluded that the use of mental load assessment methodology facilitates the identification of mental load generating elements associated with a specific task, which allows proposing a modification to the equipment focused on reducing the effect of mental load over users of AM technologies.

Keywords: Mental workload, NASA-TLX, Fused Filament Fabrication equipment.

Relevance to Ergonomics: The information obtained presents a performance scenario of a human factor during the use of Additive Manufacturing from the workload.

1. INTRODUCTION

Additive manufacturing (AM) is a manufacturing system that has been changing the paradigm of traditional manufacturing since it appeared in 1980. As a complement of subtractive manufacturing, AM has changed the way in how the resources are used in production or service processes. These changes involve the integration of new technologies, development of different materials, alternative methods of pre-processing, process and post-process, new abilities and knowledge of people involved in the process, and also a different work environment (Kalpakjian y Schmid 2014).

3D printing has been used as a tool to support a great diversity of research, micro productions, prototyping, and also hobbies. Even this technology represents a small market today, it will be a further alternative of employment with more than 133 million jobs for 2022 (Polli, 2018). This projection not only represents more opportunities to increase capital and develop of technologies, but this projection also represents an approximate number of people involved directly or indirectly with AM for 2022 (Wagner, Dainty, Hague, Tuck, & Ong, 2008).

As a consequence of this projected demand, ergonomics will play an essential role in the protection of users across the analysis of workstations, ergonomic design, cognitive ergonomics, human errors, workload, among others. All of them associated with the human-machine interaction.

There are seven AM technologies. FDM or FFF technology is the most AM technology used with 46% of all AM technologies (Statista, 2019). Besides that, the setup task is typical for most of the equipment, regardless of the brand. Activities associated with FFF could be synthesized in preprocess (design, settings properties of the design, setup of equipment, and preprinting), process (printing of the element), and post process (finishing of the component). It is important to declare that setup correctly allows to reduce the waste time generated by the correction of mistakes generates during the setup of the equipment.

Due the importance of setup activities, this research is focused on asses the workload; NASA-TLX was selected because it has been used widely to measure the workload of many tasks. In AM, NASA-TLX was used as a determining criterion for the choice of a new assembly method, in which the mental load has been a critical factor of the operator's performance (Al-ahmari, Ameen, & Haider, 2018). In many cases of manufacture and health procedures, NASA-TLX has been used to determine workload in repetitive activities as a reference point to affect the decisions taken in a long period of the task execution, achieving with the results of the analysis and improving task a significant level of workload (Buchert et al., 2019, Dodou, Fan, Sc, Jelı, & Breedveld, 2015).

2. OBJECTIVES

The objectives of the present study were two:

- Identify the group of activities that integrate the task of setting up 3D printing of FFF.

- Assessment of the mental load generated by the task of setting up FFF equipment using NASA-TLX.

3. METHODOLOGY

3.1 Study design

The first part of the study consisted of explaining to the participants the objective of the research, the methodology considered and the technology available for the study and for the development of the activity. Once the first part was covered, the task to be executed was explained as well as the evaluation method that would be carried out using the NASA-TLX. For the evaluation, the free software resource was used participants captured their evaluations on a PC with the NASA-TLX software. Once the participants made their evaluation, the research group proceeded to synthesize and analyze the results obtained.

3.2 Sample

The sample was integrated by a group of ten volunteers, eight men and two women. Four of them were students of graduate programs, and six were students of undergrad. All individuals had at least one year of experience working with FFF equipment at the moment of the evaluation. All participants receive training over how to use the NASA-TLX.

3.3 Methods

The methodology used in the present chapter was developed in three phases. The first one was the development of the Hierarchical Task Analysis (HTA); the second one was the workload assessment using NASA-TLX method; and finally, the third phase was to analyze the results obtained by the NASA-TLX. Figure 1 presents a flow chart of the methodology used in the present research. Because HTA and NASA-TLX have their methodology, those methodologies are described after Figure 1.

To achieve the objectives of the present chapter was necessary before define the characteristics of the volunteer's group, the task under analysis, the results obtained by the application of the NASA-TLX and finally the description of the findings.

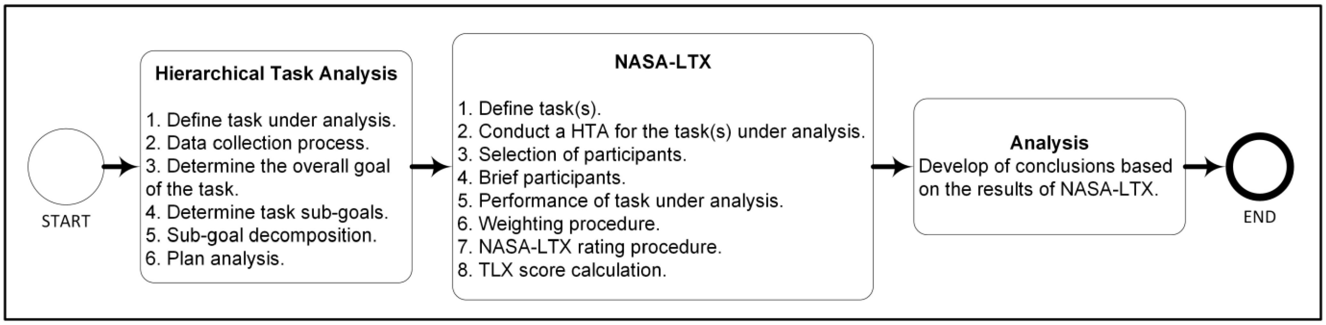

Figure 1. Flowchart of the methodology used to assess the workload in setting up FFF equipment.

3.3.1 Hierarchical Task Analysis (HTA)

According to Stanton, Hedge, Brookhuis, Salas, & Hendrick (2005), for Hierarchical Task Analysis (HTA), the description of each step that integrates the methodology is defined as follows is presented:

Step 1. Define task under analysis. This step is focused on define the task(s) under analysis. As well as the purpose of the task.

Step 2. Data collection process. Data regarding the task steps involved, the technology used, the interaction between man and machine and team members, decision making and tasks constraints.

Step 3. Determine the overall goal of the task. This should be specified at the top of the hierarchy. This enouncement describes the task in general.

Step 4. Determine task sub-goals. In this step, the goal should be broken down into meaningful sub-goals, which work together for the tasks required achieving the overall goal.

Step 5. Sub-goal decomposition. The analyst breaks down the sub-goals identified in the last step; this process should go until an appropriate operation is reached.

Step 6. Plans analysis. Plans analyses dictate how the goals are achieved. Sequences of activities are deployed in this step.

3.3.2 NASA-TLX

NASA-TLX uses six sub-scales: mental demand, physical demand, temporal demand, effort, performance, and frustration level (Hart & Staveland, 1988; Stanton et al., 2005). The procedure is described below:

Step 1. Define the task(s). It refers to define the tasks that are to be subject to analysis.

Step 2. Conduct an HTA for the task under analysis. This allows the analyst and participants to understand the task(s) entirely.

Step 3. Selection of participants. This step refers to select the participants that are involved in the analysis.

Step 4. Brief participants. Before the task(s) under analysis are performed, all participants should be briefed regarding the purpose of the study and the NASA-TLX technique.

Step 5. Performance the task under analysis. The participant(s) should perform the task under analysis. NASA-TLX can be administered either during or post-trial.

Step 6. Weighting procedure. The weighting procedure is 15 pair-wise comparisons of the six sub-scales make it by the participant. Each scale is rated by the software based upon the number of times it is selected by the participant. This is done using a scale of 0 (no relevant) to 5 (more important than any other factor).

Step 7. NASA-TLX rating procedure. Participants are asked to give a rating for each sub-scale, between 1 (low) and 20 (high), in response to the associated sub-scale questions.

Step 8. TLX score calculation. TLX software is used to compute an overall workload score. This is calculated by multiplying each rating by the weight given to that sub-scale by the participant. The sum of the weighted ratings for each task is then divided by 15 (sum of the weights). A workload score of between 0 and 100 is derived for the task under analysis.

With the aim to get standardized results an open software of NASA-TLX is used, this source is available in https://www.keithv.com/software/nasatlx/ (Vertanen, 2010).

4. RESULTS

4.1 Tasks description

The task under analysis consists of setting up Fused Filament Fabrication equipment. Most of FFF 3D printers have the same principles of operation. The first step was to verify that the equipment was plugged to the electrical terminal, and it turns on pushing the power button or turning the knob (depending on the model) (see Figure 1). Once that the equipment has been turned on, the next step was to verify that the printing bed was leveled. A leveling bed is one of the most complicated tasks of the equipment, due that an uneven bed is the principal cause of fails during the printing process. Even many of the models of FFF have electronic futures for leveling; these features work only to determinate an adjust the distance between bed leveling and extruder. The leveling bed consists of making a precisely adjust of the printing bed using the screws leveling located under the printing bed (see Figure 2).

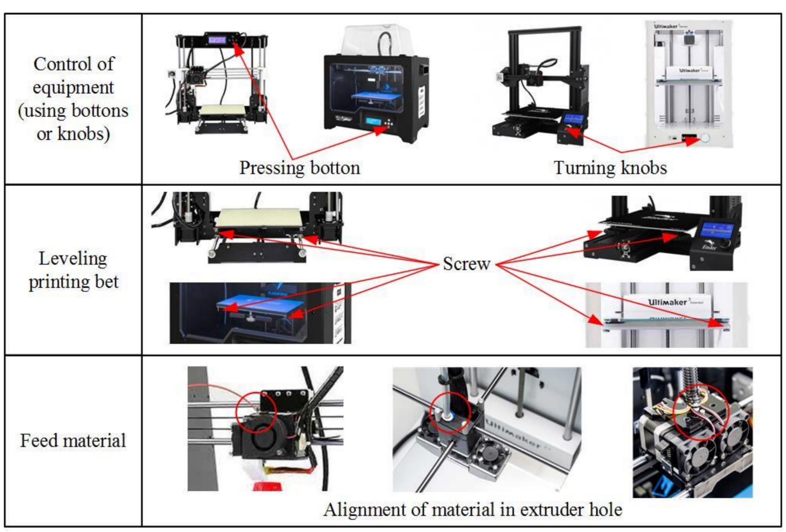

Figure 2. General elements for setting up FFF equipment.

The perfect adjust will allow that the material adheres perfectly to the surface of the printing bed. After the leveling, the next step was to verify that the motors of the equipment were working correctly. If they were working, the next step was to preheat the extruder and the printing bed to evaluate the capacity of the equipment to get the ideal temperatures. When the equipment is ready, the next step is to feed wit material the extruder. This activity consists in punt the filament inside the extruder and lines up it across the equipment. Feed the material correctly allows to get a flow material without problems during the printing process. The setting up process ends when the equipment is ready to receive information about the model to print.

3.2 Hierarchical Task Analysis (HTA)

Following the methodology proposed in this chapter, the HTA is presented in a tabular form. Table 1 presents the information on the HTA.

Table 1. HTA for setting up FFF equipment.

0. Set up FFF equipment. Plan 0: Do 1, then 2, then 3, then 4, then 5, then 6.
1. Plug in FFF equipment to an electric terminal.
2. Turn on equipment (pressing on the start button).
3. Leveling printing bed. Plan 3: Do 1, then 2, then 3 (if wrong, then 4, otherwise 5), then 5 (if wrong, then 6, otherwise 7), then 7 (if wrong, then 8, otherwise 9), then 9 (if wrong, then 10, otherwise 11), then 11 (if wrong, then 12, otherwise 13), then 13 (if wrong, then 14, otherwise 15), then 15 (if wrong, then 16, otherwise 17), then 17 (if wrong, then 18, otherwise 19), then 19 (if wrong, then 20).
3.1 Disable engines. 3.2 Move the printing bed to the front of the equipment. 3.3 Check GAP between extruder and printing bed on the left rear corner. 3.4 Make level adjustments by left rear leveling screw (turn clockwise to go up, turn counterclockwise to go down). 3.5 Check GAP between extruder and printing bed on the back center. 3.6 Make level adjustments by the left and right rear leveling screws (turn clockwise to go up, turn counterclockwise to go down). 3.7 Check GAP between extruder and printing bed on the right rear corner. 3.8 Make level adjustments by right rear leveling screw (turn clockwise to go up, turn counterclockwise to go down). 3.9 Check GAP between extruder and printing bed on the center right side. 3.10 Make level adjustments by front and rear right leveling screws (turn clockwise to go up, turn counterclockwise to go down). 3.11 Check GAP between extruder and printing bed on the center. 3.12 Make level adjustments by four leveling screws (turn clockwise to go up, turn counterclockwise to go down). 3.13 Check GAP between extruder and printing bed on the center left side. 3.14 Make level adjustments by front and rear left leveling screws (turn clockwise to go up, turn counterclockwise to go down).

3.15 Check GAP between extruder and printing bed on the left front corner. 3.16 Make level adjustments by the front left leveling screw (turn clockwise to go up, turn counterclockwise to go down). 3.17 Check GAP between extruder and printing bed on the center front. 3.18 Make level adjustments by front leveling screws (turn clockwise to go up, turn counterclockwise to go down). 3.19 Check GAP between extruder and printing bed on the right front corner. 3.20 Make level adjustments by front right leveling screw (turn clockwise to go up, turn counterclockwise to go down).
4. Enable engines. Plan 4: Do 1, then 2, then 3, then 4.
4.1 Press the central button or knob. 4.2 Select QUICK SETTINGS. 4.3 Press the central button or knob. 4.4 Select HOME ALL.
5. Preheat equipment. Plan 5: Do1, then 2, then 3, then 4, then 5, then 6.
5.1 Press the central button or knob. 5.2 Select QUICK SETTINGS. 5.3 Press the central button or knob. 5.4 Select (type of material) PREHEAT. 5.5 Check the temperature increase in LCD. 5.6 Verify the temperature with an infrared thermometer.
6. Feed and line up filament. Plan 6: Do 1, then 2, then 3, then 4, then 5, then 6, then 7, then 8, then 9, then 10, then 11.
6.1 Check the date of manufacture of the material. 6.2 Take out packing material. 6.3 Place roll of material in roll holder. 6.4 Cut 60 degrees at the tip of the material. 6.5 Press the central button or knob. 6.6 Select QUIT SETTINGS. 6.7 Press the central button or knob. 6.8 Select CHANGE FILAMENT 6.9 Insert filament in extruder feed. 6.10 Press top button or knob until the filament comes out of the nozzle. 6.11 Push the middle button or knob.

3.3 Workload assessment

After the HTA, the workload was assessed using the NASA-TLA method. The individuals of the group received training over the use of the method. After the performance of the task, participants used open source software. The results are shown in Table 1. These results expose that mental demand was the subscale with higher punctuation with an average of 79. Even the participants were familiar with the task; they expressed that the task was demanding and complex. The level of complexity is due to the adjusting of the bed requires a high grade of precision that is different between the participants. This adjust is the most important of all the setting process due that a bad adjust result in future process problems.

The second sub-scale with higher punctuation was temporal demand with an average of 59. As it had mentioned, temporal demand was associated with time pressure. During the task, participants had the restriction of time. Twenty-three minutes is the standard time of setting up for FFF 3D printing (The models used in this research were Prusa I3 and Ultimaker). Even the participants were familiar with the procedure, components, and tools used in the setup; they feel pressure for the time before starting with the task.

Table 1. NASA-TLX scores for setting up FFF equipment.

Individual	MD	PD	TD	P	E	F	Score	Workload level
1	95	45	70	80	65	30	76.00	Very High
2	90	30	60	70	55	30	65.66	High
3	80	25	75	70	70	35	69.66	High
4	75	30	80	70	80	40	72.33	High
5	75	25	40	25	30	20	45.66	Low
6	75	5	70	35	50	15	55.66	High
7	70	5	40	25	40	20	46.66	Low
8	70	25	55	25	35	25	50.00	Low
9	80	25	45	60	70	35	65.66	High
10	80	25	55	65	75	45	70.00	High
Average	79.00	24.00	59.00	52.50	57.00	29.50		

MD (Mental Demand); PD (Physical Demand); TD (Temporal Demand); P (Performance); E (Effort); and F (Frustration).

The effort was the third subscale with important average punctuation. As a result of the mental demand and temporal demand, it is possible to assimilate that individuals perceive specific grade of mental demand associated with the development of the task. In this point and due that physical demand was the lowest average punctuation, it is possible to ensure that the effort is represented firstly by activities as a thinking (about the correct adjust or the correct gap used), deciding (if the adjust was correct or incorrect, if the tool used was appropriate or inappropriate, if turn the screw clockwise or in the opposite direction, etc.), and remembering (the sequence displayed by the software, even they were familiar with the commands and the sequence).

Finally, it is necessary to declare that the task was developed using Prusa I3 and Ultimaker equipment. The importance of this research is evident, for 2022 the setting up of equipment will be developed in more than one equipment (mostly in companies), the projection is that industrial companies will have their prototyping area with many types of equipment's as is showed in Figure 2. As a consequence, the workload could increase significantly because the tasks required in the pre-processing, process, and post-process of 3D printing will increase in quantity.

Figure 2. Industrial prototyping areas, FFF 3D printers.

5. CONCLUSIONS

Additive manufacturing is an alternative manufacturing of production, emerging from industrial production systems. The inclusion of the human factor in this new technology represents a challenge for researchers in the ergonomics field. The objective of this chapter was to assess the workload of setting up FFF equipment. Although the task was developed in just one equipment, it is essential to expose the potential of this technology. Today, Figure 2 is a reality inside companies with many types of equipment's demanding the attention of the human factor.

The results inform that participants were exposed to specific workload, where NASA-TLX identified that mental demand subscale was the significant score in which researchers should propose an alternative to improve the task. The activities of setting up equipment are highly demanded, due that the perfect adjust will eliminate or reduce future problems during the. In this case, the precision activities demanded for the task are the key to reduce the effect of workload.

Finally, considering that this technology will increase its impact over the industry, it is remarkable that the workload of this task should be analyzed using other workload assessment methods to compare more results.

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