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Physiological and Subjective Responses Associated to Physical and Mental Load in a Simulated Task

Respuestas fisiológicas y subjetivas asociadas a la carga física y
mental en una tarea simulada

Respostas fisiológicas e subjetivas associadas à carga física e
mental em uma tarefa simulada

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Abstract: *Objective:* To develop a quasi-experimental study to know the changes in physiological responses and perceived efforts of a group of fifteen healthy students that performed a simulated task related with the operation of a CNC lathe in a lab environment. *Materials and Methods:* The participants were asked to randomly complete a total of eight sessions including single and combined test of physical and mental load. Low/High Physical Load and Low/ High Mental Load were established as independent variables. Heart rate, physical performance, mental performance, and effort perception were established as dependent variables. *Conclusions:* High load levels have a significant effect on the heart rate increasing, but not in the perception of effort. High levels of mental load have a significant effect on physical and mental performance. **Keywords:** physical effort, mental effort, physical performance, mental performance, task simulation.

Resumen: *Objetivo:* desarrollar un estudio quasi-experimental para conocer los cambios en las respuestas fisiológicas y esfuerzos percibidos en un grupo de quince estudiantes sanos que realizaron una tarea simulada relacionada con la operación de un torno CNC en ambiente de laboratorio. *Materiales y métodos:* los participantes completaron un total de ocho sesiones que incluyeron pruebas individuales y combinadas de esfuerzo físico y mental. La Carga Mental Baja/Alta y Carga Física Baja/Alta fueron establecidas como variables independientes. Frecuencia cardíaca, desempeño físico, desempeño mental y la percepción de esfuerzo fueron establecidas como variables dependientes. *Conclusiones:* los niveles altos de carga física tienen un efecto significativo en el incremento de la frecuencia cardíaca, pero no en la percepción de esfuerzo. Los niveles altos de carga mental tienen un efecto significativo en el desempeño físico y mental.

Palabras clave: esfuerzo físico, esfuerzo mental, desempeño físico, desempeño mental, tarea simulada.

Resumo: *Objetivo:* desenvolver um estudo quase-experimental para conhecer as mudanças nas respostas fisiológicas e esforços percebidos em um grupo de 15 estudantes saudáveis que realizaram uma tarefa simulada relacionada com a operação de um torno CNC em ambientes de laboratório. *Materiais e métodos:* os participantes completaram um total de 8 sessões que incluíram provas individuais e combinadas de esforço físico e mental. A Carga Mental Baixa/Alta e a Carga Física Baixa/Alta foram estabelecidas como variáveis independentes. Frequência cardíaca, desempenho físico, desempenho mental e a percepção de esforço foram estabelecidas como variáveis dependentes. *Conclusões:* os níveis altos de carga física têm um efeito significativo no incremento da

frequência cardíaca, mas não na percepção de esforço. Os níveis altos de carga mental têm um efeito significativo no desempenho físico e mental.

Palavras-chave: esforço físico, esforço mental, desempenho físico, desempenho mental, tarefa simulada.

Introduction

With the implementation of new, better, and more sophisticated technologies, the effort performed by workers has had significant changes (1, 2, 3, 4), and now the workers perform to complex tasks demanding combined physical and mental efforts (2). A few years ago, workers performed only physical tasks; in contrast, today it is possible to find jobs where physical effort is practically zero, for example, office work, control room operation, among others.

The work/job/activities/tasks developed by the advanced manufacturing technology (AMT) operators are considered complex (4). One example of complex work is the operation of lathes of computer numerical control (CNC). In this type of work, the operators must develop both, physical (load and unload parts to/from the machine) and mental tasks (change of model, parameter setting, and inspection). Some studies have concluded that the duality of tasks can generate diverse fatigue symptoms (2, 4, 5).

Because manipulating variables (for example: mental workload, heart rate, handled weight, among others) in industrial environments to get data is complex and practically impossible, the measurement of physiological indices in these conditions has been relatively unexplored. In contrast, it is common to simulate work conditions in lab settings. For example, some authors have developed research in laboratory environments where the effects of physical and mental fatigue have been analyzed in certain circumstances (2, 6, 7, 8, 9). Although lab experiments have important limitations such as not consider all the stimuli, simulated time is shorter than a working day, and it is difficult to reach the external validity, in ergonomics, lab experiments are a common practice to explore the behavior of variables to explain certain phenomena or constructs. However, simulated tasks in the cited studies are different from those performed by lathes operators.

The general objective of this research is to simulate, in a lab environment, the physical and mental load in two levels (low and high) to know the effects on heart rate (HR), effort perception (EP), physical performance (PP), and mental performance (MP). The specific objectives are as follows:

- To quantify heart rate (HR), effort perception (EP), and physical performance (PP) when physical load (low and high) is simulated.
- To quantify the heart rate (HR), effort perception (EP), and physical performance (PP) when mental load (low and high) is simulated.
- To quantify the heart rate (HR), effort perception (EP), physical performance (PP), and mental performance (MP) when mental

load (low and high) and physical load (low and high) are simulated in combination.

Materials and methods

Study Design

In order to quantify the physiological responses of mental and physical load stimulation a quasi-experimental, descriptive, cross-sectional, and correlational study design was performed in lab settings.

Sample

A convenience sample was chosen according to the following inclusion criteria:

- Being a student of the Autonomous University of Ciudad Juarez.
- Not having heart and respiratory problems, hypertension or injury in the last year prior to the experiment.
- Non-smokers.
- Having not drunk alcohol two days before the sessions.

During the study, participants could be excluded if they suffer an injury in upper or lower limbs, presenting a mental problem, or miss more than two sessions being unable to reschedule. The subjects wore tennis shoes, jeans, cotton shirt, and cotton socks. At the end of the session, participants received a small gift.

Variables

Independents

Levels of physical and mental load considered the proposal of DiDomenico (2) who established values/scores for these two variables. As a result, two independent variables were manipulated, physical load and mental load. For low physical load (LPL) participants manipulated/handed a 10-lb. weight disc, while for high physical load (HPL) a 20-lb. weight disc was used. For low mental load (LML) participants solved addition and subtraction arithmetic problems, while for high mental load (HML), participants solved multiplication and division arithmetic problems.

Dependents

The values of four dependent variables were recorded. Heart rate (HR) was recorded using the heart rate monitor Suunto software. The physical performance was measured counting the number of times that

participants moved the disc. The mental performance was measured as the ratio of the questions answered correctly divided between the number of questions answered. Effort perception was assessed using the 6-20 Borg rating of perceived exertion (RPE) (10). Participants were asked every minute during the test about their perception of global efforts performed to complete the assigned tasks (see table 1).

Table 1
Borg Scale 6-20

Value	Effort interpretation	Value	Effort interpretation
6	No exertion at all	14	
7	Extremely light	15	Hard (heavy)
8		16	
9	Very light	17	Very hard
10		18	
11	Light	19	Extremely hard
12		20	Maximal exertion
13	Some light		

*The variables considered in the study are shown in table 2.

Table 2
Variables of the Study

Independent			Dependent		
Name	Levels	Code	Name	Measure unit	Code
Low Physical Load	10 lb	LPL	Heart rate	(bpm)	(HR)
High Physical Load	20 lb	HPL	Effort perception	6-20	(EP)
Low Mental Load	Addition and subtraction	LML	Mental performance	# correct answers/# questions	(MP)
High Mental Load	Multiplication and division	HML	Physical performance	# of movements	(PP)

Materials

The following materials were used in the development of the experiment:

- Suunto heart rate monitor wireless band
- Suunto software training manager V 2.2.0.8
- Two circular disks of 10 lb and 20 lb for testing low and high physical load, respectively.
- Portable computer

- Desktop computer

Methods

Once the subjects arrived at the lab, participants read and signed a consent form to accept their voluntary participation. Next, in a private room, the participants set the heart rate band on their chest. To stabilize the heart rate signal, participants remained seated for five minutes. When the heart rate-computer communication was confirmed, the test was ready to start.

Before starting, a research assistant explained the test activities, and two full series of the cycle were developed. Those data were eliminated from the data analysis. Every minute, participants were asked about their effort perception based on the Borg RPE scale (6-20) (10). Figure 1 shows the layout developed in the ergonomics lab at the Autonomous University of Ciudad Juarez where the experiment was conducted.

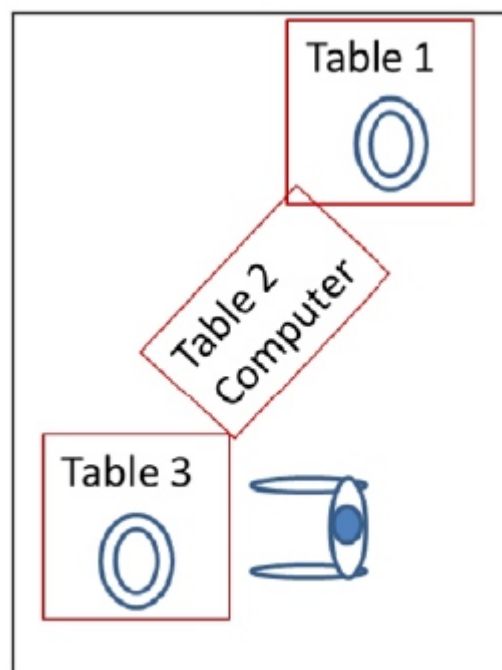


Figure 1
Layout Experiment

Because the design of the experiment involves testing with single and combined efforts, in four sessions, participants developed single effort tests. In the remaining four sessions, combined efforts tests were performed. To avoid fatigue effects, only one session was programmed per day. Hereunder, test conditions are described.

Single Test

The sequence of activities performed in the single effort is shown in table 3. Four different sequences were developed using a Latin square array (see table 4).

Table 3
Activities Developed in Single Effort

Step	Only physical activities	Only mental activities
1	Place the elbows at 90-degree position, back straight, and using both hands, take the disk in point 1	Stand in front of point 2
2	Walk 2 meters to point 3	Read the sentence (arithmetic problem) in the screen
3	Leave the disk in the point	Answer the arithmetic problem using the keyboard
4	Place the elbows at 90-degree position, back straight, and using both hands, take the disc in the point 3	Read and answer next arithmetic problem
5	Walk 2 meters to point 1	Repeat the sequence for 7 minutes
6	Leave the disk in point 1	
7	Repeat the sequence for 7 minutes	

Table 4
Latin Square Array for Individual Efforts Tests

Day	Sequence 1	Sequence 2	Sequence 3	Sequence 4
First	LPE (1)	LME (2)	HPE (3)	HME (4)
Second	LME (2)	HPE (3)	HME (4)	LPE (1)
Third	HPE (3)	HME (4)	LPE (1)	LME (2)
Fourth	HME (4)	LPE (1)	LME (2)	HPE (3)

Combined Test

The sequence of activities performed in the combined effort tests is shown in table 5. Four different sequences were developed using a Latin square array (see table 6).

Table 5
Activities Developed in the Combined Efforts Tests

Step	Activities
1	Stand in front of point 2
2	Read the arithmetic problem on the screen
3	Answer the arithmetic problems using the keyboard
4	Walk 1 meter to point 1
5	Place the elbows at 90-degree position, back straight and using both hands, take the disc
6	Walk 2 meters to point 3
7	Leave the disc in point 3
8	Walk 1 meters to point 2
9	Read the arithmetic problems in the screen
10	Answer the arithmetic problems using the keyboard
11	Walk 1 meter to point 3
12	Repeat the sequence for 7 minutes

Table 6
Sequence of the Combined Tests

Day	Sequence 5	Sequence 6	Sequence 7	Sequence 8
Fifth	LPE - LME (1)	HPE - HME (2)	LME - HPE (3)	HME - LPE (4)
Sixth	HPE - HME (2)	LME - HPE (3)	HME - LPE (4)	LPE - LME (1)
Seventh	LME - HPE (3)	HME - LPE (4)	LPE - LME (1)	HPE - HME (2)
Eighth	HME - LPE (4)	LPE - LME (1)	HPE - HME (2)	LME - HPE (3)

Data Analysis

Tests of normality of heart rate data were performed using the Anderson Darling test. Paired T-test was used for data comparisons between the sample. The nonparametric comparisons were made using the Wilcoxon Rank test. All data were captured in Excel software and then exported to SPSS v17 software for analysis. A significance level of 0.05 was used for all comparisons and hypothesis testing performed.

Results

Sample

A total of 15 volunteer students (10 men and 5 women) participated in the study. All of them with no apparent health problems. The average age was 23.4 years (± 2.27), the mean weight was 65.8 kg (± 8.81), height 165.3 cm (± 11.07). The 15 participants completed the 8 sessions of the experiment.

Heart Rate

Single test HPE and the combinations HPE-LME and HPE-HME yielded the highest values of heart rate being significantly higher ($p < 0.05$) than those that do not include HPE. In contrast, the single test LME and the combination HME-LPE got the lowest values of heart rate (see figure 2).

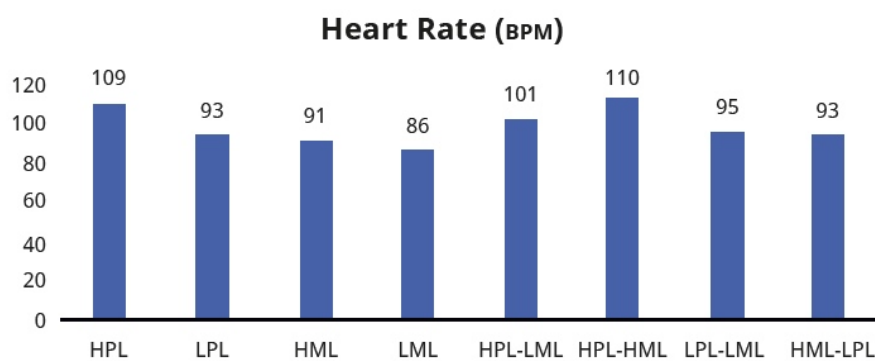


Figure 2
Heart Rate Results

Effort Perception

In general, tests that include HPE got the highest values of effort perception. However, no significant differences among the effort perception were found ($p > 0.05$) in the eight tests (see figure 3).

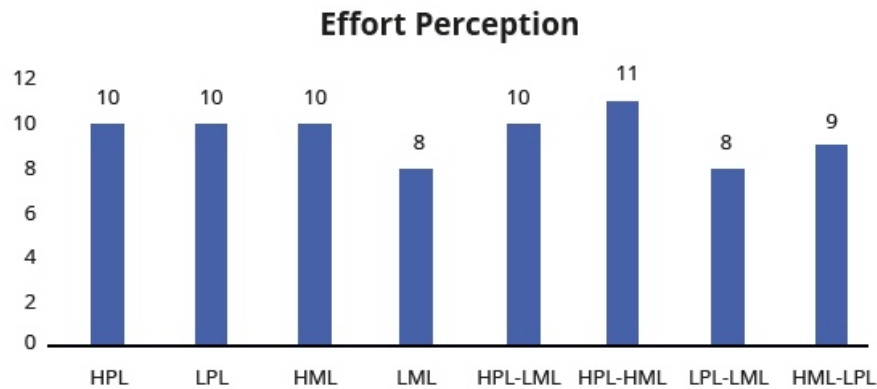


Figure 3
Effort Perception Results

Performance

For mental performance, results for tests without HME are, in average, 20 % higher than tests including this condition. For example, LME, LPE-LME, and HPE-LME scored 93 %, 95 %, and 95 % efficiency, respectively, being significantly higher than the values obtained for the remaining five tests ($p < 0.05$) (see figure 4 and table 7).

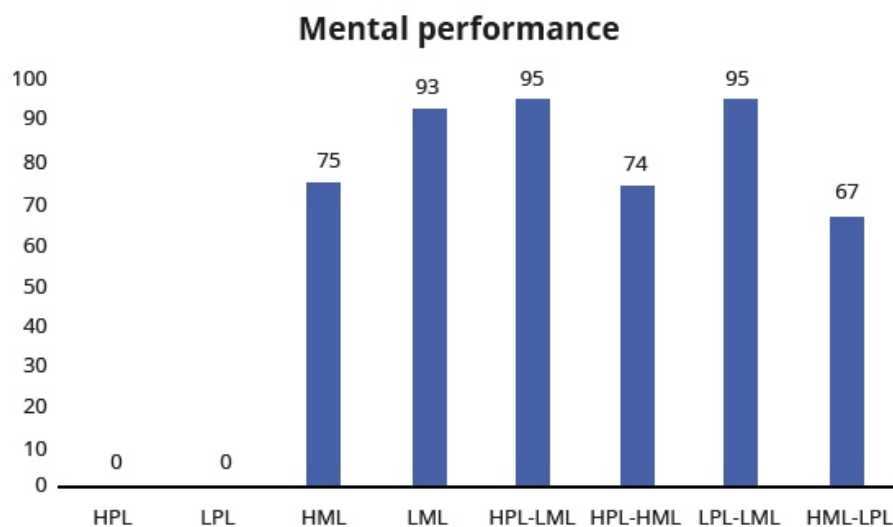


Figure 4
Mental Performance Results

Data expressed in percentages

The results of physical performance showed a similar behavior when HME is not present. For example, HPE, LPE, LPE-HPE, LPE-LME scored 35, 42, 20 and 20 moves, respectively, being significantly higher than the values obtained for the remaining tests ($p < 0.05$) (see figure 5 and table 7).

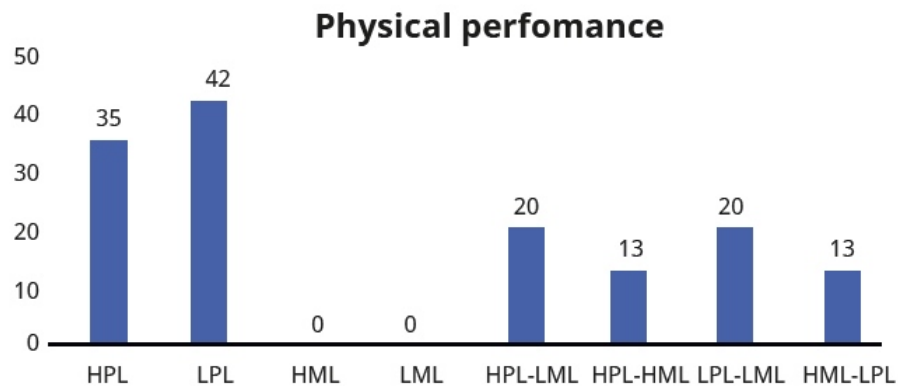


Figure 5
Physical Performance Results

Table 7
Global Results

Test	Heart Rate (BPM)	Effort Perception	Mental Performance	Physical Performance
HPE	109	10	NA	35
LPE	93	10	NA	42
HME	91	10	75%	NA
LME	86	8	93%	NA
HPE-LME	101	10	95%	20
HPE-HME	110	11	74%	13
LPE-LME	95	8	95%	20
HME-LPE	93	9	67%	13

Discussion

According to the results, the presence of levels of load considered as high increases significantly the heart rate. In this case, high physical load was represented by a disk of 20-lb. For example, tests where high physical load was present got at least 14 BPM higher than others.

On the contrary, no significant differences in effort perception for all tests were found. In this case, the most probable cause was the short duration of the test (only 7 min). However, the study of DiDomenico (11) found significant differences in the effects caused by the manipulation of the physical and mental load with only five minutes of simulation. Duration of the experiment is the most relevant limitation of this study. As mentioned above, some lab experiments have been successful with short time of simulation. In this specific case, another variable influencing the outcomes was the rate/speed the participants used to complete the task, that is, they were not asked to complete the

study in a determined time, on the contrary, participants performed the tasks at their own pace.

The presence of high mental load decreased significantly the values of mental and physical performance getting scores between 18 and 28 %. The decrease of the mental performance is mainly due to the level of complexity of the arithmetic tasks where participants solved compounds statements of multiplication and division for high mental load.

For the case of physical performance, reduction in the number of movements is attributable to the time used by the participants to answer the questions of the mental load being higher for the high mental load than low mental load. As a result, high mental load got a significant decrease in the number of movements.

Findings of this study show the importance of the load levels. High load levels (physical and/or mental) have an important effect on physiological indices (i.e. heart rate) and performance. In an effort to improve the productivity, companies should analyze current workload levels, design new tasks, and implement lower levels of workload.

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Additional information

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